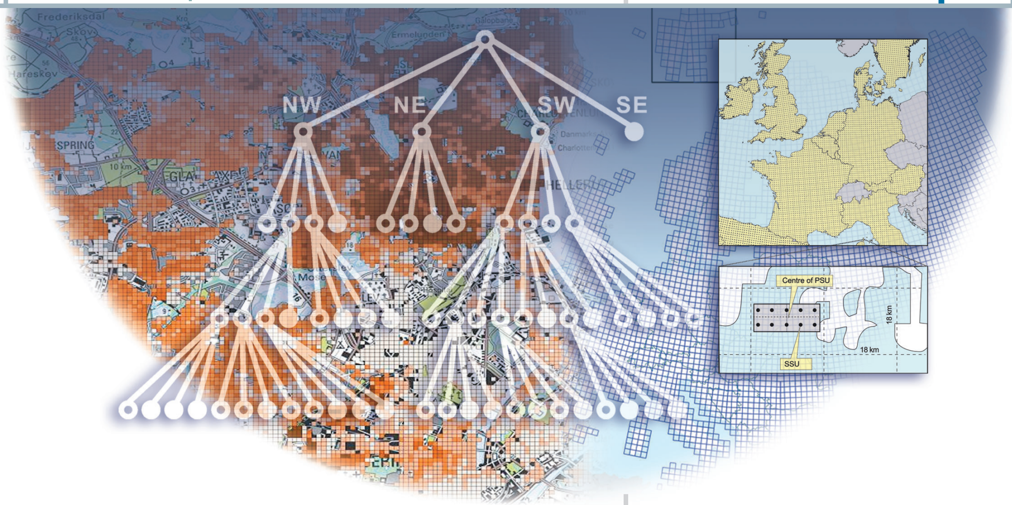
Institute for Environment and Sustainability

European Reference Grids

Ispra, 27-29 October 2003

Workshop



Proceedings & Recommendations

Proposal for a European Grid Coding System

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

2005

EUR 21494 EN

Institute for Environment and Sustainability

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Edited by:
Alessandro Annoni

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MISSION STATEMENT

The mission of the **Joint Research Centre** is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of European Union policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Community. Close to the policy-making process, it serves the common interest of the Member States, while being independent of commercial or national interests.

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Workshop summary

Alessandro Annoni

The 1st Workshop on European Reference Grids was organized by the Joint Research Centre (JRC) of the European Commission following the recommendations by the European Environmental Agency[1] and the INSPIRE[2] Implementing Strategies Working Group that a Europe-wide reference grid be devised and adopted to facilitate the management and analyses of spatial information for a variety of applications. These recommendations echoed the position taken by the National Statistical Institutes at the Working group meeting held at Eurostat in Luxembourg in 1999[3] in favour of a common coordinate reference system and a common equal-area grid to represent the EU and Pan-Europe.

Given the complexity of the issues involved, the JRC organized the workshop inviting leading experts of different communities representing Users of European Grids (including European Commission Directorates General), National Statistical Institutes, National Mapping Agencies, GIS Software Industry, European Organizations and Agencies but also inviting experts in Geodesy, Spatial Analysis, and Geo-Spatial Data Modeling, Standardization and Interoperability.

The workshop was articulated in various thematic sessions, with working groups established to address specific issues in depth. In particular it was possible to: have a detailed overview and comparative analysis of existing EU initiatives, projects and regulations making use of geographical grids (e.g. ICP-Forest, LUCAS, ESPON, EEA Atlas, Atlas Florae Europaeae); evaluate current and previous technical work to build trans- national grids (e.g. TANDEM, Nordvic); give specific attention to the spatial methods needed to transform information between grids, including aggregation and disaggregation of statistics, spatial entities, etc..

The last topic addressed related to the geodetic aspects including the reaffirmation of the European standards selected in two previous workshops jointly organized by JRC and EuroGeographics: the European Datum ETRS89[4] and related map projections[5].

This part of the workshop considered the problems related to the transformations needed between geodetic datum, map projections and geographical grids in geodesy and geoinformation.

The workshop participants were asked to answer specific questions like:

- Is a unique EU grid possible (long term vision)?
- How can convergence in the future be achieved?
- How to increase the integration between existing grids?
- Which spatial-statistical methods are available and recommended?
- How to address the Standardisation and Certification of the proposed solution(s)?

The flow of information was considerable and the debate was rich and productive. Even though different groups were working independently and addressing different issues, what was remarkable was the extent of convergence among the conclusions reached, and the limited degree of divergence. As a result, it was possible to arrive quickly at a common position and identify a technical solution (standard) to be recommended for future adoption. Because the adoption of a future European standard on this matter needs to be accompanied with adequate documentation

[1] "The European Environment Agency needs a grid for immediate use and will use it until there are agreements on a common grid system, maybe being ready by 1-3 years. We would like to ask you for some advise on the choice"- Arvid Lillethun, EEA, 27 November 2002
[2] INSPIRE - Infrastructure for Spatial Information in Europe– http://inspire.jrc.it
[3] JRC (IES)/European Commission 2003: Map projections for Europe, page 20
[4] Spatial Reference System workshop, Marne-La Vallée, 29-30 November 1999
[5] Map Projections for Europe workshop, Marne-La Vallée, 14-15 December 2000

on how to convert existing grids to the new standard, it was agreed to test the proposed solution in current initiatives.

In this respect, the proposal by the participants in the Nordvic project to use their project across Scandinavia it as a test bed of the proposed standard was warmly endorsed by the Workshop.

The selected grid will be used in future for spatial and statistical analyses, and for the reporting of other sources of information to a common European grid. Due to the limited time available, the discussion of a possible unique grid for data collection was not exhausted and the workshop recommended leaving any decision to a second edition of the European Reference Grids workshop. In that occasion it will be possible to focus on data collection related issues and at the same time to analyse the results of the one year of testing prior to the final adoption of the proposed standard.

The workshop resulted in a set of recommendations to move forward, and an action plan for 2004 (additional workshop material is available at: http://gi-gis.jrc.it/ws/grid2003/index.html).

The recommendations in short

> **"A grid for representing thematic information is a system of regular and geo-referenced cells, with a specified shape and size, and an associated property".**

The workshop recommends to the European Commission:

1. To reaffirm the recommendations of the Spatial Reference Systems workshop [2]:
   - To adopt **ETRS89**[6] as geodetic datum and to express and store positions, as far as possible, in ellipsoidal coordinates, with the underlying GRS80[7] ellipsoid [ETRS89].
   - To further adopt EVRF2000 for expressing practical heights (gravity-related).
   - To identify coordinate reference systems and transformations in the format required by International Standard **ISO 19111**.

2. To reaffirm the recommendations of the Map Projection Systems Workshop [1], i.e. to adopt the following map projections to supplement the ellipsoidal system:
   - To adopt ETRS89 Lambert Azimuthal Equal Area coordinate reference system of 2001 [ETRS-LAEA], for **spatial analysis and display**.
   - To adopt ETRS89 Lambert Conic Conformal coordinate reference system of 2001 [ETRS-LCC] for conformal pan-European mapping at scales smaller or equal to 1:500,000.
   - To adopt ETRS89 Transverse Mercator coordinate reference systems [ETRS-TMzn], for conformal pan-European mapping at scales larger than 1:500,000.

3. To continue to promote the wider use of these standards within all member states and internationally, by appropriate means (recommendations, official statement, …).

[6] European Terrestrial Reference System 1989
[7] Geodetic Reference System 1980

4. **To adopt a common European Grid Reference System for Reporting and Statistical Analysis.** The system should be able to store regular grids and should be designed as reference for future Grids related to European territory. The system must satisfy the following principles:

    - easy to manipulate
    - hierarchical
    - based on a common European Grid Coding System
    - based on units of equal area
    - adopting ETRS-LAEA and having a clear and simple relation to it
    - able to manage time stamps
    - following the quality principles described in ISO 19113-11915
    - the Grid Data Model should be fully and publicly documented
    - transfer of Grid data must be based on non proprietary open formats
    - Metadata (following ISO specifications) must be produced and regularly updated to describe specific Grid characteristics and information related to a specific grid unit.

5. For **converting to and from existing grid structures**, it is highly recommended to generate data from the original detailed information.

6. To test for a period of one year ETRS–LAEA[8] with the aim:
    - to demonstrate benefits of the proposed solution,
    - to identify and develop tools, establish technical guidelines and best practice examples to support the convergence of existing grid data to a standard grid.

7. To encourage future European projects to make use of a standard European grid.

8. To help in **ensuring the future on-line interoperability of existing Grid systems** at European and National level (GRID Net) by providing examples of best practices and technical guidelines to be followed in establishing conversion/transformation procedures.

9. To continue the process of educating the users of geographic information in the complex issues associated with coordinate reference systems, map projections, grids, transformations and conversions, including working with software and system suppliers to enable 'on the fly' transformations between commonly-used coordinate reference systems.

[8] in collaboration with on going initiatives (e.g. the Nordvic project)

Workshop structure

The following sections describe the structure of the workshop. Additional information is given in the Annexes:

- Annex 2 the abstracts of the presentations made during the workshop,
- Annex 3 contains the list of represented bodies and organisations,
- Annex 4 contains the list of participants

The user needs (Comparative analysis of existing European initiatives) (day 1)

The speakers were invited to address the following common elements in their presentation (where appropriate):

1. Rationale of their Project
2. Why a grid?
3. Major characteristics of the grid
4. Does the grid meet your needs
5. Link of your project with other (spatial) data.

The problem statement (morning session)

- The ICP-Forests sampling scheme (Javier Gallego)
- LUCAS: monitoring the European Union territory using a grid approach. (Manola Bettio, Maxime Kayadjanian)
- Towards participatory approaches to a Multiscale European Soil Information System (Nicola Filippi, Borut Vrscaj)
- EU regional policy and grids (Hugo Poelman)
- ESPON (Volker Schmidt-Seiwert)
- Current use of spatial reference grids in European Environment Agency (Andrus Meiner)
- Atlas Florae Europaeae (AFE) – Mapping European Vascular Plants with 50 × 50 km grid (Pertti Uotila and Raino Lampinen)
- TANDEM (Lars Backer)
- Mapping and analyzing the distributions of plant species across the countries of Europe − an overview of research schemes and grid systems (Harald Niklfeld)
- The grid reference system used for CGMS (Giampiero Genovese)
- TREES sampling schema (Javier Gallego)

Identify common requirements (afternoon session)

- Working Groups Discussion
    - typologies of used grids (chair: M Greaves)
    - user requirements(chair: J.Gallego)
- Plenary: Report from working groups and Final Discussion

Grids and Spatial analysis (day 2)

Grid conversion (morning session)

- The European Datum ETRS89 and its realisation (Johannes Ihde)
- Transformations between geodetic datum, map projections and geographical grids in geodesy and geoinformation (Johannes Ihde)
- Grid estimation. Application to datum distortion modelling (Javier González-Matesanz)
- Direct transformations between neighbour TM systems (Jorge Teixeira Pinto)
- The design and introduction of a new map projection and grid system for Ireland (Ken Stewart)
- Very high resolution raster digital data: datasets for the Common Agricultural Policy (Simon Kay)
- Aggregation and disaggregation of statistics (Erik Sommer)
- In search of an infrastructure for spatial analysis (Lars Backer)
- Dissemination of grid-based statistics in Finland and a case study about dissemination of multinational grid data of the four Nordic countries (Marja Tammilehto-Luode)
- The modifiable areal unit problem in the context of a standard grid (Javier Gallego)

Grids and Spatial Analysis (afternoon session)

- Working Groups Discussion
  - Grid definition and properties(chair: A.Lillethun)
  - Grid conversion(chair: J.Gallego)
  - Grid structure(chair: A.Annoni)
- Plenary: Report from working groups and Final Discussion

Formulate a Grid initiative (day 3)

Final Recommendations (morning session)

- Working Groups Discussion
  - Is a unique EU grid possible
  - How to increase the integration between grids and which methods are recommended
  - Standardisation and Certification of proposed solution(s)
- Plenary: Report from working groups and Final Recommendations

Action Plan (afternoon session)

- Plenary: Action Plan

Introduction

The concept of a general, multi-purpose grid requires consideration of various elements related to the grid characteristics as well elements related to the methods applied for grid generation and conversion (Table 1). In order to address most of these issues various working groups were created looking at these aspects from several points of view. The first part of the workshop focused on existing grids initiatives and on understanding various user requirements. The following chapters report the results of the discussions.

Table 1 – some aspects be considered about Grids

Grid Shape	Rectangular (square) / Hexagonal / Based on lat-long intervals	**Geo-Referencing**	Coordinate Reference System
Grid Scale	Up-Down scaling	**Certification / Validation**	Lineage
Use of Grid	Data Storing / Data Collection / Spatial Analysis	**Aggregation of data to Grid**	Smoothing …
Grid Structure	Hierarchical / Quadtree.. Coding system (Global/EU/National/Local)	**Conversion between different Grids**	Datum changes / Content change
Grid Database	Time stamp / Data model / Output formats	**Data collection using a Grid**	Precision / Accuracy / Interpolation
Quality	Description based on ISO 19113-11915	**Networking and Distributed Grid systems**	Interoperability of different Grid systems
Metadata	Profiles [Grid characteristics/ data, ..] based on ISO 11915		

User Perspective

A working group was created to analyse the common requirements and listen to the users for identifying critical issues and commonalities. Table 2 shows examples of grids used in different initiatives.

Table 2 – examples of Grid parameters used in different initiatives

Project	Datum-Projection	Extent	Resolution Step	Origin	Unique [9]	Satisfactory [10]	Documentation [11]	Reference	Purpose [12]	Shape
ICP-Forest	Not defined	Pan-EU (Russia not yet included)	16 Km	50°14'15" N 9°47'06"	No	Medium	Low	EU Regulation 1696/87	Sampling Collection	Square
TREES	WGS84 Lat-Long	Global	3,000-3,500 km2	Unknown	Yes	Low	Medium		Sampling	Hexagonal
LUCAS	Extended UTM (one zone by country)	EU15-25	18 km	Various National	No	High	High		Sampling Collection	Square
AFE	WGS84 Multiple UTM zones	Pan-European	50 km		No	Low	Low		Mapping	Mostly squares
National Square Grid	UTM-projection, zone 32. Datum: EUREF89	Denmark	100, 250 meter 1,10, 100 km	North= 6.000.000 East= 400.000	Yes	High	High	www.kms.dk	Reporting Mapping	Square
DEM (GISCO DEEU3M) as used by DG REGIO	LAEA	Pan-European	30 arcsec. (1km)	48°N 9° E	Yes	Medium[13]	High	See GISCO DBM	Reporting and mapping	Square
Land Cover (GISCO LCEUGR100) as used by DG REGIO	LAEA	EU27 + (excl. SE)	100 m	48°N 9° E	Yes	Medium[14]	Medium[15]	See GISCO DBM	Reporting and mapping	Square
European Soil Information System	Lambert Equal Area (GISCO)	Pan-European	1 Km	(see projection)	Yes	High	High		Integrated Spatial Analysis	Square

9 Is the grid unique or is it a collection of several grids?
10 Did the grid satisfy user needs? Low, Medium, High
11 Is the grid well documented? Low, Medium, High
12 Sampling, Collection, Reporting, Mapping
13 Rather coarse resolution for some mountain areas definition purposes.
14 temporal diversity - absence of integrated and comparable data (eg for Sweden)
15 information on diversity of reference dates needed

Grids for what?

The comparative analysis of the grids used in various European projects / initiatives and policies show that grids are used for several purposes:

- Surveys on a sample
  - Systematic unbiased sampling (e.g. LUCAS)
  - Data Collection (e.g. ICP forest)
- Organising information on the whole territory
  - Mapping (e.g. IMAGE2000)
  - Spatial Analysis (e.g. CORINE Land Cover)
  - Reporting and spatial analysis (e.g. ESPON, Atlas Florae Europaeae, Nordvic, ..)

Spatial Analysis and Reporting can be considered as a similar item if the grid requirements are the same (e.g. if the grid should be based on an equal area projection).

Mapping is a specific issue because in some cases the grid is mapped or re-mapped using a conformal coordinate reference system for cartographic purposes. The Map Projections workshop already considered and selected the systems to be used for Mapping. For this reason the workshop recommends to the European Commission:

- To reaffirm the recommendations of the December 2000 Workshop on Map Projection Systems, i.e.
  - to use the ETRS89 Lambert Conic Conformal coordinate reference system of 2001 [ETRS –LCC] that is specified by ETRS89 as datum and the Lambert Conic Conformal (2SP) map projection for conformal pan-European mapping at **scales smaller or equal to 1:500,000** and
  - to uses the ETRS89 Transverse Mercator coordinate reference systems [ETRS-TMzn], that are specified by ETRS89 as datum and the Transverse Mercator map projection for conformal pan-European mapping at **scales larger than 1:500,000**.

The workshop initially focused on Grid for Data Collection and Grid for Reporting.

From a user point of view the following items were investigated.

Comparability

What does comparability really mean? Many uses are driven by equal-area requirement, is it more important than equidistant? Potential users are often spatial scientists (emphasis should be given to simplification of data collection or to preserve the scientific quality of the historical observations)

From a user point of view it means:

- A clear distinction emerges between grids for collection and grids for analysis/reporting
- Comparability means the possibility to combine data stored or collected using different approaches.

From a technical point of view:

- Meta-data are clearly needed to describe grids and their definition unambiguously
- Comparability can be achieved by using the same geodetic datum (e.g. using ETRS89 as defined by the Spatial Reference Systems workshop)
- Comparability can be facilitated by having a standard projection system (e.g. using the standard projections defined by the Map Projections workshop)

Multi-Resolution and Multi-Purpose

In the context of User Requirements the issues of precision and purpose must be considered. In addition resampling or resolution reduction could be sometime necessary to avoid copyright or data sensitivity problems. A hierarchical approach seems to be essential as it is the basis for aggregation (e.g. for confidentiality / sensitivity, transformation between administrative levels), but, how detailed do you go? How many levels?

Obviously one size doesn't fit all – but it is possible to define systems which meet common needs. We have to avoid grid proliferation. We need to try and establish commonality but don't enforce a single grid. A clear distinction is needed between new projects from those already running.

Location accuracy

Locational accuracy strongly depends on what is being observed. It is not a characteristic of the grid, but it is part of the metadata of specific layers. If grids are used for sampling, it should be possible to accurately locate the points in the field with the help of topographic maps.

Distortion

There is some distortion (angles, distances) intrinsic to the grid (e.g. up to 3% in Turkey for ETRS-LAEA). For applications for which this cannot be accepted, the grid-raster approach may be unsuitable.

Usability

It should be easy to use current GIS software to convert existing vector data to the grid and to convert between different grids.

Repeatability and Re-Use

This seems an implementation issues. The grid should be a sound basis for time-series requirements. A single type of grids makes it more reusable and more efficient. In this context Metadata are fundamental to document both grid characteristics and the process to rasterise the data originally collected. For sampling grids, the number of points should be sufficient to allow for rotation of samples as subsets of a single constant grid.

Extent

The European grid should be used mainly for European purposes, but it can be useful also for national purposes. The grid must be scalable (in fact the European Union is expanding and can further expand in the near future). However the anchor point (origin) should be fixed and clearly defined at the beginning!

Other issues

Grids can be useful for sampling, but the details of the sampling techniques applied with the support of the grid do not need to be addressed in the definition of the grid. A clear distinction is needed between theoretical grid and existing data. Recommendations can be useful on how to fill a new proposed grid with data collected according to a different scheme.

Grid Definition (for Spatial Analysis and Reporting)

A second working group was created to provide a common definition for a grid and to identify main requirements and properties. For lack of time the working group focused on the grid to be used for Spatial Analysis and Reporting and not for Data Collection.

The working group found it necessary to find a common understanding of the concept of grids. A simple definition was formulated:

> ***"A grid for representing thematic information is a system of regular and geo-referenced cells, with a specified shape and size, and an associated property".***

Requirements

A series of requirements and properties were discussed, based on the lists of issues to be addressed as defined in the chapter "Introduction". The following requirements were identified:

1. The Grid must have a common datum for geo-referencing. The datum to be used is ETRS89 as previously identified by the Spatial Reference System workshop.

2. The Grid must be based on an equal area projection. Such a projection is usable for most of themes; for some kinds of mapping, for spatial assessment and for statistical purposes.

3. Area of validity. Different user communities have different needs concerning a common grid. Several of the represented organisations are responsible for handling information at a Pan-European scale. The specific outer boundaries for the proposed Grid where defined to be:
    - West: All Atlantic islands including Greenland;
    - East: Ural mountains;
    - South: Northernmost areas of Africa, including the southern coast of the Mediterranean Sea, including the Tripoli bay;
    - North: to include the northern tip of Greenland, thus also covering Svalbard and polar areas.

4. Negative values in the coordinates must be avoided.

5. Grid coding system.
    - It must be a simple system and not repeating all coordinates
    - It should be possible to identify the hierarchical level of the current grid cell

For other purposes (e.g. Mapping) other projections may be used.

Properties

The following properties were identified for the proposed Grid:

1. The Grid should be based on the projection system Lambert Azimuthal Equal Area (ETRS-LAEA). This projection has previously been identified by the Map Projections workshop [1] as suitable for such uses (see detailed definition in Annex 1).

2. Centre of projection: 52N, 10E (follows the recommendation of the Map Projections workshop[1]).

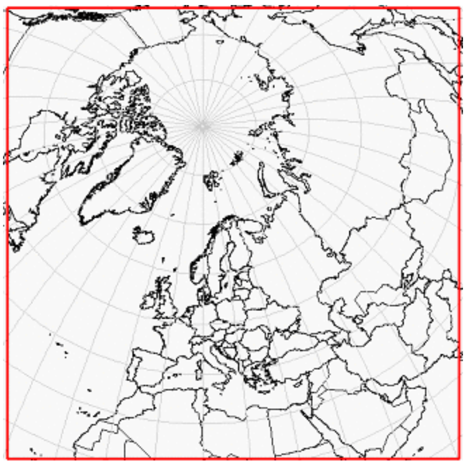
3. False easting: 4321000,0 m, False Northing 3210000,0 m.

4. Precision (the significant number of digits to be used). Origin for the projection should have an exact location (mm precision), in practical work and operation of the grid and its coordinates number of digits should be at dm or meter accuracy.

5. Resolution of grid. Three different options were considered (but the first was selected):
   - Metric: 1,10,100,1000,10.000,100.000
   - The quad tree approach, 1,2,4,8, ….. gives a higher number of levels.
   - A mixed approach where e.g. the main focus is on the metric, but where one allows the 250 and 500 m cells
6. Grid centre point: LAEA 52N 10 E.

7. Grid origin: to be defined as the south-western corner of the area of validity (see figure 4). This has been stipulated to be 4321000,0 m west of centre point of the projection (52N, 10 E), and 3210000,0 m south of projection centre point (52N 10 E). The location of the grid origin far to the west and south would mean that negative values in the coordinates are avoided in all foreseeable uses. The extent is large enough to cover the areas of interest. The false easting and northing values do not have to be moved. Figure 1 shows a quadrant of 10 000 km by 10 000 km.

Figure 1 - The LAEA projection



8. Grid shape: rectangular and not hexagonal, more precisely square. The square shape will appear when used in the defined projection, smaller or larger distortions will appear when re-projected to other projections.

9. Grid orientation: south - north, west – east.

10. Grid structure - coding system: The group did not have time available for further specifications; other working groups were also to handle this issue.

Grid Data Conversion

A second working group was created to analyse the issues related to grid conversion.

As previously defined GRID Conversions means:

- Geometric transformation (e.g. change of Datum)
- Content change

Geometric Transformation was already the subject of the Map Projections workshop that concluded: “because any change of datum is potentially introducing distortion is highly recommended to use ETRS89 a common European datum and to provide “certified” formulas and parameters on the Public domain to make the necessary transformations”. EuroGeographics and Euref have already setting-up a specific website “European Coordinate Reference System Portal (http://crs.ifag.de) managed by BKG that needs to be completed and improved in the future.

Content transformation is instead a different and more complex issue.

Scope

The various groups decided to only refer to data conversion towards grids of tiles to be treated in raster format, i.e. one figure is available for each tile of the grid. Recommendations for co-ordinate conversion of point, line, or polygon data have been widely studied in the scope of ExG G by EuroGeographics. Conversion from point, line or polygon (vector) layers to similar layers in different spatial reference systems (Datum and projection) is widely available in GIS tools. Conversion from raster to vector is out of the scope of the discussions.

Problems related to grid data conversion depend on the resolution of the original data (finer, similar or coarser). Transformation can involve disaggregation to a finer resolution and re-aggregation to a new system.

Resampling

When a raster layer of a relatively fine resolution is converted to a different grid of similar resolution, standard methods of image resampling are acceptable (nearest neighbour, bicubic convolution, etc..).

Aggregation

For transformation from small cells to large cells in a different grid system or to polygons (geographic units), simple methods, such as adding small cells with the centre inside the new cell or polygon, or simple areal weighting (allocation proportional to area) are acceptable. National organizations should be encouraged to collect and stock geo-referenced data and with the maximum possible geographic detail.

Disaggregation

Although disaggregation can be made from statistical data on administrative units (NUTS) to a finer grid, data computation bottom-up (from detailed data to aggregated) is always preferable. If starting data are available only for large geographical units (large cells or polygons), re-allocation of data by methods such as simple area weighting should be avoided. The search of suitable co-variables (proxies) is a keypoint. For some data (e.g. data linked to biodiversity concerns: species and habitats/ecosystems) only available for large units, co-variables are difficult. In this case, analysis should be adapted to these units.

Who should make the conversion?

If data exist at a detailed scale and cannot be disseminated at that scale, the organization with access to these data should be in charge of aggregation to the common grid.

Is a common European grid possible?

The discussion between the participants came to the conclusion that the adoption of a common European grid for Reporting and Statistical Analysis is highly recommended and that such system should follow recommendations of previous workshops on Spatial Reference Systems and Map Projections. In addition the adoption of a common system must have a minimum impact on existing systems and should be mainly considered as a way to avoid proliferation and obtain a conversion in the future (when possible and appropriate).

The complex issue of a European grid for data collection (and sampling) was considered.

Among possible obstacles related to the adoption of a common grid are the lack of European maps in a common projection system, the need for flexibility in sampling schemas, the need for documentation and tools supporting different grid operations. At the same time some communities seem sceptic that the new methods of data collection could be significantly changed in the near future (e.g. use of PDA with GPS, Galileo, ..).

Mainly for these reasons and also considering the very limited time to discuss this specific issue there was no agreement about common unique strategy for data collection. This topic requires further investigation and discussion in incoming months and should be one of the topics to be addressed in a future 2nd edition of the European reference grid workshop.

So the workshop participants agreed to focus their attention for a grid to be used only for reporting and spatial or statistical analysis. The following considerations refer only to the grid to be the used in this context. As identified by the workshop participant, the users (existing and potential) of a European common grid are respectively:

- the National Statistical Institutes
- the Scientific Community, National Research Institutes and NGOs making research on spatial phenomena
- Institutes and organisations involved in Cross-Regional and Trans-National Spatial Planning Projects/Processes
- Regional Convention (HELCOM OSPARCOM,…)
- The International Catchments River Basin Authorities
- Environmental Impact Assessment (particularly in cross-border areas), other example could be monitoring of Natura 2000 at biogeographic level
- European TEN
- The European Commission (DG ENV, DG REGIO, DG AGRI, DG TREN, DG FISH, ESTAT, JRC …)
- The EEA and other European Agencies and Organisations

To guarantee the correct management and handling of the collected information, the entire data flow has to be considered. This implies various steps/phases that need to be addressed and, if possible formalised and certified in case of adoption of a unique European grid of certified quality.

Data capture

This phase concerns the way in which data are originally collected. Only if quality principles are applied since the beginning it will be possible to obtain aggregated data of certified quality. This issue relates to both the digitization process in case of data available in paper form and the conversion process in case of data directly acquired in digital form but that need to be converted before their use.

Data cleaning or data validation

Data collected are often affected by errors, imprecision and redundancies. The validation phase is a prerequisite to assess the quality of the original data. Data cleaning is a way to improve the quality, in particular if connected to the possibility of re-acquiring data of lower quality.

Data simplification

This phase has been identified by the workshop as potentially critical if not well understood. In fact often the collected data are simplified to minimise the amount of information that must be handled. The simplification is driven by a specific application (user need) and does not take into account future needs that could require the access to not-simplified data.

Data management

Accurate data collection and validation is only one prerequisite for high quality data. Data management is often more critical than data collection. For example data acquired according to a specific geodetic datum are often transformed and store in a different datum without being aware that datum transformations introduce possible deformations. In addition, the importance of documenting data and all the applied processes and operations is often underestimated. The need to compile accurate Metadata is an important aspect that needs to be emphasised. Also the way to store the data often can alter their quality or limit the possibility to use and access them in the future. Time stamp management is an obvious example that requires a clear decision on the way to store and model the information (e.g. requiring object modelling and unique identifier)

Data sharing and interoperability

In the context of the emerging need of distributed systems addressed within the framework of the so called Spatial Data Infrastructures, emphasis is also on the possibility to share and interoperate grids collected by different organisations. In this context the adoption of a common grid is a important step to simplify this process. Having said that, the following recommendations were agreed:

- Original data should be maintained in the highest possible resolutions even if aggregation is required for dissemination or for particular applications.
- The whole data flow must be considered. ISO standards should be applied in the future to ensure the quality of new collected data and to describe unambiguously their quality.
- To reaffirm the recommendations of the December 2000 Workshop on Map Projection Systems, i.e. to adopt ETRS89 Lambert Azimuthal Equal Area coordinate reference system of 2001 [ETRS -LAEA], for statistical analysis and display for any new project affecting Europe or cross border areas (and when a equal area grid is appropriate).
- To ensure harmonised access to existing systems (when required) it is recommended to use appropriate documented (possibly certified) tools for data conversion and to take strong action to support the work of EUREF, EuroGeographics and the NMAs in collecting and making publicly available the definitions of various coordinate reference systems, and definitive transformation parameters between ETRS89 and national systems.

This proposed solution has several possible advantages:

<u>Facilitate integration</u>. It will be easier to combine "disaggregated" data using a common grid (with well known characteristics and appropriate certified conversion tools) and it will be also easier to exchange data using a common "non proprietary" data format.

<u>Non Proliferation</u>. The adoption of a common European grid will be an obstacle toward the proliferation of incompatible grid initiatives. Independently from the obligation to use it will easily become a reference for all new projects.

<u>Cross Border Areas</u>. A common European grid will facilitate the work not only for studies addressing the whole Europe but also for several studies on cross-border areas where there is a need to analyse and manage a territory going out of the national boundaries (e.g. the river basin management plans of the Water Framework Directive, the Trans-European Transport Network "TEN-T", the environmental impact assessment,...).

Amongst the potential disadvantages, it was considered that the obligation to adopt the system could potentially have an immediate economic/scientific impact, because it could require some efforts and investments for converting existing grids and for some of them, would possibly result in the loss of a part of the scientific values. Some participants also underlined that existing grids are in some cases regulated by existing International Conventions that could not change in a short time framework.

Standardisation and certification

The issue of standardisation and certification was also carefully investigated.

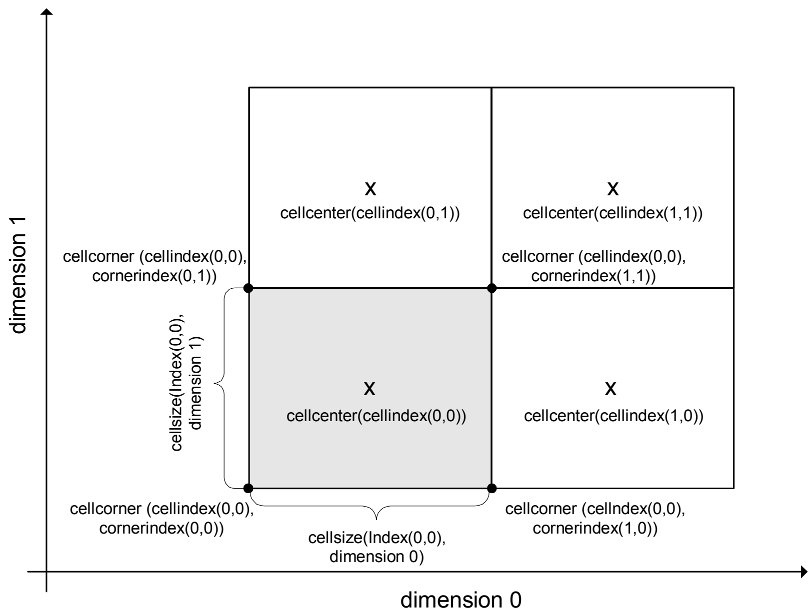
To obtain some kind of standardisation / certification the following issue must be considered..

The Grid Data Model should be as generic as possible and should be compatible with the ISO and CEN standardizations as well as the OpenGIS implementation specifications.

Following these guidelines the Grid Data Model should be as an object oriented conceptual data model, addressing the following issues:

1. Grid geometry and geometrical interpretation of the attribute data. Rectangular Grids, for instance, may be either cell-based or corner-based. In cell-based grids the thematic attributes are geometrically associated with the center of a grid cell and interpreted as an averaged cell value (see lower left cell in figure 2). Cell-based grids are mostly - but not only - used for categorical information (Molenaar 1998). In corner-based grids the thematic attributes are geometrically associated with a cell corner and interpreted as a value being valid for this specific point (see black points in figure 2). Thus corner-based grids are mainly used to model rational scaled information.

Figure 2 - Distinguish cell-based and corner based grids.



2. Structure (including encoding, compression methods used, etc.)

3. Properties (semantics). This is a difficult part and contains reference to the various grid definitions in use.

4. Methods for aggregation and disaggregation, compressing, etc. using the benefits offered by the object oriented approach (for an example see figure 3).

5. Support of 3D and temporal variations of the attribute data.

6. Geological applications for instance may need 3D-Grids and temporal variations (also considering temporal resolution) are relevant in several applications. The issue of 3D identifies the need to select a common geodetical vertical datum (EVRF2000 is a suitable candidate. This issue should be debated in the next EVRS workshop).

7. Multiscale and multilevel representation in a grid.

8. Needed Metadata (following the ISO Standards).

9. Encodings (GML, HDF, GeoTIFF, etc.).

We should also identify the procedures that are necessary to obtain standardisation and interoperability. In order to agree upon standardisation, Workshops and Expert Group meetings are necessary as well as consultation of other communities.

The link with CEN, ISO and OGC Technical Committees should be reinforced to address the following aspects:

- Are the existing Standards and Specifications a suitable and sufficient framework to describe the needed Grid Specification?
- How to introduce new specifications when needed?

Figure 3 - An object oriented approach avoids application of incorrect sampling methods.

Introduce semantic plausibility check using an object oriented approach:

Example of incorrect disaggregating as a result of a linear interpolation on categorical land cover data:

Source (water is blue, urban is red, etc.) Derived Data with artifacts

Example of semantic plausibility check in an object oriented approach:

```
class LinearGridPointSampler : public VgPointSamplerInterface {
public:
 bool init(VgGridInterface gridIn) {
   if (grid->descriptor()->scale() != VgFeatureDescriptorInterface::Ratio) {
     error ("Using linear interpolation requires ratio scaled data");
     return false;
   }
...
```

Dissemination and Communication

Dissemination of the results and proposals is important. We need to communicate results both inside the European Commission (providing for example guidelines and/or recommendation to COGI) and outside using the INSPIRE network. During the preparation phase of INSPIRE this activity should be considered as part of the work programme and outreach activities, whereas in the transposition phase the results should be proposed for approval by means of comitology procedures. Access to the information on available grids (definition, transformation, user groups, etc.) should be provided though a dedicated website or in a dedicated section of the INSPIRE web site[16].

Implementation - First steps required to make a common grid successful

We need to encourage data providers (National Statistical Institutes) to provide data in the common grid. This generally implies an additional burden for data providers.

To stimulate data providers two actions are needed:

- Facilitate the task, especially for teams that do not often use GIS, providing user-friendly tools for data projection, visual checking of projections, data aggregation, etc.
- Show the interest with a number of spatial analysis applications with data that can be made available in a common grid at short term.

The implementation of a website as central information point has been identified as the key tool for this purpose. This website should give free access to all needed information to support the dissemination of the common grid to the greatest possible extent. Such a website should contain at least the following elements:

- Precise definition of the grid, datum, projection parameters, indexing system.
- Recommendations on best practices for data conversion to the grid and reports on methods.
- User-friendly tool for co-ordinate transformation into the projection of the grid, including visual check of the results.
- Reports on spatial analysis performed with data on the common grid.
- Online survey on potential users to identify the most widely requested layers: population, environmental features (e.g. Natura 2000 information simplified to a grid), CLC2000, agricultural and other economical statistics, etc.).
- Providing freely available services, following international standards, and accessible in a user-friendly way, to:
    - Download grid templates in several GIS-formats (sensu stricto; without thematic information).
    - Visualize grids using an OpenGIS compliant Web Map Service supporting different scales and projections (Lat-Long, LAEA, LCC, UTMzn)
    - Transform grids from different projection systems into a common system and to visualize the results using an OpenGIS compliant Web Coordinate Transformation Service, that is linked to the Web Map Service mentioned above.
    - Search for existing data using the suggested grid and getting access to appropriate metadata, including contact points and conditions to have access to the data using an OpenGIS compliant Web Catalogue Service.

It would be good that European Institutions take the lead by inserting the links to information concerning the available pan-European or EU layers.

The implementation process should be also supported by measures that realize:

- Quality checks of needed tools in form of a certification.
- Dissemination of software libraries to support the installation of the needed grid tools.

[16] http://inspire.jrc.it

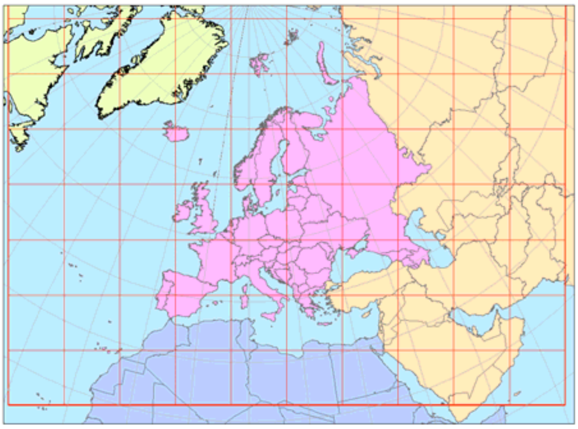
Final Recommendations

Considering the recommendations of the previous workshops, this workshop recommends:

1. To reaffirm the recommendations of the Spatial Reference Systems workshop [2]:
   - To adopt **ETRS89**[17] as geodetic datum and to express and store positions, as far as possible, in ellipsoidal coordinates, with the underlying GRS80[18] ellipsoid [ETRS89].
   - To further adopt EVRF2000 for expressing practical heights (gravity-related).
   - To identify coordinate reference systems and transformations in the format required by International Standard **ISO 19111**.

2. To reaffirm the recommendations of the Map Projection Systems Workshop [1], i.e. to adopt the following map projections to supplement the ellipsoidal system:
   - To adopt ETRS89 Lambert Azimuthal Equal Area coordinate reference system of 2001 [ETRS-LAEA], for **spatial analysis and display**.
   - To adopt ETRS89 Lambert Conic Conformal coordinate reference system of 2001 [ETRS-LCC] for conformal pan-European mapping at scales smaller or equal to 1:500,000.
   - To adopt ETRS89 Transverse Mercator coordinate reference systems [ETRS-TMzn], for conformal pan-European mapping at scales larger than 1:500,000.

Figure 4 - The LAEA extent



Considering that:

- A specific system for grid points seems to be not necessary and the first recommendation should be applied for storing point coordinates,
- A hexagonal grid is not supported by the current conception of raster mode (as implemented in software available on the market for grid analysis),
- Efficient Spatial Indexing technology is now available (a quadtree structure is no more a prerequisite for efficient data handling),
- Equal area grids based on geographical coordinates (e.g. authalic latitudes) have not been considered because such kind of grids will be difficult to manage on the level of the user as wella as on the data capture level[19].

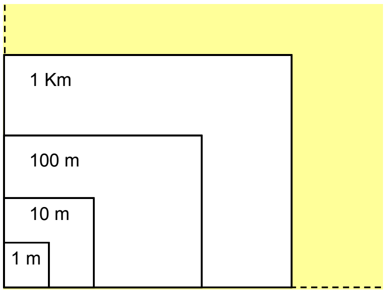
[17] European Terrestrial Reference System 1989
[18] Geodetic Reference System 1980
[19] Considering that Equal Area is important, but also Equal Distance and Equal Angles are relevant a grid in geographical coordinate is less appropriate than the selected one.

The workshop also recommends:

3. To adopt a common European Grid Reference System for Reporting and Spatial Analysis. The system should be able to store regular grids and should be designed as reference for future Grids related to European territory. The system must satisfy the following principles:

    - The system should be simple for users (**easy to manipulate**) and should be designed in a way that GIS system (in the market) can support it.
    - The system should be **hierarchical**. This will allow data storage at different levels of resolution. This structure should be linked to the Coding System and should make use of Spatial Indexing capabilities of the Modern Geo-Spatial Data Bases. A hierarchical metric structure is proposed for testing (figure 5).

Figure 5 - Hierarchic principle of data structure



    - The system should adopt a common **European Grid Coding System**. This is a strict requirement for the interoperability of distributed GRID databases and as well to support the capability to link applications within Europe. A Coding System has been proposed (see Proposal for a European Grid Coding System in this book).
    - The system should have a **clear and simple relation to the coordinate reference systems** recommended by the Spatial Reference and the Map Projections workshops in Marne la Vallee [1][2].
    - The purpose of the European Grid Reference System is **primarily for analysis**, and **inventorying** of phenomena with a geographic reference. For this reason the coverage must be uniform and that every element of area must have an equal probability of entering the system. This suggests that the European Territory should be partitioned into units of equal area.
    - For the reasons above **it is proposed to build the system using the European Coordinate Reference System ETRS-LAEA**.
    - In building the system the **quality principles** described in **ISO 19113-11915** should be followed.
    - **Time stamp is a prerequisite of the system.**
    - The grid data model should be documented and made available using XML schema.
    - The format of grid data outputs should be based on non proprietary open format.
    - **Metadata are a indispensable component of any future grid system** based on the European Grid Reference System. Metadata should follow ISO specifications and be produced both to describe each specific Grid (Grid-Metadata) and to describe information related to a specific unit of the Grid (Record-Metadata).

The workshop further recommends:

4. For **converting to and from existing grid structures**, it is highly recommended to generate data from the original detailed information.

5. To test for a period of one year ETRS –LAEA with the aim to demonstrate benefits of the proposed solution, identify and eventually develop tools, establish technical guidelines and best practice examples to **support the convergence of existing grids** or new future projects making use of European grids and to help in **ensuring the future on-line interoperability of existing Grid systems** at European and National level (GRID Net) by providing examples of best practices and technical guidelines to be followed in establish conversion/transformation procedures.

6. To support the technical development of the proposed solution after the workshop[20].

7. To continue the process of educating the users of geographic information in the complex issues associated with coordinate reference systems, map projections, grids, transformations and conversions, including working with software and system suppliers to enable 'on the fly' transformations between commonly-used coordinate reference systems.

How can convergence in the future be achieved?

The discussion focused on the measures to be accomplished in near future for assessing the impact of the adoption of the proposed grid, to identify and remove any eventual bottlenecks and to facilitate the use through the preparation of technical guidelines and the setting-up of all necessary components and services.

For this reason the discussion was focused on setting-up a draft Action Plan for the European Grid initiative as originally foreseen.

Action Plan

1. Disseminate results and involve all stakeholders to achieve a broader consensus about the selected standards. The responses of the following communities should be coordinated by the respective umbrellas, organisations ,..,..:
   - National Statistical Institutes (responsible : Nordvic Project coordinator or Eurostat)
   - ESPON Network (responsible : ESPON Coordinator)
   - National Mapping Agencies (responsible: EuroGeographics)
   - EUREF (responsible : BKG)
   - National Geological Institutes (responsible : EuroGeoSurveys)
   - EIONET and ETCs (responsible : EEA)
   - National Soil Institutes (responsible : ESB Net + JRC-IES-SW unit)
   - CAP requirements (responsible : JRC-IPSC-MARS unit)
   - GI community in a broader sense (responsible : EUROGI)
   - Research Organisations such as EuroSDR, AGILE (responsible: JRC-IES)
   - European Commission (responsible : COGI, GISCO User Committee) ...

2. Setting up a specific Test Bed including the Demonstrator making profit of the on going development of the Nordvic Project (responsible: Nordvic Project coordinator)
   - The Nordvic team should prepare a Action plan for integration (responsible : Nordvic Team, Deadline: end 2003)
   - The candidate partners that shoul be involved in the test bed having European or National grid systems in place have to be identified (responsible: all workshop participants, Deadline: end January 2004)

[20] in collaboration with on going relevant initiatives (e.g. the Nordvic project) that could be used as Pilots of the proposed standard.

- Link and coordination with standardisation bodies including careful evaluation of proposed ISO, OGC standard models for Grid (responsible : JRC-IES-LMU)
    - Workshops / expert group
    - Hearing in other communities
    - ISO TC 211 – OGC, CEN/TC 287
    - Introducing new specs when needed
- A first version of the prototype system should be available for discussion at mid of June. It could be presented in the occasion of the 10th EC GI-GIS workshop
- The final version of the Prototype System should be available at the end of 2004

3. The Information System for European Coordinate Reference Systems –CRS Internet Portal - developed by BKG, EUREF and EuroGeographics should be improved and made available for the test base.
    - It will be important to collect feedback from users, GIS industry and application providers. Such feedback should make possible to identify possible areas of improvement
    - The current system needs to be revised to better support interoperable services such as for example Web coordinate transformation services ISO compliant
4. The second edition of the European Reference Grid should be organised in about one year when the first results of the Pilots will be available. The topics of the second edition should be identified. The following topics are currently proposed (other topics could be proposed during a broad consultation):
    - European Reference Grid for Data Collection
    - How can convergence in the future be achieved.
5. The development of the INSPIRE initiative should be closely followed and the Action Plan should be revised (when appropriate) o take into account new INSPIRE requirements and to synchronise with the development of INSPIRE technical specifications (responsible: JRC-IES-LMU).

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[4] Claude GRASLAND, Hélène MATHIAN, Jean-Marc VINCENT , Multiscalar analysis and map generalisation of discrete social phenomena: statistical problems and political consequences

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[7] Waldo R. TOBLER, Smooth Pycnophylactic Interpolation for Geographical Regions

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Annex 1 - Description sheet for ETRS-LAEA

This chapter contains the description of ETRS89 Lambert Azimuthal Equal Area Coordinate Reference System (ETRS-LAEA) with details and structure following ISO standards (as specified by the Map projection workshop 2000).

The European Terrestrial Reference System 1989 (ETRS89) is the geodetic datum for pan-European spatial data collection, storage and analysis.

This is based on the GRS80 ellipsoid and is the basis for a coordinate reference system using ellipsoidal coordinates. For many pan-European purposes a plane coordinate system is preferred. But the mapping of ellipsoidal coordinates to plane coordinates cannot be made without distortion in the plane coordinate system. Distortion can be controlled, but not avoided.

For many purposes the plane coordinate system should have minimum distortion of scale and direction. This can be achieved through a conformal map projection. The ETRS89 Transverse Mercator Coordinate Reference System (ETRS-TMzn) is recommended for conformal pan-European mapping at scales larger than 1:500 000. For pan-European conformal mapping at scales smaller or equal 1:500 000 the ETRS89 Lambert Conformal Conic Coordinate Reference System (ETRS-LCC) is recommended.

With conformal projection methods attributes such as area will not be distortion-free. For pan-European statistical mapping at all scales or for other purposes where true area representation is required, the ETRS89 Lambert Azimuthal Equal Area Coordinate Reference System (ETRS-LAEA) is recommended.

The ETRS89 Lambert Azimuthal Equal Area Coordinate Reference System (ETRS-LAEA) is a single projected coordinate reference system for all of the pan-European area. It is based on the ETRS89 geodetic datum and the GRS80 ellipsoid. Its defining parameters are given in Table 1 following ISO 19111 Spatial referencing by coordinates.

With these defining parameters, locations North of 25º have positive grid northing and locations eastwards of 30º West longitude have positive grid easting. Note that the axes abbreviations for ETRS-LAEA are Y and X whilst for the ETRS-LCC and ETRS-TMnz they are N and E.

Table 1 – ETRS-LAEA Description

Entity	Value
CRS ID	ETRS-LAEA
CRS alias	ETRS89 Lambert Azimuthal Equal Area CRS
CRS valid area	Europe
CRS scope	CRS for pan-European statistical mapping at all scales or other purposes where true area representation is required
Datum ID	ETRS89
Datum alias	European Terrestrial Reference System 1989
Datum type	geodetic
Datum realization epoch	1989
Datum valid area	Europe / EUREF
Datum scope	European datum consistent with ITRS at the epoch 1989.0 and fixed to the stable part of the Eurasian continental plate for georeferencing of GIS and geokinematic tasks
Datum remarks	see Boucher, C., Altamimi, Z. (1992): The EUREF Terrestrial Reference System and its First Realizations. Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Heft 52, München 1992, pp 205-213 - or - ftp://lareg.ensg.ign.fr/pub/euref/info/guidelines
Prime meridian ID	Greenwich
Prime meridian Greenwich longitude	0°
Ellipsoid ID	GRS 80
Ellipsoid alias	New International
Ellipsoid semi-major axis	6 378 137 m
Ellipsoid shape	true
Ellipsoid inverse flattening	298.257222101
Ellipsoid remarks	see Moritz, H. (1988): Geodetic Reference System 1980. Bulletin Geodesique, The Geodesists Handbook, 1988, Internat. Union of Geodesy and Geophysics
Coordinate system ID	LAEA
Coordinate system type	projected
Coordinate system dimension	2
Coordinate system axis name	Y
Coordinate system axis direction	North
Coordinate system axis unit identifier	metre
Coordinate system axis name	X
Coordinate system axis direction	East
Coordinate system axis unit identifier	metre
Operation ID	LAEA
Operation valid area	Europe
Operation scope	for pan-European statistical mapping at all scales or other purposes where true area representation is required
Operation method name	Lambert Azimuthal Equal Area Projection
Operation method formula	US Geological Survey Professional Publication 1395, "Map Projection – A Working Manual" by John P. Snyder.
Operation method parameters number	4
Operation parameter name	latitude of origin
Operation parameter value	52° N
Operation parameter name	longitude of origin
Operation parameter value	10° E
Operation parameter remarks	
Operation parameter name	false northing
Operation parameter value	3 210 000.0 m
Operation parameter remarks	
Operation parameter name	false easting
Operation parameter value	4 321 000.0 m
Operation parameter remarks	

Conversion formulas

To derive the projected coordinates of a point, geodetic latitude (φ) is converted to authalic latitude (β). Formulas[21] to convert geodetic latitude and longitude (φ,λ) to northing (Y) and easting (X) are:

northing, $Y = FN + (B / D) . \{(\cos \beta_0 . \sin \beta) - [\sin \beta_0 . \cos \beta . \cos (\lambda - \lambda_0)]\}$

easting, $X = FE + \{(B . D) . [\cos \beta . \sin (\lambda - \lambda_0)]\}$

where

$B = R_q . (2 / \{1 + \sin \beta_0 . \sin \beta + [\cos \beta_0 . \cos \beta . \cos (\lambda - \lambda_0)]\})^{1/2}$

$D = a . [\cos \varphi_0 / (1 - e^2 \sin^2 \varphi_0)^{1/2}] / (R_q . \cos \beta_0)$

$R_q = a . (q_p / 2)^{1/2}$

$\beta = \arcsin (q / q_p)$

$\beta_0 = \arcsin (q_0 / q_p)$

$q = (1 - e^2) . ([\sin \varphi / (1 - e^2 \sin^2 \varphi)] - \{[1/(2e)] . \ln [(1 - e \sin\varphi) / (1 + e \sin\varphi)]\})$

$q_0 = (1 - e^2) . ([\sin \varphi_0 / (1 - e^2 \sin^2 \varphi_0)] - \{[1/(2e)] . \ln [(1 - e \sin\varphi_0) / (1 + e \sin\varphi_0)]\})$

$q_p = (1 - e^2) . ([1 / (1 - e^2)] - \{[1/(2e)] . \ln [(1 - e) / (1 + e)]\})$

and where

a	ellipsoidal semi-major axis, 6378137.0 metres
f	flattening of the ellipsoid where 1/f = 298.2572221
e	eccentricity of the ellipsoid where e2 = 2f – f2
φ	latitude of the point to be converted, positive if North and negative if South of the equator
λ	longitude of the point to be converted, positive if East and negative if West of the prime meridian (Greenwich)
φ0	latitude of the natural origin
λ0	longitude of the natural origin (with respect to the prime meridian Greenwich)
X	easting measured from the grid origin
Y	northing measured from the grid origin
FE	false easting, the eastings value assigned to the natural origin
FN	false northing, the northings value assigned to the natural origin

The reverse formulas to derive the geodetic latitude and longitude of a point from its northing and easting values are:

$\varphi = \beta' + [(e^2/3 + 31e^4/180 + 517e^6/5040) . \sin 2\beta'] + [(23e^4/360 + 251e^6/3780) . \sin 4\beta'] + [(761e^6/45360) . \sin 6\beta']$

$\lambda = \lambda_0 + \arctan \{(X-FE) . \sin C / [D. \rho . \cos \beta_0 . \cos C - D^2. (Y-FN) . \sin \beta_0 . \sin C]\}$

where

$\beta' = \arcsin\{(\cos C . \sin \beta_0) + [(D . (Y-FN) . \sin C . \cos \beta_0) / \rho]\}$

$C = 2 . \arcsin(\rho / 2 . R_q)$

$\rho = \{[(X-FE)/D]^2 + [D . (Y - FN)]^2\}^{1/2}$

and D, R_q, and β_0 are as in the forward equations.

Table 2 – Examples

ETRS89		*ETRS-LAEA*	
geodetic latitude	*geodetic longitude*	*northing (Y)*	*easting (X)*
50°00'00.000" N	5°00'00.000" E	2999718.85 m	3962799.45 m
60°00'00.000" N	5°00'00.000"E	4109791.66 m	4041548.12 m

Caution

All EU projections are based on ETRS89 datum and therefore use ellipsoidal formulas. In some GIS applications the Lambert Azimuthal Equal Area method is implemented only in spherical form. Geodetic latitude and longitude must not be used in these spherical implementations. To do so may cause significant error (up to 15 km !). Use the example conversions above to test whether software uses appropriate formulas.

[21] Source: US Geological Survey Professional Publication 1395, “Map Projection – A Working Manual” by John P. Snyder.

Annex 2 - Abstracts

The ICP-Forests sampling scheme

Javier Gallego

The International Co-operative Programme on European Forest (ICP-Forest) was launched in the 80's as a response to the concern on the impact of pollution on the health state of forest. Tree defoliation and decolouration of leaves is observed every year on a sample of plots. The sampling scheme is systematic, theoretically based on a regular grid of 16 km. The practical application of the sampling rules has been rather heterogeneous in different countries. This presentation[22] analyses the difficulties arisen to use this sample for statistical or spatial analysis.

LUCAS: monitoring the European Union territory using a grid approach

Manola Bettio, Maxime Kayadjanian

LUCAS is a pilot project launched by Eurostat in close co-operation with the DG Agriculture and the Joint Research Centre. LUCAS is an area frame statistical survey that aims at obtaining harmonised data at EU level on land use, land cover and environment. The survey consists in the ground visit in springtime of about 100 000 points sampled according to a regular grid. The paper gives an overview of the methodology and the results of the survey that was carried out in 2001 and in 2003. In more details, the sampling plan design, its geometrical quality as well as precision of point location on the ground are reviewed.

Towards participatory approaches to a Multiscale European Soil Information System

Nicola Filippi, Panagos Panos, Borut Vrscaj

The multi-functionality of soils, as medium for biomass production, biochemical cycling, water storage and its filtering and redistribution, as well as gene pool and habitat of a high diversity of life forms, is increasingly being understood and valued. In the EC Communication "Towards a Thematic Strategy for Soil Protection" it is recognised that there is an actual and future need for better information on the soil resources, and that the current state of soil resource information is often incomparable between member states and regions.

EU regional policy and grids

Hugo Poelman

In EU regional policy, geographic data are mainly used within the framework of statistical regions, but indicators developed out of georeferenced data sources are also needed. Specific territories need to be defined and analysed at various non-administrative levels. Hence, grids can be used as a framework for data collection and analysis. Results of raster-based analysis will often have to be converted to the regional framework. Recent grid uses include the definition of mountain areas, use of land cover data, and the development of regional typologies. Future grid systems will have to enable efficient aggregation and disaggregation. European-wide raster data sets should be defined in a coherent way, and should be compatible with register-based national statistical systems.

[22] http://gi-gis.jrc.it/ws/grid2003/ICP Forest EuroGRID.ppt

The ESPON 2006 Programme

Volker Schmidt-Seiwert

The ESPON (European Spatial Planning Observation Network) programme[23] is implemented within the framework of the Community Initiative INTERREG III. Thematic oriented transnational project groups deal with the diagnosis of the principal territorial trends, difficulties and potentials within the European territory in order to improve the spatial co-ordination of sector policies. The projects are roughly divided into: i) Thematic studies on important spatial development, ii) Policy impact studies, iii) Coordinating cross-thematic studies.

The final results will produce cartographic pictures of the major territorial disparities and of their respective intensity; a number of territorial indicators and typologies assisting a setting of European priorities for a balanced and polycentric enlarged European territory; some integrated tools and appropriate instruments (databases, indicators, methodologies for territorial impact analysis and systematic spatial analyses). The range of topics from urban-rural relations, accessibility, structural funds and CAP to cultural assets just to mentioned a few, show, that regional statistical data only will not satisfy the demand on data. Geographical data (grids) must be used in this cases to guarantees at first to get data at all and second in a harmonized form on the European territory.

Current use of spatial reference grids in EEA

Andrus Meiner

This paper gives an overview of current use of spatial reference grids in EEA main products: EMEP grids for air pollution and deposition, UTM based grids for biodiversity mapping, equal area grids with different resolution for land cover assessments, lat/long grids for variety of other uses. It outlines the points of main interest of EEA in development of common European reference grid, seeing this as support to European Spatial Data Infrastructure development and the INSPIRE initiative.

Atlas Florae Europaeae – Mapping European Vascular Plants with 50X50 Km grid

Pertti Uotila and Raino Lampinen

Atlas Florae Europaeae (AFE) is a pan-European project for mapping the distribution of the vascular plants of the continent. The project was launched in 1965, and has so far produced 3270 grid maps of the distribution of European vascular plants in 12 printed volumes (1972 – 1999), covering c. 20% of all the European vascular plants. The project has collaborators throughout Europe, and the secretariat editing the data is located in Helsinki. In this paper a short description is given of current and previous *Atlas Florae Europaeae* grids, mostly based on 50 x 50 km cells. The difficulty in converting the grid to the proposed common European grid is emphasized.

The TANDEM project

Lars Backer

The Consortium of three members (from Statistics Finland, Statistics Sweden and the Office of National Statistics, UK) studied the feasibility of a common base for statistics across Europe. The report of the first phase of the study is published via Eurostat web-pages (http://europa.eu.int/comm/eurostat/Public/datashop). The second phase of the study will be reported by the end of November 2003. The presentation will cover the basic ideas of the Tandem consortium including a vision to develop a System of Small Area Statistics integrated into the European Spatial Data Infrastructure. The focus of the presentation[24] will be on ideas concerning a regular tessellation approach (grid approach).

[23] http://www.espon.lu/online/homepage/index.html
[24] http://gi-gis.jrc.it/ws/grid2003/On%20Tandem_2.pps

Mapping and analyzing the distributions of plant species across the countries of Europe − an overview of research schemes and grid systems in use

Harald Niklfeld

The distribution patterns of native plant species concern many issues of botany, biogeography, ecology, and conservation, and have become subject to manifold comparative and causal analyses. Therefore, floristic mapping schemes were launched throughout many regions of Europe, mostly using grid cells of various types as topographical reference units. Thousands of botanists were, and are, engaged in field-work, computer databases were established, and a considerable number of distribution atlases have been published or are in progress. Wide territories, particularly of northern, western and central Europe, but also some regions of Spain and Italy are already covered by such schemes, which here are shortly reviewed..

The grid reference system used for CGMS

Giampiero Genovese

The MARS Stat Action of the JRC has been using since 1992 a reference grid system within the CGMS (Crop Growth Monitoring System). The basic function is to serve the agrometeorological analysis at European scale allowing meteorological data interpolation. Crop growth simulation calculation are made at Elementary Mapping Unit level and stored at grid-cell level. The resulting parameters are organized in a DB and further analyzed in near real-time.

Hexagonal tessellations to sample sites for the assessment of tropical forest change

Javier Gallego

The TREES Project made an estimation of the change in tropical rainforest between 1990 and 1997. Forest change was carefully mapped and quantified on a sample of 100 sites. Each site corresponded to a Landsat-TM frame or quarter of frame. The tropical belt was stratified using a coarse forest map and deforestation hot spots delineated by a group of regional experts. The units for stratification were hexagonal tiles of a spherical tessellation. Hexagons were linked with Landsat observation units. The sampling scheme allowed the computation of forest change estimates with their precision and confidence intervals. However the use of hexagonal tessellations, that can provide a good tool for global sampling frames, was not necessary in this case and it introduced additional complication and reduced the efficiency of the procedure.

The European Datum ETRS89 and its Realization

Johannes Ihde

With the Spatial Reference Workshop 1999 and the European Map Projection Workshop 2000 the basis for the introduction of uniform European coordinate reference systems was established. Four coordinate reference systems are intended for the use of referencing of geoinformation in the European Commission. The basis for these pan-European spatial reference systems are the European datum ETRS89 and the realization by the European GPS Permanent Network EPN.

Transformations between Geodetic Datum, Map Projections and Geographical Grids in Geodesy and Geoinformation

Johannes Ihde

The transformation of coordinates, which refer to different geodetic datum and map projections, is a standard task for the referencing of geoinformation and one of the basic tasks of geodesy. Principles of transformation, conversion of coordinates and information transfer that are dedicated to grids or compartments are being described and discussed. An outlook for the further development of the existing information system for European coordinate reference systems will be given.

Grid estimation. Application to datum distortion modelling

Javier González-Matesanz

In this communication, three methods of estimating grid values from scattered data are presented: Rubber Sheeting, Minimum Curvature Surfaces and Least Squares Collocation. These methods have been employed successfully in grids of datum transition models in other countries as Canada or Australia. The first part of this presentation consists on explaining very detailed the methods and the second one is an application to allow an effective change between classical datums (as ED50) and ETRS89, a datum distortion concept is needed in grid format.

Direct transformations between neighbour TM systems

Jorge Teixeira Pinto

In boundaries regions overlapping adjacent Transverse Mercator zones there are, sometimes, the need to transform coordinates of points from one TM zone to the other. This transformation is normally performed in a two-step conversion: from TM (zone1) to geodetic (Lat.; Long.) and from geodetic to TM (zone2). These conversions can be made without uncertainty, preserving, the initial coordinates precision, if the two regions shares the same Datum. If not, the transformation will be done with some degree of uncertainty. In this paper we will deal with some direct methods to transform the TM coordinates between adjacent zones, loosing some precision, but without performing the conversions to geodetic and back to TM.

The Design and Introduction of a New Map Projection and Grid System for Ireland

Ken Stewart

Ireland's current mapping grid is based on observations and computations dating from the nineteenth century. This means that accurate measurements including those made using the Global positioning System (GPS) have to be distorted to fit the grid. In addition, the use of different reference surfaces leads to further complexity, potential inaccuracy, and difficulty in combining data sets. The paper describes how OSNI and OSi, the national mapping agencies responsible for the mapping of the island of Ireland, are developing the positioning infrastructure and the mapping grid for the island. The varying requirements of different groups of users can create conflicting demands and the paper discusses how OSi and OSNI have met the needs of users.

Very High Resolution Raster Digital Data: Datasets for the Common Agricultural Policy

Simon Kay

The Common Agricultural Policy manages the payment of subsidies to farmers for the cultivation of land. In return for payment, farmers must identify their fields in national GIS databases. By 31st Dec 2004, 25 countries will have implemented this approach, and nearly all (23) will use high resolution orthoimage data as a primary data source. These raster datasets are both an important source for many grid based surveys, as well as an important consideration in the technical realignment of raster/gridded data with new, pan-European specifications.

Aggregation and disaggregation of statistics

Erik Sommer

Kort & Matrikelstyrelsen – KMS (the National Survey and Cadastre) and Statistics Denmark have in 2001 established a national system of vector grids, the so-called "National Square Grid – Denmark". The National Square Grid – Denmark is constructed in a rectangular system of coordinates, but it has been decided that it should refer to the UTM projection, zone 32. The datum used is EUREF89. This paper presents the work with statistical griddata in Denmark and an introduction to the work with griddata in a Nordic context.

In search of an infrastructure for spatial analysis

Lars Backer

In this paper we would like to discuss the special requirements on a system of grids from a users perspective, represented by spatial analysts working with statistics. There is a need for a clear awareness of "real" user needs in terms of spatial data. We suggest that inductive methods are needed that will reveal the need for both descriptive and analytic information for the design and implementation of central overriding projects like spatial development. In current efforts to provide a effective SDI for Europe (as in the case of INSPIRE), we stress the need for standard infrastructures suitable for spatial analysis. Much analytical work in this and related areas are based on information collected as points. In some cases however, data are collected as aggregations to a give set of small areas (irregular tessellations), that in turn may be analysed as clusters of (gravity-) points. For analytical purposes, irregular tessellations of this type are too large to be presented as surfaces, and are therefore generally represented as point clusters. A standard common system of grids for Europe represents therefore the main infrastructure needed for (point-based) spatial analysis. Its definition will therefore involve a series of design choices that should be based on the role they play in these user production processes (e.g.: data capture, data cleaning and pre-processing, analysis, integration with other data and dissemination etc.) Grids are widely used in all connections where point- based data are used as raw material for spatial analysis. We would like to suggest that the question of a system of grids suitable for spatial analysis could be discussed from a broader perspective (in windows larger than 1000 by 1000 km?) or a more narrow, limited perspective (involving windows smaller that 1000 by 1000km?).

Dissemination of grid-based statistics in Finland and a case study about dissemination of multinational grid data of the four Nordic countries

Marja Tammilehto-Luode

Statistics Finland has produced and disseminated data by geo-referenced 1 km x 1km grid squares (or smaller) more than ten years. Users of grid-based data have increased continuously. The presentation[25] includes review of how the grid data is produced and examples of studies where this kind of data has been applied. The other part of the presentation describes an effort to harmonise grid-based data of the four Nordic countries of Finland, Denmark, Norway and Sweden. It covers an effort to compile a multinational grid-based reference data and an effort to define common terms of releasing such a data. The experiences are based on the work of the Forum of the Nordic Geo-statistics and on the results of a survey made by Statistics Finland in December 2002.

The modifiable areal unit problem in the context of a standard

Javier Gallego

Data associated to territorial units, such as socio-economic, demographic or epidemiological data, can lead to different conclusions if the territorial units change. For example the correlation between variables often increases when data are aggregated to larger units.

Transforming data from an areal system to a different one often involves two steps: disaggregation into small units and re-aggregation. Disaggregation is always possible, but generally introduces a considerable inaccuracy. The quality of disaggregation depends above all on the quality of covariables used to guide the attribution of values to different units. If no covariables can be used, simple areal weighting is possible, but this option is not recommended in general.

[25] http://gi-gis.jrc.it/ws/grid2003/Gridstat2.ppt

Annex 3 - Represented bodies and organisations

DG Joint Research Centre (JRC)

The JRC is the European Union's scientific and technical research laboratory and an integral part of the European Commission. The JRC is a Directorate General, providing the scientific advice and technical know-how to support EU policies. Its status as a Commission service guarantees the independence from private or national interests, which is crucial for pursuing its mission. The JRC consists of seven different institutes, each with its own focus of expertise, on five separate sites around Europe. The aim of Institute for Environment and Sustainability (IES) is to provide scientific and technical support to European Union strategies for the protection of the environment contributing to a sustainable development. The combination of complementary expertise in the fields of experimental sciences, modeling, geomatics and remote sensing puts the IES in a strong position to contribute to the implementation of the European Research Area and to the achievement of a sustainable environment. The mission of Institute for the Protection and the Security of the Citizen (IPSC) is to provide research-based, systems-oriented support to EU policies so as to protect the citizen against economic and technological risk. The Institute also continues to maintain and develop its expertise in information, communication, space and engineering technologies. The JRC, through the action "European Spatial Data Infrastructure" (ESDI), has the task to technically coordinate the INSPIRE initiative and to shepherd it the various steps working towards the realization of a European Spatial Data Infrastructure.

DG Eurostat - GISCO

Eurostat is the Statistical Office of the European Communities situated in Luxembourg. Eurostat has for mission “to provide the European Union with a high-quality statistical information service”. Its task is to provide the European Union with statistics at European level that enable comparisons between countries and regions. Eurostat’s main role is to process and publish comparable statistical information at European level. We try to arrive at a common statistical ‘language’ that embraces concepts, methods, structures and technical standards. Eurostat does not collect data. This is done in Member States by their statistical authorities. They verify and analyse national data and send them to Eurostat. Eurostat’s role is to consolidate the data and ensure they are comparable, using harmonized methodology. Eurostat is actually the only provider of statistics at European level and the data we issue are harmonized as far as possible.

GISCO (Geographic Information System of the COmmission), is the sector of Eurostat responsible for managing the geographical reference database for the European Commission. Additionaly GISCO promotes and participates in Commission activities in the field of GI and GIS. Within the European statistical system, GISCO ensures standardisation and harmonisation in the exchange of geographical information between Members Staes and Eurostat.

DG Regional Policy

The Regional Policy Directorate-General is the department in the European Commission responsible for European measures to assist the economic and social development of the less-favoured regions of the European Union under Articles 158 and 160 of the Treaty. Supporting regional development is vital for stability in the European Union. The aim is to promote a high level of competitiveness and employment by helping the least prosperous regions and those facing structural difficulties to generate sustainable development by adapting to change in the labour market and to worldwide competition. The Regional Policy DG is in charge of the administration of three major funds: a) the European Regional Development Fund (ERDF), which operates in all 15 Member States; b) the Cohesion Fund, which assists environment and transport projects in the Member States whose GNI/head is below 90% of the Community average; c) the Instrument for Structural Policies for Pre-Accession (ISPA), which is assisting the central and eastern European candidate countries to improve the environment and develop their transport networks.

European Environment Agency (EEA)

The European Environment Agency (EEA) was launched by the European Union (EU) in 1993. The EEA mission' aims to support sustainable development and to help achieve significant and measurable improvement in Europe's environment, through the provision of timely, targeted, relevant and reliable information to policy making agents and the public.' The EEA is a European Union body but is open to non-EU countries that share its objectives. All 15 EU Member States have been Agency members since the start. The European Economic Area countries — Iceland, Liechtenstein and Norway — also joined from the beginning. Membership applications were received in the late 1990s from the 13 EU candidate countries in central and eastern Europe and the Mediterranean area. By 2003, they have become full EEA members following ratification of their membership agreements, making the Agency the first EU body to open its doors to the accession countries. EEA and its EIONET partners in 31 member countries comprise wide range of organisations who act as European Topic Centres, National Focal Points and National Reference Centres.

EUREF

EUREF (European Reference Frame) is the Regional Reference Frame Sub-Commission for Europe of IAG’s (International Association of Geodesy) Commission 1 Reference Frames. EUREF was established in 1987 at the IUGG/IAG General Assembly in Vancouver, Canada, as a continuation of the RETrig Sub-Commission. The purpose of EUREF is to focus on the variety of European control networks (horizontal or vertical) as well as their connections and evolutions by means of:

- an array of GPS permanent sites - the EUREF Permanent Network
- a network of high-precision geodetic reference sites determined by various GPS campaigns
- the computation of the vertical network (UELN – Unified European Levelling Network / EVRS - European Vertical Reference System) and its integration in the European Vertical GPS Reference Network (EUVN)
- an integrated network of space and gravity technologies (ECGN - European Combined Geodetic Network).

The forum where these activities are discussed and decisions are taken is the annual symposium, organized since the EUREF foundation. The annual symposia are usually attended by more than 120 participants coming from more than 30 member countries in Europe. Current activities are governed by the Technical Working Group (TWG).

EuroGeographics

EuroGeographics is the organization that pools together the skills, information and experience from its members, currently 43 of the National Mapping and Cadastral Agencies from 40 European countries. EuroGeographics, the 2001 merger of CERCO and MEGRIN, builds on 23 years of active collaboration between the European NMCAs, and is the well recognized and trusted voice of Europe’s national main custodians of geographic Reference Data. EuroGeographics is developing products and services that address problems – at the technical as well as at legal and business levels – such as non-matching datasets and incompatible cross-country topographic information. Its vision is to achieve interoperability of European mapping (and other GI) data and so, buy contributing to a major building block of the European Spatial Data Infrastructure, help the public and private sectors develop good governance, sustainable growth and benefit future generations.

The Bundesamt für Kartographie und Geodäsie (BKG)

The Federal Agency for Cartography anf Geodesy (BKG) is a German Federal authority. Its kernel tasks are to provide geodetic reference data and basic spatial data of the Federal Republic of Germany, to advise the Federal Government in the fields of geodesy and geoinformation as well as to safeguard the relevant interests of the Federal Government at the European and global level. BKG maintains the technical contacts with the National Mapping Agencies and other scientific institutions abroad. As a member of EuroGeographics it actively takes part in several European and international projects.

The BKG has the following central tasks:

- Serving as the executive secretariat of the Inter-Ministerial Committee on Geoinformation (IMAGI) which aim is to co-ordinate the application of geoinformation in the Federal administration;
- in the fields of cartography/geoinformation the BKG department Geoinformation has to edit, update and provide digital topographic data of Germany for all kinds of users. It contributes substantially to projects serving the setup and maintenance of European spatial data bases like SABE (Seamless Aministrative Boundaries of Europe), EuroGlobalMap, EuroRegioMap, EuroSpec and EuroGeoNames;
- in the geodetic field the provision and maintenance of the geodetic reference networks of the Federal Republic of Germany including the relevant surveying techniques and theoretical work on the acquisition and editing of the measuring data, and also the cooperation in bilateral and multilateral activities on the determination and updating of global reference systems as well as on the further development of the measuring and observation techniques employed. The national geodetic reference networks are part of European and global geodetic reference frames.

Instituto Geografico Portugues

The Portuguese Geographic Institute (IGP), integrated in the Ministry of the Cities, Order of the Territory and Environment, is the responsible organism for the execution of the politics of geographic information. Its creation occurred in 2002, supported for a decision of administrative modernization and consolidation of the public finances express in the Resolution of Cabinet nº 110/2001, of 10 of August. The IGP succeeded in all the extinct rights, obligations and attributions to the National Center of Informacao Geografica (CNIG) and Portuguese Institute of the Cartography and Cadastro (IPCC). IGP is the Portuguese National Authority on Geodesy, Cartography and Cadastre. The mission and the attributions of the IGP are consecrated in its Statutes, approved under the law 59/2002, of 15 of March."

Botanical Museum, Finnish Museum of Natural History

The Finnish Museum of Natural History is an independent institute of the University of Helsinki. Its Botanical Museum is the main scientific botanical institution in Finland holding ca. 3 million herbarium specimens of plants and fungi. The Botanical Museum also maintains a national distribution database of the Finnish flora, at the moment with ca. 3.7 million records. The secretary of the Committee for Mapping the Flora of Europe is located in the museum and produces the volumes of Atlas Florae Europaeae (AFE) on the basis of the distribution data provided by national collaborators throughout Europe.

Norwegian Mapping Authority

The Norwegian Mapping Authority (NMA) is a public management company under the Norwegian Ministry of Environment. The core activities include the principal task of creating and operating "Norway Digital", the national geographic information infrastructure. NMA coordinates cooperation with a wide range of partners (data owners) at local, regional and national levels. NMA handles geodesy, positioning services, national maps for land and sea, property information and has a separate division of sales - products and services.

European Topic Centre/Nature Protection & Biodiversity (ETC/NCB)

The European Topic Centre on Nature Protection & Biodiversity (ETC/NPB) is designated by the European Environment Agency (EEA) to assist in its work of collecting, analyzing, evaluating and synthesizing information relevant to national and international policies for the environment and sustainable development. The ETC/NPB supports also the implementation of the European Union network of sites designated by Member States under the Bird Directive and under the Habitats Directive. In the topic of Biodiversity Indicators and Monitoring, efforts are focused on two related tasks: definition of agreed Core Set of Indicators and cooperation and collaboration with other international initiatives. In relation with these activities, ETC/NPB has issued several major products such as the European Nature Information System (EUNIS) including both reference tools and databases to assess Europe major biodiversity issues. The ETC/NPB is involved, on behalf of the EEA, in various working groups, steering committees, fora of international or European programmes. This proves to be of major importance for the exchange of information and for maintaining and developing contacts with the network of experts, as a complement to EIONET.

Bundesamt für Bauwesen und Raumordnung (BBR)

The BBR (Federal Office for Building and Regional Planning) is Leadpartner of project 3.1 of the ESPON 2006 programme titled "Intergrated tools for the European spatial development"The project tasks include technical and analytical support and coordination (data-base, GIS and mapmaking, concepts and typologies for spatial analyses, spatial concepts), territorial and thematic coordination of the ongoing projects, preparation for the exploitation of results of all projects, the compilation and structuring of recommendations to further policy development in support of territorial cohesion, assistance in the promotion and networking of the ESPON programme and offering scientific support for the achievement of the objective of the ESPON 2006 Programme. The work of the BBR itself focuses on aspects of spatial planning, of building technology and of housing at the federal level. In this function it is also the contact partner for equivalent authorities in the international context. The scientific part of the BBR concentrates on departments I (Spatial Planning and Urban Development) and II (Building, Housing, Architecture). This part has been accepted as a federal research institution. Department I deals with research tasks and gives scientific advice to the Federal Government in the field of spatial planning and urban development. Important tasks are to draw up relevant spatial planning and urban development reports, to operate a spatial information system, to elaborate prognoses (e.g. population prognosis, spatial planning prognosis), to attend and evaluate research projects scientifically, to draw up reports and expert's reports, to implement and evaluate model projects of spatial planning and urban development, to issue publications as well as to carry out conferences. Department II mainly deals with housing aspects from the scientific point of view.

Autodesk

Autodesk is the world's leading design software and digital content company, offering customers progressive business solutions through powerful technology products and services. Autodesk helps customers in the building, manufacturing, infrastructure, digital media, and wireless data services fields increase the value of their digital design data and improve efficiencies across their entire project lifecycle management processes. For more information about the company, see www.autodesk.com.

Cyprus Department of Lands and Surveys

The Department of Lands and Surveys is a government department offering services in the areas of land registration, survey, cartography, valuation, state land management, tenure and administration. DLS is operating under the Cyprus Ministry of the Interior. DLS undertakes all the work associated with land registration, geodesy, topography, mapping, photogrammetry, hydrography, cadastral surveys, land tenure, land consolidation, management of state land, property valuation and the implementation of an integrated national GIS.

Ordnance Survey GB

Ordnance Survey is Great Britain's national mapping agency. It is responsible for surveying the constantly-changing British landscape and maintaining the master map of the entire country, from which it produces and markets a wide range of digital map data and paper maps for business, leisure, educational and administrative use. It operates as a self-financing Trading Fund wholly owned by the UK government with an annual turnover of around £100 million. The agency is currently implementing an ambitious e-strategy to enhance still further its services to customers.

Statistics Denmark

Statistics Denmark is Denmark's central statistical office and is responsible for the co-ordination of all official statistics concerning Denmark and Danish society. These statistics cover a broad spectrum of topics within the areas of population, business, industry, the environment and the economy.

Statistics has a long history in Denmark where the first population census was conducted in 1769. In 1850 Statistics Denmark was established as an institution, and the foundations of its present day activities are to be found in the Act on Statistics Denmark, which was adopted by Parliament in 1966. This Act gives an independent Board of Governors the responsibility to determine the institution's work programme. One important provision in the act is that it allows Statistics Denmark access to data from all public administrative registers in Denmark. These have now become the institution's principle data source.

Statistics Sweden (SCB)

SCB is a central government authority for official statistics and other government statistics and in this capacity has the responsibility for coordinating and supporting the Swedish system for official statistics. In order to supply the public, users and customers with good quality statistics to be used as a basis for decision-making, debate and research, SCB shall: i) develop, produce and disseminate statistics, ii) actively participate in statistical cooperation on an international level and iii) coordinate and support the Swedish system for official statistics. SCB refines data to statistical information through high methodological competence, broad knowledge of subject matter and modern technique. The statistics produced are impartial, relevant and of good quality, at the same time as being based on scientific principles. SCB facilitates the provision of data and protects collected microdata. In cooperation with others, SCB develops common statistical systems, both nationally and internationally.

Intergraph Corporation

Intergraph Corporation is a worldwide provider of technical software, systems integration, and professional services. Tools from Intergraph are used to acquire, analyze, share, reuse, and manage engineering and mapping data. This core data is linked to other workflow and business information – a linkage which leads to more informed decision-making and more efficient business operations for the life of a project.

The company's four core businesses address these markets:

- The design, construction, and operation of process and power plants, offshore rigs, and ships.
- Computer-aided dispatching and records management for public safety agencies and others.
- Information technology (IT) services and management consulting for government and commercial clients.
- Mapping, geographic information systems, map and chart production, earth imaging, and utilities and communications.

Founded in 1969 and headquartered in Huntsville, Alabama, Intergraph currently employs approximately 3,800 people. Intergraph products are sold in more than 60 countries.

Instituto Geografico Nacional de Espana (IGNE)

The Instituto Geografico Nacional de España is the Spanish Mapping Authority for Spain. It is integrated in the Ministry of Fomento and comprises: Geomatic, National Topographic Map, Geodesy and Geophysics as Subdirectorates the National Astronomical Observatory and the

National Centre for Geographic Information (CNIG). The IGNE have been working in cooperation with multitude of European /Pan European organisms as Eurogeographic, EUREF, IAG, IberoAmerican organizations etc in order to provide geographical data or geodetic infrastructures and technical cooperation in Geosciences areas and many other tasks in mapping, remote sensing, geophysical and standardization areas.

Vilnius Gediminas Technical University, Department of Geodesy

In 1990 the Vilnius Civil Engineering Institute became Vilnius Technical University, which on August 22, 1996 was awarded the name of Gediminas, Great Duke of Lithuania. At present the University has 8 faculties, Aviation Institute named after A.Gustaitis, International Studies Centre, Centre for Continuous Education, 4 research institutes and some laboratories. The Institute of Geodesy (Faculty Of Environmental Engineering) is active in the following research areas:

- Adoption of Lithuanian state system of geodetic coordinates
- Development of Lithuanian state EPS system, gravimetric network,vertical geodetic network
- Testing of Lithuanian territory geoid
- Application of GPS system
- Investigation of geodynamic processes
- Analysis of aerophotogrammetric methods
- Creation of geodetic base information system

Aero-Topografica, Lda

Aero-Topografica, Lda. is the oldest private company in Portugal, operating since 1951, providing services in the field of geo-engineering and geo-information.

UMS 2414 RIATE

The UMS 2414 RIATE is a common research unit established through a convention between three institutional partners: Centre National de la Recherche Scientifique (CNRS), Délégation à l'Aménagement du Territoire et à l'Action Régional (DATAR) and the University Paris VII (Department of Geography, History and Social Sciences). The UMS 2414 RIATE was established at the beginning of the year 2002 in order to fulfil three specific actions of common interest for scientific research and political actions:

- French Contact Point for ESPON 2006;
- Development of the networking between French and European teams working in the field of spatial planning. Diffusion and exchange of research documentations;
- Collection and diffusion of databases and maps useful for studies and political action in the field of European spatial planning.

The UMS 2414 RIATE has developed a common project with three research teams in geography (UMR Géographie-cités, Paris), parallel computation (ID-IMAG) and cognition (LSR-IMAG) in order to develop a software for interactive mapping called the Hypercarte Project. The methods of multiscalar spatial analysis and dynamic cartography proposed by the Hypercarte Project has already been successfully presented to many institutions in Europe (EUROSTAT, EEA) and France (DATAR, INSEE, IGN). The UMS 2414 can count on the support of the following research teams: UMR 8504 Géographie-cités, GDR LIBERGEO, LSR-IMAG, ID-IMAG. The UMS 2414 RIATE, besides its role as French Contact Point for ESPON 2006, is part of the ESPON 2006 Transnational Project Groups (TPG) 1.2.1, 3.1 and 3.2.

Annex 4 - Workshop Participants

Joint Research Centre (JRC) - Host and Organiser

Alessandro Annoni, JRC – IES

Javier Gallego, JRC – IES

Stephen Peedell, JRC – IES

European Commission

Maxime Kayadjanian, Eurostat

Manola Bettio, Eurostat

Albrecht Wirthmann, Eurostat

Hans Dufourmont, Eurostat

Hugo Poelman, DG Regional Policy

National Statistical Institutes

Erik Sommer, Statistics Denmark

Marja Tammilehto-Luode, Statistics Finland

Lars Backer, Statisics Sweden

National Mapping Agencies

Javier Gonzalez-Matesanz, IGN Spain

Mark Greaves, OS GB

Johannes Ihde, Federal Agency for Cartography and Geodesy

Arvid Lillethun, Norwegian Mapping Authority

Ken Stewart, OS Northern Ireland

Klito Demetriou, Department of Lands and Surveys Cyprus

Jorge Teixeira Pinto, Instituto Geografico Portugues

European Organizations/Agencies

Andrus Meiner, EEA

Sophie Condé, ETC/Nature Protection and Biodiversity –MNHN

Experts in Geodesy, Spatial Analysis, and Geo-Spatial data modeling

Raino Lampinen, Botanical Museum, Finnish Museum of Natural History

Liliane Lizzi, UMS 2414 RIATE (ESPON)

Harald Niklfeld, Institute of Botany, University of Vienna

Volker Schmidt-Seiwert, Bundesamt für Bauwesen und Raumordnung (ESPON)

Joao Torres, EUREF

Egle Tumeliene, Vilnius Gediminas Technical University, Department of Geodesy

Hermann Seeger

Pertti Uotila, Botanical Museum, Finnish Museum of Natural History

GIS Software Industry

Vladimir Spacek, INTERGRAPH

Stanislav Sumbera, INTERGRAPH

Michel Rives, Autodesk Europe, Middle-East & Africa Headquarters

JRC – others

Simon Kay, JRC – IPSC

Giampiero Genovese, JRC – IPSC

Nicola Filippi, JRC– IES

Tore Tollefsen, JRC – IES

Vanda Lima, JRC – IES

Michele Conti, JRC – IES

Panos Panagos, JRC – IES

Borut Vrscai, JRC – IES

Lars Bernard, JRC – IES

Proposal for a European Grid Coding System

Albrecht Wirthmann, Alessandro Annoni, Lars Bernard, Joanna Nowak

This proposal is based on the initial discussion during the workshop that continued during the preparation of the short proceedings. A decimal grid Coding System was initially proposed by Albrecht Wirthmann during the workshop. Successively during the consultation phase a second proposal was submitted by Mark Greaves. The discussion involved other experts (e.g. Lars Bernard, Andrus Meiner,.) and demonstrated the need to modify the initial proposals introducing additional levels in addition to the different hierarchical levels of the proposed decimal grid system.

After analysing advantages and disadvantages of different solutions we are now able to formulate a new proposal that needs to be tested on different applications before to be proposed for adoption as European specification for INSPIRE.

Basic assumptions and definitions

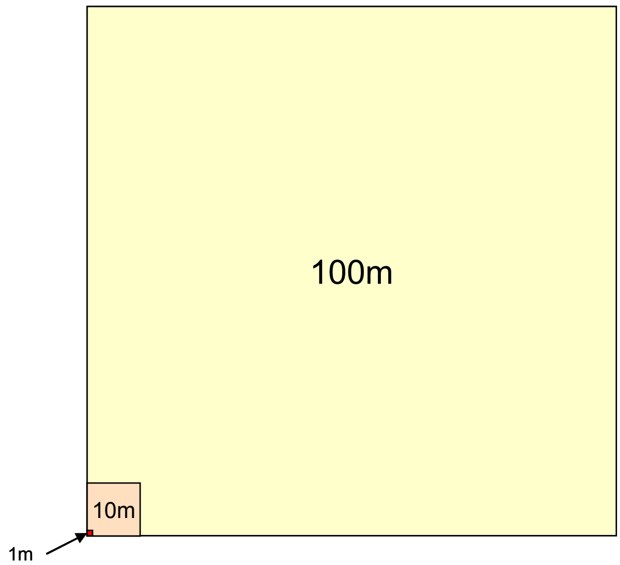
Coordinate Reference System

The geographical location of the grid points are based on the Lambert Azimuthal Equal Area coordinate reference system (ETRS-LAEA) as defined by the Spatial Reference and the Map Projections workshops in Marne la Vallee (1999, 2001)[26]. The cartographic projection is centred on the point N 52°, E 10°. The coordinate system is metric.

Hierarchical Structure

The grid is defined as hierarchical grid in metric coordinates in power of 10. The hierarchical structure is determining the structure of the grid coding system.

Figure 1 - Hierarchical grid structure for the first 3 levels



[26] Annoni A., Luzet C, Gubler E., hde J. (Eds.): Map Projections for Europe, A joint initiative of Eurogeographics and the Institute for Environment and Stability; Workshop 14-15 December 2000, Marne – La Vallée; Proceedings and Recommendations; European Commission EUR 10120 EN, 2003

Code Definition

In agreement with the workshop recommendations the coding system must satisfy the following principles:

- easy to manipulate,
- hierarchical,
- having a European Unique Code Identifier

For these reasons <u>all systems proposed in the following sections are based on the coordinates of the Grid</u>. For clarity all examples refer to the same given pair of “raw” coordinates (5780354, 436102) that are given in meters.

Ordering of Axes

It is assumed that the first coordinate (in the example 5780354) identifies the Easting of the point, i.e. the coordinate value along the west-to-east axis. The second coordinate (in the example 436102) identifies the Northing of the point, i.e. the coordinate value along the south-to-north axis.

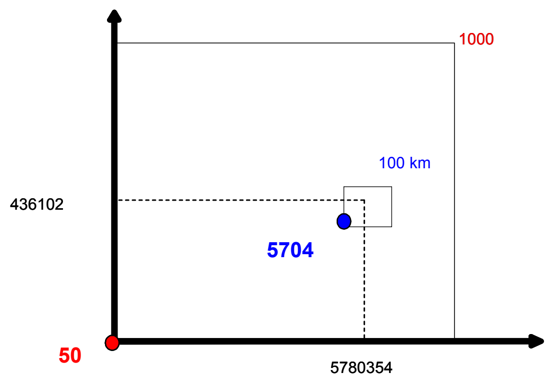
Grid code identifies south-western corner of a cell

To derive a code at an accuracy level that is less accurate than the one given by a pair of coordinates always a truncation method is used, i.e. the grid code coordinates for a coarser resolution are always describing the lower left corner of the cell that includes the given coordinates.

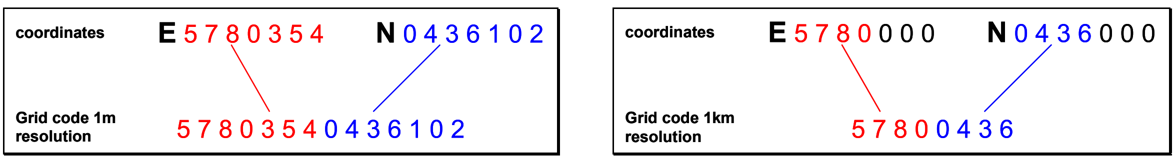
Direct Coordinate Coding System

The first coding system concatenates the coordinates of Easting and Northing of a grid point. The length of the coordinates defines the precision of the grid. A grid with a precision of 1 m would require a maximum of 7 digits by each dimension. The resulting code would have 14 digits. A grid with a precision of 1 km would be defined by a code comprising 8 digits. <u>Leading zeros are coded in order to preserve the precision information</u>.

Figure 2 - Direct Coordinate Coding System for 100 km & 1000 km resolution



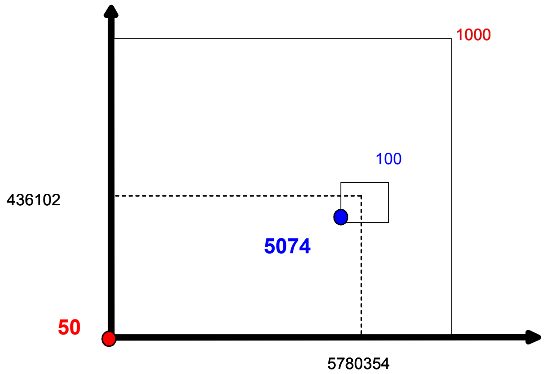
Taking the example coordinates grid codes with a resolution of 1 m and 1 km are respectively:



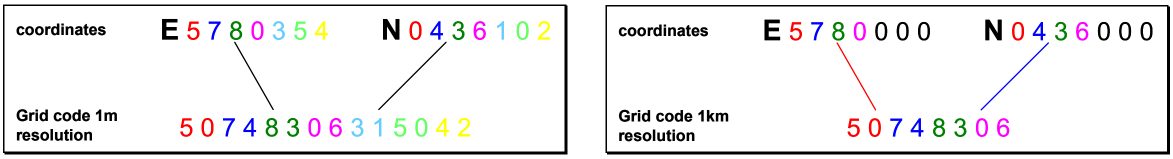
Resolution based Coordinate Coding System

The grid code is composed of the values for Easting and Northing. The figures are re-arranged according to their precision level. The Easting and Northing values on each precision level are paired. Changing to a higher grid level is done by simply deleting trailing digits.

Figure 3 - Resolution based Coordinate Coding System for 100 km & 1000 km resolution



With this second method of coding the grid codes with a resolution of 1 m and 1 km are respectively:



Both systems have an inherent hierarchy that reflects the hierarchy of the defined grid. The Resolution based Coordinate Coding System follows conventional statistical coding systems, which append additional figures or characters for defining a new hierarchical level. In this system traversing the figures from left to right, the user zooms from the top level to the specific cell on the lowest level (however, deriving co-ordinates from the code requires re-arranging of digits).

Quad-tree Subdivision

The difference in resolution between the different hierarchical levels of the proposed decimal grid system is rather large. For some applications, it might be necessary to insert additional levels in between. This could be done by simply dividing a grid into 4 equally spaced sub cells. Thus, a grid with a distance of 1 km could be divided into cells of 500 m length. A second level could be introduced by dividing each sub cell again into 4 equally sized cells of 250 m length. A next sub division would lead to grid cells of 125 m length. This is close to the next lower hierarchical level of the decimal grid. Therefore, it is suggested to introduce a maximum of 2 sub divisions for each grid level. This method of sub dividing a grid is called quad-tree, as each cell is divided into 4 quarters. The graphical representation of the grid structure when traversing the grid from its root cell to its smallest sub cell results in a tree structure with 4 branches at each level (see Figure 4).

Direction coding

With the addition of a "quadrant" (NE, SE, SW, NW) a square can be further divided into 4 (see Figure 5)

Figure 4 - Quad-tree subdivision

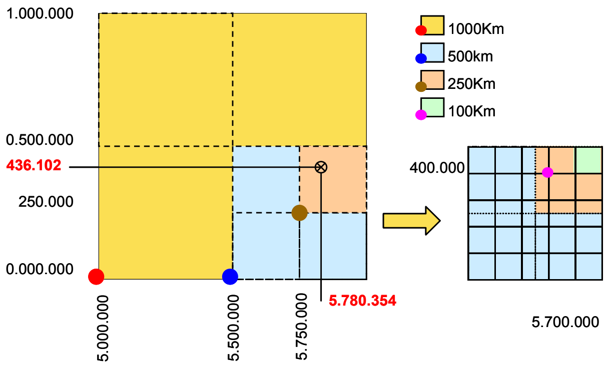
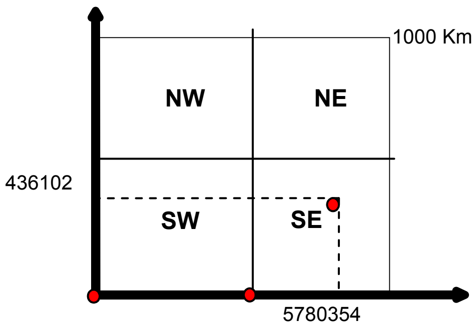


Figure 5 - Quad-tree subdivision for a 1000 Km resolution using orientation for quadrants



In order to define the sub-square, it would be necessary to add the code for the direction to the code of the grid cell. In this case the quadrant would be defined by adding “NE”, “NW”, “SE”, “SW”. A second subdivision would entail to add the direction code a second time. Table 1 shows examples of the coding.

Table 1 - Application of a quad-tree using orientation of quadrants

		Resolution based Coordinate Coding System	**Direct Coordinate Coding System**
Cell Square	*Level*	*Cell Code*	*Cell Code*
1000 km	19	50	50
500 km	18	50SE	50SE
250 km	17	50SENE	50SENE
100 km	16	5074	5704
50 km	15	5074SE	5704SE
25 km	14	5074 SENE	5704SENE
10 km	13	507483	578043
5 km	12	507483NW	578043NW
2.5 km	11	507483NWSW	578043NWSW
1 km	12	50748306	57800436
500 m	9	50748306SW	57800436SW
250 m	8	50748306SWSE	57800436SWSE
100 m	7	5074830631	5780304361
50 m	6	5074830631SE	5780304361SE
25 m	5	5074830631SESW	5780304361SESW
10 m	4	507483063150	578035043610
5 m	3	507483063150SW	578035043610SW
2.5 m	2	507483063150SWSE	578035043610SWSE
1 m	1	50748306315042	57803540436102

Byte coding

Using directions codes would not be that easy to be interpreted by machines and also a bit inflexible. In alternative a Byte Code (00 01 10 11) for (NE, SE, SW, NW) is proposed. This would give the same information and is more machine readable (as therefore all parts of the code are numbers) and easy to extent for higher resolutions (example in Table 2).

Table 2 - Application of a quad-tree using binary coded orientation of quadrants

		Resolution based Coordinate Coding System	**Direct Coordinate Coding System**
Cell Square	*Level*	*Cell Code*	*Cell Code*
1000 km	19	50	50
500 km	18	5001	5001
250 km	17	500100	500100
100 km	16	5074	5704
…			
10 m	4	507483063150	578035043610
5 m	3	50748306315010	57803564361210
2.5 m	2	5074830631501001	5780350436101001
1 m	1	50748306315042	57803540436102

Character coding

In order to distinguish between the grid and the quad-tree subdivision, the characters “A”, “B”, “C” and “D” are used for the cell identification. The code “A” is indicating the southwestern, “B” the southeastern, “C” the northwestern and “D” the northeastern sub-cell (see Figure 6). Using only one character extends the length of the code in a minimal way (see Table 3).

Figure 6 - Quad-tree subdivision using characters

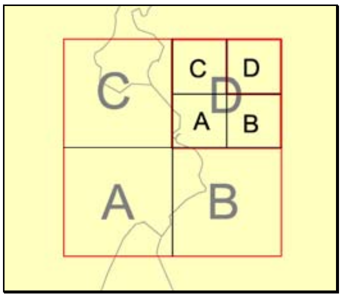


Table 3 - Application of a quad-tree using character coded orientation of quadrants

		Resolution based Coordinate Coding System	**Direct Coordinate Coding System**
Cell Square	*Level*	*Cell Code*	*Cell Code*
1000 km	19	50	50
500 km	18	50B	50B
250 km	17	50BD	50BD
…		…	…
10 m	4	507483063150	578035043610
5 m	3	507483063150A	578035643612A
2.5 m	2	507483063150AB	578035043610AB
1 m	1	50748306315042	57803540436102

Explicit indication of hierarchical (resolution) level

Instead of using the length of the code as an indication of the hierarchical level of the grid, the level could be explicitly expressed as part of the code. Including the level in the code would avoid mistakes due to misinterpretation of the code. Additionally, it would not be necessary to code the quadtree subdivisions as they could be expressed as part of the coordinate values.

In the following proposals the subdivision of a grid with a resolution of 1 km in 4 quadrants could be expressed using the m values (0, 250, 500, 750). A disadvantage would be that the 2.5 m grid size falls out of this rule. To preserve this information the code would have to be expressed in decimetre coordinate precision. The level could be indicated by simply numbering the existing levels from 01 corresponding to a resolution of 1m to 19 expressing a resolution of 1000km (Option 1 in Table 4). As an alternative, the resolution could also be expressed using characters from A to S (Option 2 in Table 4) or by a prefix indicating the order and coordinate precision (e.g. dm, m, km; Option 3 in Table 4). The advantage of both is that confusion with the coordinate part of the code would be avoided and the use of prefix leaves the possibility to extend the coding to other resolutions not initially foreseen.

Table 4 - Three Applications of an explicit indication of the quad-tree level for the example coordinates (578035, 436102)

Cellsize	Cell coordinates [dm]	Option 1	Option 2	Option 3
1000 km	050000000_000000000	19_5_0	S_5_0	1000km_5_0
500 km	055000000_000000000	18_55_0	R_55_0	500km_55_0
250 km	057500000_002500000	17_575_250	Q_575_250	250km_575_250
100 km	057000000_004000000	16_57_4	P_57_4	100km_57_4
50 km	057500000_004000000	15_575_400	O_575_400	50km_575_400
25 km	057750000_004250000	14_5775_4250	N_5775_4250	25km_5775_4250
10 km	057800000_004300000	13_578_43	M_578_43	10km_578_43
5 km	057800000_004350000	12_5780_4350	L_5780_4350	5km_5780_4350
2.5 km	057800000_004350000	11_57800_43500	K_57800_43500	2500m_57800_43500
1 km	057800000_004360000	10_5780_436	J_5780_436	1000m_5780_436
500 m	057800000_004360000	09_57800_43600	I_57800_43600	500m_57800_43600
250 m	057802500_004360000	08_578025_436000	H_578025_436000	250m_578025_436000
100 m	057803000_004361000	07_57803_4361	G_57803_4361	100m_57803_4361
50 m	057803500_004361000	06_5780350_436100	F_5780350_436100	50m_5780350_436100
25 m	057803500_004361000	05_5780350_436100	E_5780350_436100	25m_5780350_436100
10 m	057803500_004361000	04_578035_43610	D_578035_43610	10m_578035_43610
5 m	057803500_004361000	03_5780350_436100	C_5780350_436100	5m_5780350_436100
2.5 m	057803525_004361000	02_57803525_4361000	B_57803525_4361000	25dm_57803525_4361000
1 m	057803540_004361020	01_5780354_436102	A_5780354_436102	1m_5780354_436102

Except for the 2.5 m level, a code length of 14 digits plus the indication of the level would be sufficient for constructing the grid code. A common length for all codes would require enlarging the code length to 16 digits. All coordinate values would then be expressed in decimetre.

To be able to distinguish between the hierarchical level and the coordinate values of the code, an underscore is inserted in the grid codes for all options.

Explicit indication of resolution level using powers of 10 and 2

An explicit indication of hierarchical (resolution) level seems an asset, but all systems proposed in the previous section presented hide the notion of primary and secondary level and require some effort to remember the correspondence between level and precision.

A new proposal is formulated in this chapter (with two options) that seems to overcome most of the problems identified in previous proposals.

It is suggested to use a coordinate coding system for constructing the grid code with the following characteristics:

1. The system is based on a primary grid and in two additional sub-levels (secondary and tertiary grid)

2. The coordinate values are expressed in **decimetres**.

3. The primary grid (metric) will have **7 primary levels** (first column in Table 5)

4. **Two additional sub-levels are authorised as quadtree subdivision** of the primary grid (second column in Table 5) except as for level one, where only on sublevel is authorised to not have sub-decimetre resolution.

Table 5 – Primary (power of 10) and quad-tree levels (power of 2) for explicit indication

Primary Level	Quadtree Level	Value	in dm	in m/km
1	0	$10^1/2^0$	10	1m
1	1	$10^1/2^1$	5	0.5m
2	0	$10^2/2^0$	100	10m
2	1	$10^2/2^1$	50	5m
2	2	$10^2/2^2$	25	2.5m
3	0	$10^3/2^0$	1000	100m
3	1	$10^3/2^1$	500	50m
3	2	$10^3/2^2$	250	25m
4	0	$10^4/2^0$	10 000	1000m / 1km
4	1	$10^4/2^1$	5 000	500m
4	2	$10^4/2^2$	2 500	250m
5	0	$10^5/2^0$	100 000	10km
5	1	$10^5/2^1$	50 000	5km
5	2	$10^5/2^2$	25 000	2500m/ 2.5km
6	0	$10^6/2^0$	1 000 000	100 km
6	1	$10^6/2^1$	500 000	50km
6	2	$10^6/2^2$	25 000	25km
7	0	$10^7/2^0$	10 000 000	1 000km
7	1	$10^7/2^1$	5 000 000	500km
7	2	$10^7/2^2$	2 500 000	250km

Two ways to express the code are proposed:

1. A **fixed length code** (here a point is used as a delimiter, which increases readability but is not necessary for automatic processing):
   `Code = Level.QuadtreeLevel.EastCoordinate.NorthCoordinate`

2. A floating length code (again a point as delimiter) which makes the quad-tree level code (the last part) optional, i.e. it has only to be indicated if a quad-tree level is used:
   `Code = EastCoordinate.NorthCoordinate.Level[.QuadtreeLevel]`

Table 6 shows examples for both codes.

Table 6– Two applications for the explicit indication coding for the example coordinates (578035, 436102)

Primary Level	Quadtree level	m	East	North	Fixed Length Code	Floating Code
1	0	1	57803540	4361020	1.0.57803540.04361020	5780354.0436102.1[.0]
1	1	0.5	57803540	4361020	1.1.57803540.04361020	57803540.04361020.1.1
2	0	10	57803500	4361000	2.0.57803500.04361000	578035.043610.2[.0]
2	1	5	57803500	4361000	2.1.57803500.04361000	5780350.0436100.2.1
2	2	2.5	57803525	4361000	2.2.57803525.04361000	57803525.04361000.2.2
3	0	100	57803000	4361000	3.0.57803000.04361000	57803.04361.3.[0]
3	1	50	57803500	4361000	3.1.57803500.04361000	578035.043610.3.1
3	2	25	57803500	4361000	3.2.57803500.04361000	5780350.0436100.3.2
4	0	1000	57800000	4360000	4.0.57800000.04360000	5780.0436.4[.0]
4	1	500	57800000	4360000	4.1.57800000.04360000	57800.04360.4.1
4	2	250	57802500	4360000	4.2.57802500.04360000	578025.043600. 4.2
5	0	10000	57800000	4300000	5.0.57800000.04300000	578.043.5[.0]
5	1	5000	57800000	4350000	5.1.57800000.04350000	5780.0435.5.1
5	2	2500	57800000	4350000	5.2.57800000.04350000	57800.04350.5.2
6	0	100000	57000000	4000000	6.0.57000000.04000000	57.04.6[.0]
6	1	50000	57500000	4000000	6.1.57500000.04000000	575.040.6.1
6	2	25000	57750000	4250000	6.2.57750000.04250000	5775.0425.6.2
7	0	1000000	50000000	0	7.0.50000000.00000000	5.0.7[.0]
7	1	500000	55000000	0	7.1.55000000.00000000	55.00.7.1
7	2	250000	57500000	2500000	7.2.57500000.02500000	575.025.7.2

Conclusions

Both coding systems with the explicit indication of resolution level using powers of 10 and 2:

1. can be easily derived from the coordinate values,

2. are easily understandable.

Clearly the fixed length code shows more redundancy and less flexibility – i.e. for a change of precision - but the coding rules are straightforward and thus seem to be easier to handle by computers.

The ICP-Forests sampling scheme

Javier Gallego

Summary: The International Co-operative Programme on European Forest (ICP-Forest) was launched in the 80's as a response to the concern on the impact of pollution on the health state of forest. Tree defoliation and decolouration of leaves is observed every year on a sample of plots. The sampling scheme is systematic, theoretically based on a regular grid of 16 km. The practical application of the sampling rules has been rather heterogeneous in different countries. We analyse the difficulties arisen to use this sample for statistical or spatial analysis.

Keywords: Systematic sampling, Forest monitoring

Objectives and context of ICP-Forest

The International Co-operative Programme on the assessment and monitoring of air pollution effects on forests (ICP) was launched under the UN/ECE Convention on long range trans-boundary air pollution in 1985. Currently more than 30 European countries carry out this survey.

The survey covers every year a systematic sample of plots based on a 16 km grid (called level-1 plots), although some countries use a grid with a different density, for example in northern Finland the grid has a step of 32 km. In the Czech Republic the step is 8 km.

The target of the programme is providing information to assess the long-term sustainability of forest ecosystems in view of adverse environmental impacts, such as air pollution and climate changes (de Vries et al, 2003). The main data observed on the level 1 plots relate to the crown condition (defoliation and decolouration of leaves). The data should allow to analyse the geographic and temporal variations in forest condition and its relationship with stress factors, including air pollution.

The sampling grid

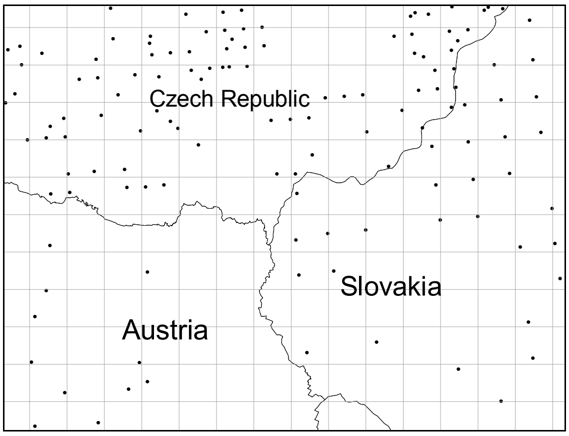
In the framework of the European Union (EU), the legal basis for the Programme was set up by the Regulation 3528/86, and some rules for the implementation are specified by the Regulation 1696/87, that specifies that the origin of the 16 km grid is the point 50°14'15" N 9°47'06" E, but does not give any specification of spheroid, datum and projection, that would have been necessary for a unique definition of the grid.

Some countries that had already set up a sample generally kept the sample selected before the regulation. In some cases, the programme is based on a subsample of the sample used for the national forest inventory.

Figure 1 illustrates some differences of sample pattern between countries: the points correspond to the locations of the level-1 plots. A 16 km grid has been outlined in a Lambert-Azimuthal projection to help the visual assessment of the grid, that follows a regular pattern in Slovakia (in a different projection), but corresponds to different choices in the Czech Republic and Austria.

The documentation on the precise rules followed to define the sample is sparse and difficult to find. If a point of the grid falls in a non-forest area, it does not generate a sample plot. To increase the chances of having plots in areas with sparse forest, the rule is slightly modified using a square of 1km^2 with a grid of 121 ranked points 100 m apart from each other: If the central point (number 0) is not forest, point number 1 is considered, then number 2, and so on. If none of the 121 points falls on forest, no plot is selected.

Figure 1 - ICP level-1 grid (partial view)



However it is not clear in which countries this rule has been applied, and how strictly sampling rules have been applied. It might happen that in some areas priority is given to points with easier access or to species that surveyors considered more interesting.

Shape of the plots

The shape of the plots is also heterogeneous from country to country and even from region to region in the same country. The most frequent shape is made of four circle whose centres make a cross with 25 m sides (Figure 2), but trees are selected in some regions along the sides of the cross (some German Länder), in a rectangle (Italy), or in a circle with a size that depends on the forest type (Sweden, Austria).

Again it is rather difficult to find the information on the criteria followed by each country or region to choose a plot shape.

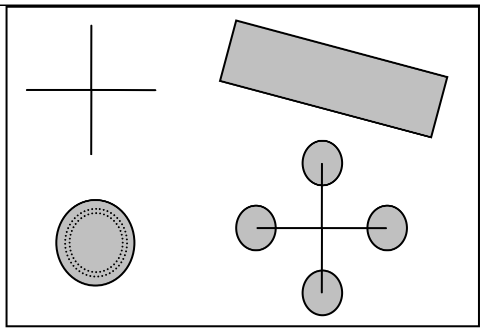


Figure 2 - Different shapes of plots

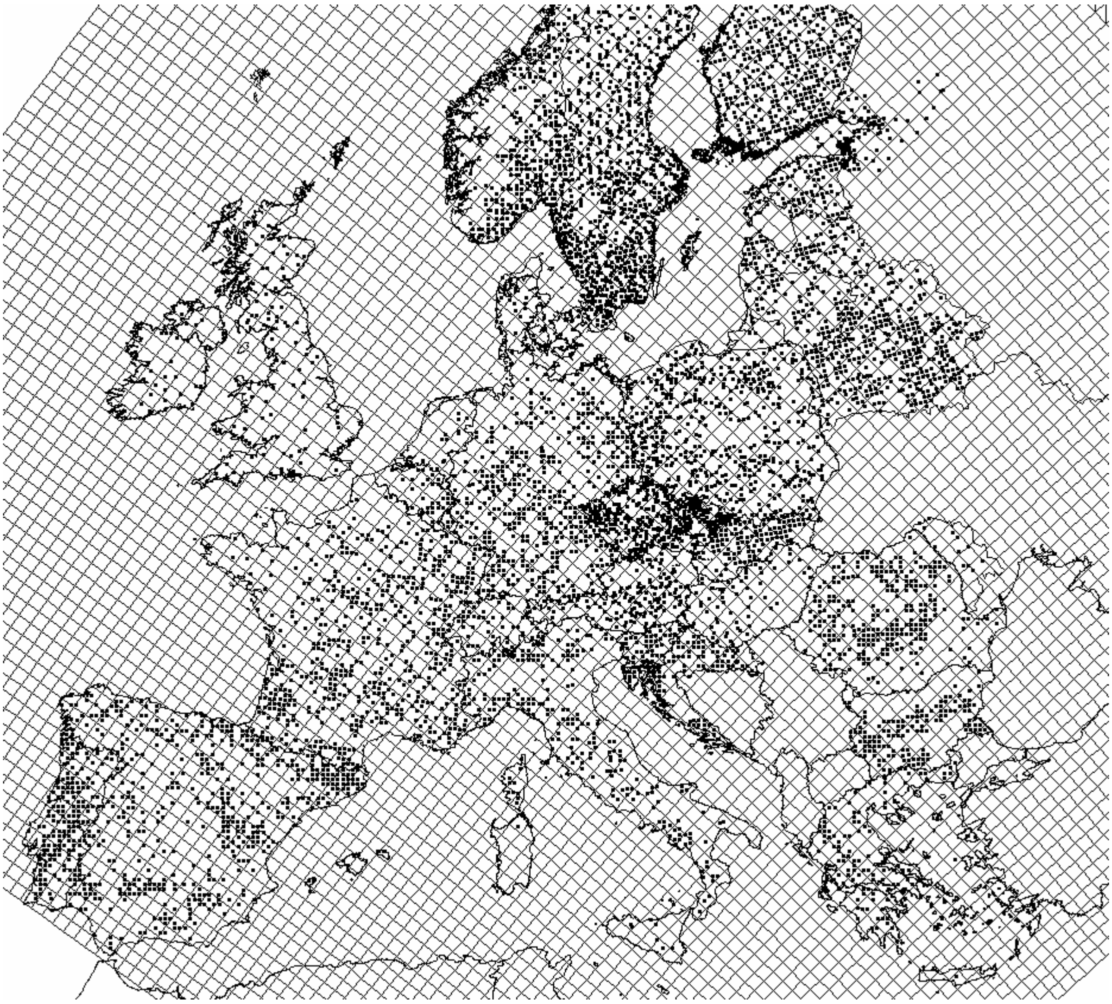
Using ICP-Forests Level 1 data with other grid data

Let us consider two examples of analysis with raster data on different grids: medium resolution satellite images with pixels about 20-30 m (SEMEFOR, 2000), and models of atmospheric pollution on a 50 km grid (Saint Jean, 2003).

The study made by L. Saint Jean explored to which extent tree defoliation could be explained by air pollution estimates produced by the Danish Eulerian Model (Zlatev, 1995). The output of this model is geographically organised on the EMEP 50 km grid defined on a polar stereographic projection (Figure 3). In the western-European area, the cells of this grid are not arranged in north-south rows and east-west columns, but this fact did not add any specific difficulty to the study, since the main point was knowing which ICP plots fell inside each grid cell.

What is needed to improve the statistical validity of this and other studies (for example Jewell and Kennedy, 2001), is a better documentation on the sampling approach in each country or region, that would allow to compute weights for unbiased estimation. In exchange the fact that the ICP grid was not the same across Europe and did coincide with the EMEP grid was not a real drawback.

Figure 3 - Level-1 plots and the EMEP grid



The problem is different merging crown condition data with medium resolution satellite images. For this purpose a major obstacle was the insufficiently precise knowledge of the plot co-ordinates, that made it difficult to link ground observations with image pixels. Again the absence of a common grid for ICP was not a real problem.

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LUCAS - Monitoring EU territory using an area frame sampling approach

Maxime Kayadjanian and Manola Bettio

Summary: LUCAS is a pilot project launched by Eurostat in close co-operation with the Directorate General of Agriculture. LUCAS is an area frame statistical survey that aims at obtaining harmonised data at EU level on land use, land cover and environment. The survey consists in the ground visit in springtime of about 100 000 points sampled according to a regular grid. The paper gives an overview of the methodology and the results of the survey that was carried out in 2001 and in 2003. In more details, the sampling plan design, its geometrical quality as well as precision of point location on the ground are reviewed.

Keywords: systematic sampling, area frame survey, UTM projection, land use, land cover

Introduction

To support policy formulation, Eurostat launched - in close co-operation with the Directorate General responsible for Agriculture - the pilot project “Land Use/Cover Area frame statistical Survey (LUCAS)”, following the Decision N°1445/2000/EC of the European Parliament and of the Council of the 22.05.2000 “On the application of area-frame survey and remote-sensing techniques to the agricultural statistics for 1999 to 2003”.

In 2001, the first LUCAS pilot survey was carried out in 13 of the 15 Member States of the European Union. It had to be postponed to 2002 in the United Kingdom and Republic of Ireland because of the foot and mouth disease[27]. In 2002, in the framework of the PHARE programme, LUCAS was carried out in Estonia, Hungary and Slovenia. In 2003, a second survey was carried out in the EU15 as well as in Hungary[28].

The survey is organized in two phases: a field survey in springtime (phase I) to collect data on land cover/use, as well as on the environment, and a farmer interview survey in autumn (phase II) to gather additional information on yields and agricultural techniques.

The present paper focuses exclusively on the phase I survey methods and results: after the general description of the methodology of the project (paragraph 2 and 3), paragraph 4 describes and analyses the sampling plan applied and its accuracy in precisely locating the points to be surveyed while the last section of the paper (paragraph 5) focuses on 2001 summary results.

Objectives of the LUCAS survey

The LUCAS survey was carried out in 2001 and 2003 in a pilot phase. The pilot exercise can be seen as having two main purposes:

1. the implementation of the surveys themselves during the years 2001 and 2003, which has provided for 2001 and for 2003 a picture representative at EU level;
2. the detection of changes in land use/cover. In fact, besides the picture given in a specific year by LUCAS estimates, one of the strengths of the project is the opportunity it offers to monitor and quantify changes in land cover, land use and landscape structure over time. This temporal comparison is of major importance, first of all thanks to the uniqueness and

[27] Due to the foot-and-mouth disease occurred in 2001, it was impossible for the surveyors to move around the countryside.
[28] The statistical office of Hungary took in charge the full realization of the survey

richness of the information provided, and secondly due to the fact that this information constitutes a precious data source for many other analysis and studies (e.g. the implementation of agri-environmental indicators).

The outcomes of the first two pilot surveys already proved evidence and a strong belief that the survey is a dynamic and efficient system capable of answering to the following objectives:

- to obtain harmonised information, trying to overcome the lack of tightly harmonised data at European level;
- to represent an extension of a pure land use/land cover information system towards a multi-purpose and multi-user system: the information collected does not only satisfy agricultural statistical users, but also environmental experts who can have at their disposal a homogeneous database for various environmental related questions such as soil erosion, landscape, natural hazards, noise, etc.;
- to offer a common methodology and nomenclature for data collection and computation of estimates, as well as a co-ordinated survey execution, enabling a complete comparability of results between different years and geographical areas once the desired geographical representativeness is achieved: a complete set of technical reference documents have been drafted describing e.g. the sampling design, the nomenclature, the observation process, issues of quality assurance and control, data control procedures, reporting and estimation methods;
- to get early estimates of areas that refer to the current year, and the possibility to quantify in real-time the changes with previous situations;
- to provide the statistical information needed for the implementation of indicators to monitor the integration of environmental concerns into the Common Agricultural Policy, as described in the Commission Communications COM2000(20) and COM2001(144): on-going analysis and studies are concerned with the potential of the LUCAS data to satisfy data needs to fill some of the described indicators.

It is important to emphasise that for the time being many of these objectives are not fulfilled regarding the state of land cover statistics at EU level, a domain in which data are often out-of-date, incomplete or not enough harmonised.

Methodological implementation

In the present paragraphs the methodology of the survey is reported. For a detailed description of the methods, a set of nine documents was drafted, each one focusing on a specific aspect of the survey. The complete series of Technical Reference Documents is available on the CIRCA Web site[29] of the Commission.

A two-stage area frame systematic sampling design

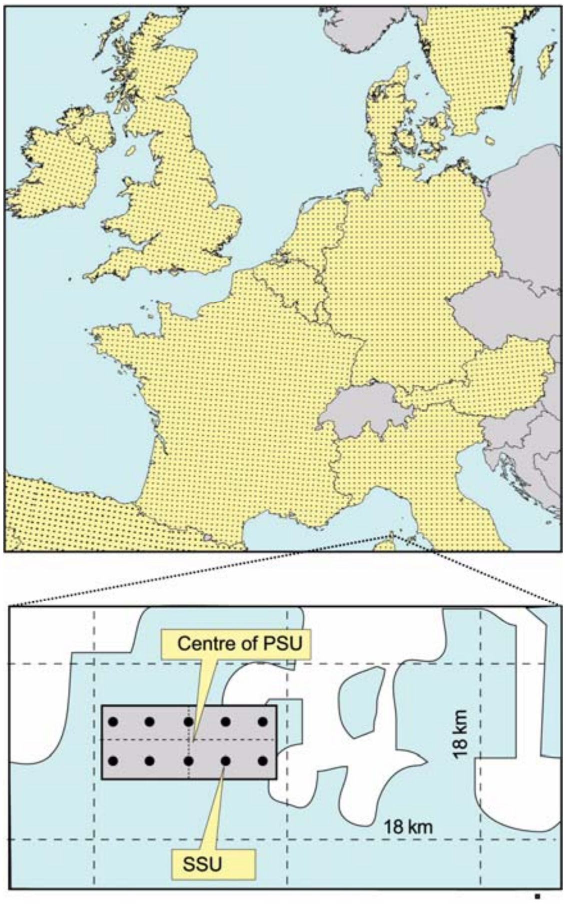
Systematic area frame sampling has been chosen as sampling design method, since LUCAS is designed to provide multi-purpose information and therefore needs to cover not only the agriculture area, but the whole territory of EU Member States (DELINCÉ 2000, AVIKAINEN & al. 2001).

The sampling design of the survey enables the production of area estimates for land cover/land use categories at the European level; nevertheless interested countries can acquire results at national or regional level by increasing the number of sampled points.

The LUCAS phase I survey adopts a two-stage sampling design: at the first level, Primary Sampling Units (PSUs) are defined as cells of a regular grid with a size of 18 × 18 km. At the second level, the Secondary Sampling Units (SSUs) are 10 points, distant 300 m apart, regularly distributed in two lines distant as well 300 m apart around the centre of each PSU (Figure 1). Two exceptions were the countries of Spain and Italy, in which the LUCAS sampling plan was slightly adapted to comply with already established area frame systems (see section below “Definition of the GRID”).

[29] http://forum.europa.eu.int/Public/irc/dsis/landstat/library

Figure 1 - The LUCAS two-stage sampling



The sampling results in approximately 10.000 PSUs over all the EU territory; the number of PSUs was chosen to optimise the cost structure and the precision at European level (Table 1).

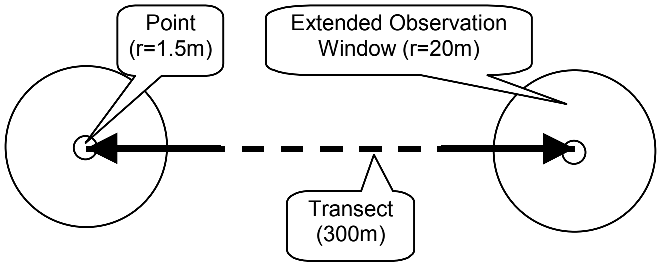
Table 1 - Number of observed PSUs and SSUs per Member State, and area

Country		Number of PSU	Number of SSU	Area (KM²)	Area in %
Austria	AT	255	2.528	83860	2.59
Belgium	BE	100	989	30520	0.94
Germany	DE	1.105	10.981	356970	11.02
Denmark	DK	147	1.373	43090	1.33
Spain	ES	1.268	12.670	504790	15.58
Finland	FI	1.073	10.410	338150	10.44
France	FR	1.702	16.916	549090	16.95
Greece	GR	419	4.051	131960	4.07
Ireland	IE	218	2.163	70290	2.17
Italy	IT	941	9.275	301280	9.30
Luxembourg	LU	8	80	2570	0.08
The Netherlands	NL	117	1.154	41570	1.28
Portugal	PT	277	2.731	91910	2.84
Sweden	SE	1.407	13.808	449960	13.89
United Kingdom	UK	775	7.499	244150	7.54
EU15		9.812	96.633	3240160	100.00

The observation unit of the LUCAS phase I survey is the point, defined as a circle of 3 m diameter (Figure 2). Data on land cover, land use as well as environmental features are collected in the field on these observation units; considering the heterogeneity of land cover types, in some particular cases an enlargement of the observation window up to a circle with 20 m radius is foreseen[30].

Data are collected as well along the straight line that connects the observation points located in the first row (the transects) (Figure 2).

Figure 2 - The Point and the Transect



A multi-purpose information system

According to the objectives, the survey targets not only the observation of the agricultural domain, but a much wider range of possible land cover types (i.e. built-up areas, forests and wooded lands, bushes and grassland, wetland, water and bare soil areas) and land use categories (residential, industrial, commercial, recreational, etc.); moreover, some environmental-related information is collected.

Land cover and land use information

The LUCAS classification system was established by applying best practise for the construction of land cover and use classifications, as recommended in Eurostat "Manual of Concepts on land use/cover" (Eurostat 2000).

The LUCAS concept of "LAND" is extended to inland water areas (lakes, rivers, coastal areas), and it does not embrace uses below the earth's surface (mine deposits, subways, mushroom beds, ground levels of buildings). Land Cover is the observed physical cover of the earth's surface, and the Land Use is the description of the same areas in terms of their socio-economic function.

The land cover classification is defined in 3 hierarchical levels of detail with 57 classes at the 3rd level; land use nomenclature is distinguished in 14 classes at the 3rd level. The complete nomenclature scheme is annexed.

Environmental information

Qualitative information on the existence of infrastructure for irrigation, as well as data on presence of isolated trees is collected in the field within an extended observation window of 20 m. Soil erosion and accumulation is also noted when observed in an extended window of observation around SSUs in arable land (land cover classes B1-B6). Traces of Natural Hazards are recorded as well.

Along the transect, the change of land cover and the occurrence of linear features[31] is registered.

Photographs of the landscape are taken at SSU13; these pictures create a photo sample of European landscapes.

[30] The extended window of observation is applied in the following situations: heterogeneous areas where land features alternate with distances of around 20-25 m.; alternation of permanent crops and bare soils and/or grassland or another crop; crops under cover; wooded and semi-natural areas. The existence of certain features (e.g. isolated trees, soil erosion) is also observed in this extended observation window.

[31] Hedge and tree rows, stonewalls and dykes, water channels, tracks and roads, railways, electric lines.

Technical implementation of the surveys

The phase I field observation is carried out on the exact geographic location of the sampled SSU, therefore surveyors need to locate very precisely the points to be visited. To this purpose, a set of documents and material were produced and provided them: topographic maps, the most recent and available orthophotos at scales 1:10.000 - 1:2.000, compasses and GPS. A survey form to be filled out in the field was drafted, and adapted to country specific conditions.

The qualification of surveyors is of crucial importance for the quality of the results. Surveyors need skills not only in agriculture and more specifically in crop recognition, but in addition they have to be familiar with the use of supporting tools (maps, orthophotos, compass, GPS). Specific training is organised to this purpose.

Data treatment and estimates

The codification of the collected data was defined together with rules to check data entry and the coherence with the previously recorded information. Data consistency is controlled during data entry at country level; additional integrity controls are carried out centrally by Eurostat.

For the area estimates, LUCAS observations are extrapolated taking into account the characteristics of the 2-stage sampling. The estimates are computed at the level of each item of the classification, multiplying the observed frequency by the total area of the geographical level considered.

Detailed information on the algorithms used to calculate the estimates and the variances is available in the LUCAS technical reference document n.° 9: "Estimation methods" (AVIKAINEN & BERTIN 2001).

Quality assurance

To validate the inputted data, quality assurance and control procedures were defined (LUCAS technical reference document n°7: "Quality Assurance and Control procedures", ORESNIK et. al. 2001). In addition, Eurostat assures continuous assistance by means of electronic communication to help the partners that carry out the survey in each country.

In addition to the above mentioned quality assurance measures, further internal quality checks are carried out by the survey-managing organisations during the field work, in order to detect and correct eventual misinterpretations or systematic errors. A double-blind control survey is carried out on 5% of the phase I sample to assess the accuracy of the observations.

Eurostat’s follow-up of the survey includes the organisation of plenary co-ordination meetings; in addition, bilateral follow-up meetings are planned in each country.

Sampling plan layout

Specifications and choices

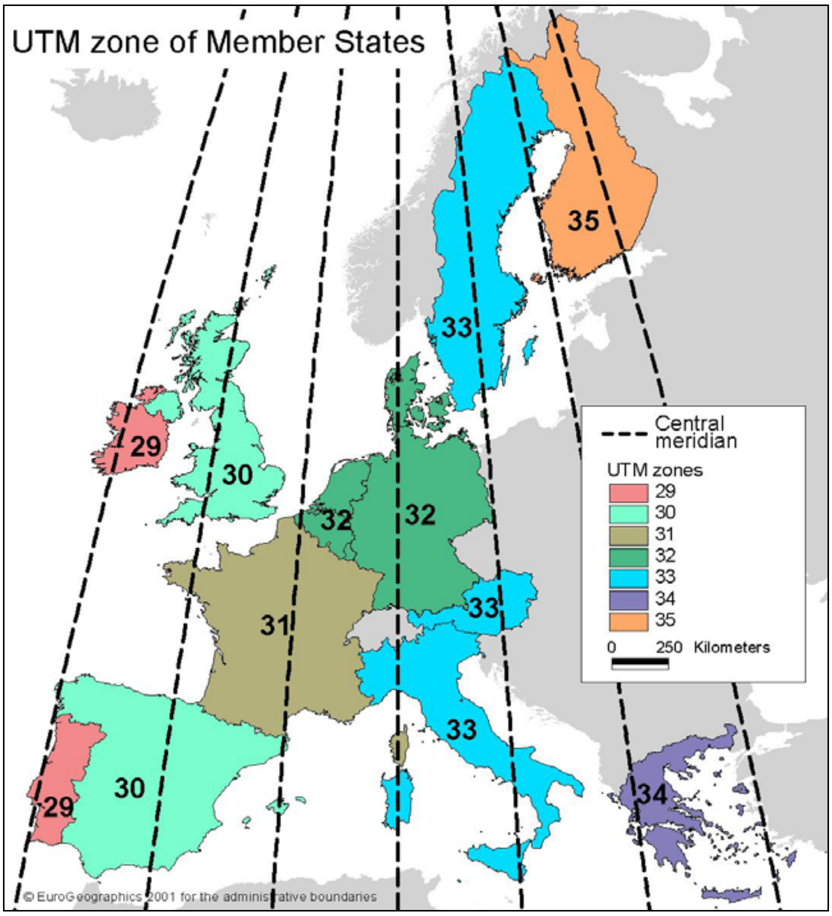
The specifications of the LUCAS pilot project stipulated to reach a precision of 2% at EU15 level for the main land cover classes (e.g. cereals).

Concerning the adopted sampling plan, a systematic approach was adopted to cover the different parts of the territory with an equal probability of observation. On the basis of the described requirements and the available budget, the optimal sampling size was fixed at 100.000 points; the choice of a two-level sampling plan with two lines of SSUs per PSU was mainly inspired by the French Teruti system, which allows optimising trips on the ground for visiting points.

The size of 18 km x 18 km regarding distance between PSUs was chosen for practical reasons. Value 18 being able to produce many integer divisions, allows some flexibility for enlargement of the sample for national purposes: densification of the GRID can be done using step of either 2 km, 3 km, 6 km or 9 Km to increase the precision of estimates.

In order to limit as far as possible distortion of distance between PSUs on the ground, the sampling plan was generated independently in every Member State; to comply with the European reference system the grids are based on UTM projection and the ellipsoid is GRS80. Finally, the most central standard UTM meridian defines the projection scheme in each country (Figure 3).

Figure 3 - UTM zone and Member States



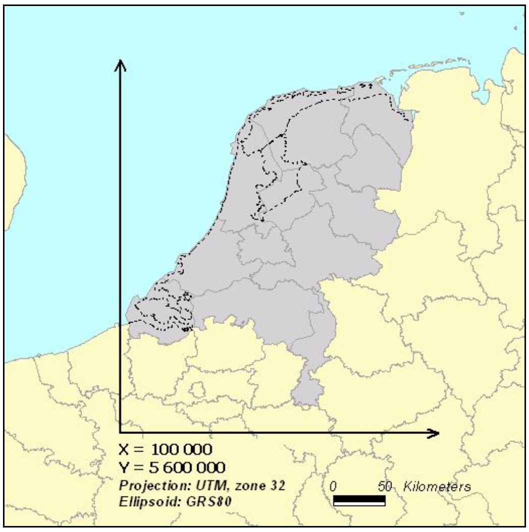
Definition of the GRID

Although theoretically the origin of the systematic sample grid had to be chosen randomly, for practical reason the UTM grids are established by selecting the most southern point of the country as X-axis and the most western point as Y-axis of the grid. The suitable origin is chosen to be a rounded value close to this point: e.g. in the Netherlands X=100.000 and Y=5.600.000 (Figure 4).

The central point of the lower-left PSU is located at the distance of 18 km in X and Y direction from the south-west corner (origin of the grid). The locations of SSUs are then defined around each central point (Figure 5). Complete PSUs located outside the country's boundaries are left out from the sample as well as SSUs that are located outside the boundaries of the country.

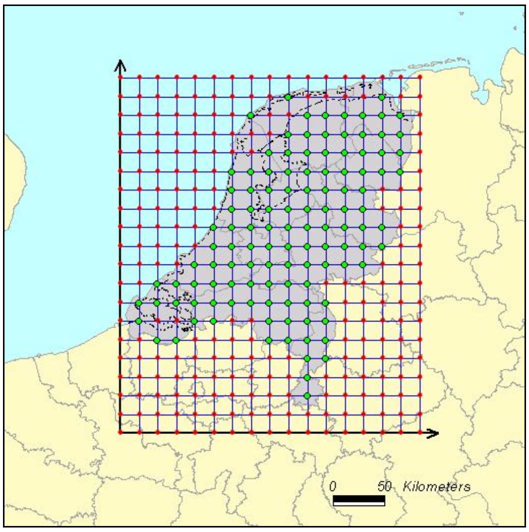
Consequently, some PSUs do not have a total number of 10 SSUs (Figure 6 and 7). GRIDs are generated using a GIS application that enables to create automatically points once the origin is chosen and to make the selection by spatial query. Country boundaries used to select points are the SABE administrative boundaries at scale 1.000.000, and SCOLE, defining the shoreline at scale 100.000.

Figure 4 - Definition of the origin of the grid in The Netherlands



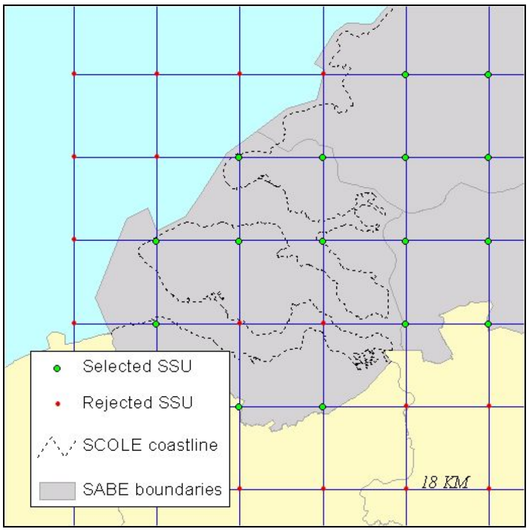
The origin includes the whole territory of the country. The co-ordinates are rounded figures.

Figure 5 - Generation of the grid



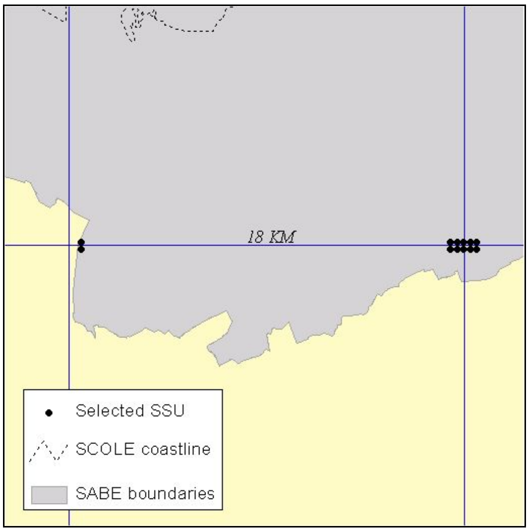
The nodes of the grid represent the centre points of the PSUs.

Figure 6 - The selected PSUs



The PSUs falling onto the territory of the country (green) are selected; the others (red) ignored.

Figure 7 - The selected SSUs



The grey-shaded area is limited by the SABE boundaries. This area has been clipped using the SCOLE boundaries (dotted line) to exclude sea area.

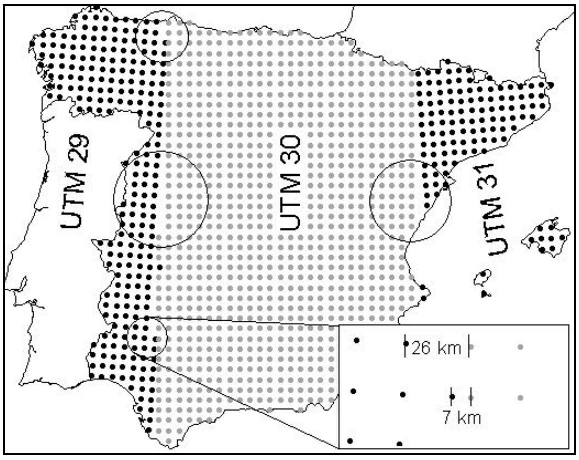
The Spanish case

In Spain the sampling for LUCAS is based on the already established area frame sampling for the territorial panel of the Ministry of Agriculture (**M**arco de **A**reas-**S**egmentos **T**erritoriales MAST).

The MAST segment survey grid is based on a sampling grid of 10 km x 10 km grid size. It is divided according to three UTM zones: 29 for the western part, 30 for the central part and finally 31 for the eastern part of the country; this means that there is not one contiguous grid but 3 grids (Figure 8).

This stratification is due mainly to the fact that at the time of the grid design the GIS technology was not yet widely spread, therefore the co-ordinates of segments were generated as integer values in the national cartographic system (3 UTM zones; Potsdam Datum 1950, Hayford Ellipsoid) to easier their printing on existing maps and aerial photos. Consequently, as shown in map 6, the whole territory is not covered systematically, and some gaps remain along the border between two adjacent UTM zones.

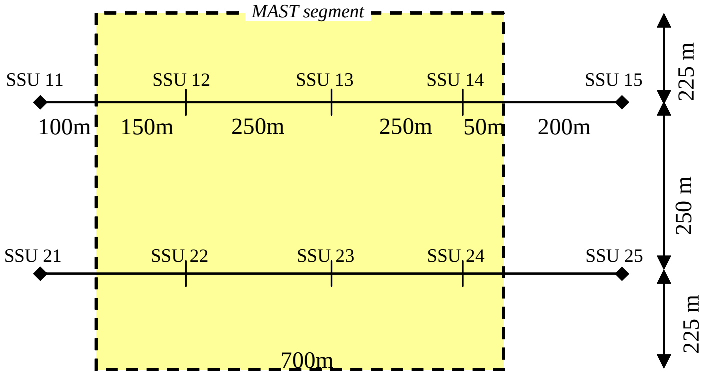
Figure 8 - LUCAS sampling plan in Spain



The data collection in MAST consists in the exhaustive mapping of the 700 x 700 m size segments; the LUCAS grid for Spain has been adapted locating PSUs every second MAST segment.

The Spanish LUCAS PSUs are therefore segments distant 20 km apart; PSUs are centred on MAST segments, as shown in Figure 9, with a slight shift on X-axis to the West. The distance between SSUs is 250m.

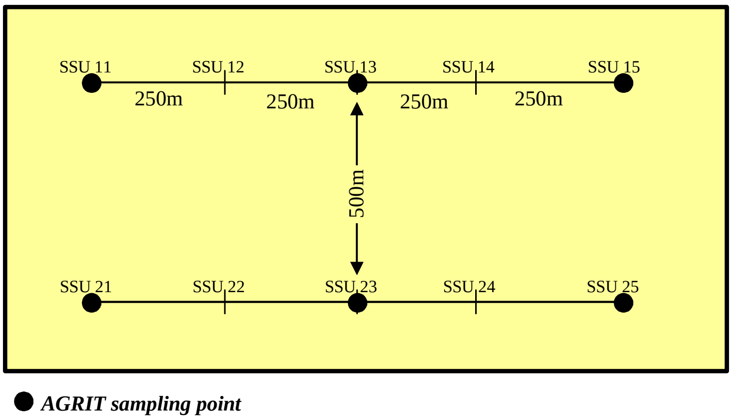
Figure 9 - Location of LUCAS SSUs within MAST segment



The Italian case

In Italy the sampling plan for LUCAS is based on the already established area frame sampling used in the national system AGRIT. The AGRIT sampling points are based on a 500m x 500m grid cell size. The grid was generated in the Italian 'Gauss-Boaga' projection system (international 1909 ellipsoid), and projected on meridian 9°. The adapted LUCAS sample still presents PSUs located on the 18 x 18 km grid. SSUs are then selected in two parallel lines of five points each, located at intervals of 250 m apart; the two rows are 500 m apart. In this way it is possible to overlay six LUCAS points on the AGRIT samples (Figure 10).

Figure 10 - SSU distribution in Italy

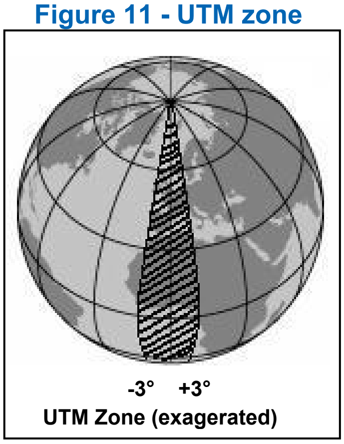


Geometrical quality of the GRID

The present section is focused on the distortion of the sampling plan and its effects on the modification of the ground distance between PSUs due to the geographical projection[32]. Does the LUCAS GRID remain regular once projected on the ellipsoid? If not, does it have any impact on the statistical representativeness of the sampling points?

As already described, in order to limit ground distortions the sampling plan adopted for the LUCAS project was stratified by country, and the positioning of the grid in space was defined according to the most central UTM standard meridian for each country separately. The UTM system defines a central zone delimited by the two meridians distant 3 degrees apart from the central meridian (Figure 11); in this area, ground distortions can be considered as negligible.

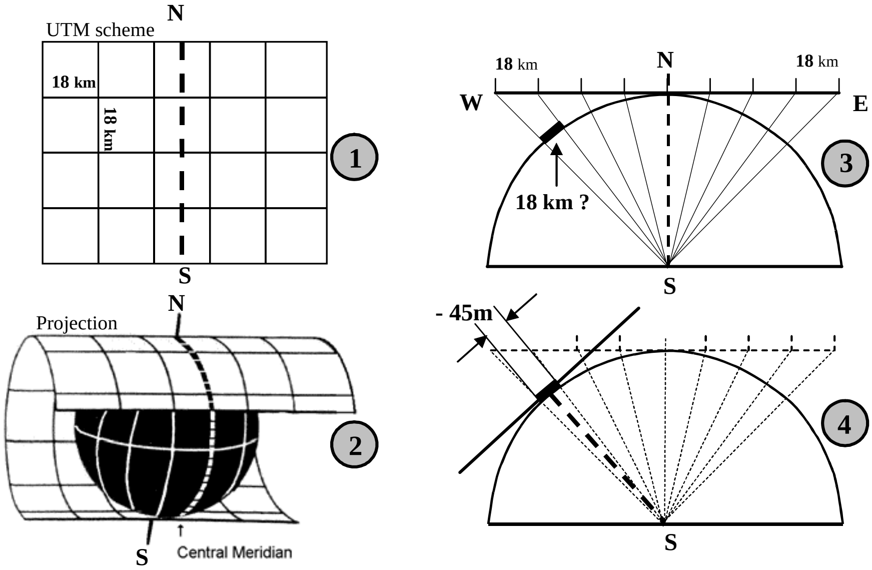
Figure 11 - UTM zone



[32] Only distortion due to projection on the ellipsoid is taken into account here. The relief is not considered although its effect can be important in mountainous areas where ground distances are elongated.

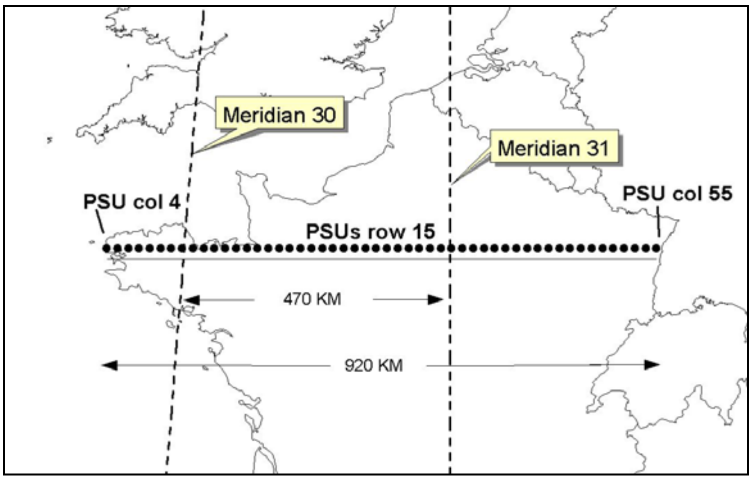
Certain parts of the Member States territory are relatively offset in relation to the central meridian (Figure 3): Brittany in France (UTM 31), North-western Italy and Western Austria (UTM 33), Benelux and Eastern Germany (UTM 32). When the longitudinal distance to the central meridian is large, the distance on the ground tends to be reduced both in the east-west and north-south directions (Figure 12). However, this effect tends to diminish towards low latitudes, where the angles decrease and UTM central zone gets larger.

Figure 12 - Projection of the sampling plan and ground distortion



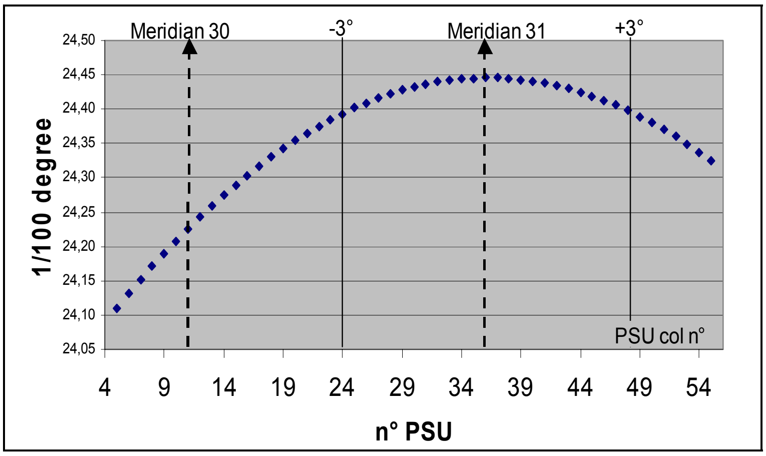
Due to the characteristics of UTM projection, the distortion of the grid has more effect on the countries which are elongated in longitude (e.g. FR, DE, IT, ES) than the countries elongated in latitude (e.g. SE, FI). To measure the distortion of ground distances, let's analyse as an example France that has some PSUs quite remote from the central meridian UTM 31 (Figure 13).

Figure 13 - Location of PSUs row n°15 in France



The graph in figure 14 reports the decrease of longitudinal angle between the PSUs along the 15th row in France. This reduction corresponds to an angle of approximately 0.002 degrees between PSUs at the position of central meridian n°30. When sampling points of this area are projected in UTM 30, the distance between PSUs decreases approximately to 17955 m in comparison with a distance of 18000 m in the UTM 31 scheme, and equivalent to a negligible reduction of 45 m (Figures 12,13,14).

Figure 14 - Variation of angles between contiguous PSUs



The above mentioned distortion due to the geographical projection affects less than one-third of the PSUs at EU14 level (Table 2), of which only a minor percentage is placed in remote areas located far away from their respective UTM central meridian.

Table 2 - % of PSUs out of UTM zones

Country	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	EU14
%	13	97	26	7	n.a.	25	33	25	0	50	50	67	0	31	17	29

Precision of the location

The technical conditions under which sampling points are observed on the ground are fundamental to ensure high quality of results. The point location on the ground has to be as precise as possible in order to respect the systematic character of the sampling plan, and to detect correctly the changes that occur on the ground once the survey is carried out periodically. In fact any shifts in the exact location of a surveyed point could induce the detection of changes between two consecutive surveys which did not actually occur.

Location of the points on the ground

Three different tools are used to locate the points on the ground:

- aerial photographs;
- topographic maps;
- compasses and eventually GPS.

These instruments are used in a combined way. The topographic maps (from 1/100 000 to 1/50 000 scale) are used to define the best route to reach PSUs. At the level of SSUs, it is primarily the aerial photographs that are used to determine the precise location of surveyed points, with the additional support of GPS, compasses, and of large scale topographic maps (1/25 000 to 1/5 000). DGPS were used in two countries; they can reach a precision of 1 meter. However, such a tool causes severe logistical problems: it requires powerful batteries and its use is limited to the emission area of the corrected signal sent by the terrestrial station.

In order to be correctly located on the ground, the sampling points are preliminary printed on aerial photographs and on large scale topographic maps. Therefore the quality of the aerial photographs is decisive for the orientation of surveyors in the field, and in order to ensure the correct location of the surveyed SSUs.

Aerial photographs allow the best transcription of ground reality, once it has a good degree of accuracy. Their quality is related to two different parameters: the resolution and the positional accuracy. The date of the snapshot is very important as well, in particular in the areas where changes are rapid (i.e. border of urban areas): the landscape grasped on the photograph has to correspond as much as possible to that observed at the time of the survey.

The resolution of a photograph is the area that one image pixel represents on the ground. An object on the ground is in general recognisable on a photograph when its size is 2 to 3 times greater than the ground resolution of the image. This rule is important in particular when the land cover is heterogeneous.

Table 3 - Characteristics of aerial photographs used in the 2001 survey

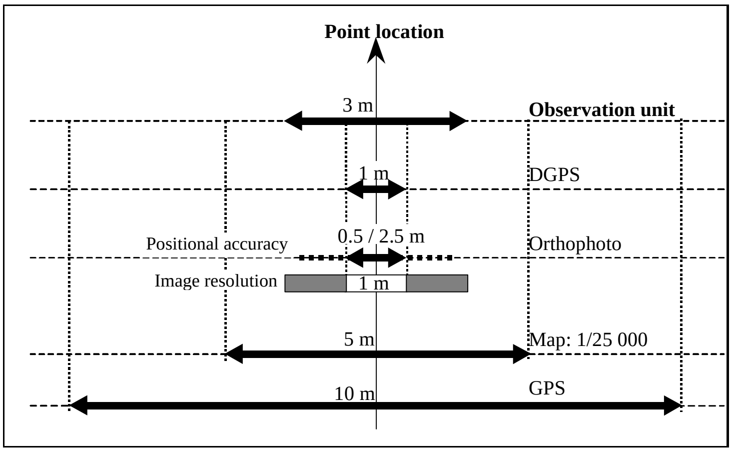
Country	Resolution/scale	Year of acquisition	Type	Use of GPS
AT	0,5 m	1990/2000	Orthophoto	yes
BE	1 m	1995/2000	Orthophoto	yes
DE	0,25 - 0,8 m	>1995	Orthophoto & aerial photo	yes +DGPS
DK	0,4m	1999	Orthophoto	yes
ES	0,75 - 2 m	1985/2000	Orthophoto & aerial photo	no
FI	1 m	1996	Orthophoto	yes
FR	0,5 - 1 m	>1995	Orthophoto & aerial photo	no
GR	1 m	1990/1998	Orthophoto	yes
IE	1m	1995	Orthophoto	yes
IT	1 m	n.a.	Orthophoto	yes
LU	1/5000	1997	Topogr. Map	yes
NL	1m	>1995	Orthophoto	DGPS
PT	1 m	2000	Orthophoto	yes
SE	1 m	>1995	Orthophoto	yes
UK	1m	1988/2001	Orthophoto	yes

Since the size of the LUCAS observation unit is equal to 3 metres, the resolution does not have to exceed 1 meter in order for the surface type to be easily recognisable on a photograph (Figure 15).

The photographs used for the 2001 survey had a resolution equal to 1 m in the majority of cases (Table 3); their overall quality in terms of resolution can therefore be considered satisfactory.

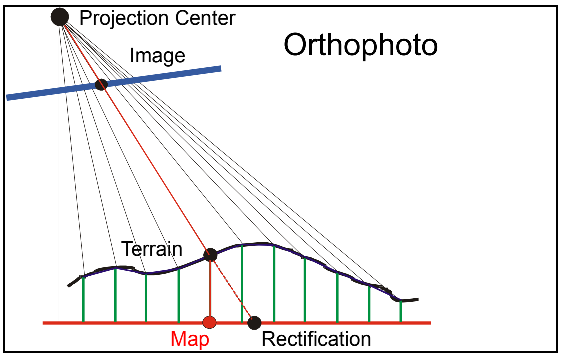
Concerning their positional accuracy, this feature depends on the geometrical corrections they have undergone, that define the precision of the geographical co-ordinates of an image pixel. In the majority of cases, orthophotos were used for the LUCAS survey (Table 3).

Figure 15 - Precision of the topographical instruments



Orthophotos are georeferenced aerial photographs for which corrections were applied in order to take into account distortions due to relief (Figure 16).

Figure 16 - Scheme of the ortho-rectification process



The positional accuracy of orthophotos depends on the precision of the digital elevation model used to correct the effects due to relief, and on the location precision of the control points used to georeference the image. On the average, this precision varies between 0.5 and 2.5 m.

In a minority of cases, simple aerial photographs (georeferenced but not orthorectified) were used in the 2001 survey; their geometrical quality is lower than the one of orthophotos, since they remain sullied of the errors due to relief distortion[33]. The use of simple photos is acceptable and was allowed in areas where relief is not accentuated (e.g. plain, plateau).

Precision of the printing of the sampling points on maps and photographs

In order to print the LUCAS points on aerial photographs and/or topographic maps, SSUs were projected in the same national geographical system in which topographical documents were referenced. A different system is used in each country, that consists in a specific ellipsoid (i.e. Datum) and projection type (e.g. Lambert, Mercator). The projection of LUCAS sampling points from UTM/GRS80 to a national one was easily done with map-making software available on the market; this process induced only few geometrical distortions (lower than 1 m).

Nevertheless, in Greece, Portugal and Luxembourg this operation caused some problems. In the two first countries, due to the malfunctioning of the software used to convert geographical coordinates (change of datum parameters not taken into account) points were not properly projected. In Luxembourg, uncommon national projection parameters were not well implemented in the conversion programme.

In the three countries, a shift of about 200 m was detected during the control visit on the ground, comparing the theoretical location of points as printed on the aerial photo and the one suggested by the GPS. Since this shift was systematic on the whole grid, statistically it did not introduce any bias in the estimation process. Therefore the shifted sampling points were converted back to UTM/GRS80 and replaced the original ones in the official LUCAS sample.

Main results of phase I survey in 2001 at EU 15 level

In the following chapter the main results of phase I survey in 2001 are presented. In particular, land use, land cover and their cross distribution are analysed; the presence of linear features, the risk of natural hazards and the perception of noise are reported as examples of the environmental variables collected.

The tables of results hereafter reported include the coefficient of variation ($CV = \frac{\sigma}{area}$), which indicates in percentage the achieved precision of each estimate. The specifications of the LUCAS pilot project stipulated to reach a precision of 2% concerning the main land cover classes.

[33] It is however possible to project the geographical co-ordinates of a SSU on a photo not orthorectified. This method allows using an unprocessed image which has the advantage to better represent the relief. But its costs would have been prohibitive in the framework of the LUCAS project.

Land cover

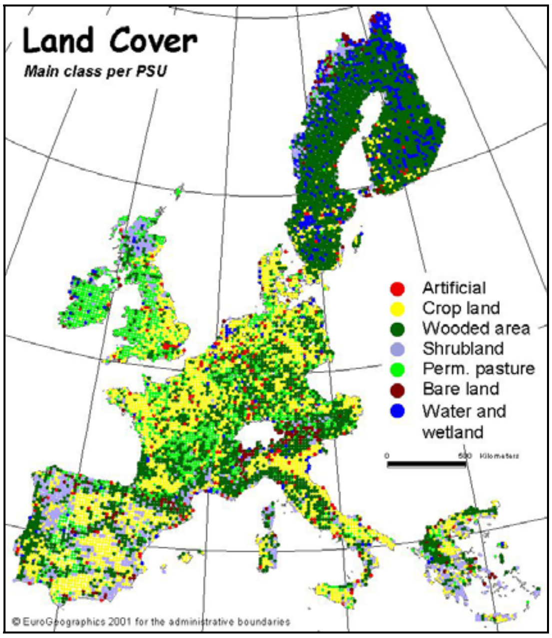
Woodland covers almost 1,2 million km^2, or 35% of the total area of the 15 EU countries concerned by the survey. This makes it the leading type of land cover in 2001. Areas under crops account for 26% of the territory, and grassland for 16%.

Table 4 - Land cover estimates

Land Cover	KM^2	%	CV
Woodland	1.134.606	35,0	1,0
Cropland	837.536	25,8	1,3
Permanent grassland	509.573	15,7	1,4
Shrubland	268.693	8,3	2,9
Water and Wetland	236.111	7,3	3,0
Artificial land	153.912	4,8	2,7
Bare land	99.729	3,1	5,3
Total	3.240.160	100,0	

At EU 15 level (Table 4), the main type of land cover consists of areas that are entirely or more or less in their natural state. On the other hand, the artificial areas represent only 5% of EU surface (154.000 km^2). The concentration of wooded areas and of inland water (lakes and wetlands) in the Scandinavian countries is very high, especially when compared to the rest of EU territory (Figure 17).

Figure 17 - Main Land Cover per PSU[34]



The intensive agricultural zones are located in Denmark, eastern part of England, north-western half of France, Po river plain and Adriatic coast in Italy, south of Portugal and Spain. Shrublands are mainly concentrated in Mediterranean countries, but their presence is noticeable in the north-west border of Sweden and in the highlands in Scotland as well.

[34] Warning: maps report the most represented class for each PSU.

Land Use

Agriculture accounts for more than 41% of the territory, making it the leading type of land use in the 15 countries investigated (Table 5). This category includes land used directly for production as well as land used generally for farming purposes (buildings, farmyards, etc.). Apart from the extreme situations of the Nordic countries and Austria, on the average around half of the territory or more is used for farming.

Forestry comes second, with a percentage of 30%. If this criterion is used, the order of countries is the reverse of farming. In Sweden and Finland, forestry accounts for over half of the territory; in the remaining countries more than 20% of the territory is used for forest purposes (apart from The Netherlands and Denmark).

Almost 19% of the territory of the 15 countries is classified as being without apparent use. The differences are attributable to geographical conditions (altitude in Austria) or type of predominant cover (heath in Portugal and Greece, inland waters in Finland).

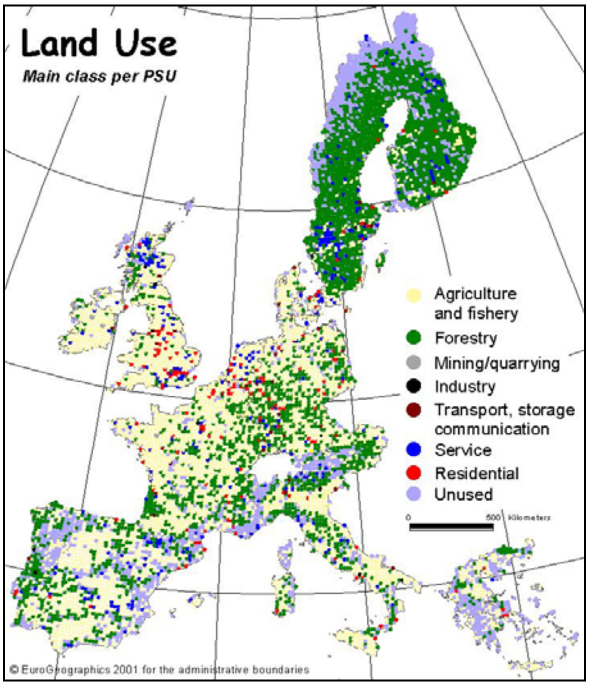
These three headings (agriculture, forestry, unused) account for 90% of the territory of the EU15. Of the remaining types of use, only three exceed 1% - (i) recreation, leisure and sport, (ii) residential and (iii) transport and communications.

Table 5 - Land Use estimates

Land Use	KM²	%	CV
Agriculture	1.343.180	41,5	0,9
Forestry	972.952	30,0	1,2
Unused	603.630	18,6	1,6
Recreation, leisure, sport	131.805	4,1	4,7
Residential	74.584	2,3	4,4
Transport, communication, storage, protective works	65.644	2,0	3,6
Community services	11.745	0,4	16,6
Fishing	9.743	0,3	17,5
Industry, manufacturing	6.861	0,2	16,1
Commerce, finance, business	6.458	0,2	16,3
Mining, quarrying	6.137	0,2	22,4
Construction	2.668	0,1	23,7
Water, waste treatment	2.566	0,1	21,4
Energy production	2.187	0,1	31,8
Total	3.240.160	100,0	

Agricultural and forestry activities occupy the majority of the EU territory (Figure 18). The location of the other activities needs to be put in relation to the location of artificial areas, with the exception of leisure and sport activities, that are connected with a higher number of land covers (see following paragraph).

Figure 18 - Main Land Use per PSU[34]



Mixed land use-land cover

Artificial surfaces show a great diversity of use, two thirds of such areas being accounted for by settlements, transport and communications. At over 10%, agriculture is the third largest user of this type of cover (Table 6).

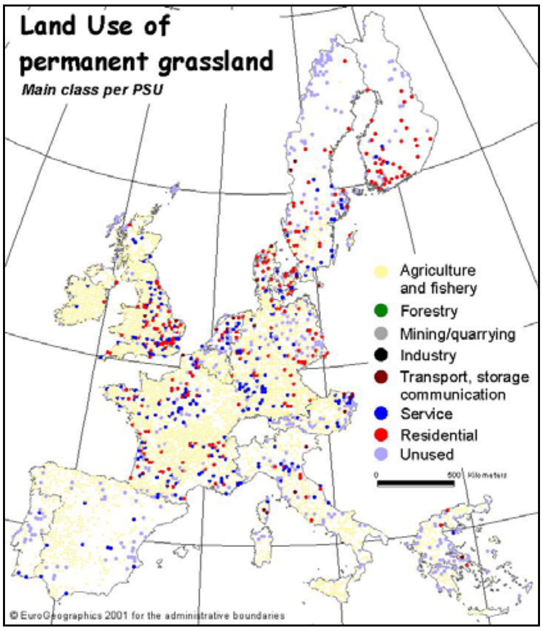
Table 6 - Uses of the main covers (%)

Cover / Use	Artificial Land	Crop land	Wood land	Shrub land	Perm. Grass land	Bare land	Water and Woodland	Total
Agriculture	0,5	25,7	0,7	1,5	12,9	0,1	0,2	41,5
Forestry	0,1	0,0	29,2	0,7	0,0	0,0	0,0	30,0
Transport, Communication, Storage, Protective works	1,7	0,0	0,0	0,0	0,1	0,0	0,2	2,0
Recreation, leisure, Sport	0,2	0,1	0,9	0,7	0,7	0,2	1,2	4,1
Residential	1,4	0,0	0,2	0,0	0,6	0,0	0,0	2,3
Others	0,6	0,0	0,1	0,0	0,1	0,1	0,5	1,4
No apparent use	0,1	0,0	4,0	5,2	1,4	2,5	5,4	18,6
Total	4,8	25,8	35,0	8,3	15,7	3,1	7,3	100,0

Approximately 82% of areas under grass are used for agricultural purposes, 9% are unused, residential, leisure and recreation areas account for 8% and the remaining 1% for transport, storage and protective works. The use of areas under grass varies greatly. In Spain, France, Greece and Germany, over 80% of this type of land is used for agriculture. "Other uses" increase from South to North, the trend being for grassland to be used for dwellings (lawns) or recreational purposes (sports grounds). The extreme is Finland, where just 4% of the area under grass is devoted to agriculture and almost 60% to dwellings (Figure 19).

Shrubland is not generally used (65%). Agriculture accounts for 19% of such type of area, and is the second largest user. Generally speaking, this type of land has a greater utilisation rate in the southern countries (between 20 and 30%). Spain is a special case, as use for forestry exceeds agricultural use.

Figure 19 - Main Use of permanent grassland[34]



Environmental variables

One of the objectives of the LUCAS pilot project is to widen the purpose of the survey in the field of environment. The main results concerning three environmental variables are presented hereafter as an example.

Visible traces of Natural Hazards

Globally, it appears that natural disasters affect about 2,7% of the territory of the European Union (Table 7). Among them, gales (36,4%) and fires (32,9%) cause most of damages. The right column of the table 5 shows the percentage of each hazard in the total of damaged areas.

Table 7 - Surface of areas affected by natural hazards

Natural Hazard	km²	%	Damaged areas (%)
Avalanche	1.099	0,0	1,4
Land slide	9.635	0,3	10,1
Flooded area	16.756	0,5	19,2
Burned area	29.778	0,9	32,9
Gales	30.519	0,9	36,4
no hazard	3.152.373	97,3	100,0
Total	3.240.160	100,0	

The southern countries are affected most, France included, the main cause being fires and gales, accounting both for two thirds of all damages.

In France, effects of gales are still visible eighteen months after the two storms of December 1999 (Figure 20).

Figure 20 - Visible traces of Natural Hazards[34]

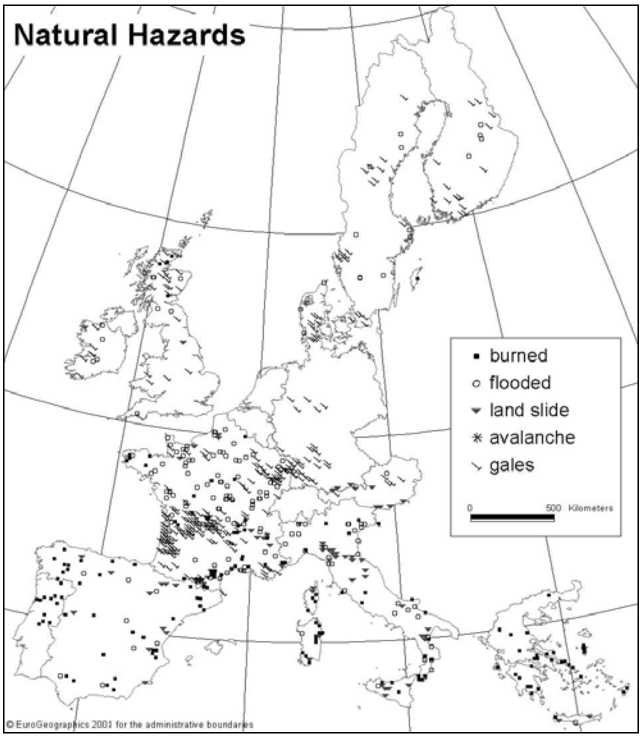


Table 6 reports the distribution of the natural hazards recorded within each land cover class; the last column of the table reports the contribution of each land cover class in the total of damaged areas. Most of the disasters affects forests (51,4%), shrubland (18,4%) and permanent grassland (10,8%). Most forest damages are the result of gales, accounting for 65,0%, compared with 20,8% for fire damage. Conversely, 81,2% of natural disasters on shrubland are caused by fire while damaged croplands are due for 59,8% to floods (Table 8).

Table 8 - Type of natural hazard by land cover (%)

Land Cover	Gales	Burned	Flooded	Land slide	Ava-lanche		All Hazards
Woodland	65,0	20,8	5,6	7,8	0,8	100	51,4
Shrubland	3,6	81,2	4,5	8,5	2,2	100	18,4
P. grassland	11,5	29,8	39,7	18,3	0,8	100	10,8
Cropland	1,1	25,3	59,8	13,8	0,0	100	7,2
Water/Wetlan	6,0	3,6	88,0	1,2	1,2	100	6,8
Bare land	3,8	39,6	17,0	30,2	9,4	100	4,4
Artificial	38,5	23,1	30,8	7,7	0,0	100	1,1
							100,0

Focusing on damages caused by gales, the analysis of the covers shows that they involve mainly forest areas, for more than 90% (Table 9). Coniferous trees are mostly affected by gales, representing 47% of all damaged land covers.

Table 9 - Land covers affected by wind gales (%)

Gales	%
Coniferous forest	47,3
Broadleaved forest	23,8
Mixed forest	18,8
Permanent grassland	3,4
Shrubland	1,8
Poplar, Eucalyptus	1,4
Other Covers	3,6
	100,0

The perception of noise

Noise is one of the variables used to assess the environmental quality of daily life. During their observations, surveyors noted the existence of noise during their stay at the SSU, and classified it according to typology, intensity and origin. It turns out that according to this subjective observation over 20% of the territory of the 15 countries is considered noise-free, two-thirds has an acceptable level of noise and 10% is classed as having a level of noise that is considered a nuisance.

Noise perception depends on human activity. In countries with a high concentration of human activities (such as the Netherlands and Belgium), the portion of the territory deemed noise-free is virtually non-existent. By contrast, almost three-quarters of Finland is deemed noise-free.

When noise is classified as intensive, road traffic is the main source of disturb, followed by agriculture, forestry and lawn moving (16,4%) and natural noises (wind in the forest, wild animals, running water, etc) in third position, accounting for 10,3% of the sources (Table 10).

Table 10 - Intensive noise by source (%)

Noise source	%
Road traffic	58,2
Agriculture, forestry,lawn mowing	16,4
Wild noise	10,3
Air traffic	5,2
Industry	3,7
Rail traffic	3,1
Others	2,2
Human voices	0,8
Total	100,0

Linear features

Linear features are important elements of a landscape due to their ecological function as habitats and influence on the human perception (appearance).

In the framework of the LUCAS project, surveyors have to register linear features crossed while walking along the straight line that connects the first five SSUs of each PSU, the so-called transects (Figure 21). The number of intersections counted along the transects makes it possible to estimate by extrapolation the length of the linear elements recorded, according to the Buffon's needle theory.

Figure 21 - Accounting linear elements along a transect

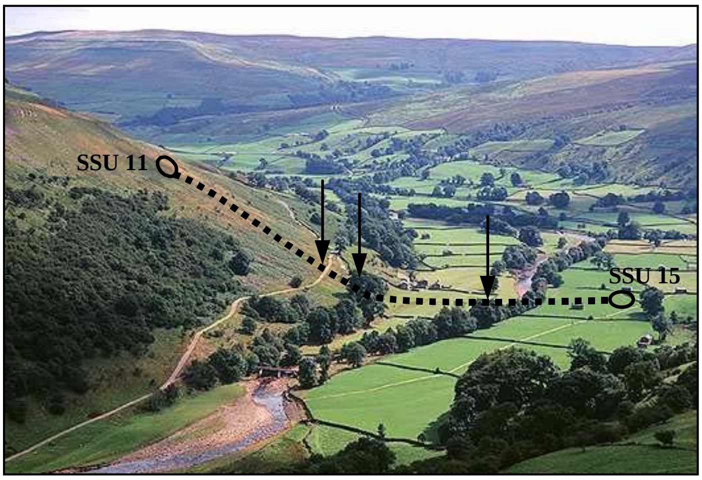
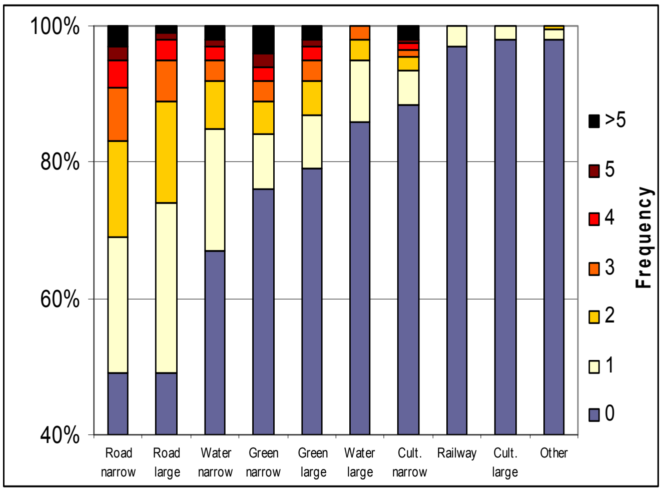


Figure 22 shows the frequency of the different linear features recorded within the transects. Roads are the most common feature encountered: more than 50% of all transect are dissected by roads, whereby in 30% of all transects more than one road is present. Narrow and large green linear features are important as well, and they constitute quite a distinctive characteristic of the European landscape.

The so-called "cultural linear features" (see codification annexed) and railways are quite rare, found in a percentage between 2 and 4% of all the crossed transects.

Figure 22 - Frequency of the number of linear features per transect



Landscape photos

In addition to LUCAS data collection on land cover / land use and some environmental features, it was decided to add photographing of landscape from a systematic observation point for each PSU (SSU n. 13). Surveyors took one photo in each of the four directions North, East, South and West (Figure 23); each photo is referenced to the number of the PSU, to preserve its location in space.

20.000 photos approximately were taken in the 2001 data collection. These photos constitute a unique archive of European landscapes, to be exploited with the aim to open new perspectives of landscape analysis, in particular in combination with other sources of information such as aerial photos or satellite images.

The LUCAS pilot project gives therefore a unique opportunity to collect a broad, systematic landscape image material, which will create a base for a new kind and a long term monitoring of landscape changes.

Figure 23 - Example of four landscape photos taken in France

Conclusions

The experience acquired with the LUCAS pilot survey has made it possible to validate the area-frame methodology applied, and the survey has proved its reliability in providing for the first time harmonised and comparable data at EU level. The summary results reported here show the richness of the data collected up to now. Moreover, in providing temporal data, LUCAS shows that it constitutes a strong system to monitor and quantify changes in land cover, land use and other environmental variables in the EU territory. This capacity is for a large part based on the exhaustiveness of the documentation, the precision of the field documents to locate precisely the points and the quality of the design of the sampling plan.

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Annex – Nomenclatures

Table 1 - 2001 Land Use nomenclature

U1	U11	AGRICULTURE
	U12	FORESTRY
	U13	FISHING
	U14	MINING, QUARRYING
U2	U21	ENERGY PRODUCTION
	U22	INDUSTRY, MANUFACTURING
U3	U31	TRANSPORT, COMMUNICATION, STORAGE, PROTECTIVE WORKS
	U32	WATER, WASTE TREATMENT
	U33	CONSTRUCTION
	U34	COMMERCE, FINANCE, BUSINESS
	U35	COMMUNITY SERVICES
	U36	RECREATION, LEISURE, SPORT
	U37	RESIDENTIAL
U4	U40	UNUSED

Table 2 - 2001 Transect nomenclature (linear feature)

LINEAR FEATURES	
Green 1m - 3m	Hedges, rows of trees, baulks
Green > 3m	
Cultural 1m - 3m	Stonewalls*, terrace boundaries, dykes
Cultural > 3m	
River 1m<< 3m	Rivers, drainage/irrigation channels or ditches, gullies
River > 3m	
Electric line	Low/high voltage lines, telephone lines
Road 1<< 3m	Roads and tracks including the road sides
Road > 3m	
Railway-track	
Other linear features	e.g. pipelines (water, gas oil)

Table 3 - 2001 Land Cover nomenclature

A	ARTIFICIAL LAND	A1	BUILT-UP AREAS	A11	Buildings with 1 to 3 floors
				A12	Buildings with more than 3 floors
				A13	Greenhouses
		A2	ARTIFICIAL NON BUILT-UP AREAS	A21	Non built-up area features
				A22	Non built-up linear features
B	CROPLAND	B1	CEREALS	B11	Common wheat
				B12	Durum Wheat
				B13	Barley
				B14	Rye
				B15	Oats
				B16	Maize
				B17	Rice
				B18	Other cereals
		B2	ROOT CROPS	B21	Potatoes
				B22	Sugar beet
				B23	Other root crops
		B3	NON PERMANENT INDUSTRIAL CROPS	B31	Sunflower
				B32	Rape seeds
				B33	Soya
				B34	Cotton
				B35	Other fibre and oleaginous crops
				B36	Tobacco
				B37	Other non permanent industrial crops
		B4	DRY PULSES, VEGETABLES AND FLOWERS	B41	Dry pulses
				B42	Tomatoes
				B43	Other fresh vegetables
				B44	Floriculture and ornamental plants
		B5	TEMPORARY, ARTIFICIAL PASTURES	B50	Temporary, artificial pastures
		B6	FALLOW LAND	B60	Fallow land
		B7	PERMANENT CROPS: FRUIT TREES, BERRIES	B71	Apple fruit
				B72	Pear fruit
				B73	Cherry fruit
				B74	Nuts trees
				B75	Other fruit trees and berries
				B76	Oranges
				B77	Other citrus fruit
		B8	OTHER PERMANENT CROPS	B81	Olive groves
				B82	Vineyards
				B83	Nurseries
				B84	Permanent industrial crops
C	WOODLAND	C1	FOREST AREA	C11	Broadleaved forest
				C12	Coniferous forest
				C13	Mixed forest
		C2	OTHER WOODED AREA	C21	Other broadleaved wooded area
				C22	Other coniferous wooded area
				C23	Other mixed wooded area
		C3	POPLARS, EUCALYPTUS	C30	Poplars, eucalyptus
D	SHRUBLAND			D01	Scrublands with sparse tree cover
				D02	Scrublands without tree cover
E	PERMANENT GRASSLAND			E01	Permanent grassland with sparse tree/shrub cover
				E02	Permanent grassland without tree/shrub cover
F	BARE LAND			F00	Bare land
G	WATER AND WETLAND			G01	Inland water bodies
				G02	Inland running water
				G03	Coastal water bodies
				G04	Wetland
				G05	Glaciers, permanent snow

Towards participatory approaches to a Multiscale European Soil Information System

Nicola Filippi, Panagos Panos, Borut Vrscaj, Jean Dusart, Marc Van Liedekerke and Luca Montanarella

Summary: The multi-functionality of soils, as medium for biomass production, biochemical cycling, water storage and its filtering and redistribution, as well as gene pool and habitat of a high diversity of life forms, is increasingly being understood and valued. In the EC Communication "Towards a Thematic Strategy for Soil Protection" it is recognized that there is an actual and future need for better information on the soil resources, and that the current state of soil resource information is often incomparable between member states and regions.

Keywords: Soil Policy, European Soil Information System.

Introduction

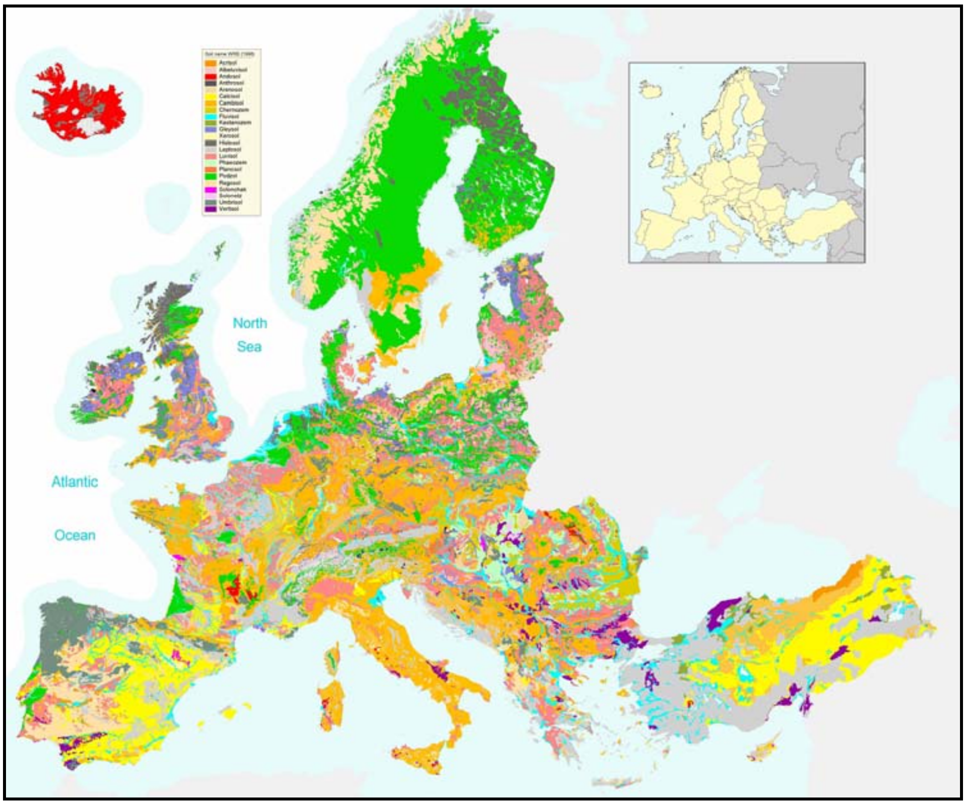
Soil protection has never been ranking high among the priorities for environmental protection in Europe. Soils are commonly not well known by the European citizens, particularly since only a small fraction of the European population is currently living in rural areas and having a direct contact with soils. The majority of the urban population in Europe has only little understanding for the features and functions of soils. The most common perception is usually that soils are a good dumping site for all kind of wastes and that soils can be quite useful as surfaces for building houses and infrastructure. Only during the last 2-3 years the need for a coherent approach to soil protection has come on the political agenda in Europe and was therefore introduced as one of the thematic strategies to be developed within the Community's 6th Environment Action Programme (6th EAP).

The rationale behind the development of a coherent approach to soil protection is based on the recognition of the multi-functionality of soils. Soils are not any more considered only as dumping sites, construction surfaces or means for production (agriculture) but also as a fundamental environmental compartment performing vital ecological, social and economic services for the European citizens: filtering and buffering of contaminants allowing us to have clean drinking water, pool of biodiversity, source of raw materials, sink for atmospheric carbon dioxide, archive of cultural heritage etc. These functions are now recognized of equal importance as the traditional soil functions commonly attributed to soils: production of food, fibre and wood (agriculture and forestry) and surface for housing and infrastructure (spatial development).

In order to develop a soil protection policy it is important to recognise that soils have distinctive features that make them quite different from the other environmental compartments, like air and water. Soils are first of all highly diverse both in space and over time. Soil properties can be completely different for soils only at few meters distance one from the others. The development of a common soil map of Europe has helped describing the very high spatial variability of soils across the European continent (figure 1). Soils are not static but develop over time. The timescale for these changes is usually very long (hundreds of years).

Therefore, for policy-making purposes, we consider soils as essentially a non-renewable resource. The high variability of soils implies that any soil protection strategy needs to have a strong local element build in. It is at local level that we can act in specific ways that are appropriate to the features of these particular soil types. This of course brings up the important distinction that needs to be made in identifying the actors that must develop and implement soil protection measures. It should be recognised that, while there are important local elements that need to be build in any soil protection strategy, there are nevertheless, clearly identified off site effects of soil degradation that justify an European or even global approach to soil protection. Erosion, decline of organic matter, soil contamination, soil compaction, soil sealing, loss of biodiversity have very important off-site consequences, like silting of hydropower stations, increase of atmospheric carbon dioxide, contamination of drinking and bathing waters, contamination of food, increased frequency of flooding and landslides, etc. All these off-site effects seriously threaten human health and have substantial economic implications. A key feature for developing a soil protection strategy is the recognition of the implications linked with the fact that soils in Europe are commonly submitted to property rights. The majority of soils is in private property and this brings up a series of environmental liability implications.

Figure 1 - Soil map derived from the Soil Geographical Database of Europe at scale 1:1,000,000.



The EU soil protection strategy builds upon the recognition that the important functions of soils are threatened by severe degradation processes. The major threats identified so far are soil erosion, decline in organic matter content, loss of soil biodiversity, soil contamination, salinization, soil compaction, soil sealing and major hydro-geological risks (flood and landslides).

European Soil Information System (EUSIS)

The European Soil Information System (EUSIS) has been developed over the past years in the framework of the activities of the European Soil Bureau. It is a large collaborative project covering the entire European Union and bordering countries and involving National soil surveys and soil science institutions in more then 45 countries. The current coverage of the system includes continental Europe, Siberia and part of North Africa and the Middle East. The backbone of the system is the Soil Geographical Database of Europe (SGDBE) at scale 1:1,000,000 that has been created starting from the first digitized soil map of Europe in 1985. This database has been developed jointly with partners in participating countries allowing achieving the only harmonized coverage with digital soil information for Europe. The database is extensively used for applications in the most diverse fields: agriculture, water protection, climate change, flood forecasting, desertification assessment, etc. The recent development of an EU Thematic Strategy for Soil Protection has been mainly based on data and assessments derived from this soil database. The status reports from the Technical Working Groups on soil erosion and soil organic matter has been mainly derived by interpretation of the SGDBE.

Increased demand for soil data has also put in evidence the large shortcomings of the 1:1,000,000 SGDBE. Data are essentially derived from surveys done in the 1950-60 and are obsolete for many countries. Parameters contained in the database only seldom respond to the users needs. Therefore a large number of pedo-transfer rules had to be developed in order to derive useful and policy relevant information out of these data. New initiatives were launched during the recent years in order to collect new, updated and policy relevant soil information for Europe. Several strategies were chosen in order to achieve the goal gathering useful soil information in a reasonable time frame.

Firstly, the development 1,000,000 SGDBE has continued and will incorporate new soil profile information (Soil Profile Analytical database of Europe, SPADE II). It will also be converted into WRB as the standard soil classification system for Europe. This will also require consequently the re-definition of pedo-transfer rules and functions.

Secondly, the implementation of the INSPIRE directive will allow to build a common framework for spatial data in the EU. Implementation of the directive should allow the construction of a nested system of soil data, from the data producer up to the final user, responding to the various needs at different scales. In order to achieve this, a common standard for the collection of harmonized soil information will have to be developed and implemented. The current Manual of Procedures of the Geo-referenced Soil Database for Europe will therefore have to be updated.

A close link with the planned European soil monitoring initiative will have to be created in order to allow regular reporting about changes in soil properties over time. In order to avoid un-necessary duplication of initiatives a joint effort should be made in order to develop soil monitoring procedures jointly with the on-going soil monitoring in forestry (ICP-Forest, Forest FOCUS) and the National initiatives on soil monitoring, where they exists.

The final result of these developments should be the creation of an harmonized soil information system for Europe streamlining the flow of information from the data producer at local scale to the data users at the more general Regional, National, European and Global scales. Such a system should allow deriving the data needed for the regular reporting about the state of European soils by the European Environment Agency and the European Commission.

Participatory approach towards a Multiscale European Soil Information System (MEUSIS) within the INSPIRE framework

Among the spatial themes identified in the annexes of the proposed INSPIRE Directive, the creation of an harmonized hierarchical grid with a common point of origin and standardized location and size of grid cells could constitute an ideal framework for the building of a nested system of soil data. This reference grid will be based on agreed implementing rules facilitating interoperability: a common coordinate reference system, such as the ETRS89 Lambert Azimuthal Equal Area CRS (ETRS-LAEA), a unique grid coding system, a set of detailed and standardized metadata, an exchangeable and open format. Hierarchical structure of the grid may give answers to different questions from global assessment to detailed soil monitoring sites.

The use of a common reference grid offers the opportunity to deliver soil information on a multi-resolution raster basis rather than the traditional vector approach. In addition, it reduces the problems of cross-border harmonization and polygon rubber sheeting. It contributes to the Inspire principles in the sense that spatial data might be combined across the EU seamlessly and being shared between users and applications. Much more, modelling and analysis of environmental issues related are based on raster layers (land cover, DEM, satellite images, interpolated meteorological data).

From the upper level point of view (European or National), it reduces the restrictive access to the data by offering degraded data that respect ownership rights and facilitating access to environmental information as requested by the re-use of Public Sector Information Directive (2003/98/EC) or the Aarhus Convention (The UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters).

However, this bottom-up approach is not necessarily perceived as pertinent by the local or regional levels, in the sense that return on investment can hardly be demonstrated without an explicit financial support from the upper levels. Converting data at degraded levels requires additional work that often goes beyond their political duties. This can only be achieved if the national level offers additional funding and/or mandates explicitly the regional/local levels to provide the data.

Rasterizing existing vector data at specific grid sizes is technically simple but collecting soil data or other thematic information on a grid basis is far away from the traditional approach in soil mapping. Collection of soil properties on existing regular grid such as LUCAS grid could be a good starting point for encouraging local levels to establish detailed survey of soils. Success will depend of the level of coherence and harmonization with the proposed Inspire guidelines that future LUCAS surveys will achieve and the possible integration of existing national surveying schemes.

Other technical issues concern the cell size, and the level each cell size has to be maintained. One can imagine that detailed information should be maintained at the most appropriate level (Inspire principle respecting subsidiarity). Another issue deals with the selection of the most appropriate generalization algorithm. Affecting one dominant value to a single pixel on basis of the highest proportion of surface occupied by this value can have secondary effects, as the spatial distribution of Soil Typological Units (STU) within a Soil Mapping Unit (SMU) is unknown.

There are still a lot of efforts and studies to be conducted for establishing an efficient workflow for updating and maintaining grid based thematic layers with highly detailed information, more particularly in a participatory approach, involving bottom-up transfer of spatial information from local to global level.

Conclusions

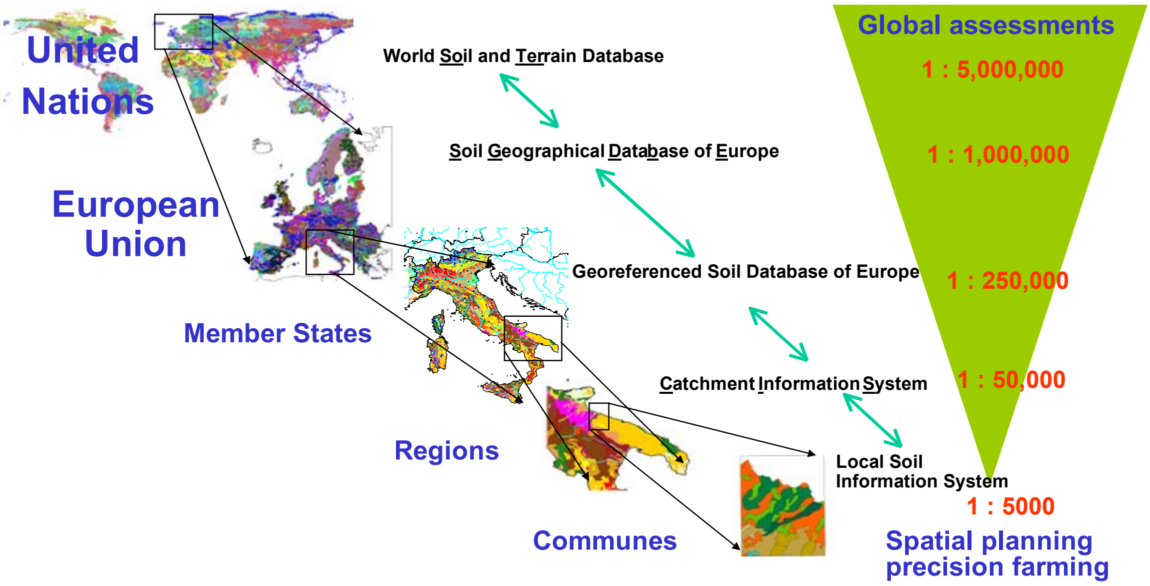
Implementing participatory approaches in the construction and management of large soil information systems requires the achievement of consensus among all stakeholders on the methods and procedures to be followed. The European Soil Bureau Network portal (http://eusoils.jrc.it) of the JRC is a good example of such participatory approaches. Nevertheless there is still a long way to the achievement of fully integrated multi-scale soil information systems like the one proposed by the European Soil Bureau Network (figure 2).

Moving away from the classical approach of soil mapping towards the creation of geo-referenced soil databases could be the first step to the achievement of that goal. Typical soil data are point data collected in geo-referenced sampling sites according to standardized methodologies (Manual of Procedures of the Geo-referenced Soil database for Europe, Doc. EUR 18092 EN). There is still a lot of research needed into solving the problem of the generation of digital soil maps starting from the field data (points). The traditional method was based in the deep knowledge and experience of local soil scientists. This knowledge has been largely lost in many European countries. New approaches are needed that could integrate ancillary data sources (DTM, geological maps, land cover, etc.) in the process of deriving spatial entities (soilscapes) out of the observed point data.

A more feasible alternative seems to be, in the short term, the approach by grids. This implies that no immediate effort is needed into harmonizing soilscape delineations, which are often subjective, and also it would allow an easier construction of nested systems using different grid spacing. The JRC has launched several pilot studies in this sense in 2004. The results of these studies will eventually demonstrate the feasibility of such approaches.

The use of the digital soil information is not limited only to the generalization of the vector-derived databases (SGDBE). The recent studies and test show that it is possible to improve the spatial quality and level of detail of original vector soil data with the help of raster GIS modeling techniques. The additional information on environment in a raster format (especially high resolution remote sensing data and already available elevation models) offers the opportunity to downscale the original soil information and derive the soil raster datasets in the scale needed for maintenance very diverse environment and/or for using soil data on local community or regional levels.

Figure 2 - The European Soil Information System, responding to users (in blue) needs at different scales (in red).



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EU Regional Policy and Grids

Hugo Poelman

Summary: In EU regional policy, geographic data are mainly used within the framework of statistical regions, but indicators developed out of georeferenced data sources are also needed. Specific territories need to be defined and analysed at various non-administrative levels. Hence, grids can be used as a framework for data collection and analysis. Results of raster-based analysis will often have to be converted to the regional framework. Recent grid uses include the definition of mountain areas, use of land cover data, and the development of regional typologies. Future grid systems will have to enable efficient aggregation and disaggregation. European-wide raster data sets should be defined in a coherent way, and should be compatible with register-based national statistical systems.

Keywords: Regional Policy, Statistical Indicators, NUTS regions

The geographic component of the implementation of regional policy

The European Union's regional policy is implemented within the framework of the NUTS regions (Nomenclature of territorial units for statistics). These regions form a three-level breakdown of the Member States, mainly established for the sake of statistical data collection and publication. Since 1988, regional policy makes legal references to these NUTS regions, especially when it comes to regional eligibility criteria, e.g. for Structural Funds Objective 1 (at NUTS-2 level) and Objective 2 (mainly at the more detailed NUTS-3 level). In 2003, principles underpinning the NUTS classification have been laid down in a Regulation of the European Parliament and the Council.

Data needs for regional analysis: problems and opportunities

A legal link exists between the NUTS classification and its use for implementation of regional policy, so this also implies that the NUTS breakdown is the main framework for socio-economic and territorial analysis within the context of the conception of regional policy.

Translating this into geographic data, this means that regional data analysis essentially relies on polygon and boundary (line) data. Currently, indicators and data related to this geography mainly come from Eurostat (and from the national statistical offices). Using regional data series at European level is not unproblematic. One of the main problems is the presence of data gaps, especially when considering time series. Changes in the regional breakdown are often responsible for these gaps.

Moreover, there is a growing need for a more diverse collection of thematic indicators, to feed the analysis of economic, social and territorial cohesion. This creates the need for less "traditional" indicators, or at least for indicators that can not easily be gathered by the "classical" procedures of most statistical offices. Hence, alternative or complementary indicators could be developed directly out of georeferenced data sources.

Apart from using the NUTS framework, regional policy conception also needs to define and analyse specific areas at various non-administrative levels. Typical examples are the eligible areas for specific structural funds interventions (e.g. local eligible areas under Objective 2 for the programming period 2000-2006, URBAN II areas, some INTERREG IIIA programme areas, etc.), areas with certain natural handicaps (as there are islands and mountain areas), or areas with functional specificities (e.g. functional urban areas). Substantial problems of statistical data collection and availability occur when trying to analyse these ad-hoc defined areas.

Potential uses of grids

What could be the potential of grids to help overcome these problems?

Grids can be used as a framework for the collection and analysis of "alternative" data. Examples could be the analysis of point-based (sample) data (e.g. in the field of indicators on environmental conditions or sustainable development), or grid aggregations of individually recorded georeferenced information (e.g. records at the level of inhabitants, households, addresses or local economic units, as in register-based statistical systems).

Basic raster-based data (as obtained from remote sensing) could be further analysed, producing grid-based statistical indicators.

Seen from the regional policy perspective, the production of grid-based indicators, although benefiting from a homogeneous framework, will most often be an intermediate step in the analysis. Indeed, these data will also have to be converted to NUTS-based indicators, mainly because of policy conception and implementation constraints. Although one could imagine a potential interest to convert data the other way round, i.e. from NUTS-based data to raster data, this procedure would be definitely less oriented towards policy development and implementation.

Recent grid uses in regional policy

Grid-based data have been used in several circumstances to feed specific topics of analysis.

One key example is the development of a EU-wide harmonised definition of mountain areas (European Commission, 2004 [1]). Starting from a digital elevation model, a morphological definition has been implemented, not only using altitude criteria, but also slope, local elevation range and climatic contrast. The resulting morphological mountain areas have been overlaid with local administrative boundaries (lines and polygons), to determine an "administrative" definition of the mountain areas. This overlay was necessary to enable the collection and analysis of statistical data, often only available at the level of local administrative entities.

Grid-based CORINE Land Cover data have been used for basic indicator development at regional level. Examples are the definition of the extent of morphological urban areas versus other main land cover classes, or the development of estimates of fragmentation of natural areas at NUTS-3 regional level (European Commission, 2004 [2]). Land cover and elevation data have also been used as complementary data sources in the analysis of island regions (European Commission, 2003).

One of the aims of the study projects of the ESPON programme (European Spatial Planning Observation Network) is the development of typologies of European regions. In this scope, grid-based data, especially land cover data, are being used, in combination with NUTS-3-based territorial indicators (ESPON, 2003). As ESPON projects try to examine the territorial dynamics, change information on grid-based indicators (e.g. land cover changes), will be most useful as soon as it will become available.

Basic requirements of grids for use in regional policy

The regional NUTS classification is most likely to remain a key element in regional policy conception. This implies that any grid use has to guarantee efficient methods of aggregation and/or disaggregation towards and from the NUTS breakdown.

Regional policy has an interest in the analysis of the complete EU territory, from a pluri-thematic perspective. Therefore, relevant raster data sets should have a Europe-wide coverage, and be defined in a way ensuring optimal coherence amongst each other. The use of regular equal area grid cells will be an essential requirement for data analysis and aggregation.

Grids can be a useful tool to exploit individually registered data. Consequently, these grids should ensure optimal compatibility with register-based (national) statistical systems.

Conclusions

Grid-based information can be used as a partial alternative of complement to NUTS based information. There is a definite need for awareness raising about the potentials of this alternative data source. The efficiency and validity of the use of grid-based indicators will depend on the degree of harmonisation and coherence, gradually achieved by European-wide grids.

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Current use of spatial reference grids in European Environment Agency

Andrus Meiner

Summary: Paper gives an overview of current use of spatial reference grids in EEA main products: EMEP grids for air pollution and deposition, UTM based grids for biodiversity mapping, equal area grids with different resolution for land cover assessments, lat/long grids for variety of other uses. It outlines the points of main interest of EEA in development of common European reference grid, seeing this as support to European Spatial Data Infrastructure development and INSPIRE initiative.

Keywords: spatial reference grid, environment, reporting, maps, land cover

Direct and indirect spatial reference

Spatial reference is fundamental property of the data used in environmental analysis and assessments. Reference, which establishes the location of the object is in most cases determined and stored as direct position based on coordinate reference system with specification of geodetic datum and coordinate system. For several reasons, spatial reference, based on indirect position is also interesting in managing environmental data. One of the most common methods of storing spatial information with indirect reference is usage of spatial reference grids. Omitting direct spatial position and averaging the qualitative properties inside each of the cells can be regarded as disadvantages of grids. On the same time grids are powerful tools for data harmonization and reducing the complexity of spatial data sets. Spatial reference grids are also effective communication means for reporting spatial distribution and variability of features.

Environmental issues and use of reference grids

EEA is working with wide array of environmental issues in order to meet it’s main goal of the provision of timely, targeted, relevant and reliable information to policy making agents and the public. Spatially referenced data and, more specifically, maps showing the distribution of natural phenomena or environmental pressures is often used in the Agency’s reports and other communication. Considerable part of these output products employ spatial reference grids for data presentation. However, in most cases Agency does not develop itself the spatial reference grids and does not perform primary data collection on grids. Another aspect of spatial data handling in EEA is related to European scope, which makes Agency interested mostly in grid systems with pan-European coverage.

Air pollution, ozone and UV

Grids are used for presenting data related to atmosphere and air pollution. This concerns data on emissions and deposition of air pollutants such as nitrogen or sulphur, but also concentrations in soil as a result of air-borne deposition (for example for HCB). Specific usage of spatial reference grid is related to ecosystem exposure expressed through calculated critical loads and exceedances of ecosystems buffering capacity. Grids are also used for indicating spatial variation of UV exposure and depletion of stratospheric ozone layer.

Biodiversity assessment

Species distribution (atlases) is the main area of reference grid applications in biodiversity mapping and assessment. Several European research institutes are using coordinated approach to map the distribution of plant species, birds, amphibians and mammals.

Climate change and hydrology

Change of annual temperature, which is registered on the longitude/latitude grid and average annual runoff distribution are examples of applying reference grids in area of climate change and hydrology.

Land cover and soil

Grids are also used for illustrating land cover distribution, as mapped through the CORINE Land Cover project. Even if the original data is created as high-resolution vector database the grids are used for data dissemination. This format has less volume and is often more suitable for analysis on the regional and European scale, such as ecosystem fragmentation assessment. Grids have been also applied in mapping the soil erosion risk.

Current use of reference grids

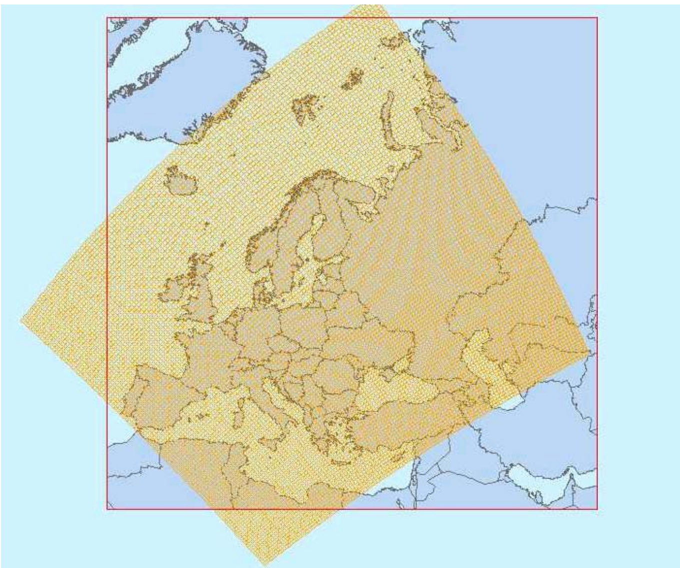
EEA is not developing itself the spatial reference grid systems, but maps based on grids are often used in EEA reports (table1). Due to EEA's mandate to act on European level these maps are normally having European Union or pan-European map extent. This requirement makes useable only these grid systems, which allow for extension across the whole continent.

Table 1 - Number of grid maps in latest EEA assessment reports (EEA, 1998,1999, 2003)

Type of grid	Grid maps	Environmental issue
EMEP grids: 50 km and 150 km cells	17 maps	air pollution modelling, deposition
UTM 50 km grid	5 maps	species distribution mapping (atlases)
Equal area 10 km grids	10 maps	geographical comparisons based on area; land cover, river basin management
Lat / Long cells 30' x 30', also others	8 maps	various uses: deposition of hazardous substances, erosion risk, mean temperature, seismicity
Regular sampling grids	2 maps	ICP Forest 16 km grid for forest health monitoring

Some of the grids used are typical grid applications, where value of certain environmental feature is defined for each cell and spatial distribution is presented by grid coverage. In these grids cells have regular distribution and rectangular shape, but they are not necessarily representing equal area and they aren't always squares. Such systems are represented by EMEP and UTM grids (figure 1, Table 2).

Figure 1 - 50 x 50 km EMEP grid, re-projected EEA version (Source: EEA)



Other kind of grid applications is using cells defined by parallels and meridians (latitude/longitude grids), with typical resolution of 30 arc minutes, but also others.

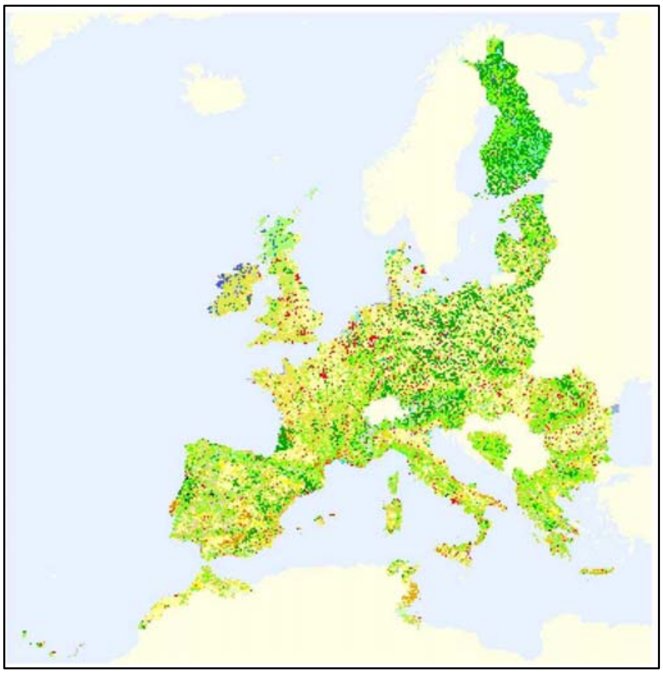
Table 2 - Main parameters of some spatial reference grids (commonly used in EEA publications).

EMEP grid Monitoring for Convention on Long-Range Trans-boundary Air Pollution Projection: Polar Stereographic, reprojected in EEA version Resolution: Original 50 x 50 km (on project plane), also 150 km cells
UTM grid by CGRS/AFE Chorological Grid Reference System/Atlas Florae Europaeae widely used in species distribution mapping Projection: Universal Transverse Mercator (WGS84 datum) Grid is based on Military Grid Reference System Resolution: standard 50 x 50 km with irregular cell size on the UTM zone boundaries

However, more important for EEA has been converting the CORINE Land Cover vector data base to the raster grid in Lambert Azimuthal Equal Area projection (on WGS84) with centre point 52N 20E. This results in array of grids, where original conversion product of 100 m cell size is consequently generalised to 250 m, 1 km and 10 km resolution, according to spatial analysis needs in various scales.

Since land cover data often lays in the basis of environmental assessments, these land cover grids are widely used in EEA. The 10 km equal area grid is often used to present European land cover (figure 2).

Figure 2 - Example of 10 km equal area grid: CORINE Land Cover (Source: EEA)



Conclusions

EEA is not a grid developer, but is interested in European common grid. EEA sees this as support to European Spatial Data Infrastructure development and INSPIRE initiative, where geographical grid systems are identified as one of the basic data component. EEA priorities for common European grid can be summarised in the following points:

- Compatibility through clear relation to European Terrestrial Reference System (ETRS89) and use of WGS84 datum.
- Agreed projections such as Lambert Azimuthal Equal Area, Transverse Mercator and Lambert Conic Conformal.
- Guaranteed convertability to geographical lat/long coordinates.
- Efficiency for data storage and access, assured through hierarchical data structure.

EEA is looking forward for the common grid solution as basis for data presentation and reporting, but in future also for harmonization and streamlining of spatial data collection from the countries and other members of its network.

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Atlas Florae Europaeae – Mapping European Vascular Plants with a 50 x 50 km grid

Pertti Uotila and Raino Lampinen

Summary: A short description is given of current and previous *Atlas Florae Europaeae* grids, mostly based on 50 x 50 km cells. The difficulty in converting the grid to the proposed common European grid is emphasized.

Keywords: *Atlas Florae Europaeae*, distribution, Europe, grid, vascular plants

Atlas Florae Europaeae

Atlas Florae Europaeae (*AFE*) is a pan-European project mapping the distribution of vascular plants of the continent. The mapping area covers Europe as defined in *Flora Europaea* (Tutin et al. 1964, 1968, 1972, 1976, 1980), including western Kazakhstan, Svalbard and the Azores, and excluding the other Macaronesian islands, Greenland and Novaya Zemlya. It extends in the east to the Ural Mountains and in the south-east to the northern foothills of the Caucasus Mts.

The project was launched in 1965, and its aim is to complete the territory level distribution data of *Flora Europaea* (Jalas & Suominen 1967). Between 1972 and 1999, *AFE* has thus far produced 3270 grid maps of the distribution of European vascular plants in 12 printed volumes (Jalas & Suominen 1972–1994, Jalas et al. 1996, 1999).

The published volumes of *AFE* cover the first volume of *Flora Europaea* (Tutin et al. 1964) and ca. 20% of all European vascular plant species. The project has collaborators throughout Europe (Committee for Mapping the Flora of Europe), and the regional collaborators of each territory are responsible of providing data on their respective territories.

The number of regional and assistant collaborators for each volume has been 68–150. The secretariat, located in Helsinki, is responsible for writing the text for mapped taxa, inputting data provided by the regional collaborators into a database, editing the data and publishing the Atlas volumes. Up to volume 12, the data were received on paper cut-outs, thereafter data have been largely collected digitally by using special software for data recording.

Data from scanned printed maps were recently extracted by custom software into an Oracle database (Lahti & Lampinen 1999). This enables the use of distribution data in scientific research (e.g. Humphries et al. 1999, Pearson et al. 2000, Williams et al. 2000a,b, Araújo et al. 2001).

Grid system of Atlas Florae Europaeae up to 1999

Grid mapping was selected for *Atlas Florae Europaeae* because grid maps are relatively easy to produce (a limited number of localities needed) and, in contrast to point data, the large grid cell size partly hides the uneven knowledge.

Further, when this project commenced, grid mapping was already common in floristic mapping, with a new model being offered by the Atlas of the British Flora, which used a 10 x 10 km cell size (Perring & Walters 1962). Computers and databases were not yet available, and all work was done on paper.

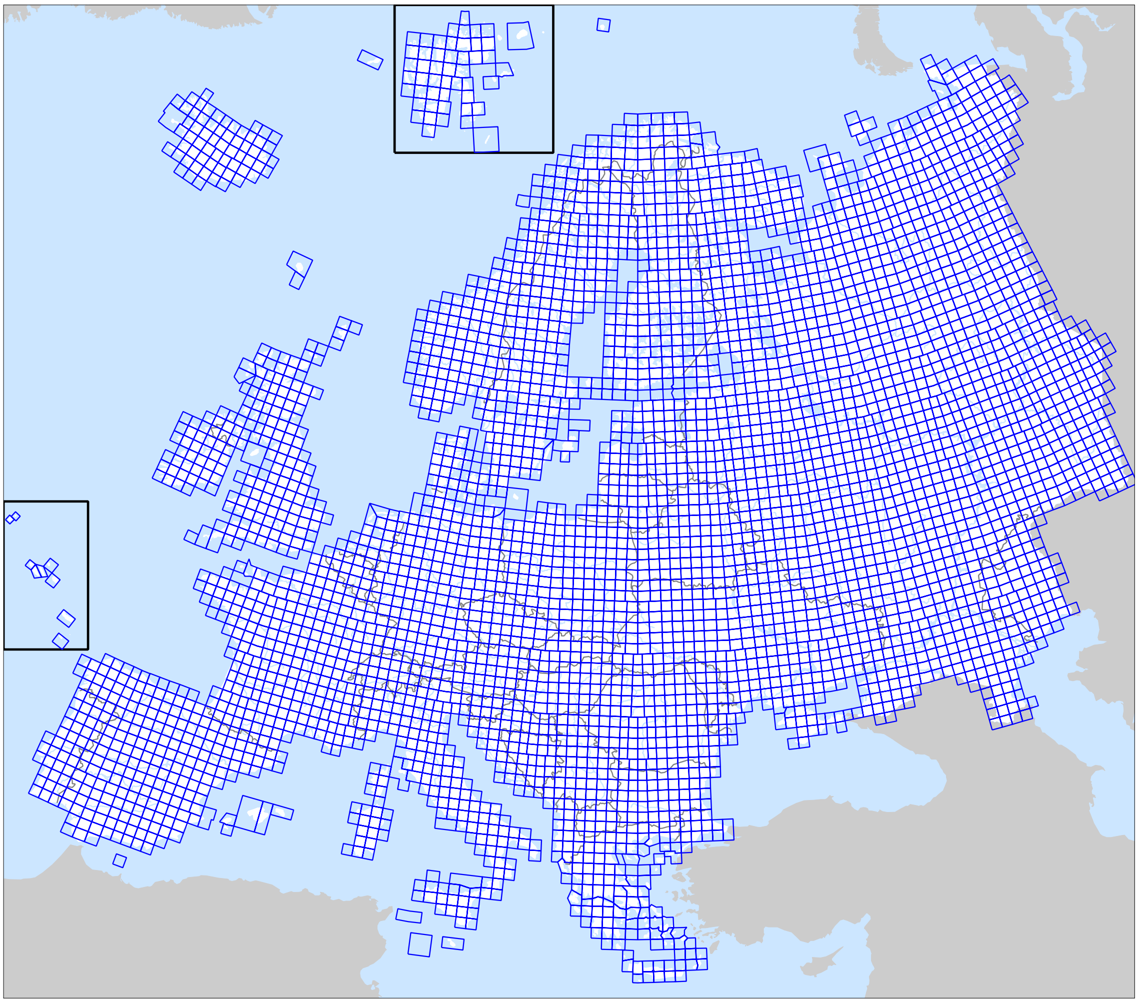
The UTM projection and the Military Grid Reference System (MGRS) were chosen for *AFE* since in the mid-1960s maps showing the MGRS grid for the continent became available at a scale of 1:1 000 000. The *AFE* grid was drawn onto these maps, and these were then distributed to the national *AFE* collaborators.

In the grid used in the *AFE* volumes published hitherto (Figure 1), there are altogether 4419 grid cells with land in Europe. The grid cell size used is mostly 50 x 50 km, with special adjustments at the UTM zone boundaries to decrease the size variation between cells.

Many deviations from the general pattern occur (e.g., hundreds of coastal grid cells with little land joined to neighbouring cells; long peninsulas, certain isolated islands, some mountains and Istanbul given their own grid cells). In addition, several minor (coastal areas) and major (Greece, Svalbard) changes in the grid system have taken place over the years. The geodetic datum is not specified.

The *AFE* grid was later adopted by several faunistic European mapping projects. Unfortunately, it was not used in a standardized way due to the lack of a proper published description of the system.

Figure 1 - Grid cells used in *Atlas Florae Europaeae* volumes 3-12 (Jalas & Suominen 1976-1994, Jalas & al. 1996, 1999), and with minor differences in volumes 1 and 2 (Jalas & Suominen 1972, 1973)



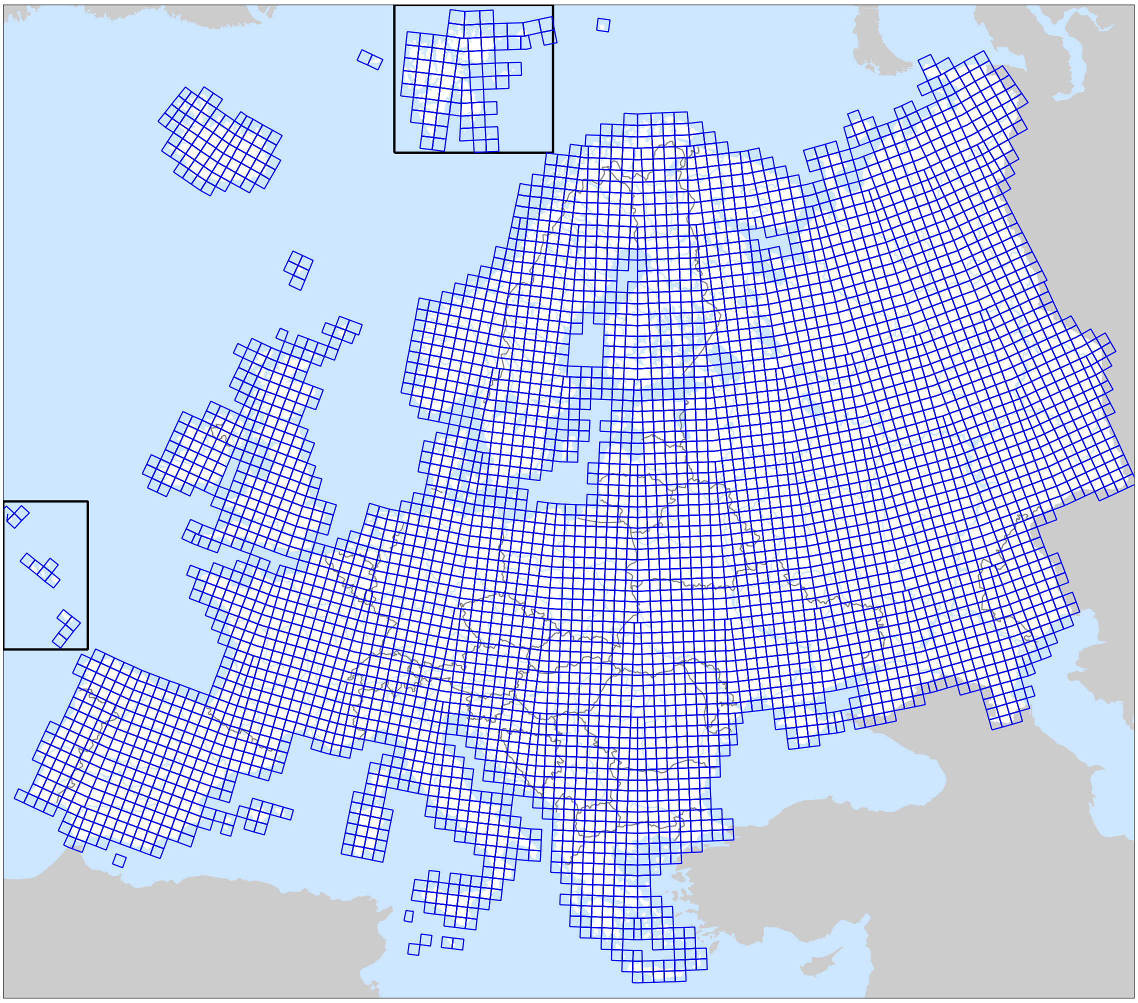
Revised grid system

The grid system used by *Atlas Florae Europaeae*, including the variants used by other mapping projects, has recently been revised in co-operation with other mapping projects and the European

Topic Centre on Nature Conservation and Biodiversity. In the revised grid system, 4748 grid cells with land in Europe are specified (Figure 2).

This grid extends over terrestrial and marine areas following a predetermined pattern, with no deviation for coasts, islands, peninsulas, mountains, towns, etc. A new solution has been adopted for the treatment of partial slices at UTM zone boundaries, and WGS84 datum is used.

Figure 2 - Grid cells currently used in *Atlas Florae Europaeae*



Problems with the Atlas Florae Europaeae grids

While the grid system meets the needs of *AFE* in the production of plant distribution maps, it is, even after its recent revision, still far from satisfactory for statistical analysis. The *AFE* data collected in or converted to the new grid system can be directly combined with faunistic atlas datasets (*European Amphibians and Reptile Atlas*, *European Mammal Atlas* and *European Bird Atlas*), but linking it with other data is tedious. The grid cell size varies considerably, and the edge problem persists at UTM zone boundaries.

The grid proposed at the 1st Workshop on European Reference Grids would undoubtedly be more suitable for the pan-European biological mapping projects than the present UTM-based grids with problems at zone boundaries. However, adopting the new grid would strongly conflict with the existing data.

The editors of *Atlas Florae Europapeae* and the faunistic atlas projects have typically received data from their national collaborators at the 50 x 50 km accuracy, mostly with no detailed background information. At the national level, faunistic and floristic distribution data are generally collected using the 1 x 1 km or 10 x 10 km grid cells of the national co-ordinate systems, and very seldom as point data with high location precision. Thus, conversion of existing data in the biological atlas projects to the new grid would be problematic and would result in a decreased level of accuracy.

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Mapping the distributions of plant species across the countries of Europe − an overview of research schemes and grid systems

Harald Niklfeld

Summary: The distribution patterns of native plant species concern many issues of botany, biogeography, ecology, and conservation, and have become subject to manifold comparative and causal analyses. Therefore, floristic mapping schemes were launched throughout many regions of Europe, mostly using grid cells of various types als topographical reference units. Thousands of botanists were, and are, engaged in field-work, computer databases were established, and a considerable number of distribution atlases have been published or are in progress. Wide territories, particularly of northern, western and central Europe, but also some regions of Spain and Italy are already covered by such schemes, which here are shortly reviewed.

Keywords: Plant distribution, Floristic mapping, Grid systems, Europe

Floristic mapping: a network of research schemes

The manifold distribution patterns of native plant species have since long attracted the interest of botanists, biogeographers, ecologists, and people concerned with conservational issues, and have become subject to a broad variety of comparative and causal analyses. For the purpose of obtaining appropriate knowledge of these distribution patterns on a detailed scale, first approaches to cover whole countries by systematic and organized floristic mapping schemes started in 1902 in the Netherlands and in 1904 in Denmark.

During the last decades a steadily increasing number of such projects were launched, and partly already finished, throughout many regions of Europe − parts of countries, whole countries, or groups of neighbouring countries.

Thousands of botanists were, and are, engaged in methodical field-work (most of them on a voluntary basis), computer databases were constructed and filled with many millions of records, and a considerable number of comprehensive distribution atlases have been published, or will be published in the future. At present, wide and coherent territories, particularly of northern, western and central Europe, but also some regions of Spain and Italy are already covered by such atlases.

Most of these atlases comprise more or less the total number of the Vascular or "Higher" plants (Pteridophyta and Spermatophyta, or roughly spoken, Ferns and Flowering Plants) that occur in the wild in the respective region, and thus contain often between 1500 and 3000 detailed distribution maps. The data collected by this type of mapping, and presented by this type of atlases, are also an important primary source for the national contributions to the all-European but less detailed Atlas Florae Europaeae (see e.g. Suominen 1999 and Uotila & Lampinen [this volume]). Furthermore, also a number of distribution atlases referring to Lower Plants (mainly Bryophytes, Lichens, and Fungi) have been published or are under progress in various countries, using similar methods. The same holds for many groups of animals.

Methods and Grid Systems

Regarding the methods of topographical referencing and cartographical presentation that are applied by the various botanical mapping schemes, databases, and atlases, the great majority use “cellular” methods, where the location of a record is defined by its presence within a cell, or mesh, of a defined recording system. This is a consequence of the need to carry out the underlying field observations in the most efficient way. Dependent on traits of national cartographies and other reasons, different such cellular reference systems are in use in various regions or countries of Europe.

These are dealt with below. As to the size of the grid cells, most regional or national schemes are based on units with side-lengths between 4 and 20 km, whereas on the local scale even more detailed resolutions are used.

The reference systems in use can be grouped as follows:

Kilometrical grid cells

1. National kilometrical grids (e.g. Belgium [extensions of the Belgian grid being used also in Luxemburg and in a major part of northern France], Britain, Finland, Ireland, Netherlands, Poland, parts of Sweden; also, since 1993, the CRSF database [but not the national distribution atlas] for Switzerland, and the new floristic mapping project for Denmark) [together 10 different systems]. – See e.g. Rompaey & Delvosalle 1972, Delvosalle 1977, Perring & Walters 1962, Croft & Preston 1999, Preston & al. 2002, Kurtto & Lampinen 1999, Mennema & al. 1980, 1985, Meijden & al. 1989, Zając & Zając 1999, 2001, Palese & Moser 1995.

2. UTM grid (e.g. some Départements in SW. and in NW. France, parts of Spain, Bulgaria, western parts of Ukraine; Atlas partiel de la flore de France [20 × 20 km, incomplete, not continued]; Orchids of the Mediterranean area; and as a synthesizing approach, on the 50 × 50 km scale, Atlas Florae Europaeae). – See e.g. Dupont 1990, 2001, Boullet & Toussaint 1998; Aseginolaza & al. 1994, Bolòs i Capdevila 1998, Villar & al. 1998; Kagalo & Systschak 1999; Suominen 1999, Uotila & Lampinen 2004.

Grid cells based on geographical longitudes and latitudes

1. Greenwich coordinates with base units of 10' long. × 6' lat. [in 50° lat. ~ about 11,9 × 11,1 km] and smaller subdivisions ("Mapping the Flora of Central Europe", in particular Austria, Croatia, Czech Republic, Germany, Hungary, northern Italy, Slovakia, Slovenia; extensions of the system also being used e.g. in Estonia, in parts of central and southern Italy, as well as for one French Département [Haute-Savoie] and one Spanish province [Navarra]); at lower resolution (20' × 12') for the high-mountain flora of the Alps and Carpathians [within "IntraBioDiv", a current project under the 6th EC Framework Programme]). – See e.g. Ehrendorfer & Hamann 1965, Niklfeld 1971, 1994, 1998, Slavík 1994; Wittmann & al. 1987, Hartl & al. 1992; Pavletić 1969; Slavík 1986, 1990, 1998; Haeupler & Schönfelder 1989, Benkert & al. 1996, Bergmeier 1992, Schönfelder 1999, Haeupler 1976, Raabe 1987, Schönfelder & Bresinsky 1990; Király 2003; Pignatti 1979, Poldini 1993, Prosser & Festi 1993; Jasičová & Zahradníková 1976; Babij & al. 1999, Jogan 2001; Charpin 1975; López & al. 1991.

2. Paris coordinates (the circle divided into 400 grades) with base units of 10 × 10 centigrades and subdivisions (recommended for France by the Secrétariat Faune-Flore at Paris; applied e.g. in Basse-Normandie, Hautes-Alpes, and for a selection of species in Bourgogne). – See e.g. Cartan 1978, Provost 1993, Chas 1994, Bugnon & al. 1998.

Non-geodetical reference cells

1. Natural landscape segments (the national distribution atlas for Switzerland: Welten & Sutter 1982).

2. Administrative reference units, e.g. municipalities (older recording systems and some regional publications, in particular from Norway and Sweden)

Non-cellular recording

1. Map series at lower density, based predominantly on specimens deposited in herbarium collections (e.g., Flora of Greece project: Strid & Tan 1997, 2002) or on older data (e.g., the distribution atlas of the Nordic countries: Hultén 1950). – The results of the Danish “Topografisk-Botaniske Undersøgelse” (see Vestergaard & Hansen 1989) combine non-cellular collection data with landscape-segment based field records.

2. Highly detailed mapping schemes, often with emphasis on rarer species (e.g., various regions of Sweden, various older map series from parts of Germany).

Conclusions

The availability, in computer databases, of georeferenced floristic data at high density and for wide territories has opened new possibilities for numerical analyses of species distribution patterns and of their correlation to climatic, geological, ecological, economical, and other relevant parameters. It has become a typical design of such studies that data referring to a selection of external parameters are transformed, partly by means of GIS, into the same cellular structure as is used with the considered region's floristic data, for the purpose of combined analysis. Pioneer studies were undertaken for southern Niedersachsen (Germany) and for Belgium already in the 1970s. In the meanwhile, advanced analyses of this type have been published for the total areas of Germany and of Switzerland, for parts of Italy and of the Czech Republic, and are at present being carried out otherwhere, too. – See e.g. Haeupler 1974, Boon 1978, Wohlgemuth 1993, 1994, 1996, Poldini & Martini 1995, Poldini & al. 1999, Korsch 1999, Haeupler & Vogel 1999.

Unique data stocks and vividly developing fields of research, like those summarized here, should certainly be taken into account during the envisaged process towards grid standardization in Europe, and should not get reduced in value or hindered by possible pressure to abandon established, well working reference systems.

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The grid reference system used for CGMS

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Summary: The MARS Stat Action of the JRC has been using since 1992 a reference grid system within the CGMS (Crop Growth Monitoring System). The basic function is to serve the agrometeorological analysis at European scale allowing meteorological data interpolation. Crop growth simulation calculation are made at Elementary Mapping Unit level and stored at grid-cell level. The resulting parameters are organized in a DB and further analyzed in near real-time.

Keywords: CGMS, Agrometeorology

Introduction

The MARS (Monitoring Agriculture with Remote Sensing) started in 1989 an Agro-meteorological system at European level with the objective of providing harmonized and timely information on the cropping season and quantitative crop yield forecasts to other European Commission DGs involved into CAP management (DG Agriculture, EUROSTAT).

The Agrometeorological system has been based on:

- Collection of Meteorological Data
- Collection of Remote Sensing Data
- Transformation and Modelling into Crop Parameters.

In particular the crop physiology modelization, or the core of the crop simulation engine, was mainly based on the WOFOST model (Diepen *et al.,* 88). As WOFOST was conceived as a "point" model, and in order to give a European Scale to the system, a geographic grid reference system was adopted. The resulting model was called Crop Growth Monitoring System (from here on CGMS).

The CGMS and the grid reference system

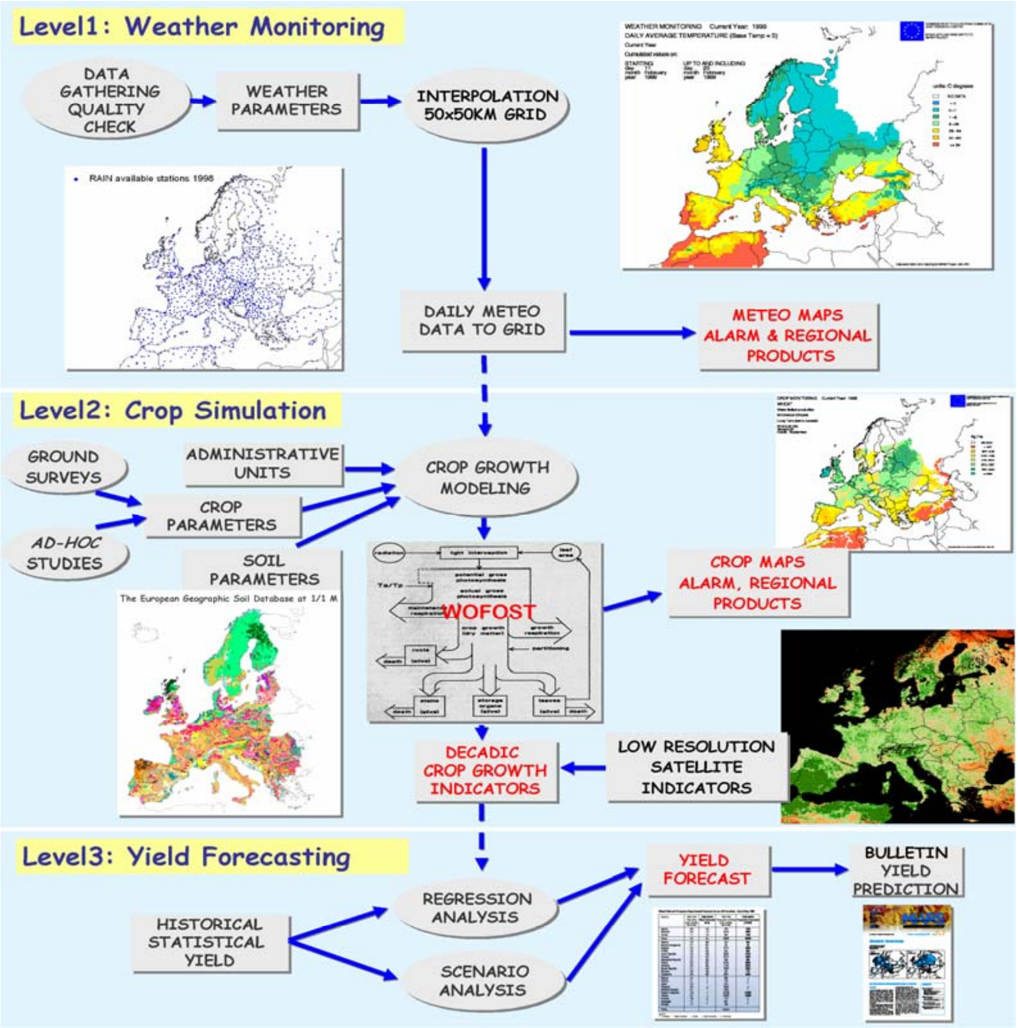
The CGMS[38] (first release in 1992, today release 8.0) has been defined at three levels:

- level 1 where the meteorological station data are interpolated using the grid system and further calculations are made
- level 2 where the interpolated meteorological data are assigned within the grid-cell to the different Elementary Mapping Units which are related to soil information and the WOFOST model run
- level 3 where the crop parameters obtained are aggregated at regional level and statistical analyses run to predict the final yield.

The output at different level of CGMS allow to monitor in near real time the extreme weather conditions, to study the influence of weather on crop growth and give input to the final quantitative yield calculation. The grid system is then a key part into CGMS as it constitutes the geographic reference where calculations are run and output, numerical and in terms of thematic meteorological and crop maps are reinstituted.

[38] For a more complete description of CGMS including simulations algorithms and parameters definition refer to Supit et al., 94, and to the following web site http://www.iwan-supit.cistron.nl/.

Figure 1 - CGMS schematization



The output from CGMS both in terms of data than in terms of maps are organized into DB partially accessible through the http://www.marsop.info. The results of the analyses are published into a bulletin available in http://agrifish.jrc.it/marsstat/Bulletins/2004.htm.

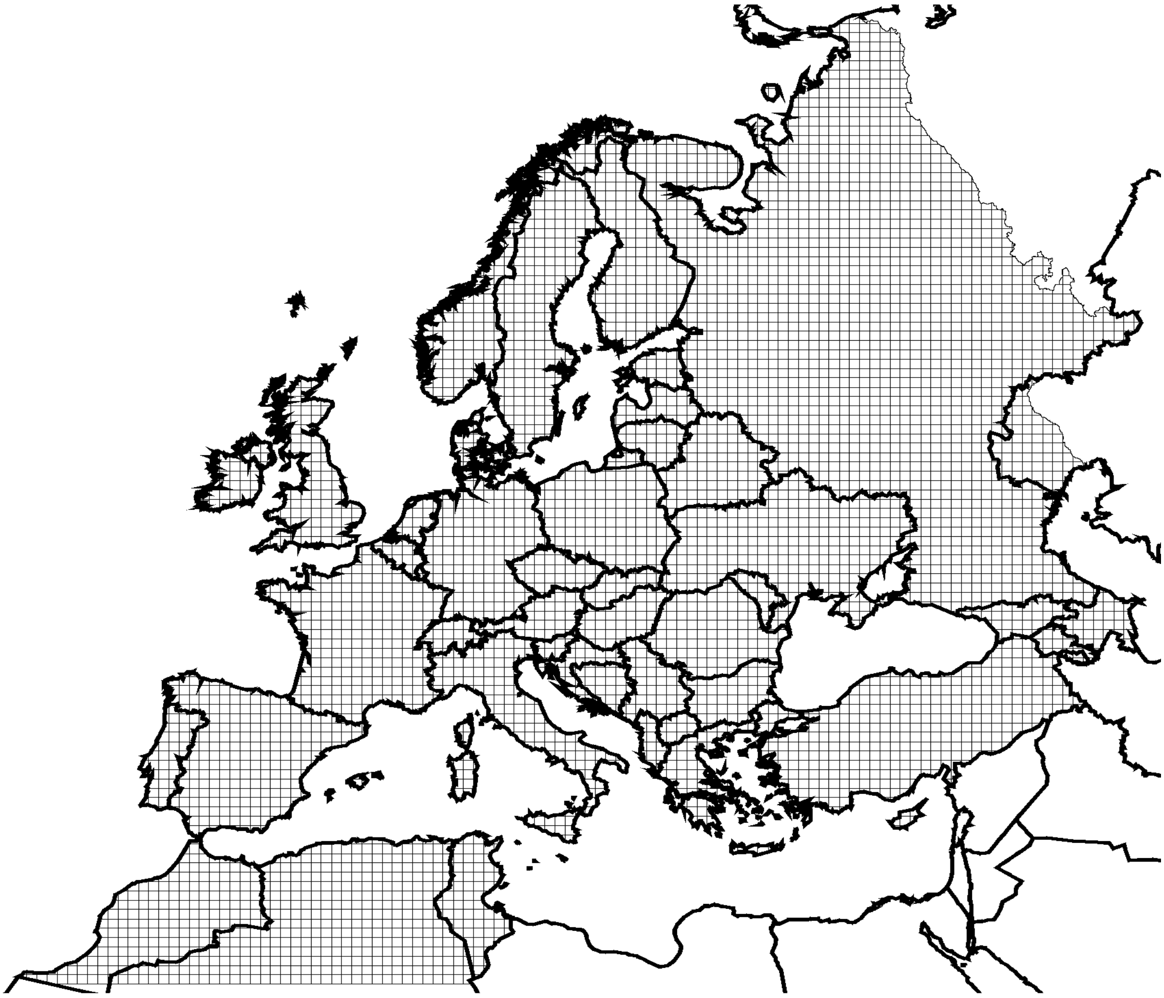
The main crops covered by the model are wheat, maize, barley, rapeseed, sunflower, sugar beet, potato. Geographically all of the European Continent and the Maghreb area are covered by the model.

The GRID System

The motivations to adopt a grid system in CGMS were given by different constraints:

- Spatial schematisation had to find an acceptable level where to match different available information (soil, climate, land use);
- Interpolate daily meteorological station data towards centres of a regular climatic grid. The grid size of CGMS was adopted basing on studies on the densities of historical meteorological stations available;
- Define a simple approach, easy to automate while accuracy is sufficient.

Figure 2 - CGMS 50x50 Km grid system



The CGMS Grid (from release 2.3 to current) was geographically defined according to the following parameters:

GRID projection and DATUM	
• Projection:	LAMBERT_AZIMUTH
• Units:	METERS
• Spheroid:	SPHERE
• Parameters	6378388
• Centre of projection	EU12 900.0 4800.0

The Datum and the Grid Projection are being updated according to the INSPIRE indications. This will be included into the CGMS release 9.0 expected for 2005.

The resulting GRID currently used by CGMS is then made by 5625 cells of 50x50 Km of which about 34% cover the EU15 area. The DB associated with this system are mainly the Interpolated Meteorological data, Crop Parameters and Crop Simulated Values.

The Interpolated Meteorological Data are:

- Max and Min temperatures, Vapor Pressure, Rainfall, E0 (evaporation from a water surface according to Penman method), ES0 (evaporation from a wet bare soil- Penman method), ET0 (evapotranspiration - Penman method), Calculated Radiation (Ångström, Supit, Hargreaves); Snow Depth.

The main simulated parameters for each of the crops are:

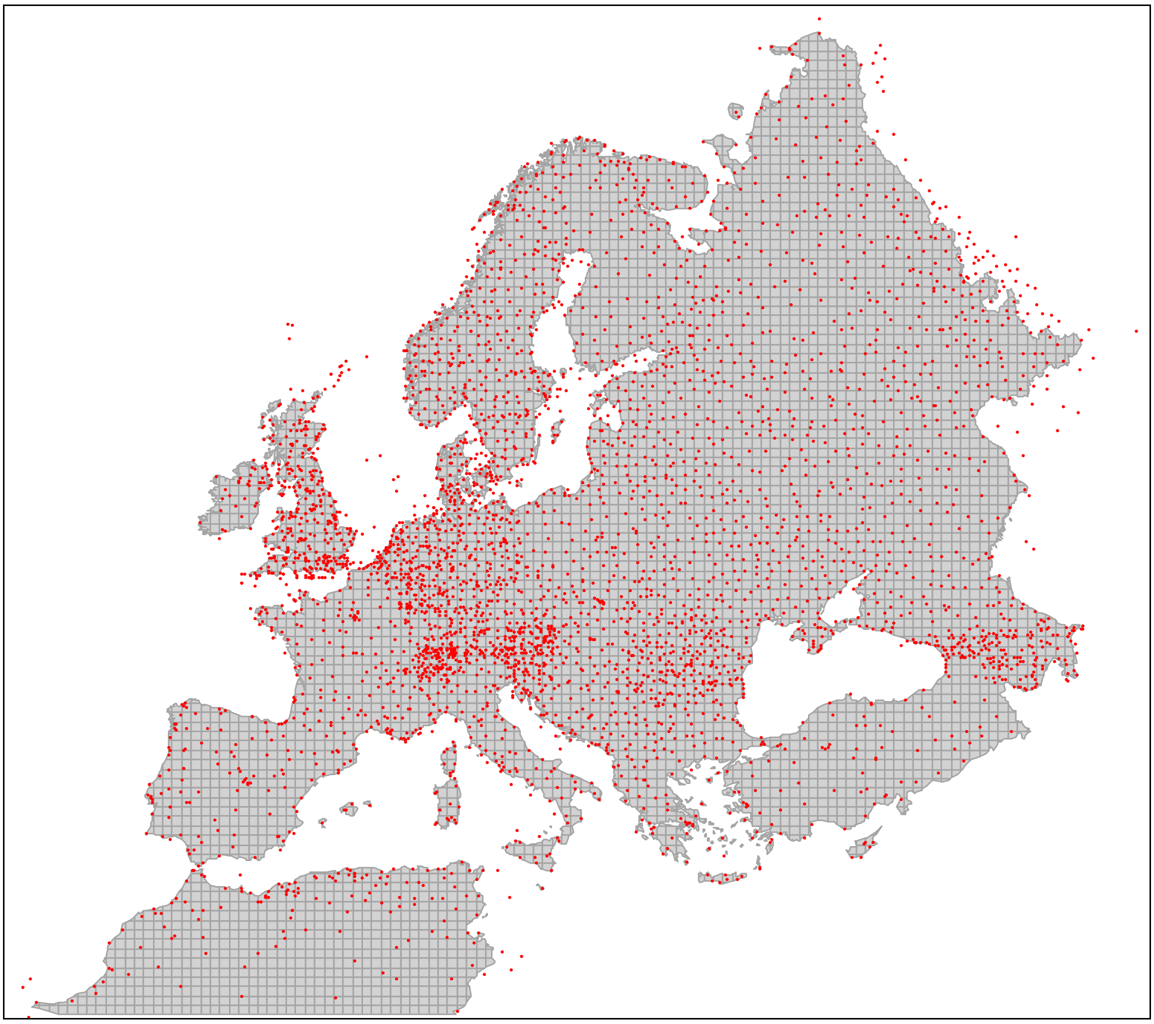
- Weight of the Above Ground Biomass for two models potential and water limited; Weight of the Storage Organs; Leaf Area Indexes; Development stage Water Requirements; Soil Moisture.

Other DB gives by cell grid other important information per crop and variety injected into the model the K-Coefficients; TSUM; Crop calendars (dates of sowing, harvesting).

The meteorological data interpolation and the Elementary Mapping Unit definition

The interpolation of the meteorological parameters starts from the information gathered at station level (mainly synop WMO network).

Figure 3 - Network of Meteorological Stations on the 50x50 Km CGMS grid system

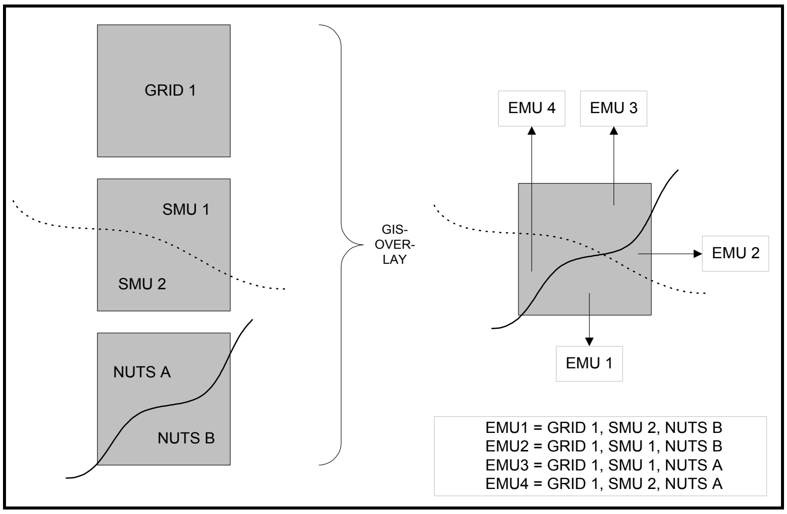


The stations stored are around 4000 while the operational are less and depend on the parameter (about 1400 for temperatures). The oldest stations stored gives parameters since 1933.

To interpolate the data to the grid cell the following steps are followed:

- temporal coverage of stations is checked;
- selection of stations is based on distance, similarity in altitude and distance to the coast, climatic barriers;
- simple average over one up to four stations are calculated and assigned to the centre of the grid-cell, corrected for altitude difference in case of temperature and vapour pressure; rainfall only most similar station.

Figure 4 - EMU concept



In the interpolation procedure the ranking of similar stations is determinant. The score is given according to the following approach:

Score = dist + Δalt*Walt + ΔdCstcorr + ClbInc *expressed in km*

Where

dist: distance between the weather station and the grid centre. [km]

Δalt: absolute difference in altitude. [m]

Walt: weighting factor for Δalt (= 0.5).

dCstcorr: absolute difference in corrected distance to coast [km]

ClbInc: climate barrier increment. (1000 km or 0)

More details are given in Goot Van der E. 1997.

The grid system is also used to calculate the EMU (Elementary Mapping Units) which the smallest geographic level where the crop simulation is run. The EMU is given by the intersection of the grid boundaries with the Soil Mapping Unit (SMU) and the artificial administrative boundaries (NUTS). In CGMS 8.0 the NUTS are not intervening anymore in this definition, but the system has been changed adding a posteriori the possibility to cross any kind of artificial boundary (NUTS, catchments boundaries…).

The EMU is the “artificial point” complete with all of the necessary parameters (meteorological, soil, crop) to run the WOFOST based crop growth simulations.

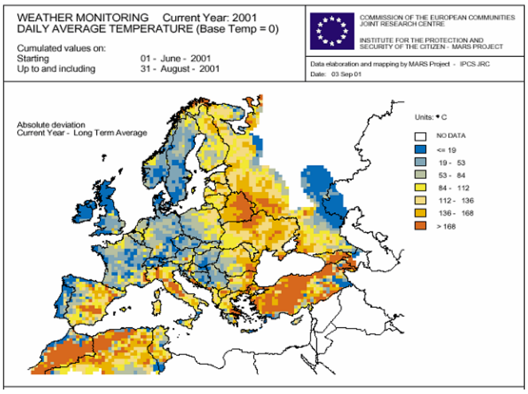


Figure 4 - grid interpolated temperature

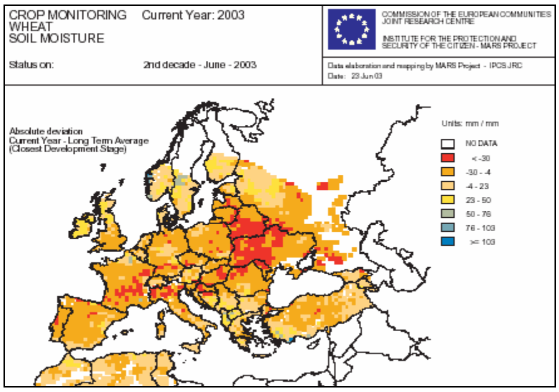


Figure 5 - CGMS crop parameter simulation at grid level: soil moisture for wheat in June 2003 (comparison with the long term average)

The EMU is given by the intersection of the grid boundaries with the Soil Mapping Unit (SMU) and the artificial administrative boundaries (NUTS). In CGMS 8.0 the NUTS are not intervening anymore in this definition, but the system has been changed adding a posteriori the possibility to cross any kind of artificial boundary (NUTS, catchments boundaries…). The EMU is the "artificial point" complete with all of the necessary parameters (meteorological, soil, crop) to run the WOFOST based crop growth simulations. The final results are then stored at grid-cell level. Today 30 years of simulations are available. The simulations are run daily; the results screened each ten days and the reports produced and published with a frequency of each 15 days during the crop vegetative and maturity period.

Conclusions and final remarks

The Agrometeorological System of the EC uses as main geographic reference a 50x50 Km grid. Upon this reference system data are collected, interpolated and crop simulations models run. An archive of interpolated data and crop simulation data since 1975 based on this grid is available in JRC (MARS-Stat).

In the future the introduction of information from other grid system likely the Global Circulation Model Data (re-analysis and forecasts) from ECMWF, will not change the reference CGMS system as downscaling procedures will be introduced.

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Hexagonal tessellations to sample sites for the assessment of tropical forest change

Javier Gallego

Summary: The TREES Project made an estimation of the change in tropical rainforest between 1990 and 1997. Forest change was carefully mapped and quantified on a sample of 100 sites. Each site corresponded to a Landsat-TM frame or quarter of frame. The tropical belt was stratified using a coarse forest map and deforestation hot spots delineated by a group of regional experts. The units for stratification were hexagonal tiles of a spherical tessellation. Hexagons were linked with Landsat observation units. The sampling scheme allowed the computation of forest change estimates with their precision and confidence intervals. However the use of hexagonal tessellations, that can provide a good tool for global sampling frames, was not necessary in this case and it introduced additional complication and reduced the efficiency of the procedure.

Keywords: Global grids, hexagonal tessellation, environmental sampling

Tropical forest change estimation in the TREES Project

The TREES project (TRopical Ecosystems and Environment observation by Satellite) has focused on monitoring of the globe's tropical forests. It includes several activities:

- Pan-tropical forest cover maps derived from coarse and medium spatial resolution satellite imagery.
- Measurement of deforestation using a sample of fine spatial resolution image pair at two dates (Stibig and Achard, 1999).
- Access to the information via a GIS based Tropical Forest Information System.

The design of the sampling scheme built upon other components of the project: mapping forest with coarse spatial resolution NOAA AVHRR data (Malingreau et al. 1995, Mayaux et al., 1998) and identifying of deforestation hot-spots (Myers,1993, Achard et al. ,1998), that were used for stratification.

During the first phase of the TREES project efforts concentrated on mapping tropical forest cover using a "wall to wall" approach with NOAA AVHRR data. Fine spatial resolution imagery was used for validation purposes and for calibration of the coarse spatial resolution maps using a regression model (Mayaux and Lambin, 1995).

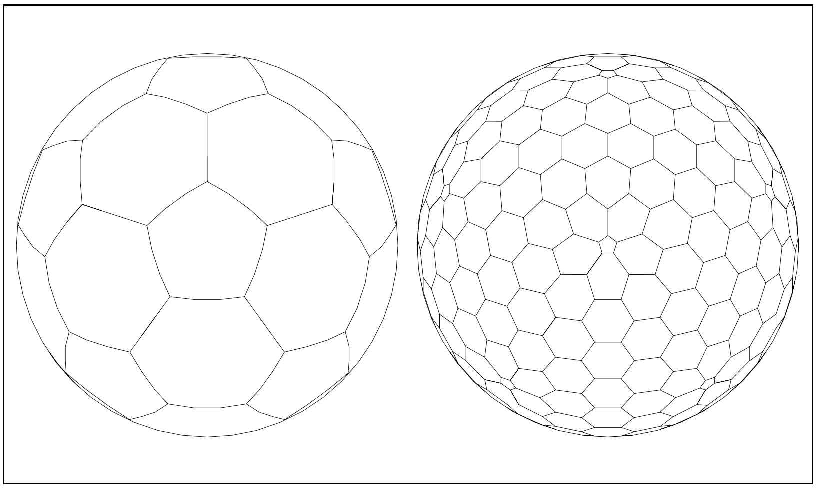
The second phase of the project gave deforestation estimates computed with a procedure that tried to keep under control as much as possible sampling and non-sampling errors (Achard et al., 2002). In this field the need of well documented procedures is critical: the Intergovernmental Panel for Climate Change (IPCC) points out that uncertainty of deforestation areas can be of the order of ±50%, and the estimated global carbon emissions to the atmosphere from land use changes in the 1990s range from 0.8 to 2.4 gigatons per year.

The sampling scheme

The basic units for stratification were tiles of a hexagonal tessellation (see Gray, 1995, for relative transformations). Hexagonal tessellations provide a very elegant approach to the partition of a spherical (or nearly-spherical) surface and they have been used for global environmental sampling (Olsen et al, 1998).

There are several ways to produce this type of tessellations. In general the first step is truncating an icosahedron to produce a sort of “soccer ball” with 20 hexagons and 12 pentagons. Successive steps produce tessellations with smaller tiles, keeping a constant number of 12 pentagons (Figure 1). There are algorithms that produce tiles of approximately the same size, but to my knowledge none of them produces tiles of exactly the same size.

Figure 1 - Tessellations of a spherical surface at two different levels



For the stratification of the TREES project, the selected tessellation had tiles with a size that roughly ranged between 3000 and 3600 km^2. For each tile we measured the forest area according to an approximate forest map, and the area of “deforestation hot spots”.

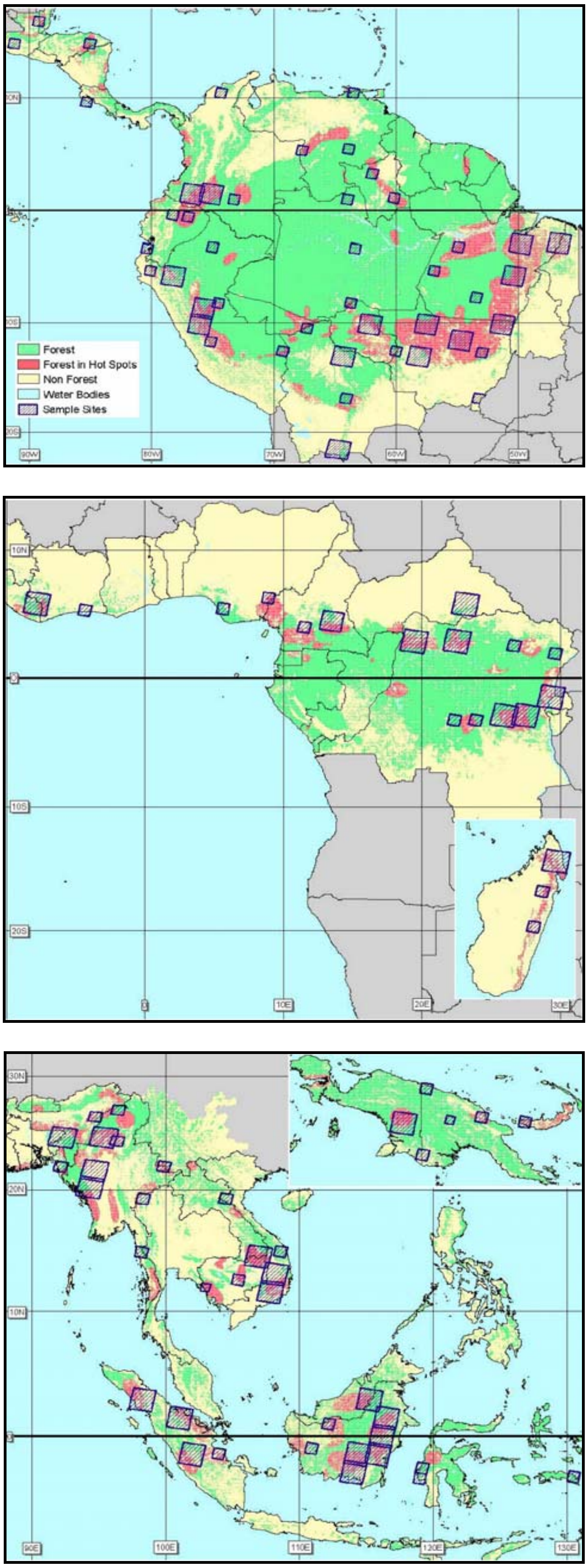
The sampling procedure was rather complicated. Details can be found in the paper by Richards et al. (2000). The main features were:

- Stratified sample of hexagons through a systematic grid of points in Lambert Cylindrical Equal Area projection (see Gallego, 2004, for an illustration of this type of sampling).
- Selecting the size of observation units: full Landsat TM scene or quarters of scene, depending on the expected spatial covariance of the deforestation amount.
- Linking hexagons to observation units and consequently selecting observation units with a probability computed as the sum of probabilities of the hexagons linked with it.

A sample of 100 sites was selected with this procedure (Figure 2). The sampling approach selected lead to an unequal probability sampling with probabilities that were not quite proportional to the size of observation units. The strata organization at the level of hexagons got lost at the level of observation units. This complicated the rest of the process and reduced the efficiency.

The Horvitz-Thomson estimator (Cochran, 1977) ensured unbiased estimates, but the estimation of the variance with traditional methods was not valid. A bootstrap estimator was used (Efron and Tibshirani, 1993), but some debate can appear on the validity of bootstrapping for variance estimation for a sampling scheme with a systematic component.

Figure 2 - Sample of sites analysed for tropical deforestation estimation



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The European Datum ETRS89 and its Realization

Johannes Ihde, Heinz Habrich

Summary: With the Spatial Reference Workshop 1999 and the European Map Projection Workshop 2000 the basis for the introduction of uniform European coordinate reference systems was established. Four coordinate reference systems are intended for the use of referencing of geoinformation in the European Commission. The basis for these pan-European spatial reference systems are the European datum ETRS89 and the realization by the European GPS Permanent Network EPN.

Keywords: Spatial reference systems, European Terrestrial Reference System ETRS89, European GPS Permanent Network EPN

The European Spatial Reference and Map Projection Workshops

The Spatial Reference Workshop 1999 and the Map Projection Workshop 2000 recommends to the European Commission to adopt ETRS89 as geodetic datum and to express and store positions, as far as possible, in ellipsoidal coordinates, with the underlying GRS80 ellipsoid [ETRS89]. Three map projections were required to supplement the ellipsoidal system. This recommendation was adopted by COGI in 2003 for geo data of the European Commission.

Furthermore was recommended to adopt the EVRF2000 for expressing (gravity-related) practical heights in Europe (In April 2004 a EVRS Workshop has considered this item).

In cooperation between the IAG Sub-commission for Europe EUREF, EuroGeographics, the German Federal Agency for Cartography and Geodesy and the European NMAs it was possible to collect the information of the definitions of the national coordinate reference systems, and the definitive transformation parameters between the national reference systems and ETRS89 (realized for 3 m accuracy level), as well as the EVRF2000. These information are available in a public domain under http://crs.ifag.de.

Realization of ETRS89 and its Practical Use

It is an objective of EUREF to establish and maintain a reference network for Europe. A European reference network in the meaning of Geodesy consists of geodetic control stations, which suitable cover whole Europe and which coordinates are known with best possible accuracy. The establishment of such a reference system requires at first to define a datum. It will then be realized as a reference frame by taking into account the datum definition and by fixing the three-dimensional coordinates of selected stations on the earth surface. The three-dimensional coordinates of the stations could be reduced to the surface of an rotating ellipsoid after the definition of the required parameters of the ellipsoid. Any projection formulas could be applied to map the surface of the ellipsoid. This simplified scheme explains the impact of the reference frame on grids.

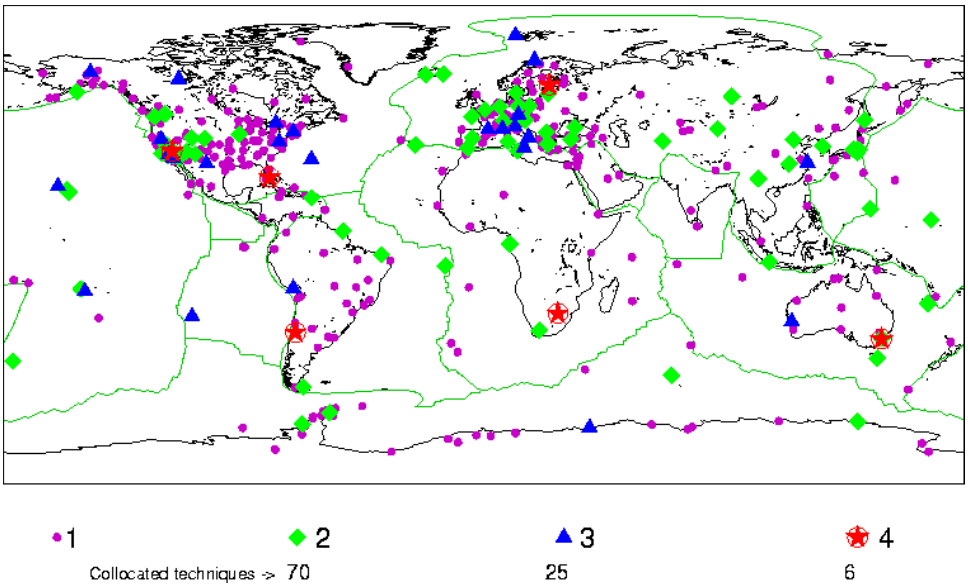
UREF Organisation

EUREF is the regional reference frame sub-commission for Europe of the IAG, deals with the definition, realization and maintenance of the European reference frame, and focuses on both, the spatial and the vertical components. It has defined the European terrestrial reference system, the ETRS89. ETRS89 is recognised by the scientific community as the European geodetic datum to be adopted. It is defined to 1cm accuracy, and it is consistent with the global ITRS. ETRS89 is available due to the EUREF GPS Permanent Network (EPN), and the validated EUREF campaign observations. It is part of the legal framework of some EU member states.

Definition of ETRS89

It needs first the definition of a terrestrial reference system (TRS). A TRS is mathematically defined as an Euclidian affine frame with an origin, scale and orientation in relation to the Earth body. It is realized by coordinates of physical points on or near the Earth surface. The International Earth Rotation and Reference Systems Service (IERS) is in charge to realize, use and promote the International Terrestrial Reference System (ITRS) as defined by the IUGG resolution No 2 adopted in Vienna,1991. The geodetic datum (origin, orientation, scale) of ITRS is defined by conventions (Conventions 2003, IERS Technical Note No. 32 - in preparation) of the IERS. ITRS is realized by a series of frames with coordinates and velocities of some hundred world wide geodetic control stations. The recent realization is the ITRF2000. A map of primary ITRF2000 sites as published on the ITRF website (http://lareg.ensg.ign.fr/ITRF/) is given in Figure1.

Figure 1 - Primary ITRF2000 Sites and Collocated Techniques



Station coordinates in the ITRF change in the order of typically 1 to 3 cm per year in Europe according to the motion of the geo-tectonic plate and may not meet the user requirements of a set of stable coordinates. EUREF decided by that reason to define the European Terrestrial Reference Frame 1989 (ETRS89), which is fixed to the stable part of Europe.

ETRS89 was identical to ITRF89 at the beginning of the year 1989. Since that time ETRS89 moves against the ITRF realizations following the movement of the European plate. Station coordinates expressed in the ETRS89 are assumed to be stable with the exception of such stations that do not belong to the stable part of Europe, e.g., stations in the Mediterranean.

There exist well known formulas to transforms between ETRS89 and ITRF with an accuracy of better than 1 cm (Memo: Specifications of reference frame fixing in the analysis of a EUREF GPS campaign, C. Boucher and Z. Altamimi, Version 5, April 12, 2001). It was decided to use the GRS80 ellipsoid parameters for the ellipsoidal coordinates and map projections.

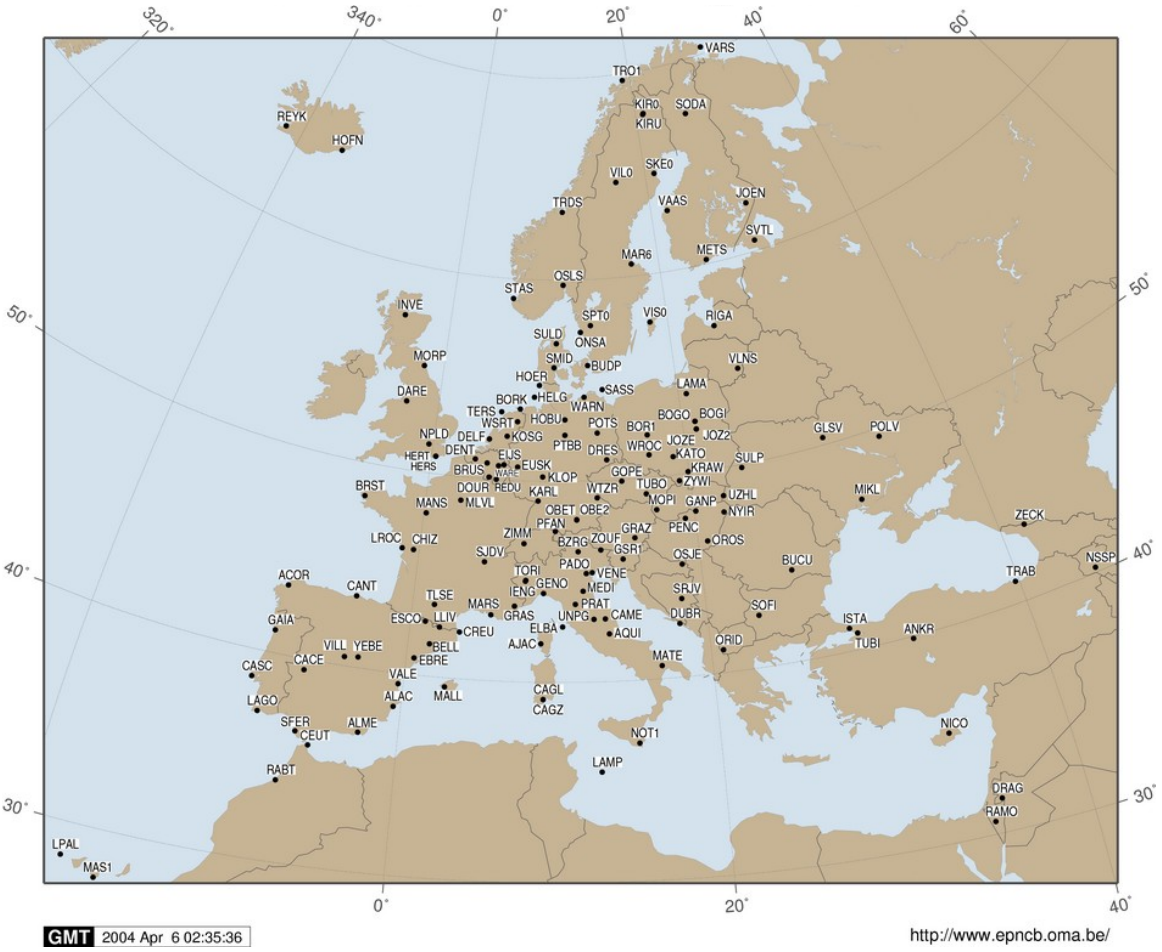
Realization of ETRS89

For each realization of the ITRS labelled ITRFyy a corresponding frame in ETRS89 can be computed and is labelled ETRFyy, using well defined transformation formulae. The EPN is today the most important contribution to the ETRS89 realization because of its continuous operation and high level maintenance. The EPN organization consists of the Coordination Group (Network Coordinator, Analysis Coordinator, Dataflow Coordinator, Technical Working Group Representative and Special Projects Representatives), the Central Bureau and the Special Projects. The Central Bureau is responsible for the day-to-day general management of the EPN.

A map of the tracking stations is given in Figure 2. It shows 150 stations, from which 60 stations are also part of the global tracking network of the International GPS Service (IGS). The EPN is a regional densification of a global network from this point of view. The EPN data analysis is distributed among 16 so-called Local Analysis Centres (LACs).

Each LAC submits weekly solutions of an EPN sub-network to the Analysis Coordinator, who combines the sub-networks into the official EPN solution. Coordinates of EPN stations are available as weekly solutions as well as multi-year solution, where the station velocities are taken into account. The weekly solutions show typically a consistency of 5 mm in horizontal and 10 mm in vertical components.

Figure 2 - EPN Tracking Stations



Planned Activities of EUREF and EuroGeographics

Within a general framework, most EuroGeographics efforts are now converging within the European specification for common reference data, which is the core set of data and related standards, products and services for general use that may contribute to the harmonization of the geographic information at European level, a European Spatial Data Infrastructure (ESDI).

The Expert Group Geodesy (ExGG) of EuroGeographics is concerned with the geodetic components of reference data: definitions, standards and products (data and services) that support the referencing of geo information. The following may be identified, resulting from the present work of the ExGG and the close cooperation with EUREF:

- Definitions (classification)
  - European spatial reference systems (geodetic and vertical reference systems)
  - Map projections to be used at European or sub-regional level
- Standards
  - Recommendation on the standards to be used in the production and dissemination of geodetic products (data and services)
  - Implementation and testing of standards defined at international level
- Products (data and services)
  - geodetic control station information
  - Heights of the UELN/EUVN references
  - Data offered by the EPN
  - Information on the CRS and on-line transformation service
  - Real-time GNSS service
  - Validation services.

The ExGG has three core projects, integrated in the activities defined in the ToR and directly related with the before mentioned group of Products (data and services):

- Geodetic control station information
- Real Time GNSS Service
- Development of the meta data base for European coordinate reference systems (CRS) under http://crs.ifag.de.

Classification, standardization and validation activities must be developed within each of the three projects.

For the realization of a European Spatial Data Infrastructure (ESDI), the ExG-G proposes to develop a set of activities related with the delivery of service components as to insure data integrity and consistency, referenced to ETRS89, namely:

Make available precise/accurate coordinates of all Geodetic Control Stations expressed in the ETRS89 in Cartesian as well as in geographical coordinate systems. As the definition stipulates that the ETRS89 is co-moving with the stable part of the Eurasian tectonic plate, for most applications coordinates will be considered (provided) without time variation.

However, for applications requiring high/great accuracy, residual velocities could be applied, for stations having long observing history. In addition if useful for INSPIRE project, the ExG-G may consider providing coordinates of centimetric accuracy of all needed European stations participating in EUREF activities, e.g. GPS campaign stations, other national reference points.

ExG-G shall follow the work of ISO/TC211 and CEN/TC 287 very close, to guarantee that the products are compliant with the international standards concerning not only the information itself but also the quality evaluation and certification procedures (EuroSpec).

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Transformations between Geodetic Datum, Map Projections and Geographical Grids in Geodesy and Geoinformation

Johannes Ihde, Jens Luthardt

Summary: The transformation of coordinates, which refer to different geodetic datum and map projections, is a standard task for the referencing of geoinformation and one of the basic tasks of geodesy. Principles of transformation, conversion of coordinates and information transfer that are dedicated to grids or compartments are being described and discussed. An outlook for the further development of the existing information system for European coordinate reference systems will be given.

Keywords: Coordinate reference systems, pan-European coordinate reference systems, coordinate conversion, coordinate transformation, map projections

Spatial Reference Systems – The European Situation

In geodesy one distinguishes between the definition and the realization of a geodetic reference system. A reference frame is the realization of a defined reference system.

The definition is given by conventions describing the general principles of the model and of the realization. A reference system is realized by physical points, its coordinates and additional parameters.

Coordinate reference system (CRS) is a term which is used for geodetic reference system and spatial reference systems in the standardization. Using the term CRS there is no possibility to distinguish between definition and realization.

The model for coordinate reference systems is defined by the standard ISO 19111.

This international standard describes the conceptual schema of a CRS and defines the description for a minimum data to two cases for which 1-, 2- and 3-dimensional coordinate reference system information shall be given:

- Case A: A coordinate reference system to which a set of coordinates is related.
- Case B: An operation (transformation, conversion, concatenated operation) to change coordinate values from one coordinate reference system to another.

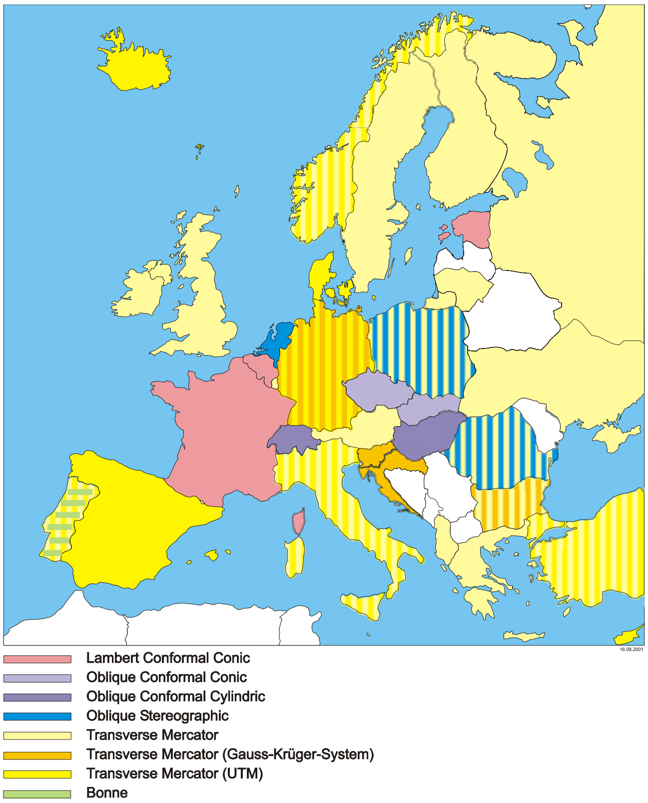
The description of a CRS is structured to a datum and a coordinate system.

The <u>datum</u> defines how the coordinate system is related to the earth (position of the origin, the scale and the orientation of coordinate axis) e.g. ED50, ETRS89. It is the physical part of a CRS.

The <u>coordinate system</u> describes the kind of coordinates by parameters e.g. as cartesian coordinates, ellipsoidal coordinates or coordinates of a map projection. It is the mathematical part of a CRS.

The history and the individual purposes of the European countries are the reason for the variety of spatial reference systems and its realizations in Europe. Every European country has fixed its own geodetic datum and coordinate system or map projection. The projections itself have individual values for the parameters. So in Europe exists more than 55 different legal national CRS (See Figure 1 and Annex).

Figure 1 - Kind of map projections in Europe



To satisfy requirements of users of geo-information systems and according the development of the European Community it is necessary to have unique Coordinate Reference Systems for European applications. The Spatial Reference Workshops in 1999 and the Map Projection Workshop in 2000 with experts for geo-information, geodetic reference systems and standardisation were held to elaborated recommendations for the European Commission. The recommended four pan-European Coordinate Reference Systems were adopted in 2003 for the referencing of geo data of the European Commission. The purposes of the pan-European CRS are given in Table 1.

Table 1 - pan-European Coordinate Reference Systems

CRS Identif.	CRS Name	Purposes
ETRS89	Ellipsoidal CRS	• for storing of positions in general ellipsoidal latitude, longitude and height • based on ellipsoid GRS80
ETRS-TMzn	ETRS Transverse Mercator CRS	• for topographic maps with scales lower or equal 1 : 500 000 • similar UTM for northern hemisphere
ETRS-LCC	ETRS Lambert Conformal Conic CRS	• for topographic maps with scales larger than 1 : 500 000 • Lambert projection with 2 parallels
ETRS-LAEA	ETRS89 Lambert Azimuthal Equal Area CRS	• for statistical purposes and all applications with equal area projections

Coordinate Operations for changing of Coordinate Reference Systems

The term coordinate operation stands for two procedures: the datum transformation and the coordinate conversion.

The change of coordinates from one CRS to another CRS based on different datum is only possible via a coordinate transformation. The transformation parameters could only determined by identical points of the involved CRS. Choice, allocation, number and the quality of point coordinates affects the parameters and the accuracy of the adjustment. It is an empirical process. Often different realisations for coordinate transformation from one datum to another exists.

Mostly the formula of 7 parameter Helmert (similarity) transformation (ISO19111) is used:

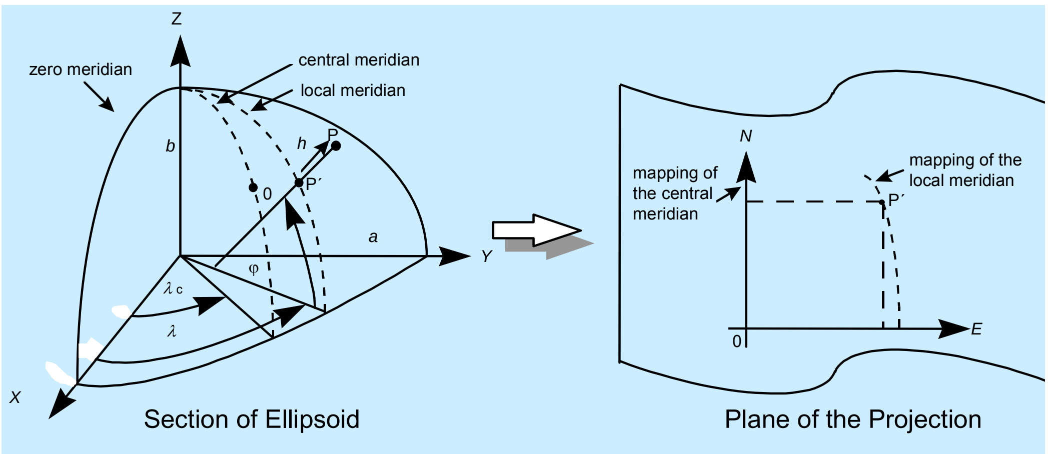
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(T)} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(S)} + \begin{bmatrix} T_1 \\ T_2 \\ T_3 \end{bmatrix} + \begin{bmatrix} 0 & -R_3 & R_2 \\ R_3 & 0 & -R_1 \\ -R_2 & R_1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(S)} + D \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(S)} = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \end{bmatrix} + \begin{bmatrix} 1+D & -R_3 & R_2 \\ R_3 & 1+D & -R_1 \\ -R_2 & R_1 & 1+D \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(S)}$$

with:

(T)…Target Datum, (S)…Source Datum, T_1, T_2, T_3 …geocentric X/Y/Z translations in m, R_1, R_2, R_3 …rotations around X/Y/Z axis in radian, D…correction of scale in ppm. (Remark: the rotations R_1, R_2, R_3 must be small)

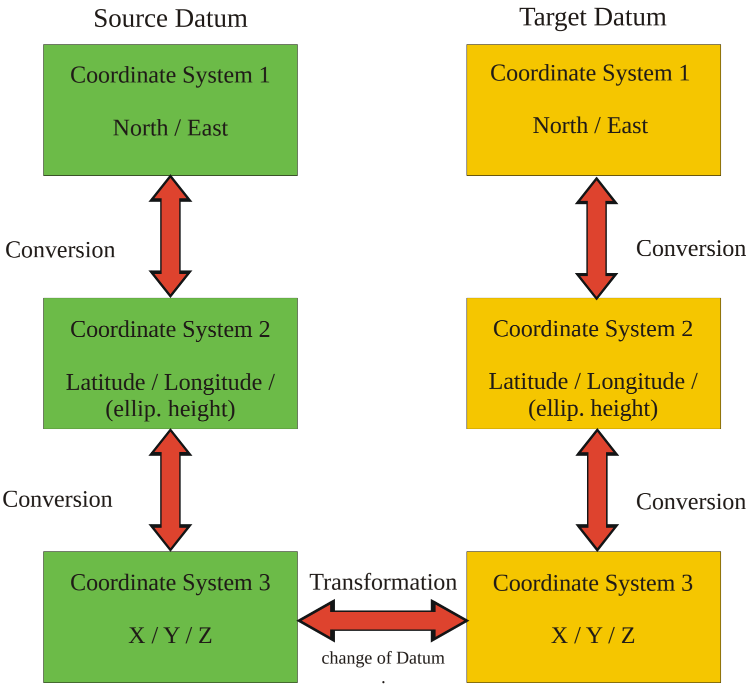
The change from one coordinate system to another coordinate system based on same datum is possible via a coordinate conversion. In this case mathematical rules (e.g. map projections) are necessary. Generally this conversions are unambiguous and can realised with high accuracy.

Figure 2 - Map projection is a conversion between ellipsoidal and plane coordinates



The change of coordinates from a CRS with a national datum and plane coordinates (e.g. Germany Datum DHDN with Gauß-Krüger-Coordinates) to a pan-European CRS (e.g. ETRS89 and coordinate system TMzn) can be realised by combinations of conversions and a datum transformation, which is shown in figure 3.

Figure 3 - Example for changes of coordinates from one CRS to another CRS



Transformation of Grid Related Information

Most of the transformation and conversion cases in geodesy and geoinformation are related to the change of coordinates of points (including raster data) witch are connected with the Earth surface topography. Point related information are not influenced by the coordinate transformation and coordinate conversion procedures.

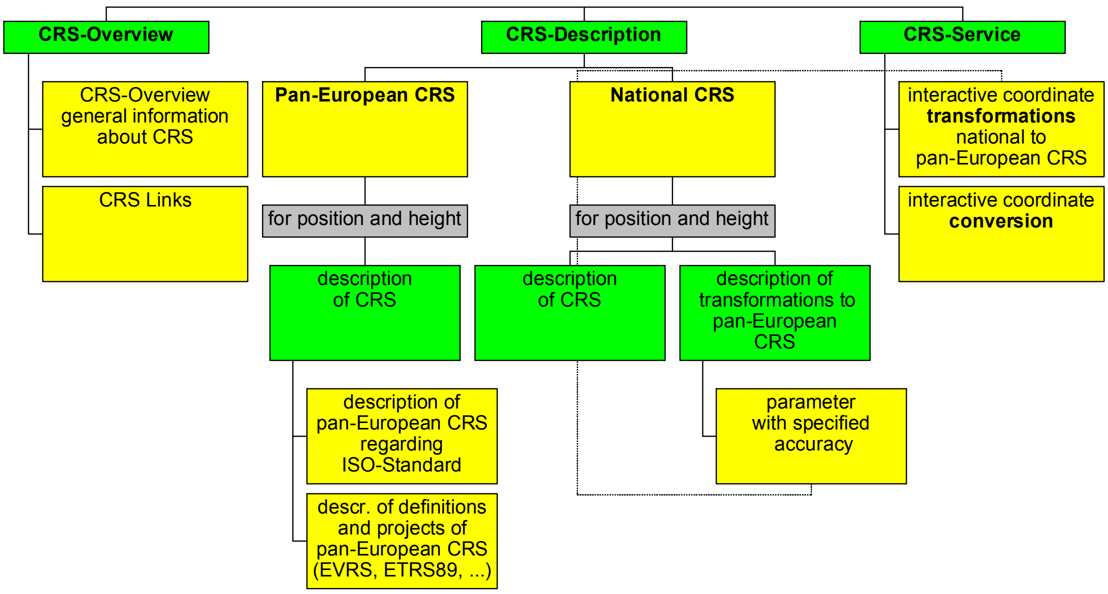
In special cases geometrical or thematic information of the Earth surface topography are related to it are the result of processes which are connected with the CRS. In physical geodesy some processing procedures bases on mean values over near equal area grids or compartments e.g. the geoid determination by the integration of mean gravity anomalies and topographic heights over the Earth surface.

If the reference CRS has to be changed e.g. in harmonisation procedures for the combination of different data files the grid related information has to be changed to. If possible the source point information has to be new processed in the new grid CRS. Mostly the source point information are not available. Then the information in the old grid CRS has to be approximated by a numerical or stochastic model which is used for the interpolation in the new CRS with round grid values. A conclusion for the future is to store all source values in a ellipsoidal coordinates in ETRS89.

Realisation of a web-based Geodetic Information and Service System

Since the year 2000 the information system for European Coordinate Reference Systems is in cooperation of IAG cub-commission EUREF, Expert Group Geodesy of EuroGeographics and the German Federal Agency for Cartography and Geodesy under development (http://crs.ifag.de). The CRS information system is a meta data base supporting a uniform European Spatial Data Infrastructure (ESDI). It contains at present the description of national and pan-European CRS and parameters for transformation form the national to the pan-European CRS in a 1 m to 3 m accuracy level. The CRS information system will be further extended by vertical reference systems and parameters describing the Earth gravity field. A single point online transformation/conversion will be developed to. The current separately existing web pages about European Vertical Reference Systems (EVRS) will be updated and integrated. (See figure 3).

Figure 4 - Structure of the CRS Information and Service System



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Annex - Map Projections / Coordinate Reference Systems used in Europe

Source (CRS information system of European CRS http://crs.ifag.de at the present status).

Country	**Coordinate Reference System Identifier** **Country-Datum / Coord. system resp. projection**	**geodetic Datum**	**Projection**
Albania	AL_ALB87 TM_6	ALB87	Transverse Mercator
Austria	AT_MGI / AT_TM	MGI	Transverse Mercator
Belgium	BE_BD72 / LAMB72	BD72	Lambert Conformal Conic
Bulgaria	BG_1942 / GK_3	1942	Transverse Mercator (Gauss-Krüger-System)
	BG_1942 / TM_6	1942	Transverse Mercator
Croatia	HR_HDKS / HR_TM	HDKS	Transverse Mercator (~Gauss-Krüger-System)
Cyprus	CY_ED50 / UTM	ED50	Transverse Mercator (UTM)
Czech Rep.	CZ_S-JTSK / KROVAK	S-JTSK	Oblique Conformal Conic
Denmark	DK_ED50 / UTM	ED50	Transverse Mercator (UTM)
Estonia	EE_L-EST97 / EST_LAMB	L-EST97	Lambert Conformal Conic
Finland	FI_KKJ / FI_TM	KKJ	Transverse Mercator
France	FR_ED50 / EUROLAMB	ED50	Lambert Conformal Conic
	FR_RGF93 / LAMB93	RGF93	Lambert Conformal Conic
	FR_NTF / FR_LAMB	NTF	Lambert Conformal Conic
Germany	DE_ETRS89 / UTM	ETRS89	Transverse Mercator (UTM)
	DE_PD83 / GK_3	PD83	Transverse Mercator (Gauss-Krüger-System)
	DE_42/83/ GK_3	42/83	Transverse Mercator (Gauss-Krüger-System)
	DE_DHDN / GK_3	DHDN	Transverse Mercator (Gauss-Krüger-System)
	DE_RD83 / GK_3	RD83	Transverse Mercator (Gauss-Krüger-System)
Gibraltar	GI_ED50 / UTM	ED50	Transverse Mercator (UTM)
Great Britain	GB_OSGB36 / NATIONALGRID	OSGB36	Transverse Mercator
Greece	GR_GGRS87 / GR_TM	GGRS87	Transverse Mercator
Hungary	HU_HD72 / EOV	HD72	Oblique Conformal Cylindric
Iceland	IS_HJ1955 / UTM	HJ1955	Transverse Mercator (UTM)
Ireland	IE_IRELAND65 / IRELAND75_IRISHGRID	IRELAND65	Transverse Mercator
Italy	IT_ED50 / UTM	ED50	Transverse Mercator (UTM)
	IT_ROMA40 / EAST_WEST	ROMA40	Transverse Mercator
Lithuania	LT_LKS94 / LT_TM	LKS94	Transverse Mercator
Luxembourg	LU_LUREF / LU_TM	LUREF	Transverse Mercator
Malta	MT_ED50 / UTM	ED50	Transverse Mercator (UTM)
Netherlands	NL_RD / DUTCH_ST	RD	Oblique Stereographic
Northern Ireland	NI_IRELAND65 / IRELAND75_IRISHGRID	IRELAND65	Transverse Mercator
Norway	NO_ETRS89 / UTM	ETRS89	Transverse Mercator (UTM)
	NO_NGO1948 / NO_TM	NGO1948	Transverse Mercator
Poland	PL_42/58 / 1965	42/58	Oblique Stereogr. (Zone 1...4) / Transv. Mercator (Zone 5)
	PL_EUREF89 / 1992	EUREF89	Transverse Mercator
	PL_EUREF89 / 2000	EUREF89	Transverse Mercator
Portugal	PT_DLX(HAY) / TM_DLX	DLX(HAY)	Transverse Mercator
	PT_DLX(BES) / BONNE	DLX(BES)	Bonne
	PT_AZO_CENT / UTM	AZO_CENT	Transverse Mercator (UTM)
	PT_AZO_OCCI / UTM	AZO_OCCI	Transverse Mercator (UTM)
	PT_AZO_ORIE / UTM	AZO_ORIE	Transverse Mercator (UTM)
	PT_MAD / UTM	MAD	Transverse Mercator (UTM)
	PT_D73 / TM_D73	D73	Transverse Mercator
Romania	RO_S42(89) / TM_6	S42(89)	Transverse Mercator
	RO_S42(89) / ST1970	S42(89)	Oblique Stereographic
Russia	RU_...		Transverse Mercator
Slovak Rep.	SK_S-JTSK / KROVAK	S-JTSK	Oblique Conformal Conic
Slovenia	SI_D48 / SI_TM	D48	Transverse Mercator (~Gauss-Krüger-System)
Spain	ES_ED50 / UTM	ED50	Transverse Mercator (UTM)
Sweden	SE_RT90 / SE_TM	RT90	Transverse Mercator
Switzerland	CH_CH1903+ / CH_PROJECTION+	1903+	Oblique Conformal Cylindric
	CH_CH1903 / CH_PROJECTION	1903	Oblique Conformal Cylindric
Turkey	TR_ED50 / UTM	ED50	Transverse Mercator (UTM)
	TR_ED50 / TR_TM	ED50	Transverse Mercator
Ukraine	UA_...		Transverse Mercator

Grid estimation - Application to datum distortion modeling

Javier González-Matesanz, Adolfo Dalda

Summary: In this communication, three methods of estimating grid values from scattered data are presented: Rubber Sheeting, Minimum Curvature Surfaces and Least Squares Collocation. These methods have been employed successfully in grids of datum transition models in other countries as Canada or Australia. The first part of this presentation consists on explaining very detailed the methods and the second one is an application to allow an effective change between classical datums (as ED50) and ETRS89, a datum distortion concept is needed in grid format.

Keywords: Least Squares Collocation, Rubber Sheeting, Minimum Curvature Surfaces, Grid prediction, datum change

Prediction of synthetic values

Let the following function:

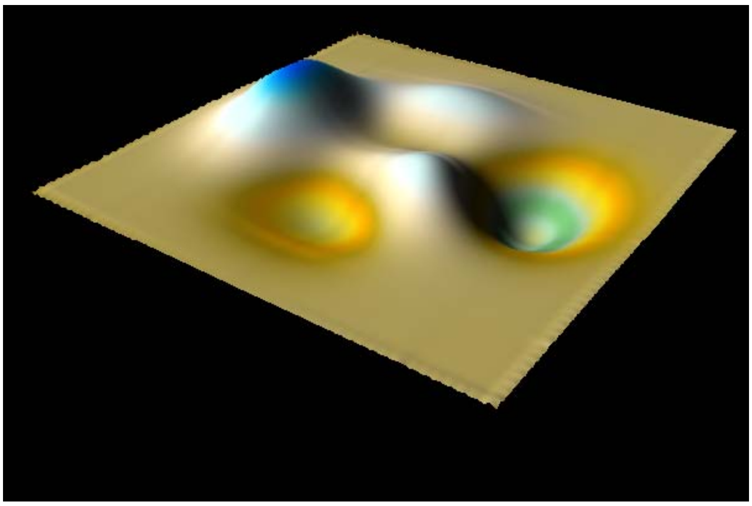
$$z = 3(1-x)^2 e^{-x^2-(y+1)^2} + 10\left(\frac{x}{5} - x^3 - y^5\right)e^{-x^2-y^2} - \frac{1}{3}e^{-(x+1)^2-y^2} \qquad (1)$$

as a well known function for building a synthetic grid data of 2401 rows:

x	y	z
-3.00000000000000	-3.00000000000000	0.00007000000000
-2.87500000000000	-3.00000000000000	0.00013000000000
-2.75000000000000	-3.00000000000000	0.00023000000000
...	...	...
2.75000000000000	3.00000000000000	0.00017000000000
2.87500000000000	3.00000000000000	0.00008000000000
3.00000000000000	3.00000000000000	0.00004000000000

Data ranges are 6,6 and 14.62181 respectively for x,y and z and the purpose is to remove some critical points (ie 0,0) to test the predicted value with the obtained one applying directly function (1).

Figure 1 - Synthetical function



Least Squares Collocation method

The most critical task is to obtain the covariance function of the data. This can be done easily from the variogram values. Variogram functions (2) can be found in the internet or in common software packages as surfer, variowin, geoeas etc. Covariance function is obtained subtracting the variance of the data (σ^2=3.49460232)

$$\gamma(h,\alpha) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(x_i + h) - z(x_i)]^2 \qquad (2)$$

With the following settings:

Direction	α=0
Tolerance	90
Max lag dist	2.8
Number of lags	25
Lag width	h=0.112

The variogram obtained is included in the following table:

Table 1 - Variogram and covariance

Distance	Variogram	Covariance
0.15062146	0.08981158	3.40479073
0.26953666	0.27928538	3.21531694
0.37975298	0.5456571	2.94894522
0.50971782	0.96268122	2.53192109
0.6299698	1.39275954	2.10184278
0.72278269	1.76326748	1.73133484
0.83857093	2.23795367	1.25664864
0.96220155	2.73341301	0.76118931
1.07123483	3.18493132	0.30967099
1.16783249	3.39919015	0.09541217
1.27745159	3.72474909	-0.23014677
1.38961329	3.91682671	-0.42222439
1.5103274	4.09755107	-0.60294876
1.62923807	4.14904575	-0.65444344
1.74520861	4.28312189	-0.78851957
1.86039465	4.28868856	-0.79408625
1.96652021	4.29920813	-0.80460581
2.06916698	4.39245286	-0.89785054
2.17454235	4.36920052	-0.8745982
2.29066708	4.40270507	-0.90810275
2.40461155	4.4847337	-0.99013138
2.51640089	4.49877513	-1.00417281
2.63084552	4.58514712	-1.09054481
2.74851153	4.67995271	-1.18535039

Fitting a theoretical covariance function is the next task. As can be observed in Figure 2 (red crosses) the covariance reaches negative values for distances greater than 1.

A useful covariance function for this case is the Reilly covariance function:

$$v = C_0 \left(1 - \frac{1}{2}\frac{s^2}{d^2}\right) e^{\left(-0.5\frac{s^2}{d^2}\right)} \qquad (3)$$

Where s is the distance and C_0, d are values that are fitted by least squares obtaining C_0=*3.60551335437890* and d = *-0.91615386244892*.

In Figure 2 can be seen the theoretical covariance function fitted to the data, although the two values separates themselves for distances greater than 1.5 this part of the function is seldom used

The prediction theory in LSC shows that two variance-covariance must be build. The first one between the known points and the one that is going to be estimated, CI and the second one between all the known points called CD.

Figure 2 - Experimental covariance vs fitted function

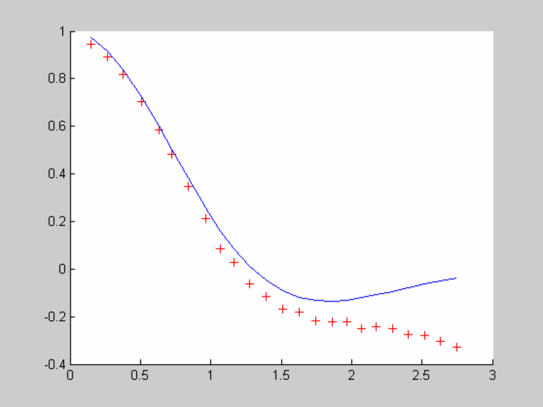
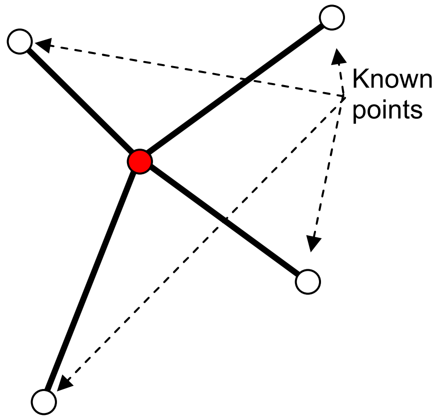


Figure 3 - LSC interpolation



Removing point (0,0) and selecting a search radius of 0.25 the following points have been found:

x	y	z
-0.12500000000000	-0.12500000000000	1.80881000000000
0	-0.12500000000000	1.27410000000000
0.12500000000000	-0.12500000000000	0.73535000000000
-0.12500000000000	0	1.44702000000000
0.12500000000000	0	0.51096000000000
0.25000000000000	0	0.19039000000000
0	0.12500000000000	0.72576000000000
0.12500000000000	0.12500000000000	0.32217000000000
0.25000000000000	0.12500000000000	0.06072000000000

The Covariance matrix CI^T is:

3.47313268445469
3.53886023571709
3.47313268445469
3.53886023571709
3.53886023571709
3.34440870009894
3.53886023571709
3.47313268445469
3.28138980434173

And *CD*:

Columns from 1 to 4

3.60551335	3.53886024	3.34440870	3.53886024
3.53886024	3.60551335	3.53886024	3.47313268
3.34440870	3.53886024	3.60551335	3.28138980
3.53886024	3.47313268	3.28138980	3.60551335
3.28138980	3.47313268	3.53886024	3.34440870
2.97928863	3.28138980	3.47313268	3.03801216
3.28138980	3.34440870	3.28138980	3.47313268
3.09757344	3.28138980	3.34440870	3.28138980
2.80804110	3.09757344	3.28138980	2.97928863

Columns from 5 to 9

3.28138980	2.97928863	3.28138980	3.09757344	2.80804110
3.47313268	3.28138980	3.34440870	3.28138980	3.09757344
3.53886024	3.47313268	3.28138980	3.34440870	3.28138980
3.34440870	3.03801216	3.47313268	3.28138980	2.97928863
3.60551335	3.53886024	3.47313268	3.53886024	3.47313268
3.53886024	3.60551335	3.28138980	3.47313268	3.53886024
3.47313268	3.28138980	3.60551335	3.53886024	3.34440870
3.53886024	3.47313268	3.53886024	3.60551335	3.53886024
3.47313268	3.53886024	3.34440870	3.53886024	3.60551335

and *lambda* comprises the known values of the points selected

1.80881000000000
1.27410000000000
0.73535000000000
1.44702000000000
0.51096000000000
0.19039000000000
0.72576000000000
0.32217000000000
0.06072000000000

Finally the LSC prediction algorithm can be used to estimate the z value for point (0,0)

$$est = CI.CD^{-1}lambda \qquad (4)$$

Est= 0.97359666217843 compared with the real value *0.98101184312385* rises an error of *-0.007*.

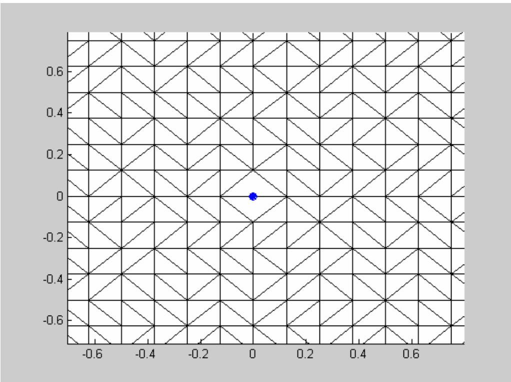
Rubber Sheeting

This method consists on creating a linear transformation between the surrounding points and to interpolate linearly the value for the unknown point. It is the simplest one but one of the preferred methods for datum distortion modelling.

The theoretical background consists on creating a topologically equivalent figure, this can be done building a Delaunay triangulation for the data.

First of all, let's create the Delaunay (see Figure 4). In this case the triangulation is absolute regular due to the nature of the data and the unknown point lines on the edge between two triangles.

Figure 4 - Delaunay Triangulation



There are lots of commercial packages that use Delaunay triangulation, in this particular case Matlab have been used to produce and identify the right triangle.

x	y	z
0.12500000000000	0	0.51096000000000
0	-0.12500000000000	1.27410000000000
-0.12500000000000	0	1.44702000000000

The interpolation can be done fitting a plane with these tree points and applying the coefficients for the (0,0) point.

$$Ax + By + Cz + 1 = 0 \qquad (5)$$

where

A= -3.82459473539056

B= -2.41154659393865

C= -1.02146089336970

For this kind of linear interpolation simpler equations can be found in the computational geometry literature. Then the result for the unknown point is 0.97899 which gives an error of -0.002.

Minimum Curvature Surfaces

This method was initially developed by Briggs (1974), fortran programmed by Swain (1976) and used for the NAD27 to NAD93 datum transition by Dewhurst (1990). The original idea comes from mechanical engineering where, if an ideal metal plate is bent by perpendicular forces, there are no shear forces or tensions in the plate (Love 1929).

The forces are the datum distortions at dual coordinate points. The theory developed for creating MCS mainly stems from elasticity theory and splines in tension (Smith 1990), and both methods achieve the same results in the data area, but the second one gives poorer extrapolation results.

Following the elasticity theory for 2D tension plates, the unique compatibility equation can be solved by the Airy function (Love 1929) and this derives in the following biharmonic equation

$$\frac{\partial^4 w}{\partial x^4} + \frac{2\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{P}{D} \qquad (6)$$

known as the Lagrange equation or thin plate equation, where D is the rigidity factor that depends on the material, P is the force applied to bend the plate, w is the displacement achieved by the forces. P equals 0 in points other than data points, and this condition is extremely important to us because there will be no bending moments in the extrapolation area, and a surface linear trend will be drawn. For our purposes, this means that the general 7P transformation will be used in the extrapolation area, because the surface deformation is zero, bearing in mind that there could be some distance between the monuments and the coastline.

This condition is guaranteed by the following equation

$$\frac{\partial}{\partial x}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = 0 \qquad (7)$$

At points where forces exist, i.e., u(xi,yi)=wi, a third order polynomial continuous up to the second derivative is generated. The biharmonic equation can be constructed from 6 finite difference expressions (Briggs 1974) and depending on the position of the interpolation point in the grid, equation (8) gives the finite difference equation for the case where the values are not in border.

$$\begin{aligned} &u_{i+2,j} + u_{i,j+2} + u_{i+2,j} + \mathrm{u}_{\mathrm{i,j+2}} + \mathrm{u}_{\mathrm{i-2,j}} + \mathrm{u}_{\mathrm{i,j-2}} \\ &+ 2(\mathrm{u}_{\mathrm{i+1,j+1}} + \mathrm{u}_{\mathrm{i-1,j+1}} + \mathrm{u}_{\mathrm{i+1,j-1}} + \mathrm{u}_{\mathrm{i-1,j-1}}) \qquad (8) \\ &- 8(\mathrm{u}_{\mathrm{i+1,j}} + \mathrm{u}_{\mathrm{i-1,j}} + \mathrm{u}_{\mathrm{i,j+1}} + \mathrm{u}_{\mathrm{i,j-1}}) + 20\mathrm{u}_{\mathrm{i,j}} = 0 \end{aligned}$$

Considering the set of finite difference equations, a modern approach can be developed using image filtering techniques. This can be applied to points on the grid, but not to general points that lie away the nodes, in which case the general equation (9) must be applied. In Briggs (1974) can be found all the finite differences equations for all the grid positions.

$$
u_{i,j} = \frac{\left[\begin{array}{l} 4\left(u_{i+1,j} + u_{i-1,j} + u_{i,j+1} + u_{i,j-1} + \sum_{k=1}^{4} b_k u_k + b_5 w_n \right) - 2\left(u_{i+1,j+1} + u_{i+1,j-1} + u_{i-1,j+1} + u_{i-1,j-1} \right) - u_{i+2,j} - \ldots.. \\ \ldots..-u_{i-2,j} - u_{i,j+2} - u_{i,j-2} \end{array} \right]}{\left[4\left(1 + \sum_{k=1}^{5} b_k \right) \right]} \qquad (9)
$$

where b_k are derived from

$$
\begin{pmatrix} 1 & 0 & -1 & -1 & x \\ -1 & -1 & 0 & 1 & y \\ 1 & 0 & 1 & 1 & x^2 \\ -1 & 0 & 0 & -1 & x\,y \\ 1 & 1 & 0 & 1 & y^2 \end{pmatrix}^{-1} * \begin{pmatrix} 0 \\ 0 \\ 2 \\ 0 \\ 2 \end{pmatrix} = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{pmatrix} \qquad (10)
$$

u_k are the values of the surrounding points and x, y the coordinates of the data point from the nearest node (Briggs 1974).

The MCS results can differ greatly, depending on which software one uses. Figure 5 displays the MCS created with commercial software using splines in tension while Figure 6 displays a grid generated following the finite differences and the original FORTRAN code given by Swain (1975). In this case the code given by Swain was used to produce a MCS that gives an estimation of *0.9814045* so the error is *0.0004*.

Figure 5 - Software differences

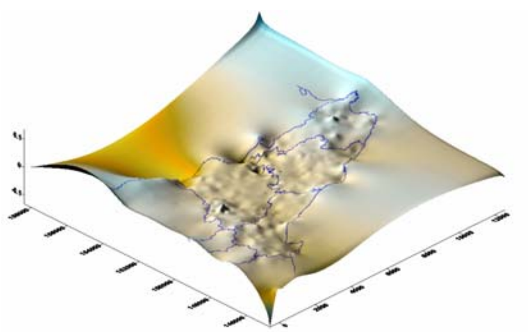
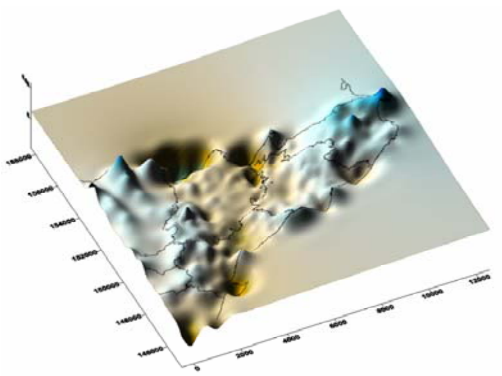


Figure 6 - Surface according to finite differences equation



Application to datum distortion modelling

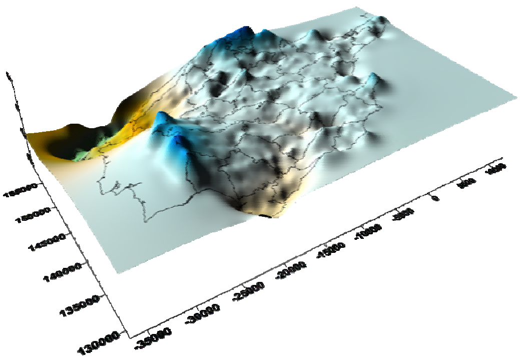
In many aspects, current users demand a unified datum that is compatible with global positioning systems. The change to a datum of these characteristics within the present information society affords the unquestionable advantage of automating the process, but at the same time is in danger of being trivialized to “menu option” in given software. The change must be gradual and must not be made official before the community of users has been informed and taught about its advantages and before a technical manual about the transformation system used, including an Annex of basic geodetic knowledge, has been prepared.

Only then should the appropriate authorities decree its use, and make available to users all the resources necessary to facilitate the transition. It is logical to endeavour not only to transform the mapping but also to recalculate the geodetic network itself in the new Geodetic Reference System, which is this paper's prime objective. The strategy followed, which must guarantee the transformation method, must:

- Involve a single transformation;
- Be simple to apply;
- Be available in a user-friendly format for space information users;
- Be capable of transforming large amounts of information efficiently;
- Be integrable in a Geographic Information System;
- Handle the theoretical conversion from one system to another;
- Imitate the results of a network readjustment, modelling small systematisms and changes of shape.

If the area of interest lies inside the data, there are no great differences, but the choice is critical if one tries to attempt an extrapolation. Bearing in mind that datum transformation using distortion modelling is 7P+surface, the extrapolation area should only contain the datum differences given by the 7P model.

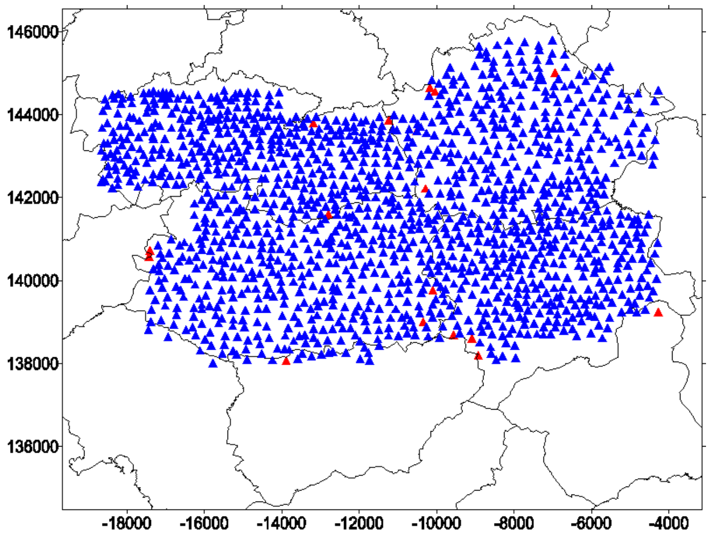
Figure 7 - Longitude MCS surface



Test area

In order to verify the goodness of the distortion modelling, a set of the low order network monuments (approx. 1400) has been readjusted in ETRS89.

Figure 8 - Test area



These points were not included in the grids generated (MCS, LSC and RS). The low order network was adjusted in ED50, strongly constrained to the border points of each province and the ETRS89 coordinates were constrained to the REGENTE points. In this case, we know the whole distortion pattern and can confirm whether the prediction of the grids generated only with REGENTE points (30Km average) can be applied to the low order network (14km average) without the need for re-adjustment.

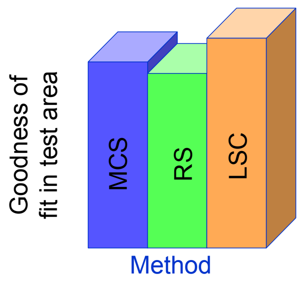
The red points in the Figure 8 show discrepancies in excess of 25cm, these points corresponding to the original monuments in ED50 where the network was constrained. The analysis has been divided in two tables: points below 25cm in Table 2, anomalous ones in histogram form can be seen in Table 3.

Conclusions

The three methods give results accurate enough for performing a datum transformation. In terms of goodness of fit, the RS method affords the best results, although virtual points have to be built in order to ensure linearity and sharp triangles at the border. LSC affords the advantage of estimating the prediction error. Finally, MCS is a balanced option of goodness of fit and use beyond the limits of the data area.

The three methods tested show similar residuals, and the overall performance of each method has been evaluated using simply the sum of the squares of the residuals. MCS was chosen as the method for the Spanish transition on account of the extrapolation advantages.

Figure 9 - Global performance



The properties of an ideal metallic plate not bent by forces beyond the data area set the value of the model to zero, so the transformation only consists of 7P. The results with independent points are approximately accurate to 15cm (95%), while another test conducted in the north of Spain obtained an accuracy of 17cm (95%), and if one considers that the global accuracy of the ED50 network is 10-20cm, the results of the transformation using distortion modelling are below the quality threshold of the worst network.

In the synthetic surface case one can observe than the goodness of fit depends highly on the kind of data being modelled. This gives no easy rules to apply to all cases.

Table 2 - Points below 25cm (MCS, LSC and Rubber-Sheeting solutions)

	MCS solution		**LSC solution**		**Rubber-Sheeting solution**	
Statistics	E TEST	N TEST	E TEST	N TEST	E TEST	N TEST
# points	1400	1400	1400	1400	1395	1395
Mean	0.01	0.02	0.00	-0.01	0.00	-0.00
Std. Dev.	0.05	0.05	0.07	0.05	0.05	0.05
Max.	0.24	0.22	0.24	0.19	0.23	0.22
Min.	-0.24	-0.24	-0.25	-0.25	-0.24	-0.24
Range	0.48	0.46	0.49	0.43	0.48	0.46
95%	0.10	0.10	0.13	0.11	0.10	0.09
99%	0.13	0.12	0.16	0.13	0.13	0.12

Table 3 - Anomalous residuals

Range(m)	Longitude	Range(m)	Latitude
Minimum Curvature surfaces			
-28.10-28.00	1	-1.30-1.20	1
-0.40-0.30	1	-0.30-0.20	2
-0.30-0.20	3	-0.20-0.10	1
-0.20-0.10	1	-0.10+0.00	3
-0.10+0.00	1	+0.00+0.10	3
+0.00+0.10	2	+0.10+0.20	3
+0.20+0.30	4	+0.20+0.30	1
+0.30+0.40	2	+0.30+0.40	1
+0.40+0.50	1	+0.40+0.50	1
+0.50+0.60	1	+0.50+0.60	1
+0.90+1.00	1	+12.30+12.40	1
LeastSquaresCollocation			
-28.10-28.00	1	-1.40-1.30	1
-0.40-0.30	2	-0.40-0.30	1
-0.30-0.20	2	-0.30-0.20	1
-0.10+0.00	1	-0.10+0.00	4
+0.00+0.10	1	+0.00+0.10	4
+0.10+0.20	1	+0.10+0.20	3
+0.20+0.30	6	+0.20+0.30	2
+0.30+0.40	1	+0.50+0.60	1
+0.40+0.50	1	+12.30+12.40	1
+0.50+0.60	1		
+0.90+1.00	1		
RubberSheeting			
-28.10-28.00	1	-1.30-1.20	1
-0.40-0.30	2	-0.30-0.20	4
-0.30-0.20	6	-0.20-0.10	1
-0.20-0.10	1	-0.10+0.00	4
+0.00+0.10	3	+0.00+0.10	6
+0.20+0.30	3	+0.10+0.20	2
+0.30+0.40	4	+0.20+0.30	1
+0.40+0.50	1	+0.30+0.40	2
+0.50+0.60	1	+0.50+0.60	1
+0.90+1.00	1	+12.30+12.40	1

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Direct transformations between neighbor TM systems

Jorge Teixeira Pinto

Summary: In boundaries regions overlapping adjacent Transverse Mercator zones there are, sometimes, the need to transform coordinates of points from one TM zone to the other. This transformation is normally performed in a two-step conversion: from TM (zone1) to geodetic (Lat.; Long.) and from geodetic to TM (zone2). These conversions can be made without uncertainty, preserving, the initial coordinates precision, if the two regions shares the same Datum. If not, the transformation will be done with some degree of uncertainty. In this paper we will deal with some direct methods to transform the TM coordinates between adjacent zones, loosing some precision, but without performing the conversions to geodetic and back to TM.

Keywords: Coordinate transformation, Transverse Mercator coordinate transformation

Conversion from geodetic to TM and vice-versa

The following formulæ for the conversion between TM coordinates (Gauß-Krüger, GK) to Geodetic latitude and longitude and back to TM used in this paper can be found in Handbuch der Vermessungskunde, Band IV, pg 1121-1123 (the formulæ here presented are slight modified because we intend to deal with the particular case of UTM coordinates, as an example. The general case of GK coordinates would be deal with in exactly the same way).

$$E = k(\delta\lambda\nu\cos\phi+\delta\lambda^3(\nu/6)\cos^3\phi(1-t^2+\eta^2)+\delta\lambda^5(\nu/120)\cos^5\phi(5-18t^2+t^4+14\eta^2-58\eta^2t^2)+\dots) \quad [A]$$

$$N = k(\sigma+\delta\lambda^2(\nu/2)\text{sen}\phi\cos\phi+\delta\lambda^4(\nu/24)\text{sen}\phi\cos^3\phi(5-t^2+9\eta^2+4\eta^4)+\delta\lambda^6(\nu/720)\ \text{sen}\phi\cos^5\phi(61-58t^2+t^4)+\dots) \quad [B]$$

Where:

E Easting coordinate
N Northing coordinate
K scale factor in central meridian (k=0,9996 for UTM system)
$\delta\lambda$ Difference of longitudes ($\delta\lambda=\lambda-\lambda_C$)
λ Geodetic Longitude
ϕ Geodetic Latitude
ν Radius of curvature of the Normal section at latitude ϕ, $\nu = a/W$
W auxiliary parameter $W= (1- e^2\text{sen}^2\phi)^{1/2}$
a Semi major axis
b Semi minor axis
t auxiliary parameter $t = \text{tg}\phi$
η auxiliary parameter $\eta^2 = e'^2\cos^2\phi$
e^2 Square of the first excentricity $e^2= (a^2-b^2)/a^2$
e'^2 Square of the 2nd excentricity $e'^2= (a^2-b^2)/b^2$
σ Length of the meridian arc from equator to latitude ϕ

There are no straight backwards formulæ. In order to compute Geodetic Latitude and Longitude from TM coordinates several methods can be used, all based upon iterative algorithms. We shall not deal with this matter here because our goal is to transform, directly, the TM coordinates from one zone to the other.

Direct transformation using multi-linear regression

A very usual and useful method to transform cartesians coordinates between two conform systems is the multi-linear regression. The following general formulæ were used in our tests:

$$\Delta E = c_0 + c_1 \times E_1 + c_2 \times N_1 + c_3 \times E_1 \times E_1 + c_4 \times E_1 \times N_1 + c_5 \times N_1 \times N_1 + ...$$

$$\Delta P = c_0 + c_1 \times E_1 + c_2 \times N_1 + c_3 \times E_1 \times E_1 + c_4 \times E_1 \times N_1 + c_5 \times N_1 \times N_1 + ...$$

where (E_1, N_1) are the given coordinates of the initial system and ΔE, ΔN the values to add to (E_1, N_1) to have the coordinates of the final system, (E_2, N_2).

The coefficients c_i, are estimated, independently for each coordinate, solving an over determined system of linear equations, using the least square approach. For this purpose a grid with a convenient unit size for both dimensions, latitude and longitude, and covering the work area, must be build up, and the nodal (ϕ, λ) points converted into TM coordinates in both systems.

The precision obtained in the conversion coordinates with this kind of approach depends upon the polynomial degree and on the size of the grid. Our tests shows that in order to keep the error of the converted co-ordinate below the meter level, a 1x1 arc degree grid (about 110x85 km) and a polynomial of the second degree is enough. In the following tables we list, as an example, the geodetic grid, table 1, the correspondent values in UTM coordinates for system 1 (λ_0=3º W) and for system 2 (λ_0=9º W),table 2, the coefficients for the Easting and Northing component of a second degree polynomial and the r.m.s. of the coefficients, table 3, and the errors of a set of control points, located somewhere on the work area, table 4[39]. In this example the grid cover an area between (41º N; 7 W) and (40º N; 5 W). Even with such a wide grid the maximum error for the Easting component is about 2 decimetres and for the Northing component about 1 decimetre.

Table 1 - Geodetic coordinates of the Grid points

Latitude N	Longitude W	Longitude W	Longitude W
41º	7º	6º	5º
40º	7º	6º	5º
39º	7º	6º	5º

Table 2 - UTM coordinates of the grid points (base points)

UTM Coordinates	of the **grid points**	(ellipsoid WGS84)	
Initial UTM System	λ_0=3º W	Final UTM System	λ_0=9º W
E_1	N_1	E_2	N_2
163555,4229	4546468,6537	668207,8852	4540683,5293
247679,1521	4543092,9544	752320,8479	4543092,9544
331792,1148	4540683,5293	836444,5771	4546468,6537
158512,5660	4435426,1715	670725,4943	4429672,9731
243900,3520	4432069,0569	756099,6480	4432069,0569
329274,5057	4429672,9731	841487,4340	4435426,1715
153573,9591	4324393,5559	673190,9003	4318679,2922
240199,8078	4321059,1165	759800,1922	4321059,1165
326809,0997	4318679,2922	846426,0409	4324393,5559

[39] All the computations were performed with TranscoordPro, a software for WindowsPC, developed under my guidance and commercialised by IGP.

Table 3 - Coefficients and theirs r.m.s. of the 2nd degree polynomial

	Easting coef.	r.m.s.	Northing coef.	r.m.s.
c_0	6.869043155914950E+05	5.200812565266620E+02	-5.259656585365880E+03	6.727696191756300E+02
c_1	3.062722728378370E-04	1.084016384207110E-04	1.142041582435200E-02	1.402267974150250E-04
c_2	-1.143003456926790E-02	2.342772894480500E-04	3.086365886433150E-04	3.030577257409460E-04
c_3	6.271888680791240E-09	4.459246433795070E-11	6.348399222604350E-10	5.768416929904870E-11
c_4	-1.271041462722040E-09	2.448360824483400E-11	1.253663149812880E-08	3.167164282160180E-11
c_5	-6.267814239624680E-09	2.639051733827010E-11	-6.355030384921490E-10	3.413839294669070E-11

Table 4 - Transformation of 4 control points and obtained errors (UTM λ_0=9º W; WGS84 ellipsoid)

True Easting	True Northing	Transf. East.	Transf. North.	True E- Transf E	True N- Transf N
682684,616	4522514,866	682684,723	4522514,786	-0,107	0,079
796597,678	4489142,098	796597,660	4489141,979	0,017	**0,119**
728744,268	4394160,752	728744,282	4394160,865	-0,014	-0,113
787993,979	4340566,329	787994,197	4340566,369	**-0,218**	-0,039

Using a higher degree doesn't ensure *per se* a higher precision. A higher degree ensure a higher precision for the grid points (which coordinates are known *a priori* in both systems) but, sometimes, not for the points inside the grid cells.

This method can, of course, be applied also between UTM coordinates belonging to different geodetic Datums. In such cases the intrinsic errors of the multilinear transformation are added with the uncertainties of the parameters to transform one Datum into the other.

Direct transformation without *a priori* known points

Before the use of modern computational means the use of the above described method was not advisable as a tool for everyday problems. Solving linear systems without automatic computational means is not an easy task! Therefore some authors have proposed interesting and ingenious methods to solve the problem, see Jordan/Eggert/Kneissl, band iv, and König/Weise. As far as I know all these methods are based upon the analytic and conformal proprieties of the GK "projection" and use an approach, rather complex, based upon a series development around the point to be transformed. The reported precision depends on the number of the terms of the series but is, in general, quiet good, far below the meter level.

Here I will use a more straight approach using directly the formulæ [A] and [B]. Let the coordinates of the point P to be transformed be (E_1,N_1) in system 1 and (E_2,N_2) in the system 2. As the point is the same, its geodetic coordinates (ϕ,λ) are, therefore, equal in both systems (assuming the same Datum). So we have:

$$E_1 = k(\delta\lambda_1 \nu\cos\phi + \delta\lambda_1^3(\nu/6)\cos^3\phi(1-t^2+\eta^2) + \delta\lambda_1^5(\nu/120)\cos^5\phi(5-18t^2+t^4+14\eta^2-58\eta^2t^2)+\ldots)$$

$$N_1 = k(\sigma + \delta\lambda_1^2(\nu/2)\mathrm{sen}\phi\cos\phi + \delta\lambda_1^4(\nu/24)\mathrm{sen}\phi\cos^3\phi(5-t^2+9\eta^2+4\eta^4) + \delta\lambda_1^6(\nu/720)\mathrm{sen}\phi\cos^5\phi(61-58t^2+t^4)+\ldots)$$

and

$$E_2 = k(\delta\lambda_2 \nu\cos\phi + \delta\lambda_2^3(\nu/6)\cos^3\phi(1-t^2+\eta^2) + \delta\lambda_2^5(\nu/120)\cos^5\phi(5-18t^2+t^4+14\eta^2-58\eta^2t^2)+\ldots)$$

$$N_1 = k(\sigma + \delta\lambda_2^2(\nu/2)\mathrm{sen}\phi\cos\phi + \delta\lambda_2^4(\nu/24)\mathrm{sen}\phi\cos^3\phi(5-t^2+9\eta^2+4\eta^4) + \delta\lambda_2^6(\nu/720)\mathrm{sen}\phi\cos^5\phi(61-58t^2+t^4)+\ldots)$$

and therefore

$$E_2\text{-}E_1 = k\nu\cos\phi(\delta\lambda_2-\delta\lambda_1)+k(\nu/6)\cos^3\phi(1-t^2+\eta^2)(\delta\lambda_2{}^3-\delta\lambda_1{}^3)+k(\nu/120)\cos^5\phi(5-18t^2+t^4+14\eta^2-58\eta^2t^2)(\delta\lambda_2{}^5-\delta\lambda_1{}^5)+\ldots \qquad [C]$$

$$N_2\text{-}N_1 = k(\nu/2)\mathrm{sen}\phi\cos\phi(\delta\lambda_2{}^2-\delta\lambda_1{}^2)+k(\nu/24)\mathrm{sen}\phi\cos^3\phi(5t^2+9\eta^2+4\eta^4)(\delta\lambda_2{}^4-\delta\lambda_1{}^4)+k(\nu/720)\mathrm{sen}\phi\cos^5\phi(61-58t^2+t^4)(\delta\lambda_2{}^6-\delta\lambda_1{}^6)+\ldots \qquad [D]$$

Analysing formulas [C] and [D] we see that in order to estimate the differences E_2-E_1 and N_2-N_1 we must have appropriate values for ν, ϕ and for the sequence of the terms in $\delta\lambda_2{}^n$-$\delta\lambda_1{}^n$. The first one of these longitude differences, $\delta\lambda_2-\delta\lambda_1$, is, equal to the difference between the longitudes of the central meridians of the TM zones, which is, in our case, 6º:

$$\delta\lambda_2-\delta\lambda_1 = 6^\circ \qquad [E]$$

The parameters ν and ϕ are inter-dependent. Once obtained one, for instances ϕ, the other is obtained via the formula for ν.

In order to estimate ϕ an iterative algorithm, similar to that employed to get the geodetic coordinates from the rectangulares, can be used. However our pourpose is to obtain the rectangulares coordinates of the final system without geting help from the geodetic coordinates. Neverthless let us, briefly, explain this classical approach, adapted to our problem, in order to compare with the new one.

In the classical approach we need a starting value for ϕ. This value can be obtained directly from the Northing, assuming a direct proportionality between this value and the meridian arc from Equator till 45º, for example.

$$\phi_0=(N_1/k)/\sigma_{45^\circ} \qquad [F]$$

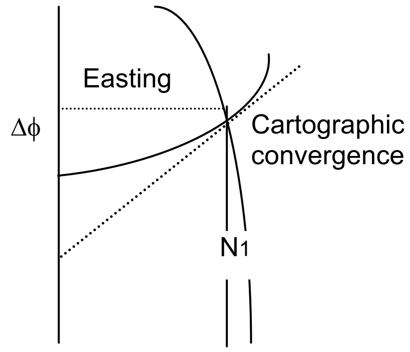
The Easting component, divided by k, gives us, divided by the parallel radius, p_0, a good starting value for $\delta\lambda_1$, and, therefore for $\delta\lambda_2$, via [E].

$$\delta\lambda 1_0=(E'_1/k)/p_0 \qquad [G]$$

with $E'=FE-E_1$ and FE=500 km

Once obtained $\delta\lambda 1_0$ we can improve our starting value ϕ_0 correcting it from the fact that N1 is not measured along the central meridian but at a distance $\delta\lambda 1_0$ from it, and, therefore, greater than the correspondent central value, see figure 1.

Figure 1 - Cartographic convergence



$\Delta\phi$ can be estimated using the value of the Cartographic convergence, CC, which is equal to $\delta\lambda\sin\phi$:

$$CC_0=\delta\lambda\sin\phi_0$$

$$\Delta\phi_0= ((p_0-p_0\cos CC_0)/\sigma_{45^o})x45^o$$

$$\phi_1= \phi_0-\Delta\phi_0$$

Playing with [F], [G], [E], [A] and [B] in a iterative way, and [C] and [D] for the final calculation, we get the requested coordinates in the second system after some steps with an accuracy better than the meter uncertainty, or if making further steps, to the exact value.

As an application example we will transform the grid point (40º N; 7º W) with E1=158512,566 m; N1=4435426,172 m, UTM coordinates in the initial system $\lambda 0$=3º W, in UTM coordinates (670725,4943; 4429672,9731) of the final system $\lambda 0$=9º W, WGS84 ellipsoid.

σ_{45^o} = 4 984 944,3780 m => ϕ_0 = 40º 03' 19",52 => ν_0= 6 386 996,591 m;

p_0=4 888 749,725 m; k=0,9996 => $\delta\lambda 1_0$=4º 00' 13"71;

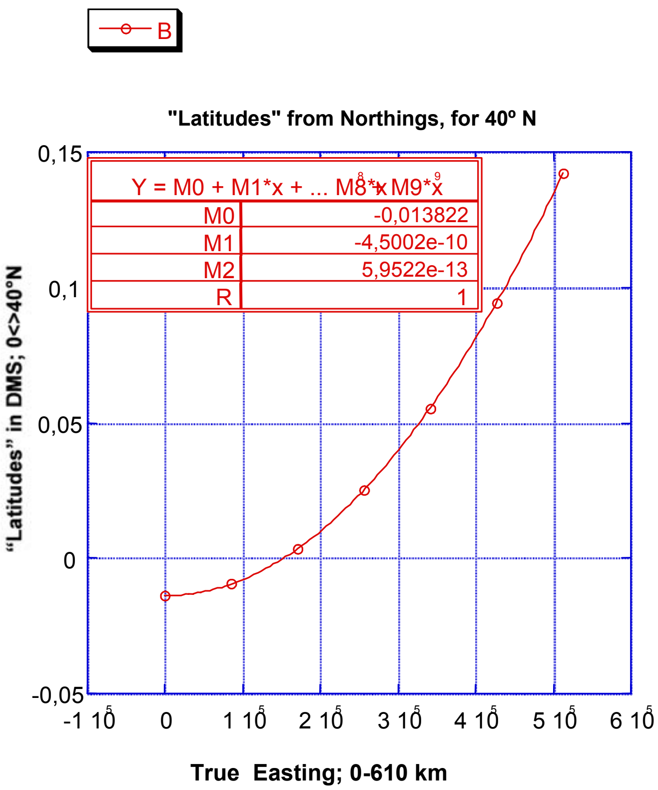
$\Delta\phi_0$=2' 40",62; ϕ_1 = 40º 00' 38",91 => ν_1= 6 386 980,148 m;

p_1=4 891 936,104 m => $\delta\lambda 1_1$=4º 00' 04",32 => $E2_0$= 670 644,196 m; $N2_0$=4 429 665,753

Now to proceed further we should use equations [A] and [B] to check for the errors in E1 and N1 when using ϕ_1 and $\lambda_1=3^o+\delta\lambda 1_1$, as geodetic coordinates for the point, and correcting ϕ_1 and λ_1 accordingly. This is again an iterative process that converges quickly to the exact values E2 and N2, and is well documented in the literature.

If some error can be allowed, this iterative process can be avoided. The error analysis of formulas [C] and [D] shows that the major concern is the latitude. The following graph depicts the behaviour of the values for ϕ obtained with formula [F].

Figure 2 - Variation of calculated Latitudes with Easting, for 40º N



Using the regression formula

$$\Delta\phi=-0{,}013822-4{,}5002E^{-10}x(TrueEasting)+5{,}9522E^{-13}x(True\ Easting)^2$$

we will get, **at once**, an accurate enough correction to be applied to the latitude value obtained by formula [F], and consequently, via the above formulas, also an accurate enough value for $\delta\lambda 1$.

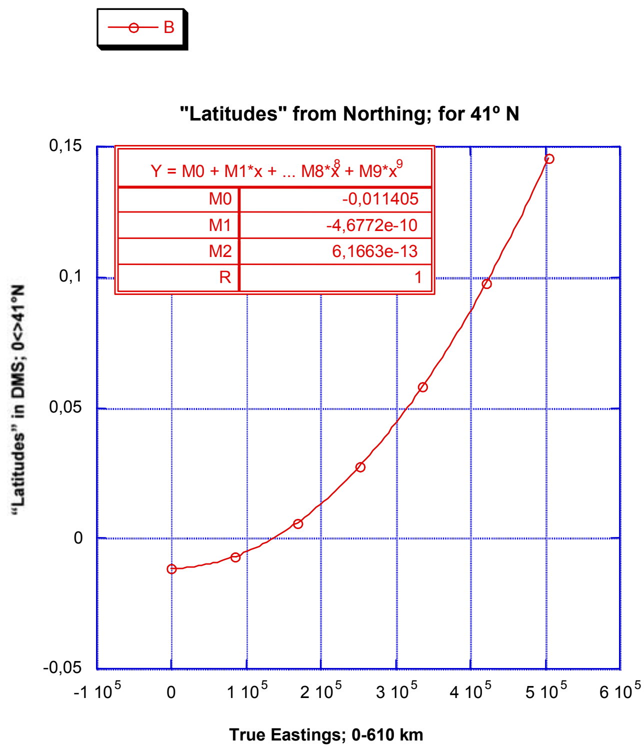
In our example:

True Easting=500000-158512,566=341487,434 => $\Delta\phi$ =3' 19,"57 =>

ϕ_1 = 40º 03' 19",52 - 3' 19,"57 = 39º 59' 59",95!

Of course, the graph in figure 2 is build up for exactly 40º N, and we don't know a priori the latitude value. But we can always build a graph for ϕ_0 or ϕ_1. The value for $\Delta\phi$ should be accurate enough to use in formula [D]. For instance, even when using a graph for a latitude 1º higher, we get still a very good correction, see figure 3.

Figure 3 - Variation of calculated Latitudes with Easting, for 41º N



In this case we will get for $\Delta\phi$ =3' 37,"23.

Let us admit that we get graphs for 40º and 41º. The corresponding correction for ϕ_0 will be directly interpolated from 3' 19",57 and 3' 37"23, giving us 3' 20,"55 for $\Delta\phi$. So:

$\phi=\phi_0-\Delta\phi$= 39º 59' 58",97 => ν = 6 386 976,060 m;

p=4 892728,020 m; k=0,9996 => $\delta\lambda$=4º 00' 01",99

Applying the above values in [C] and [D] we get:

E_2=670 721,125 m;   error= -4,4 m;

N_2=4 429 669,773 m;   error= -3,2 m

These errors can be lowered if graphs with a lower spacing were used. I have not done such experiment but it is easy to recognize that a spacing of 10’ will reduce the error about 6 times, ensuring errors below the meter level.

Conclusions

A direct transformation between adjacent TM systems can be performed getting accuracies below the meter level using several methods. If no more information is available than the definitions and parameters of the systems the classical approach using series around the point is the only choice. If we need a straightforward process, easily implemented in GIS systems, for example, the multilinear regression is strongly advisable. But If we don’t have the necessary means to compute the regression analysis and don’t know how to deal with the complexities of the classical approach, the graph procedure is a very easy and accurate enough method, which can be implemented in a spread sheet.

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The Design and Introduction of a New Map Projection and Grid System for Ireland

Ken Stewart, Iain Greenway and Colin Bray

Summary: Ireland's current mapping grid is based on observations and computations dating from the nineteenth century. This means that accurate measurements including those made using the Global positioning System (GPS) have to be distorted to fit the grid. In addition, the use of different reference surfaces leads to further complexity, potential inaccuracy, and difficulty in combining data sets.

The paper describes how OSNI and OSi, the national mapping agencies responsible for the mapping of the island of Ireland, are developing the positioning infrastructure and the mapping grid for the island. The varying requirements of different groups of users can create conflicting demands and the paper discusses how OSi and OSNI have met the needs of users.

Keywords: Coordinate reference system, GPS, geodesy, map projection

Background and Context

Ordnance Survey Ireland (OSi) and the Ordnance Survey of Northern Ireland (OSNI) are the national mapping organisations responsible for the surveying and mapping of Ireland and Northern Ireland. They are jointly responsible for the development of a geodetic framework on which all mapping is based. Without this common coordinate reference system, mapping on the island would not "fit together".

The Global Positioning System (GPS) enables precise positioning anywhere on earth with a precision of a few millimetres, if an appropriate reference frame and positioning infrastructure is in place. This framework and infrastructure is realised in Ireland through a Passive and an Active GPS Network, which are precisely positioned within the European Terrestrial Reference System, ETRS89, resulting in European Terrestrial Reference Frame, ETRF89, coordinates.

Mapping in Ireland, however, as in many places around the world, is based on a different geodetic datum from that used by GPS. Although transformation formulae and parameters are available between Irish Grid and ETRS89, it is beneficial, particularly for GPS users, to associate a map projection with ETRS89. A projection allows three-dimensional ETRS89 coordinates to be converted to a two-dimensional form that can be plotted on a map. This maintains the quality and precision of the GPS for surveying and mapping purposes, and simplifies GPS positioning on all Ordnance Survey products.

Irish Grid Coordinate System

The current coordinate reference system, which is used by OSi and OSNI is based on a rigorous adjustment of a carefully observed triangulation network, the origin of which dates back to the 19th century. The re-triangulation of Ireland and Northern Ireland in the 1950's and 1960's resulted in the Ireland 1965 datum from which latitude and longitude positions were computed in the Ireland 1975 (Mapping) Adjustment, on a modified Airy ellipsoid [1].

A Transverse Mercator projection was used to convert the latitudes and longitudes into two-dimensional Irish Grid coordinates for mapping purposes.

The original parameters for the Irish Grid specified a scale factor of unity on the central meridian and applied to the Airy ellipsoid. Discovery of scale errors in the network resulted in the adoption of a scale factor of 1.000035 on the central meridian and introduction of the Modified Airy ellipsoid to compensate. It is generally accepted that this scale factor is unusual (being greater than unity on the central meridian) and is partially due to shortcomings in measurement technology (including EDM equipment) at the time. Additional details and description of the datum and adjustment are contained in [1].

ETRS89 and the Active and Passive GPS Networks

With the advent of satellite positioning systems in the 1960's, and specifically the US Department of Defence's Global Positioning System (GPS) in the 1980's, techniques for determination of precise global positions were developed. These techniques are capable of providing significantly improved positioning compared to traditional methods, and can expose the limitations of existing control networks. This is the case in Ireland.

With almost global coverage available, it is now possible to establish precise continental coordinate reference systems. The accepted standard within Europe is the European Terrestrial Reference System (ETRS89), established by the International Association of Geodesy (IAG).

This is realised by a network of permanently recording GPS stations, and can determine, on a daily basis, solutions of the positions of the permanent sites, including movement in their relative positions due to tectonic plate activity. The resulting apparent movement has brought about the need to time-stamp positions. The adopted European System is therefore fixed at the start of 1989 (1989.00) and is known as ETRS89.

In 1994, OSi and OSNI jointly agreed to establish a new geodetic control network in Ireland based on the ETRS89. The scheme was largely observed during 1995 and 1996, and established a Passive GPS Network within Ireland. Subsequently, in 2002, thirteen continuously operating GPS receivers were established. The data from this Active GPS Network is freely available to users and, along with the Passive GPS Network, provides high precision, distortion free control for GPS surveys to international standards.

In order to establish compatibility between ETRS89 and the Irish Grid, OSi and OSNI commissioned the Institute of Engineering Survey and Space Geodesy (IESSG) at the University of Nottingham to determine the most appropriate mathematical transformation. As a result of this, and further research, transformation parameters between Irish Grid and ETRS89 have now been determined [2].

The need for a new projection

Mathematical transformations cannot provide exact results; consequently they only partially realise compatibility between the Irish Grid and ETRS89. Applying a transformation to precisely surveyed positions results in distortion of accurate GPS measurements to make them fit a less precise control network. It is more appropriate to maintain the accuracy of the survey by using mapping that is compatible with GPS, thus allowing surveys and mapping to be combined without the introduction of distortion. Therefore, to benefit fully from the accuracy achieved by the Active and Passive GPS Networks, both surveys and mapping should be based on this control network and datum.

Surveyors, engineers, navigators and a wide range of professional users, as well as the general public, increasingly use GPS. These users wish to be able to relate GPS positions to Ordnance Survey mapping unambiguously and quickly, without having to consider datum transformations, map projections, or the distortions inherent in older mapping. It is therefore desirable that OSi and OSNI provide mapping that is compatible with GPS.

ETRS89 positions are three-dimensional, in the form of Cartesian or geographical coordinates. However, because ETRS89 relates to a different geodetic datum than Irish Grid, it follows that the ETRS89 latitude and longitude of any point differ from the Irish Grid values. To calculate grid coordinates from latitude and longitude requires that a map projection is associated with the new geodetic framework, thus providing two-dimensional grid coordinates that can be shown on a map.

It follows that the grid coordinate obtained is dependent on the ellipsoid and projection parameters used.

ETRS89 relates to the GRS80 ellipsoid [3], not the modified Airy ellipsoid used by the Irish Grid. By projecting onto different ellipsoids, different grid coordinates are obtained. However, the difference between the two sets of projected coordinates is only in the order of 55m. This is not large enough to identify which ellipsoid was used, and as a consequence introduces confusion. It is therefore desirable to alter the projection parameters sufficiently to differentiate between the coordinate systems used. Introducing changes to any of the projection parameters provides the opportunity to address additional ambiguities in the projection, such as the modified scale on the central meridian.

The problem of making maps compatible with GPS is not specific to OSi and OSNI. A number of European National Mapping Agencies (NMA's) including Denmark, France, Switzerland, and Sweden have already introduced, or are actively considering, new projections to associate with ETRS89. It is therefore appropriate at this time to introduce new map projections for Ireland to ensure full compatibility with GPS. This also provides an opportunity to address historic datum anomalies.

The new projections need to be associated with the accepted global reference ellipsoid, GRS80, and associated coordinate system, ETRS89. A consequence of introducing new map projections is the need to introduce a new grid system and to consider the need for a new map indexing system.

Intended properties of the new projections

The projections adopted by OSi and OSNI must fulfil several criteria. They are intended to be GPS compatible, and therefore must be associated with ETRS89 and the GRS80 ellipsoid. They must be orthomorphic or conformal (that is, preserving local shape), and they must minimise mapping distortion throughout Ireland and Northern Ireland. The projections should also be based on formulae that are readily available. Additionally, they must allow compatibility with current mapping to be maintained.

OSi and OSNI have identified the Transverse Mercator projection as the most suitable type of map projection for the following reasons:

- It is suitable for mapping areas where the north-south dimension is greater than the east-west dimension.
- It is conformal (or orthomorphic), and therefore the relative local angles about a point on the map are shown correctly. Also, the local scale around any one point is constant, and the shape of small features is maintained. Conformal projections are standard for most NMA's in Europe.
- The formulae for Transverse Mercator projections are well defined and are included in the majority of currently available software packages.

Mapping distortions caused by the projection are dependent on, and can be minimised by, the choice of suitable parameters. Therefore, the following three forms of Transverse Mercator projection have been considered:

- the current projection, Irish Grid (IG);
- Universal Transverse Mercator (UTM); and
- a newly derived projection, Irish Transverse Mercator (ITM).

The projection parameters for IG, UTM and ITM are listed in Table 1.

Table 1 - Parameters for the three projections considered

	Current	Proposed	
	IG	**ITM**	**UTM**
Reference Ellipsoid	Airy (modified)	GRS80	GRS80
Central Meridian	8° West	8° West	9° West
Scale on CM	1.000 035	0.999 820	0.999 600
True Origin Latitude (φ) Longitude (λ)	53° 30' North 8° 00' West	53° 30' North 8° 00' West	0° 00' North 9° 00' West
False Origin (metres)	200 000 W 250 000 S	600 000 W 750 000 S	500 000 W 0 S

Irish Grid

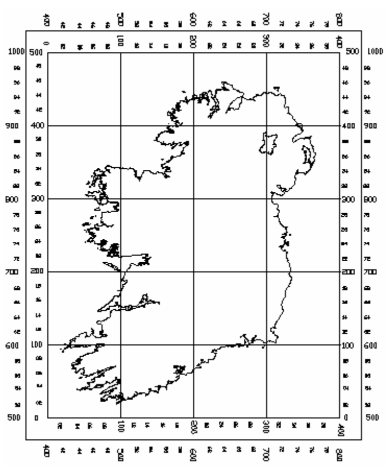
Originated as a classically derived Transverse Mercator projection, the Irish Grid was defined to meet the above criteria. The 1975 mapping adjustment resulted in alteration of the scale factor on the central meridian to 1.000035. The parameters associated with Irish Grid are unsuitable for a proposed GPS mapping projection associated with the ETRS89 and the GRS80 ellipsoid. Applying these parameters, the difference between the projected ETRS89 and Irish Grid coordinate of a point is in the order of 55 metres. It is anticipated that this will introduce confusion regarding the coordinate system and projection used to derive any given point. Moreover, because of the adjusted scale factor on the central meridian, the effects of mapping distortions are not minimised.

Universal Transverse Mercator (UTM)

UTM is an internationally recognised and widely available standard projection in mapping and GIS software. It was developed in 1947 by the US Army, and has been used for military maps throughout the world. It divides the earth into sixty zones, between latitudes 84º North and 80º South. Each zone is 6º wide, with a scale factor of 0.9996 applied on the central meridian [4].

Ireland is situated in UTM Zone 29, which has a central meridian 9º West of Greenwich, resulting in a small part of Counties Antrim and Down in the east of Northern Ireland extending outside the nominal zone width boundary of 6º West of Greenwich. However, the zone width may be altered to meet local circumstances and since the UTM grid has a standard zone overlap of 40 km on either side of a zone boundary, all of Ireland can be contained within Zone 29. Since the central meridian lies along the West Coast of Ireland, mapping distortions are not distributed evenly. Applying UTM to Ireland results in coordinates that have a 7-digit northing and 6-digit easting, compared to the current IG reference system, which has 6 digits in each.

Figure 1 - ITM and IG coordinates for Ireland



Inner co-ordinates: Irish Grid
Outer co-ordinates: ITM

Irish Transverse Mercator (ITM)

ITM is a newly derived projection that may be associated with ETRS89 and the GRS80 ellipsoid. The true origin and central meridian defined in the Irish Grid are maintained, thus distributing the distortions due to the projection evenly.

Consideration was given to the introduction of a scale factor of unity on the central meridian. However, using a scale of 0.99982 results in two standard parallels, and the magnitude and effects of scale change are minimised. The position of the false origin is moved to a point 600,000m west and 750,000m south of the true origin. This results in grid coordinates that are significantly different from Irish Grid, but does not introduce additional distortion or complexity. The magnitude of the shift ensures that Irish Grid coordinates plotted on the ITM projection do not fall on Ireland or Northern Ireland, and vice versa (see Figure 1). Figure 1 is illustrative only – the relationship between IG and ITM is not constant and varies over Ireland.

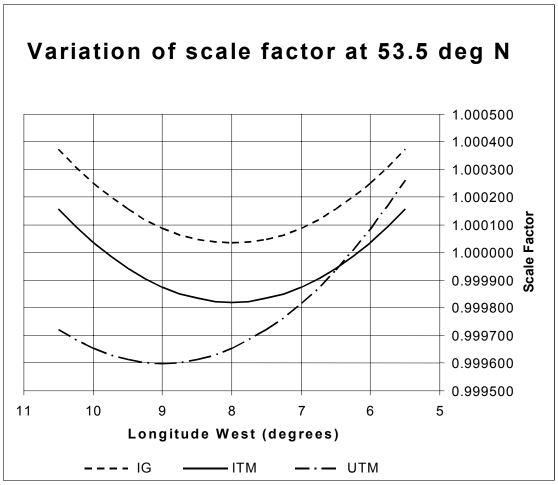
Comparison of the proposed projections

The effects of the three projections have been compared in relation to scale correction, area and convergence.

Scale Correction

For Transverse Mercator projections, scale correction is a function of grid distance from the central meridian. It is therefore constant for any given easting, and is independent of the northing. The range of scale correction resulting from both Irish Grid and ITM is 355 parts per million (ppm), whilst UTM has a range of 659 ppm. However, Irish Grid does not have a standard parallel (where scale is unity). Although UTM has one standard parallel in Ireland, the location of the central meridian results in larger scale corrections on the east coast. Since ITM is secant and centred on Ireland, it provides two standard parallels (see Figure 2).

Figure 2 - Variation of scale factor at 53° 30’ N



Area

Currently area measurements are computed by OSi and OSNI directly from the mapping (Irish Grid on the Airy modified ellipsoid), without applying scale corrections. Since all survey observations are reduced to the reference ellipsoid before being projected onto the mapping, changing the ellipsoid will introduce changes in the areas shown on maps. To quantify the magnitude of the change, an area of one hectare (100m x 100m) on the Irish Grid mapping was re-projected onto UTM and ITM. Applied to UTM, the largest change in area occurs on the central meridian at 9° West of Greenwich, and results in a decrease in area of $10.3m^2$ (0.1%). Similarly, the worst-case for the proposed ITM mapping system occurs on the ITM central meridian at 8° West of Greenwich, and results in a decrease in area of $1.7m^2$. Using the current Irish Grid projection parameters applied to the GRS80 ellipsoid results in an area increase of $2.4m^2$. When using a 1:1,000 scale map it is only possible to plot to an accuracy of 20cm, which results in a possible error in the area measurement of ±40 m^2. This is significantly greater then the area change resulting from a change in projection and therefore the effect on area measurements can be considered negligible.

Convergence

IG and ITM both use the same true origin and central meridian, and therefore using ITM projection parameters does not affect convergence. Furthermore, the change in the size of the ellipsoid from the modified Airy to GRS80 is not large enough to affect the calculated convergence. Adopting UTM implies a central meridian at 9° West, which results in an increase in convergence of between 47' and 50'. At the extremes of the projection this increases convergence from 2° 03' 39" to 2° 53' 08".

Analysis

As described in previous sections, any new map projections should minimise distortions within the new mapping system and realise grid coordinates relating to ETRS89 that are substantially different from the existing corresponding Irish Grid coordinates (thus avoiding confusion). These criteria immediately rule out the possibility of maintaining the current projection parameters. However, both ITM and UTM will provide unique grid systems with coordinates that are significantly different to Irish Grid. Considering scale correction, UTM produces the largest scale correction, of –400 ppm or 40cm per km on the central meridian. This becomes significant when plotting measurements of greater than 500m. UTM also provides the largest range of correction (659 ppm). Additionally the location of the UTM standard parallel requires that corrections of greater than 200 ppm are applied to all observations west of a longitude of 7° west.

ITM minimises and evenly distributes scale corrections, with a maximum scale correction of 180 ppm on both the central meridian and the extremes of the projection. Positioning the central meridian in the centre of Ireland at 8° west also results in even distribution of convergence and t-T corrections. The location of the UTM central meridian produces increases of 50' in the convergence calculated along the east coast. The adoption of either UTM or ITM map projections has no significant effect on area measurements.

Proposals and Implications

This paper has described some of the complexities encountered when attempting to make GPS measurements fit onto existing mapping. The growing numbers of GPS users, most of whom have no interest in issues such as transformations and adjustments, will be best served by a mapping system which is fully compatible with GPS and the ETRS89. This will also greatly simplify the process of combining data sets both locally and within Europe. There are, however, very many users of OSi and OSNI mapping, many of whom have associated their own data with the mapping data and therefore have significant databases related to the Irish Grid. There is substantial effort involved in converting these large databases into a different coordinate reference system and any proposed change cannot ignore the needs of these users. Whilst recognising that the majority of map data users in Ireland will not be concerned about the international compatibility of their work, there are important applications that will benefit significantly from such compatibility. Although UTM, for the reasons described, is not the ideal map projection when considering Ireland in Isolation, it is an internationally recognised standard, and when applied to the ETRS89 is compatible with the proposed ETRS89 Transverse Mercator Coordinate Reference System (ETRS-TMzn).

Consequently, OSi and OSNI intend to adopt the following policy:

1. Adopt and offer a range of products and services using the ITM map projection with the above parameters to be associated with the ETRS89 coordinate reference system and the GRS80 ellipsoid.

2. Offer to their customers working in the international and European context the option to use data projected on UTM (ETRS-TMzn). This will provide a standardised international way in which grid coordinates can be expressed to ease integration and data exchange across Europe and beyond.
3. Continue to offer to their traditional map users the assured use and backward compatibility of Irish Grid products and services.

By using Active or Passive ETRS89 GPS control, along with OSi and OSNI mapping projected in ITM or UTM, GPS measurements can be combined with national mapping while still maintaining survey accuracy and avoiding the current requirement to compute or apply transformations. It is further anticipated that the proposed new map projection, ITM, will simplify and encourage the use of GPS with OSi and OSNI products. Compatibility between the new projection and Irish Grid will be maintained using the derived transformations.

Relating the control networks and mapping within Ireland to the ETRS89 allows users to re-project coordinates and data to any of the proposed European Coordinate reference Systems (ETRS-Transverse Mercator, ETRS-Lambert Conformal Conic, and ETRS-Lambert Azimuthal Equal Area) without the need for a datum transformation. The intention of OSi and OSNI to make mapping available in UTM (ETRS-TMzn) will allow data to be directly combined within an accepted European format.

Following the introduction of new map projections for Ireland, all mapping must include the appropriate labelling to identify the projection used. Similar to the European recommendation to use of a range of map projections, the use of both UTM and ITM within Ireland will mean that individual points may have more than one grid coordinate. Changes to the map detail will not be significant enough to allow simple visual identification; the grid coordinates, however, will provide an easy method of distinguishing the projection and grid used. Adoption of new projections and grid systems for Ireland may also have subsequent effects on the map cataloguing systems for users. Various issues remain to be resolved, with user input a vital part of that process. Key areas for further discussion include the timescale within which users can accommodate changes, the coordinate reference system and indexing system to be used for small-scale maps, and how product design can be used to assist in the easy identification of the projection and grid being used for any particular map.

The adoption of the ETRS89, along with standard transformation parameters and an accurate geoid model, are essential to ensure that current and historical data collected by users for different applications at different times can be combined. By establishing a new control network within Ireland that is related to the ETRS89, and by developing transformations between the Irish Grid and ETRS89, OSi and OSNI have provided the means for users in Ireland to integrate their data accurately within European data sets. The introduction of ITM fulfils the needs of local surveying and engineering users who require a mapping system with minimum distortion, but the underlying use of the accepted coordinate reference system, ETRS89, enables precise GPS surveys to be combined with existing national mapping. Furthermore the adoption of the ETRS89 allows data to be re-projected to any of the recommended European map projections. The net result of the significant developments that are being implemented by OSi and OSNI is an infrastructure that will support all of Ireland's map users, while maintaining the accuracy of survey measurements to the fullest extent possible, and allowing data integration within Europe.

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Very High Resolution Raster Digital Data: Datasets for the Common Agricultural Policy

Simon Kay

Summary: The Common Agricultural Policy manages the payment of subsidies to farmers for the cultivation of land. In return for payment, farmers must identify their fields in national GIS databases. By 31st Dec 2004, 25 countries will have implemented this approach, and nearly all (23) will use high resolution orthoimage data as a primary data source. These raster datasets are both an important source for many grid based surveys, as well as an important consideration in the technical realignment of raster/gridded data with new, pan-European specifications.

Keywords: orthoimage, orthophoto, national, GIS, CAP, agriculture

Background

Since the first major reform of the European Union (EU) Common Agricultural Policy (CAP) in 1992, the technological framework to manage the identification and localisation of farmers' fields – a basic requirement of the system used to manage subsidies – has been under constant development and improvement.

Although the initial regulations establishing the *Integrated Administration and Control System* (IACS) did not specify that any geographical information needed to be managed directly, by the mid-1990's a majority of Member States (MS) had selected to use GIS technology exactly for this purpose. Furthermore, the state of art of digital orthophoto technology had evolved by this time to render feasible the creation, management and distribution of national raster datasets derived from medium-scale aerial photographic coverages.

The trend in the direction of this technical revolution in the widespread application of airborne remote sensing technology, applied in conjunction with spatial data management systems, is described already by Kay et al. (1997).

Indeed, by 1998, the first EU/CAP legislation was passed (European Commission, 1998) which obliged five Member States to create a spatial data management system for Olive Oil subsidy management (specifically, the olive trees themselves), based upon orthophotos with a cartographic equivalent to 1:10,000 mapping and with a 1m pixel size, using GIS technology. This management system has now been implemented for Portugal, Spain, France, Italy and Greece.

In addition, several other Member States had already adopted GIS technology – often with orthophotos as the data source for the field vector data – for the management for IACS; by 1999, only six Member States had not completely adopted this approach.

In 2000, Council Regulation 1593/00 (EC, 2000) was adopted, amending the original CAP reform and obliging all Member States to adopt GIS technology as the primary tool for managing field identification by the end of 2004. Although the use of orthophoto data was not obliged in this amendment (sunsequently incorporated completely into the current CAP legislation (EC, 2003)), in practice the raster orthophoto has been adopted by all Member States as part of the IACS data source.

Furthermore, nine (of ten) new Member States have today already completed the introduction of GIS/orthophoto based technology in IACS; the tenth (Poland) plans to meet the deadline with the EU15. Only two Member States do not make direct use of the orthophoto data in the aid application process.

In summary, before the end of 2004, all 25 EU Member States – excepting a few areas of low significance with respect to agriculture – will be covered by orthophotos, from frontier to frontier, offering a rich data source for many applications reaching beyond the CAP and into many areas of regional and national administration.

CAP Raster data

Technical characteristics

The EU CAP legislation makes no requirement upon the technical production of the raster image datasets. However, the European Commission has collaborated closely with Member States in identifying solutions and piloting techniques, thus ensuring some degree of standardisation of approach.

The technical characteristics of the orthoimagery can be summarised as follows:

- **Data source**: mostly airborne film metric camera, 1:40,000 flights, but many instances of larger scale (e.g. 1:25,000). Two countries (Cyprus, Poland) have used satellite imagery;
- **Final product specification**: 1:10,000 scale equivalent (2.5m RMSE on independent check points). However, 1:5,000 scale equivalent is becoming increasingly common;
- **Pixel size**: 1m obliged, but 50cm becoming frequent;
- **Channels**: Although panchromatic imagery is acceptable, colour is now becoming standard practice;
- **Frequency of update**: again, the IACS regulation makes no specific obligations: but the cycle adopted by most Member States is 3 to 5 years;
- **Digital Elevation Model data**: as a spin-off to this raster orthoimage production, large-scale wide coverage DEM datasets have been produced – although actual availability may not be in the hands of Member State administrations.

Characteristics of Member State implementation

The CAP regulations leave considerable scope to Member States to exercise subsidiarity in their choice of technical solutions. Furthermore, there is currently no framework for the EU to impose a harmonised spatial data infrastructure in the implementation of such projects.

Consequently, a number of approaches – adapted to each countries circumstances, budgets and priorities – have been devised. While most of these meet high standards, reflecting forward-looking and strategic decisions, some have inevitably been less successful in incorporating long term multipurpose potential.

For example, in absence of an EU position on harmonisation of large-scale, gridded dataset projections, each Member State has proceeded according to its usual national geodetic system definition. In some cases, the IACS implementation has not yet succeeded in producing even a harmonised approach within Member States.

In a few cases, the geographical data has been produced in geodetic systems which are already somewhat technologically outdated, and not readily compatible with other systems, the European reference frame, or GPS/GNSS technology.

To summarise, many aspects of the CAP raster dataset implementation are surely not standardised across the EU.

Some of these aspects present more reason for concern than others; the list of areas that may generate issues for organisations wishing to exploit the data may include:

- Variable geodetic reference system (projection, datum)
- File formats
- Meta data formats and availability
- Quality assessment and statement
- Image characteristics (radiometry, scale, pixel size, etc)

Nevertheless, despite these difficulties, such a resource presents a huge step forward in respect of high quality, large scale data availability across the EU. Indeed, such orthoimagery today presents the only EU coverage of its kind, offer fantastic potential for statistical survey, legislation implementation or regional planning.

Discussion

Whatever difficulties may be faced with the future use and development of the CAP orthophoto datasets, the massive effort and investment of this successful implementation by Member States should be acknowledged. With hindsight it is always possible to identify improved approaches to avoid pitfalls that were clearly not priorities in the original requirements definitions of these datasets.

However, the future integration of these datasets – for example, for statistical survey requirements – may prove to be an complex task. A major consideration is that, while vector datasets are relatively straightforward to move between geodetic systems, raster data is more voluminous and the re-projection implies degradation in image quality. The choices already made by Member States are likely, therefore, to induce significant inertia in the harmonisation of such datasets on an EU wide scale.

Such difficulties are obviously recognised already by many organisations inside Member States, and actions are being taken to ensure that the multipurpose use of such datasets is maximised. Indeed, much of the continuous improvement in the data quality used for the CAP applications (better pixel size, better geometric quality, use of colour imagery) is due to either the shared cost or the fully commercialised production of the data. Member States which have a very developed GI commercial sector, with clear GI and geodetic framework policies, have generally made the most progress in achieving sustainable technical targets.

It is worth noting that – for this dataset at least – this situation has in fact been achieved with only enabling legislation, acting as the "*pump primer*", and without a major obligation to meet specific technical goals linked to the means of achieving the implementation requirements. The most successful examples of the implementation are in Member States where the GI user community has presented a sufficient critical mass to ensure that the product is timely, cost effective and meets a range of requirements.

Conclusions

The CAP is a current major user and producer of raster and vector datasets. Some data are continuous (DEMs, orthophotos), some discontinuous (crop boundary data). The current legislation requires a strong integration of these datasets using GIS technology: consequently, the potential uses of the orthophoto data are multiple, across a range of applications.

The user requirements of the orthophotos are clearly defined within the context of the CAP, and to a general extent are embodied in regulatory requirements. Nevertheless, a large degree of harmonisation across the EU is lacking, and future grid system application specifications should consider both the relevance of these datasets, as well as any modifications to their technical characteristics.

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[2] EC, (2000) Council Regulation (EC) No 1593/2000 of 17 July 2000 amending Regulation (EEC) No 3508/92 establishing an integrated administration and control system for certain Community aid schemes, Official Journal of the European Communities, L 182 , 21/07/2000 P. 0004 - 0007

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Aggregation and disaggregation of statistics

Erik Sommer

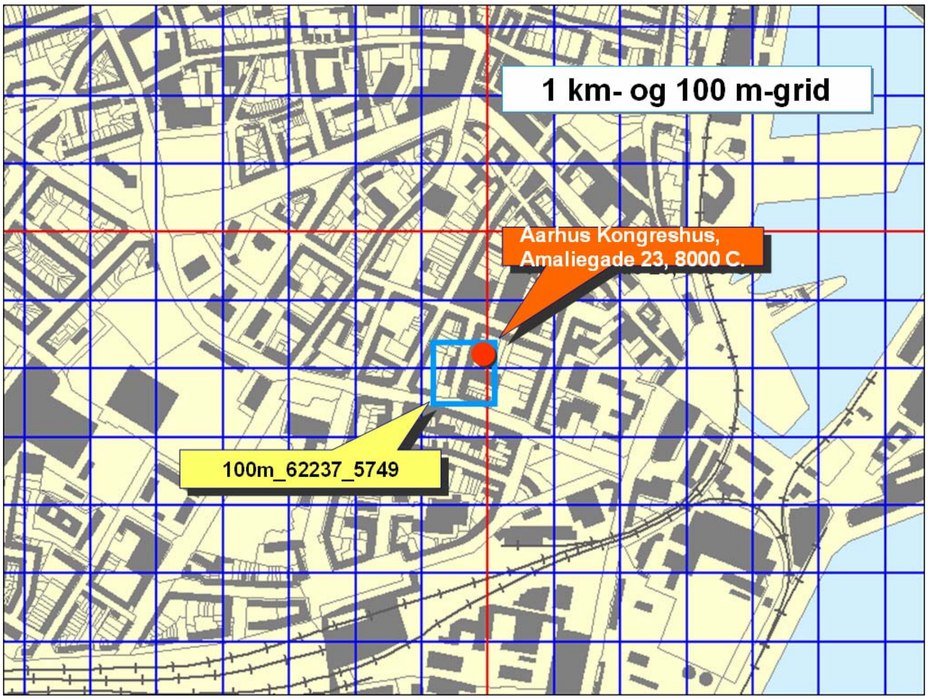
Summary: This paper presents the work with statistical griddata in Denmark and an introduction to the work with griddata in a Nordic context.

Griddata from Denmark

Establishment of the Danish Square Grid

Kort & Matrikelstyrelsen – KMS (the National Survey and Cadastre) and Statistics Denmark have in 2001 established a national system of vector grids, the so-called "National Square Grid – Denmark". The National Square Grid – Denmark is constructed in a rectangular system of coordinates, but it has been decided that it should refer to the UTM projection, zone 32. The datum used is EUREF89.

Figure 1 - National Square Grid - Denmark

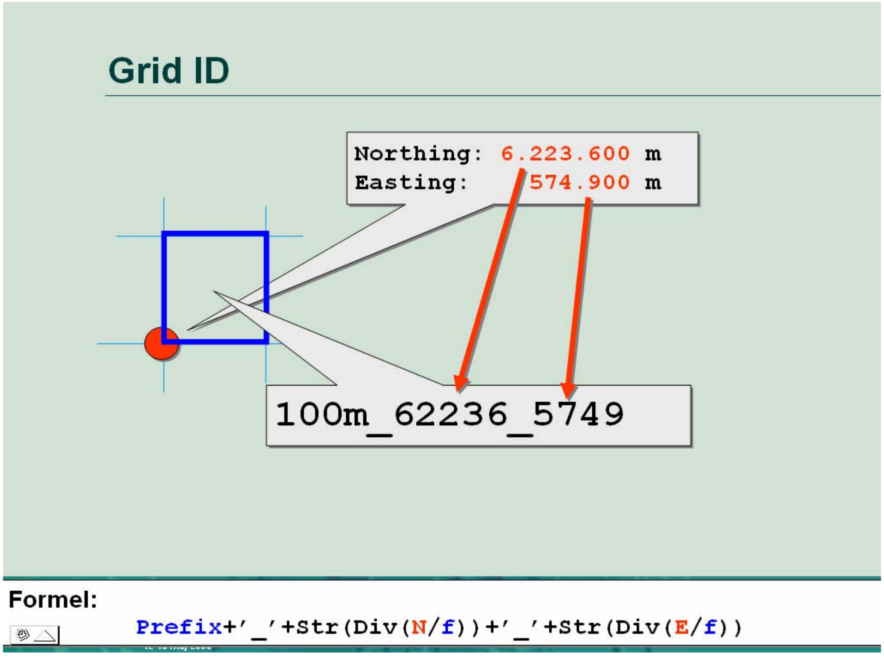


A hierarchy of square grids is constructed. Each quadratic cells constitutes a geographic region; and all addresses (BAK calculated addresses or OIS corrected addresses) within the region concerned, are linked to the cell – such a transformation can be formulated in tabular form.

Any dataset to which a geographic reference is attached, can subsequently be linked to the square grid by assigning a subset of cells to the objects or items in the dataset. Different datasets can then be aggregated and used in various spatial analyses.

Every cell is defined and given its name from the Lower Left coordinates.

Figure 2 - Grid ID for each square grid – using left lower coordinate



Uses – requirements and possibilities

Cells are static over time (as opposed to traditional domains of analyses) and they are not dependent on any predetermined division or regionalisation when the data are collected. The greatest advantage of accessibility to the square grid is that different datasets, irrespective of the distributors, can be aggregated and used in a spatial analysis of a given issue. To solve the problems of discretion, as data that may not be presented on the level of individuals can be aggregated or summed up within neighbouring cells in lieu of administrative references, such as postal code, municipality code, etc.

In relation to the current administrative divisions, a square grid structure is far more detailed. Even the detail of a relatively rough square grid is greater in relation to e.g. counties, and will make it possible to access data compilations of regional differences within the individual county. The square grids are constructed as basic grids of 100x100 metres, but alternative grids are also constructed e.g. city grids of 250x250m cells and regional grids of 1kmx1km grids.

Table 1 - Danish National Grid (5 grid sizes)

Size	Name/Net	Grid ID	Name of Cell	Colour[40]
100 km	Survey Grid	KN100kmDK	100km_61_7	Grey
10 km	Place name grid	KN10kmDK	10km_618_70	Green
1 km	Basic net	KN1kmDK	1km_6188_709	Red
250 m	250 meter grid	KN250mDK	250m_618875_70925	Orange
100 m	Hectare grid	KN100mDK	100m_61886_7091	Blue

[40] See examples in figure 1

Address data contains information about the administrative level (municipality), the streetcode, housenumber (entrance) and zipcode. Each single address with a x,y coordinate representing the main building on a parcel is linked to the square grid (here 100x100 meter and 1x1 km).

Table 2 - Address data (using calculated address material from www.kms.dk)

Address ID	Municipality-code	Street-code	House-number	Zip-code	Kn100mDK	Kn1kmDK
1810012001_	181	0012	001_	2840	100m_61907_7175	1km_6190_717
1810012001A	181	0012	001A	2840	100m_61907_7175	1km_6190_717
1810012003_	181	0012	003_	2840	100m_61907_7175	1km_6190_717
1810012010_	181	0012	010_	2840	100m_61907_7176	1km_6190_717
1810012011_	181	0012	011_	2840	100m_61908_7175	1km_6190_717
1810012015_	181	0012	015_	2840	100m_61908_7175	1km_6190_717
1810032003_	181	0032	003_	2840	100m_61909_7175	1km_6190_717

Recommended discretionary requirements

The work on Information Bearing Cells is subjected to Statistics Denmark's discretionary requirements. There must be a sufficient number of households in the combined cells until statistical data can be released. For example, key figures (average figures) are released when there is at least 20 households in an area or in a cell.

Table 3 - Discretionary requirements (Statistics Denmark)

Number of households (clusters)	*Data from Statistics Denmark*
1-19 households	No data
20-49 households	Key Figures
50-99 households	Few intervals
100-149 households	More intervals
150+ households	Statistical datasystem

Statistics Denmark releases a dataset with the number of persons and households on 100 x 100m cells, which form the basis for the work performed by the data user in combining the cells.

Table 4 - Building block of households and persons (population)

Grid ID	*Municipality*	*Households*	*Population*
61901_7126	207	1	6
61902_7126	207	3	8
61903_7126	207	12	26
61904_7126	207	3	7
61905_7126	207	3	8
61909_7126	207	5	10
61910_7126	207	3	6

Clustering

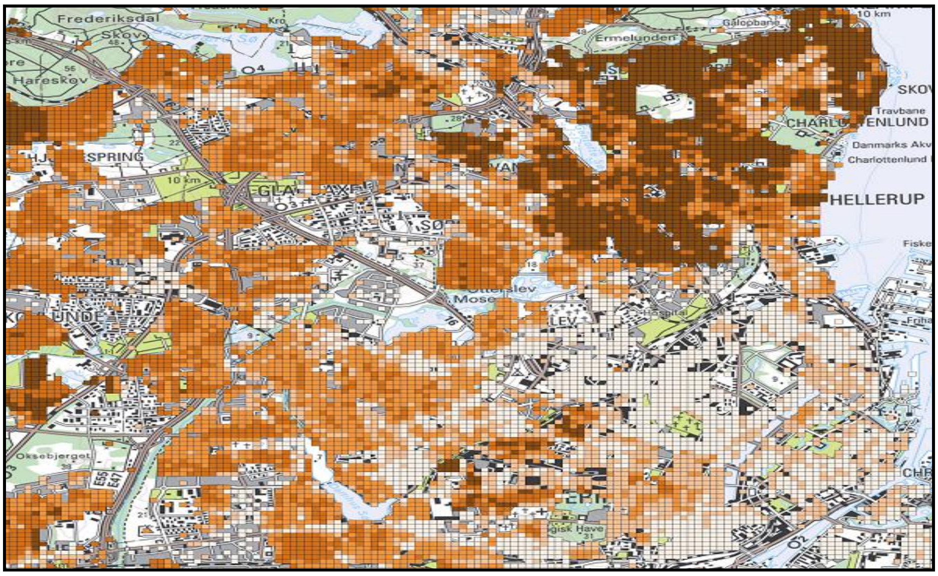
If there is not a sufficient number of households in the cell and a process of smoothing or aggregated values for cells are not applied, the cells must be combined into clusters. Overview of distribution of households in Denmark 100x100 meter Grid (1st January 2003) is listed here:

Table 5 - Distribution of households, 100x100 m 1st January 2003, Denmark (using calculated address material from www.kms.dk)

Level	Households intervals	No. Cells	% Cells	No.Households	% Households
0	0	107581		0	
1	1-19	385544	95,64%	1328931	54,55%
2	20-49	10625	2,64%	319342	13,11%
3	50-99	4126	1,02%	289163	11,87%
4	100-149	1451	0,36%	175537	7,21%
5	150-399	1287	0,32%	273017	11,21%
6	400+	89	0,02%	50051	2,05%
	TOTAL (with households)	403122	100,00%	2436041	100,00%
	TOTAL (all buildings)	510703		2436041	98,76%
	Denmark 1.1.2003			2466693	100,00%

There are differences in how each individual cluster is generated, partly depending on the hypothesis put forward for the task, the underlying method of registration and partly for reasons of the discretionary requirements. For example, if an analysis of crimes is to be conducted, we want our clusters to consist of neighbouring cells (hypothesis: that crimes are related to specific areas). In the case of a Direct Marketing (DM) campaign, we will make attempts to ensure that our cells are significant with respect to a number of background variables, and this implies that they need not be neighbours. Cluster presentation of households income for part of Copenhagen, Denmark. The darker the colour the higher is the household income level.

Figure 3 - Clusters with household income. www.conzoom.net

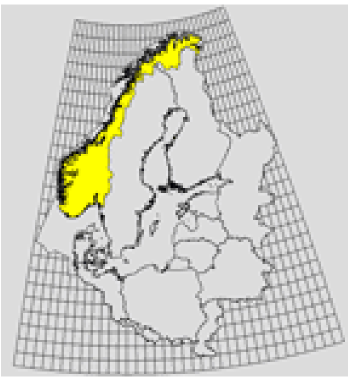


Experiences with square grids in the Nordic countries

Within the EU and more locally in the Nordic countries, attention is focussed on the need to be able to aggregate and present data across frontiers, i.e. across different national bases for registration. Work has been initiated to develop a Nordic cooperation towards establishing a pan-Nordic square grid for joint data compilations and visualisation of data.

A presentation of Grid dataset with consumer market statistical data is made available on the website www.conzoom.net

Figure 4 - Nordic Grid data www.conzoom.net



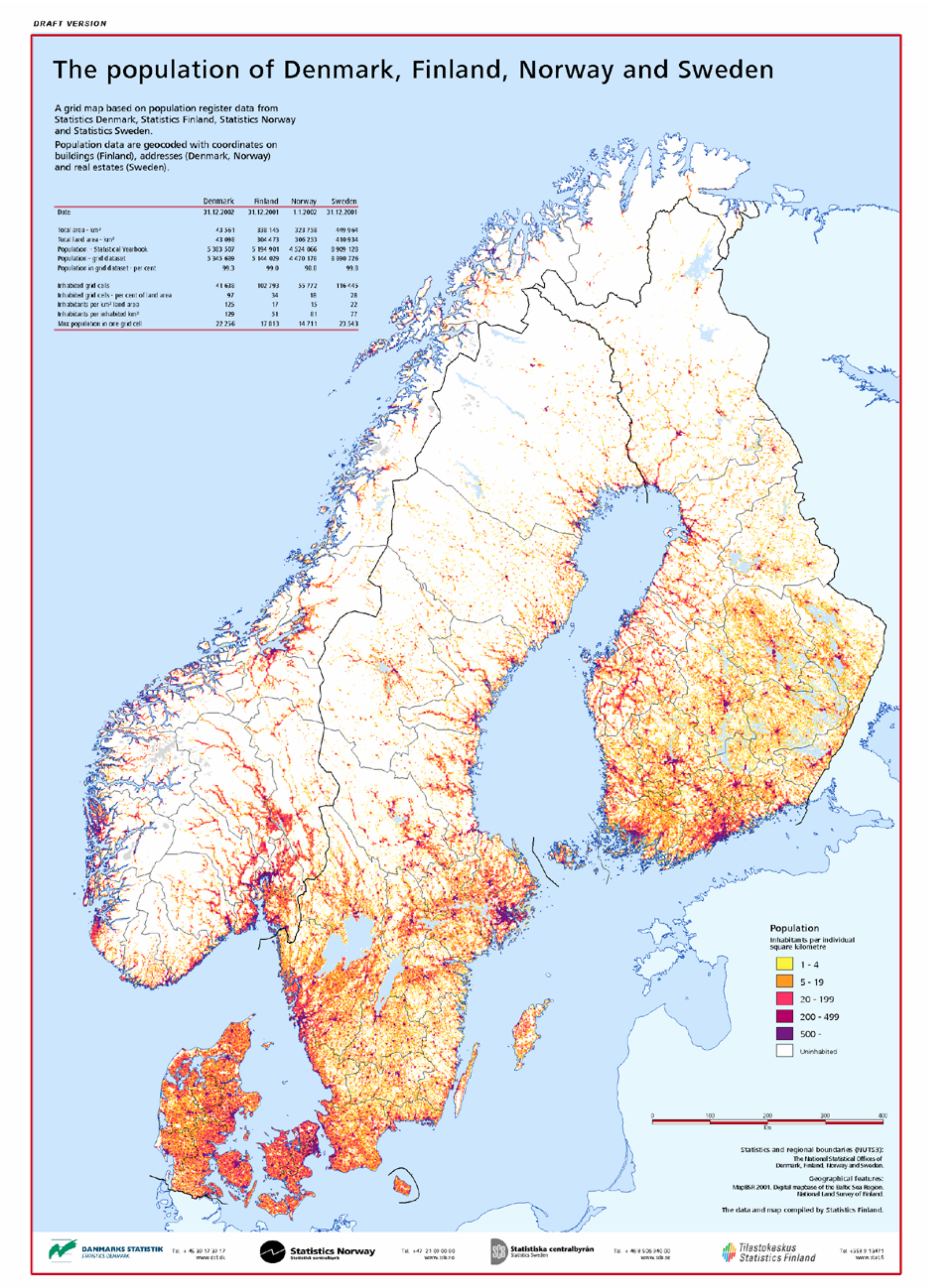
The Nordic Statistical Institutes Working Group for Grid data have in 2002 conducted a questionnaire about the use of grid data in the Nordic Countries. Here is a summary of basic characteristics of grid data in Finland, Denmark, Norway and Sweden.

Table 6 - Basic characteristics of grid data in Finland, Denmark, Norway and Sweden

	Finland	*Denmark*	*Norway*	*Sweden*
Georeferences of input data	Centroid of building, Address points, Area codes	Centroid of building, Address points	Address points	The object is real estate; coordinate point is building or median point for building
Ownership	SF: input data for statistical purposes; Output data: statistics by grids, gridnet+data or/and data with geocodes	Statistic Denmark: statistical data; National Cadastre and Survey: grid net		SCB and LMW (National Land Survey) through an agreement
Contact in NSI	Matja Tammilehto-Luode, Seija Oorni	Erik Sommer	Lars Rogstadt, Gjerdmund Nygardseter	Jette Bodin
Data distributors	one, more to come (negotiations pending)	several		several
Variables	Population by age, sex, income, education… Labour force by industry.. Households by structure, income.. Buildings by size, type, age, .. "Census data"	Statistics on persons, Families and households Labour force Households by structure, income.. Buildings by size, type, age, .. "Census data"	Population by sex and age; spec. on request	Population by age, sex, income, education… "Nighttime" labour force by industry.. Families Real estate data
Size of the grids	125 m, 250m, 500m,1km, 5km, 10km	100 m, 250m, 1km, 10km, 100km; 100m and 1km used for statistics	1km for country; 100m for the four largest cities; 250x250m for some counties	100 m, 250m, 500m, 1km
Reference years	1970, 1980, 1985, 1987-2001	1981-2002 (stats) 2001 (addresses)	2000, 2002	1996-2002

A grid map based on population register data from Statistics Denmark, Statistics Finland, Statistics Norway and Statistics Sweden has been published. Population data are geocoded with coordinates on buildings (Finland), addresses (Denmark, Norway) and real estate (Sweden).

Figure 5 - Population of the Nordic Countries 1x1 km grid



European Aspects

Internationally, several initiatives have been taken, which aim at setting up guidelines for how to conduct the collection of data in order to enable data comparability among countries e.g. the LUCAS project (Land Use/Cover Area frame statistical Survey). Where the attention of LUCAS is focussed on a sample design, there is also a general interest in the underlying issue of formulating standards for presenting data in a comparable manner. The ISO (the International Organization for Standardization) is in the process of preparing a standard for handling 'gridded data' (the standard will become part of the standard family ISO 19100).

Future Work

A number of things have to be considered if we want to further develop the use of grid data especially if we want to increase the integration between existing grids for regions across national boundaries.

- What type of addresses can be used?
- How do we get common access to statistical data?
- Disclosure policy?
- Pricing policy?
- Dissemination of data?
- How do we cooperate with the National Mapping Agencies
- How do we cooperate with private partners (value added data providers)?

In cooperation with the statistical agencies in the Nordic Countries (Denmark, Norway, Sweden and Finland) are we working together in the Nordic Grid Task Group in order to make a joint Nordic Grid Map and integrating statistical data.

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[1] The establishment of a Danish National Grid hierarchy, National Survey and Cadastre, Denmark, 2001 (*www.kms.dk*).

[2] The establishment of a Danish National Grid hierarchy. The Nordic GIS Conference in Helsinki, Finland 8th-10th October, 2001. Erik Sommer, Statistics Denmark and Hans Ravnkjær Larsen, National Survey and Cadastre Denmark.

[3] The National Square Grid – Denmark (Specification), National Survey and Cadastre, Denmark, may 2002 (*www.kms.dk*).

Related Danish web-sites

- *Address project*: www.adresseprojekt.dk (general information)
- *Conzoom*: www.conzoom.net (Internet testbed Nordic grid data)
- *National Cadastre & Survey*: www.kms.dk (calculated address coordinates)
- *Public Information Server*: www.ois.dk (public access to address coordinates)
- *Statistics Denmark*: www.dst.dk and www.dst.dk/kvadratnet

In search of an infrastructure for spatial analysis

Lars H. Backer

Summary: In our contribution we would like to discuss the special requirements of a system of grids from a user perspective, represented by spatial analysts working with statistics. At the 9th EC GI&GIS Workshop41, we expressed the need for a clear awareness of "real" user needs in terms of spatial data. We suggested that inductive methods are needed that will reveal the need for both descriptive and analytic information for the design and implementation of central overriding projects like spatial development. In current efforts to provide a effective SDI for Europe (as in the case of INSPIRE), we stressed the need for standard infrastructures suitable for spatial analysis.

Much analytical work in this and related areas are based on information collected as points. In some cases however, data are collected as aggregations to a give set of small areas (irregular tessellations), that in turn may be analysed as clusters of (gravity-) points. For analytical purposes, irregular tessellations of this type are too large to be presented as surfaces, and are therefore generally represented as point clusters. A common system of grids for Europe represents therefore the main infrastructure needed for (point-based) spatial analysis. Its definition will therefore involve a series of design choices that should be based on the role they play in these users' production processes (e.g.: data capture, data cleaning and pre-processing, analysis, integration with other data and dissemination.) Grids are widely used in all connections where point- based data are used as raw material for spatial-analysis.

We would like to suggest that the question of a system of grids suitable for spatial analysis could be discussed from a broader perspective (in frames larger than 1000x1000km?) or a narrower, limited perspective (involving frames smaller that 1000x1000km?).

In the narrow perspective we should focus on a system of what I would call a system of Discrete Local Grids. Here we should discuss the issue in view of the traditional perspective where the earth's surface is transformed into a subset of the Cartesian plane using map projections. From this point of view we need to express our needs in terms of vital questions as: a projection system (a Gauss Krueger projection?), a coordinate system (alphanumeric 7 digit system?), a primary hierarchy of discrete grids for most scales (equal area square grids etc. (powers of 10)), a secondary quadtree system to fit with the primary system (division by powers of 2?), a standard for grid denotation (based on the coordinates of the lower left corner?), a standard for a coding the grid system (through truncation?).

In a broad perspective we talk about a system of what I would call a system of Discrete Global Grids. This perspective is needed when discussing analysis's that cover very large portions of the earth's surface We should here discuss the need for data (infra-)structures which more closely retain the topology of the earths surface, made possible by recent general availability of great computing power needed for the type of data required. This also involves a series of design choices that should be discussed (e.g. the base platonic solid, its orientation, planar subdivision of the face of the earth).

Introduction

"Knowledge in the form of an informational commodity indispensable to productive power is already, and will continue to be a major, perhaps the major stake in the world-wide competition for power. It is conceivable that the nation-states will one day fight for control over information, just as they battled in the past for control over territory, and afterwards for the of access to and exploitation of raw materials and cheap labour. A new field opened for industrial and commercial strategies on one hand and political and military strategies on the other". (Lyotard 1979) The Post-modern Condition: A Report on Knowledge

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[41] Please see (Backer 2003) *On ESDI and Geo-Statistics*

The purpose of this paper is to discuss issues related to the need for a European infrastructure for geo-statistics. Most people would believe that this implies the need for a further development of the systems of administrative areas generally used in statistical reports. This however is not the case. The paper tries to argue that there is a strong case for liberating statistics from the straightjacket of administrative areas. This change has come about in consequence of the emergence of what wee now call “the informational society” and the need to describe man-environmental systems as “interacting wholes” (in terms of relations and processes) rather than “kits of parts” preferred by planners of the industrial area. The need to describe and analyse societies as wholes recognises the fact that countries, regions and cities are not trees, or rather; they <u>cannot be described in treelike hierarchies of regions</u>. This principle implies that every problem has its own geography. Some geographies overlap, others do not.

User needs for geo-statistics

“The proof of the apple is in the eating” they say, and so it must also be with geographical information from a practical point of view. In this sense there seems to exist, two major markets for information in our societies; the private sector and the public sector. Although both need to be served with information to counter threats and exploit opportunities, they represent two overriding projects that are very different. In this paper we have considered the needs for geographical information from a public sector point of view, not only because we represent a public sector institution (Statistics Sweden) but also because the public sector is by far the dominating producer and consumer of geographical information in our society.

Day- and night-time populations

Although much statistics are produced to describe and analyse physical (real) structures (described with areas) fixed in space. These, including relatively fixed administrative borders, are becoming relatively less important compared to the need for statistics on non-physical (virtual) socio-cultural and economic <u>networks</u>. From this perspective it is realised that most human activities in the informational society are best related to building coordinates, street addresses or the like that may effectively be treaded as nodes in both virtual and real systems. This allows us to study both real and virtual networks in a spatial context.

In the following, we would like to show how, parallel to traditional accounting-type statistics featuring statistics aggregated to administrative areas there has long existed another parallel trend of studies that focused on the need to describe and analyse the total man-environmental system to serve operational needs. The relation between these two perspectives represents the key to understanding also post-industrial societies. There seems to be a general agreement that we need effective indicators to assess Pressure, state and impact of driving forces on natural systems. However, in order to grasp the whole picture we must design a method that integrates descriptions of the environment with equally effective models to describe and analyse the socio- economic system. The socio-economic system in turn may be seen as a relation between a socio-cultural aspects related to the night-time population and economic aspects related to the day-time population.

Serving agrarian and industrial societies

So, if we consider the use of geographical information over time we might get a clue to the demand for spatial information through history. In a series of example we hope to show that there has been a standing demand for geo-graphical information to describe the relationship between the distribution of the population and the dominating means of production:

1. <u>In the agrarian period</u>.
   The relationship between the distribution of the population and the availability of arable land
2. <u>In the industrial period</u>.
   The distribution of the population and information to the continued improvement of agriculture but now with an emphasis on industrial production.

During this entire period right up to the present all development projects where aimed at the improvement of means of productions that where inseparable from the territory. It comes as no surprise that this period represented also the period for the rise of the nation state.

Example 1: Population distribution on arable land in Sweden 1830

In the agrarian period most of the population lived on and off the land. It will hardly surprise anybody that from this point of view, the focus will be on the land and its yields. The richer the land the greater the population it can sustain. In a period that is primarily dependent on manual labour, there is a direct relationship between the population patterns and the fertility of the land. The responsibility for producing and distributing these two types of information was given to the Swedish land survey around 1650, and the responsibility for statistics to Statistics Sweden one hundred years later.

From the seventeenth century onwards it therefore became essential to make inventories (maps) of natural resources on the one hand and counting and mapping the spatial distribution of the population on the other. From c. 1750 onwards it became possible to estimate (count) the population and describe its spatial distribution based on census data. Most emerging and established nations of the 16th to 19th centuries seem however to have been reluctant to produce data on the size and structure of the population in general, but perhaps especially information describing their spatial distribution. This was partly due to the fact that the idea of compiling reliable data of this kind was quite difficult. But more importantly, this kind of information was for natural reasons regarded as strategically important and therefore confidential.

Figure 1 - The distribution of the population in Sweden in the mid 1830'ies

This section of the so-called “Lovén map” shows a very early illustration of the population in Sweden according to the 1838 “tabulations”[42] This map may be seen as an early example of using isarithm map techniques to describe population distributions[43]. The darker the red colour the higher population density.

[42] This “Kakarta öfver Folkmängdens Läge och Täthet inom Sverige”is among the very oldest maps in the world showing the distribution of a country’s population. This map was shown in Oxford and Paris at the time together with economic geography maps produced by crown prince Carl who was very interested in economical geography. See (Öberg and Springfeldt 1991) *Befolkningen*

[43] This map was at its time shown at exhibitions in Oxford and Paris.

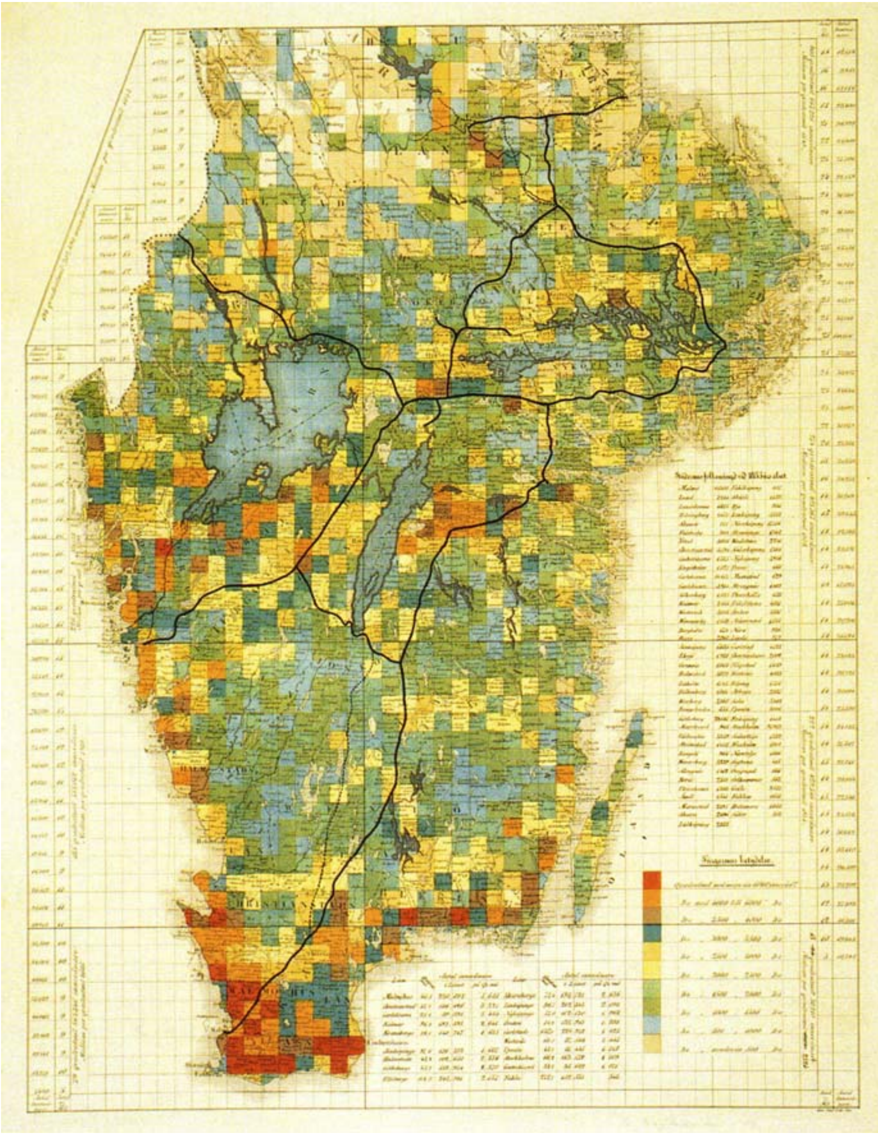
Example 2: Population distribution and the planned railroad network 1856.

Now, with the increasing industrialisation process and the emergence of the industrial period, we see a new economic system emerging that does not suppress the agrarian society but rather adds a new dimension. The new society may therefore be described as (the agrarian society + the industrial society)

Industrialisation in Sweden came late and to a great extent due to expanding markets in Europe for wood and iron. During the first half of the nineteenth century it became evident also to the Swedish public, that industrialisation was the key to progress and prosperity. To develop a country became less a question of improving the land (although still very important), but rather to build key transportation infrastructures to connect the emerging industrial clusters with the national and international markets.

Figure 2 shows a map produced to serve as a support for deciding on trajectories for a main railroad network. Here the network is optimised primarily to serve the predominantly agrarian population here aggregated to 10km grids, (this is probably the oldest known grid map).

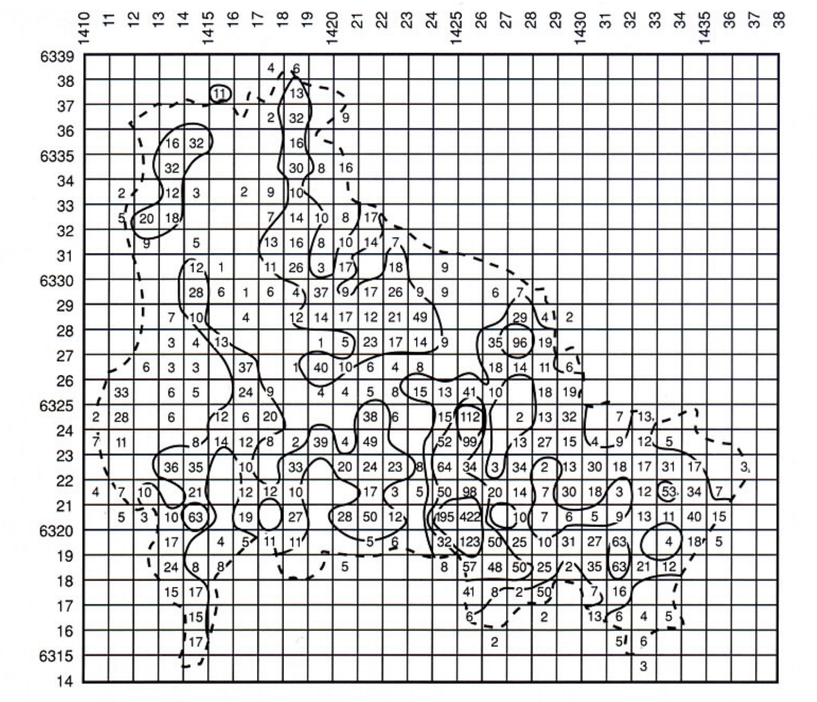
Figure 2 - The population of Sweden on 10x10km (one old Swedish mile)-grid (1856)



Example 3: Population distribution and welfare services in Sweden 1940.

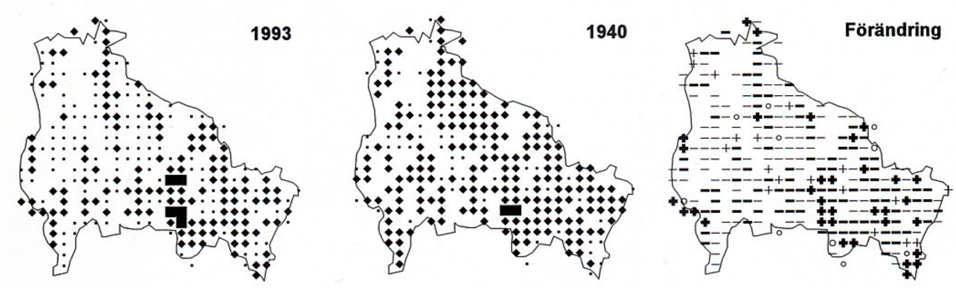
The culmination of the industrial period also represented the culmination of the success of the "Swedish model". This was brought about largely as a consequence of a no-strike in exchange of full employment agreement between industry and labour organisations[44]. This and other developments led to an expansion of the welfare state and the need for public services dimensioned and located according to settlement patterns. Figure 3 is taken from a now classic paper by Torsten Hägerstrand who tried to draw an isarithm based on census statistics (1940) aggregated to km grids.

Figure 3 - Hägerstrand's[45] study of settlement patterns in Moheda commune (1940 data)



A similar study of the same commune (Moheda) in 1993 reveals a substantial flight from agriculture clusters to central areas offering jobs in industry or even the emerging service sector directly dependent on efficient transportation infrastructures (Figure 4).

Figure 4 - The distribution of the population in Moheda commune between 1940 and 1993[46]



[44] See the Saltsjöbaden agreement 1938. (Hall 1998) *27. The Social Democratic Utopia; Stockholm 1945-1980*

[45] See (Hägerstrand 1955) *Statistiska primäuppgifter, flygkartering och 'dataprocessing' -maskiner. ett kombineringsprojekt*

[46] See (Hallén 1995) *Om lärdomsspån och skördetid*

The informational[47] society; a new situation

At the end of the 1970ies it became evident that the rationalisation potential offered by the use of machines in the production, the distribution of goods and services, was nearly spent. This meant that no substantial rationalisations could be made through improvements to physical infrastructures. Instead the emphasis shifted away from machines to focus on the importance of knowledge and effective value chains. From being “man power” employees became interesting for their ability to learn and adapt quicker than machines. This coincided with the digital revolution and opened new rationalisation opportunities by constantly improving products and production processes through information systems.

In this new situation the focus was again shifted from the old industrial clusters processing matter and energy to new enterprises specialised in the processing of information and knowledge.

The emergence of the informational society also coincided with global awareness of our dependence on, of the natural environment. This awareness is also directly connected to the importance of systems theory, in the sense that it forced us to consider all systems from two perspectives:

1. As “kits of parts”
   This perspective was greatly preferred during the industrial period and is still dominating our belief that complex systems may be explained in terms of their parts.
2. As “interacting wholes”
   This perspective admits the dominating importance of the relations in systems and suggests that we consider all complex systems as processes (as for instance the DPSIR method).

Sustainable development (two projects)

The scientific method, according to applied science, is not a quest for truth but an effort to produce utility. The proof of utility is its success on a market. We have two major markets for geographical information; the private market and the public. Here the public sector in countries is at the same time the largest user and producer of geographic information. On a very general level the current Swedish government is probably not a unique in the sense that it has termed “Sustainable development” as the overriding objective for all policy areas. If the quest for sustainable development is defined as efforts to defend and develop our welfare without diminishing the prospects for future generations, then we have to serve two projects simultaneously.

1. Defend and develop ecology[48] based systems (the Environment)
2. Defend and develop economy[49] based systems (the Socio-economic system)

A double sided DPSIR method

The European NMAs (National Mapping Agencies) and NSIs (National Statistical Institutes) are all in the business of providing qualified information to serve actions and monitor effects of political initiatives to this end. In practice this may be described with the DPSIR method preferred by the environmentalists. Business, industry and the whole socio-economic system are described as Driving forces that produce Pressures that affects the State of the Environment. The impact of the driving forces must then be assessed to trigger an appropriate Response from society.

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[47] I use the word “informational” rather than “information” society deliberately to stress the idea that all societies have been information societies, but the current use of the term refers to the new situation where information generation, processing and transmission has become the fundamental source of productivity and power.. This difference is stressed by Manuel Castells in (Castells 1989) *The Informational City, Information Technology, Economic Restructuring, and the Urban-Regional Process.* (the introduction)

[48] Eco-logy (Study of habitat) 1873, coined by Ger. zoologist Ernst Haeckel (1834-1919) as Okologie, from Gk. oikos "house, dwelling place, habitation" (see villa) + -logia "study of." Ecosystem is from 1935.

[49] Eco-nomy (Household management))c.1530, "household management," from L. oeconomia, from Gk. oikonomia "household management," from oikonomos "manager, steward," from oikos "house" (cognate with L. vicus "district," vicinus "near;" O.E. wic "dwelling, village;" see villa) + nomos "managing," from nemein "manage." The sense of "manage the resources of a country" (short for political economy) is from 1651.

This however is only half the picture, the same Driving forces that produce Pressure on the Environmental system may (or not) produce a positive Pressure on the Socio-economic system. Similarly a natural disaster like the 2005 tsunami in South East Asia has put a severe pressure on the socio-economic system in the area. In this and other comparable cases it has been argued that it would have been very advantageous to have an effective reference system with both environmental and socio-economical data to support relief actions.

"Space of place" & "Space of flows"

This development leads to concentrations of key businesses and industries along a highly structured physical and virtual network of communication channels that Manuel Castells[50]suggest we call the space of flows that spans the world. Linked to this network we find knowledge businesses and highly specialised "downstream" industrial- manufacturing and retailing clusters. In the masks of this network we find the space of place where people live mixed with the remnants of agricultural clusters primarily serving local markets. According to this theory we seem to get a split economy. One part of which thrives in the space of place and the other in the space of flows.

1. Information related to the locally connected business and industry clusters in a "Space of place"
2. Information related to the globally connected business and industry clusters in a "Space of flows"

The development of our welfare in a highly competitive world is, according to these and similar theories, directly dependent on our ability to compete with and within highly specialised clusters connected to international production processes accessible through the space of flows.

The success of regional and national policies to this end is therefore dependent on our ability to produce qualified information to analyse geographical, cultural, organisational and technological nearness of potential local actors to their competitors on global markets.

Example 5: Mapping nearness

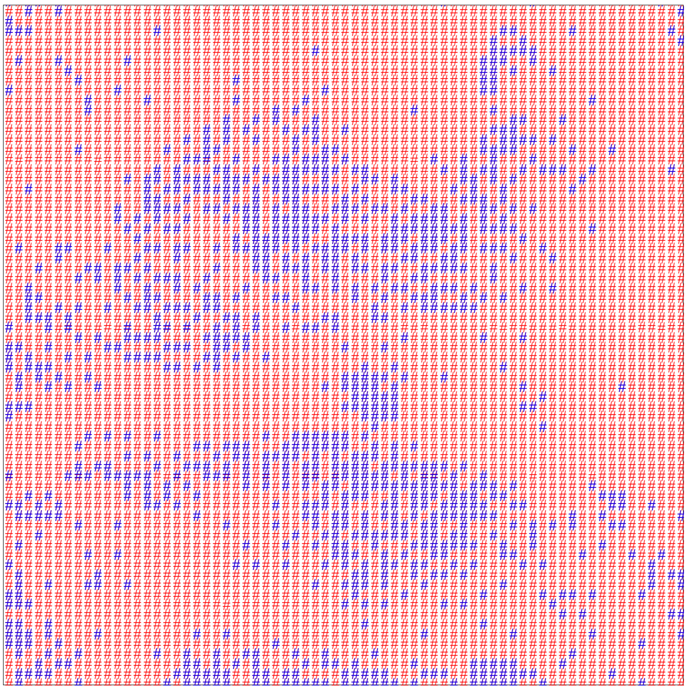
When the economy is considered as a network of processes, it soon becomes apparent that they form very complex networks (clusters) that in some instances span the globe through Castells "space of flows". The growth of a regional economy is therefore not only dependent on the emergence of isolated businesses and industries, but that they find their places in new or existing clusters. According to cluster experts like Storper, nearness between single actors within clusters and between clusters has become the decisive criteria for success[51]:

- Geographical nearness
- Cultural nearness (not mentioned by Storper)
- Organisational nearness
- Technological nearness

Acting from the nearness theory, we have tried to develop methods to describe local conditions for the emergence of new, and survival of old clusters as "opportunity fields"[52] In the example below we have aggregated the daytime and night-time population statistics to 100m grids. As the grids are relatively small (equal to 1/100 of the frame side) we use the gravity points our analysis. To suppress the interpolation methods offered by the krieging methods, we have here added points where we have no observations[53]. These points have a population = 0 ("zero") and are coloured red. All others with larger values are coloured blue.

[50] Se (Castells 1996) *The Rise of the Network Society*
[51] See (Storper 1998) *The Regional World: Territorial development in a global economy*
[52] For a discussion on nearness and spatial analysis see (Backer 2003) *2(3): Functional Regions and Opportunity Fields_II: Clusters of Nodes*
[53] This is due to the fact that the dataset used is a total register with information on all real estate units. In situations where the dataset is not complete we might enter a "naught" to activate interpolation tools. See (Backer 2003) *Tandem II: WP 5: The Swedish contribution*

Figure 5 - A 10km frame showing Stockholm centre with data aggregations to 100m grids



By using a krieging method on this dataset we may then draw an isarithm as a simple example of a spatial analysis. As an indication of possible results from data on day-time and night-time populations please consider the three figures below. The scales on the right show densities in persons per hectare.

Figure 6 - The night-time population in the centre of Stockholm (data for 2000)

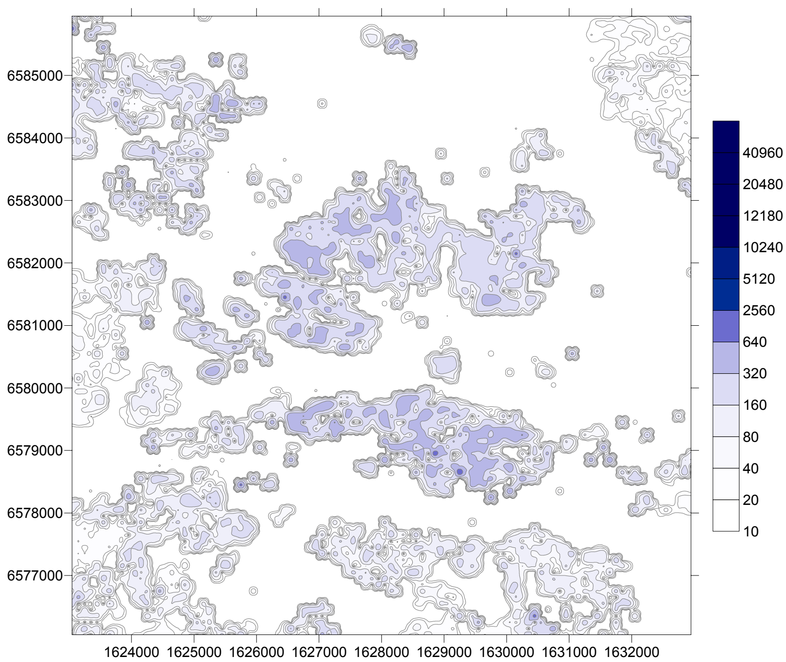


Figure 7 - The day-time population in Stockholm (data for 2000)

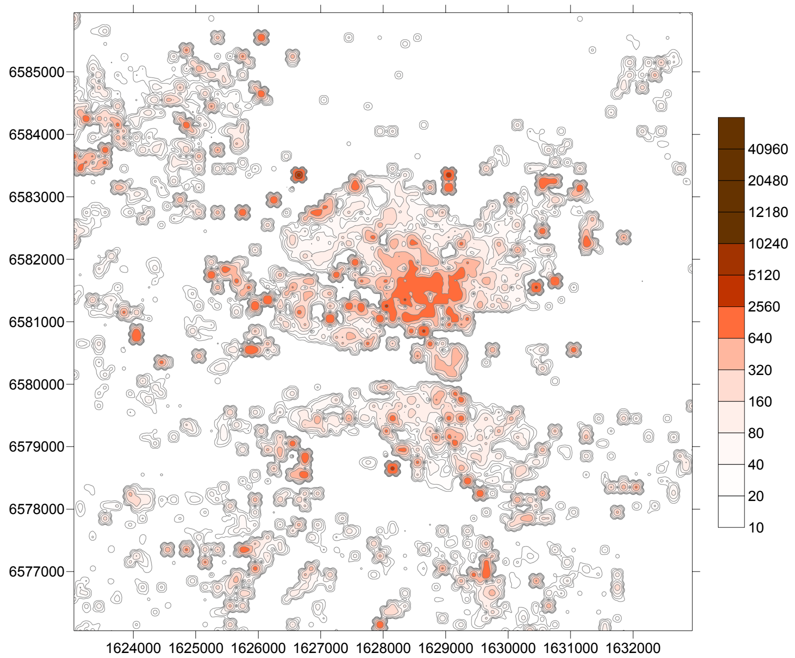
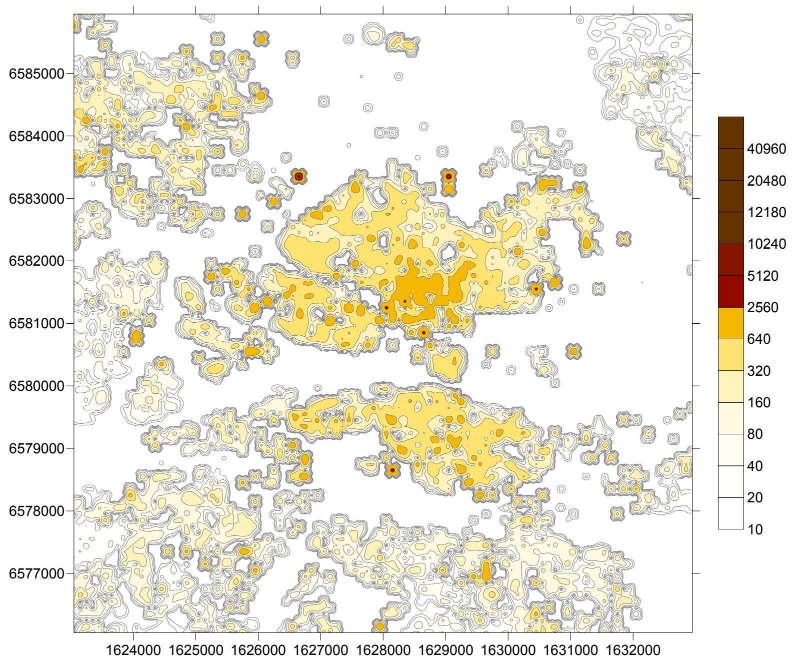


Figure 8 - The sum of daytime and night-time populations in Stockholm (data for 2000)



These two datasets may then over further steps be analysed to reveal the state of the socio-economic system according to key social and economic indicators.

A “Spatial Data Infrastructure”

The term “Spatial Data Infrastructure” is the key to all arguments in this paper. We will therefore have to agree on what we mean by this very central concept. It seems practical to start by splitting the term in two sub-concepts “Spatial data” (with focus on the contents) and “Infrastructure”(with emphasis on the form).

The word *data* is of course the plural of Latin *datum,* “something given,” Data is defined by Roget’s as “That which is known about a specific subject or situation: fact (used in plural), information, intelligence, knowledge, lore[54]. Most people would agree that we should differ between facts and knowledge. For information to become knowledge it should incorporate the relationships between ideas. In this perspective data is used to denote a wide collection of facts in different formats (alfa-numeric data, pictures, maps etc. [55]). “Spatial data” then relate to a selection of data that fulfils the criterion of being spatial. We talk about the spatial and temporal distribution of phenomena and seem to mean data with reference to its spatial extent, especially the four basic dimensions of our world. “Spatial data” is closely related to maps as conventions for the representation of spatial phenomena on a plane surface. We use spatial data for many purposes, according to a variety of user needs. We frequently refer to spatial data and maps in the descriptive sense (e.g. topographical maps, cadastral maps etc.). Spatial data in the analytical sense are spatial databases produced for the analysis of patterns in spatial distributions (e.g. studies different aspects of the spatial distribution of populations, the consequences of natural disasters etc.).

The word “*infrastructure*” is more difficult. *Infra* is easy as it comes from the Latin meaning below, beneath, underlying, within. The use of Structure however is very complex. Its primary usage is connected to permanent structures as buildings, transport systems that do not change very fast. It has also a more abstract use as something having a definite fixed pattern of organisation of more or less distinctive independent elements. One talks about “the interrelation of parts as dominated by the general character of the whole” (see the discussion on economic-, social- and cultural-structures below).

We shall not try to formulate a final definition of “Spatial data infrastructure” but suggest that it refers to a combination of data (facts, information) and a generally hidden and relatively permanent (infra-) structure.

The INSPIRE initiative seems to treat the concept “spatial data infrastructure” without reference to these, two important inherent shades of meaning and seems to make a clear separation between spatial data, and spatial data infra-structures.. From our perspective this leads to a bias towards topographical information and misses a proper reference to infrastructures needed for spatial analysis.

A system of small area statistics

INSPIRE is primarily designed to build a data infrastructure for environmental purposes. According to the DPSIR method generally referred to by environmentalists, data should be captured, stored and analysed on the highest possible resolution. If not individual coordinates are possible then socio-economic data could be captured and aggregated to address, house coordinates or real estate unit gravity points. In cases where census is used for data capture, this system should be based on a harmonised system of small areas not larger than the average census area. This should contain not much more than 250 persons or a similar amount of employees in urban situations. The area of the basic unit should not vary too much over the whole territory so that it can be used to analyse other phenomena as well.

Strictly speaking all aggregation units may be described and analysed in terms of either periphery or their centre of gravity. This gives us two main “paths” to spatial analysis; point and area based methods.

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[54] See (Houghton Mifflin Company 1995) *Roget’s II: The New Thesaurus* at http://www.bartleby.com

[55] These systems are generally terms of hierarchical semantic networks. The Encyclopaedia Britannica is an ambitious effort to describe all human knowledge in terms of a hierarchical system of concepts. “Spatial” relationships provides knowledge about spatial patterns of distributions (e.g. maps, pictures), “Temporal” relationships gives knowledge about “processes” developing over time (e.g. musical compositions).

For spatial analysis purposes however, the single spatial unit is generally far too small (in relation to the "frame" used) to be rendered in terms of its periphery. If we accept the 1/100 rule then we should stick to point based methods. In addition, currently suggested area-based methods are far too slow and impractical. If this argument holds then we may draw the conclusion that point based methods are preferable for most types of spatial analysis. The consequence is that we need of a European system of grids that may be used across all EU, National, Regional and local levels.

It seems evident that it is incomparably cheaper to define a system of small statistical areas that are represented by one gravity point than producing a seamless tessellation of small areas on the same scale. In most cases there is little use of such boundaries for spatial analysis. Also, a well defined border represents a confidentiality risk at high resolutions and should therefore be avoided in other than data capture situations.

Methods (an infrastructure for spatial analysis)

In an early paper on Spatial analysis Openshaw[56] mentions eight basic spatial analysis procedures:

1. Data simplifiers
2. Edge detectors
3. Pattern spotters and testers
4. Fuzzy pattern analysis
5. Relationships seekers and provers
6. Automatic response modellers
7. Spatial video analysis
8. Visualisation enhancers

The order of the items in this list does not correspond to the original. We have suggested an organisation that reflects the common value chain developing a product (or service) from data capture to the finished product.

If we use the DPSIR method as a reference then it seems clear that the joint NSI / NMA responsibility here will be to assess system Pressures (through monitoring), measure system States (through indicators) and help to judge the Impact of both natural and man-made Driving forces (Analysis) in order to design appropriate Responses. Now, spatial analysis has to be performed on data with sufficient resolution to discover its "patterns". Depending on the scale, it is very seldom possible to do spatial analysis on aggregated areas used for reporting (e.g. the NUTS system). For this purpose we need a system of regular and irregular tessellations.

A point based system infrastructure for spatial analysis

The activities that represent the core for all socio-cultural and economic activities in human societies are naturally related to human beings during their daytime and night-time activities. With the emergence of the informational society socio-cultural and economic patterns have become constantly more dependent on dynamic processes and less connected to fixed points in space/time.

This calls for an infrastructure for spatial analysis that is liberated from topographical features. We need a system of discrete grids.

A hierarchy of grid systems

If we study the problem of designing a traditional system of equal area grids based on the idea of transforming the earths surface into a subset of a Cartesian plane using map projections, we seem to meet an upper limit when the territories observed are in the scale of 1000x1000km or larger.

If we want to describe larger areas, then we are probably forced to consider another type of high resolution grid systems which more closely retain the topology of the earth's surface[57]. Here we

[56] See (Openshaw 1991) *Developing appropriate spatial analysis methods for GIS*

have a border situation where we should be discussing Discrete Global Grid Systems to describe and analyse global datasets.

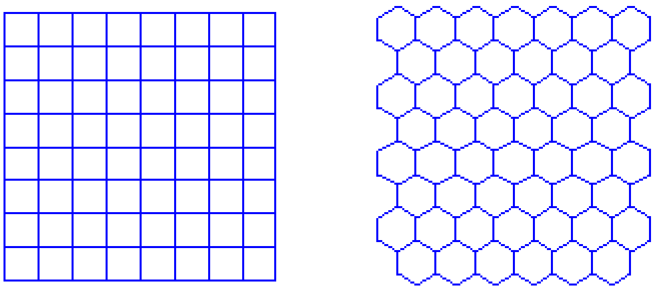
Below this limit, we generally talk about Discrete Local Grid Systems like the United States National Grid[58]. We assume that within the framework of the current project we are primarily concerned with a system of Discrete Local Grids. Local grid systems however, may generally only be used for limited portions of the EU territory. We may therefore e have to assume that we, at least for datasets covering the whole of the Union's territory should consider the use of a combination of a Discrete Global Grid Systems and a discrete Local grid system unless we decide for a UTM solution.

Below the realm of Discrete Local Grid systems we might also argue that there exists another lower limit where the use of projections does not make sense any more. We meet this limit when analysing data in frames in the scale of 1 by 1km[59]. Below this level, as for instance in building and construction projects, we will rely on drawing produced with Cartesian coordinates.

A Tiling method

We generally assume that the standard square grid tiling system is the only solution. This however is not obvious for many writers emphasizing the advantages offered by hexagonal tiling systems.

Figure 9 - Tiling methods



A list of criteria

It would be very practical to have a list of criteria that could be used to discuss global as well as local grid systems. Perhaps it could be useful to ask our peers on the subject to explain whether the "Godchild Criteria" list of rules below (the list was designed for discussing Discrete Global Grid Systems), also may serve for the design of a multipurpose Local grid System.

Here one version of these rules[60]:

1. *Areal cells constitute a complete tiling of the globe, exhaustively covering the globe without overlapping.*

2. *Areal cells have equal areas. This minimizes the confounding effects of area in analysis, and provides equal probabilities for sampling designs.*

3. *Areal cells have the same topology. Ideally, this means that every cell has the same number of edges and vertices. This may not apply to grids whose cell boundaries are some arbitrary curve.*

[57] For a presentation of this topic please see the Discrete Global Grids Project on the web or individual papers on the topic like (Sahr and White 1998) *Discrete Global Grid Systems*
[58] See (Standards Working Group 2001) *United States National Grid*
[59] This idea is not based on empirical evidence it is purely intuitive.
[60] Please see this paper at the website (Sahr, White, and Kimerling 1997) *A Proposed Criteria for Evaluating Discrete Global Grids; A Draft Technical Report*

4. *Areal cells are the same shape. Exactly what this means is highly dependant on the nature of the specific grid. In the ideal case, each cell would be a spherical polygon, with edges consisting of great circle arcs of lengths corresponding to those of every other cell.*

5. *Areal cells are compact. Since a single vector of values is going to be associated with all the points in a single areal cell, we would tend to prefer that the actual values of all the points in the cell be as much alike as possible. Maximal compactness insures that the points in a cell are as close to each other as possible, thus taking advantage of the first law of geography, which states that the closer points are in space the more likely they are to be alike.*

6. *Edges of cells are straight in some projection. Again, this assumes that the concept of edges has meaning for a particular grid (ie., that the cell boundaries are not some arbitrary curve). This criteria ensures the existence of a relatively convenient space for describing, visualizing, and working with the grid cells.*

7. *The edge between any two adjacent cells is a perpendicular bisector of the great circle arc connecting the centers of those two cells. This criterion has proven useful in calculating transport between cells using finite differences.*

8. *The points and areal cells of the various resolution grids which constitute the grid system form a hierarchy which displays a high degree of regularity. The precise nature of the regularity will be highly dependant upon the grids which constitute the system, but regularity should enable activities such as efficient computer implementation of the grid system and multi-resolution analysis using the grid system.*

9. *A single areal cell contains only one point, i.e., each point lies in a different areal cell.*

10. *Points are maximally central within areal cells. In conjunction with the last criteria, this optimally supports the common practice of using the point grid as an approximation to the area grid.*

11. *Points are equidistant from their neighbours.*

12. *The points and areal cells display regularities and other properties which allow them to be addressed in an efficient manner. The grid system should provide an addressing system which supports efficient algorithms for common grid operations like determining cell and point neighbours, determining grid distances, moving between grid resolutions, etc.*

13. *The grid system has a simple relationship to the traditional latitude-longitude graticule. Since for the indefinite future most data will be geo-referenced using the latitude-longitude graticule, efficient ways of transferring data to and from this system will be required. As in the case of the planar rectilinear grid, this is a practical consideration that, while perhaps almost arbitrary from a mathematical viewpoint, cannot be ignored in the short term.*

14. *The grid system contains grids of arbitrary resolution.*

15. *The n grid points are arranged so that the maximum distance from any point on the sphere to the nearest grid point is minimal.*

16. *Each areal cell is the Voronoi cell of the enclosed point(s).*

A hierarchy of frames (windows)

Scales have an important function as part of a quality declaration, where it is interesting to understand the sources of the data. If the digital map is digitised from a 1:50 000 paper map this information is important for the user. The idea of scales is, at least for the non specialist, quite problematic when displayed on a computer monitor

We would therefore suggest that we discuss maps suitable for certain fixed size frames or windows that are practical for different purposes. In the scheme described below we have divided the hierarchy into two parts.

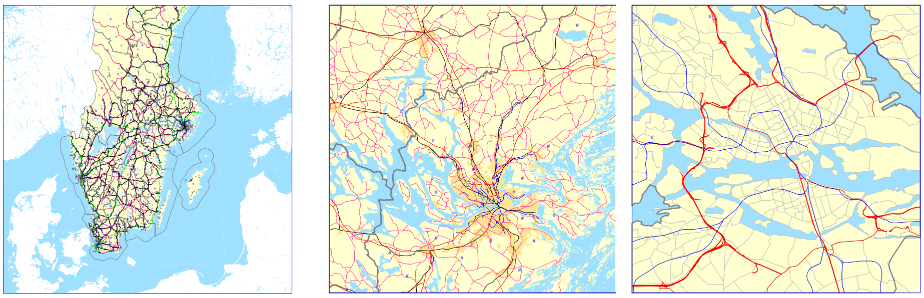
Scale	Frame size	Grid size
10^1	Frame:10mx10m Houses	depicting object in the scale of min 10cm to max 1m. Collapsing point 10cm (use 10cm grids)
10^2	Frame: 100mx100m Urban Blocks	depicting object in the scale of min 1m to max 10m Collapsing point 1m (use 1m grids)
10^3	Frame: 1000mx1000m Urban Neighbourhoods	depicting object in the scale of min 10m to max 100m Collapsing point 10m (use 10m grids)

The upper section of the hierarchy is generally used for activities related to architecture and urban design. Planning activities on this scale provides the foundation for activities on larger scales. Objects are generally depicted as points as they are too small to be defined in terms of polygons.

Scale	Frame size	Grid size
10^4	Frame: 10 km Large Urban districts to small Urban system	depicting object in the scale of min 100m to max 1000m (1km) Collapsing point 100m (use 100m grids)
10^5	Frame: 100 km Large Urban system to small national Region	depicting object in the scale of min 1km to max 10km Collapsing point 1km (use 1km grids)
10^6	Frame: 1000 km International Region	depicting object in the scale of min 1km to max 10km) Collapsing point 10km (use 10km grids)

The upper section of this hierarchy constitutes the backbone for all key spatial planning activities. These will generally depend on the high resolution data aggregated from lower levels.

Figure 10 - The 3 major scales suggested for the discussion of development issues in the intermediate realm

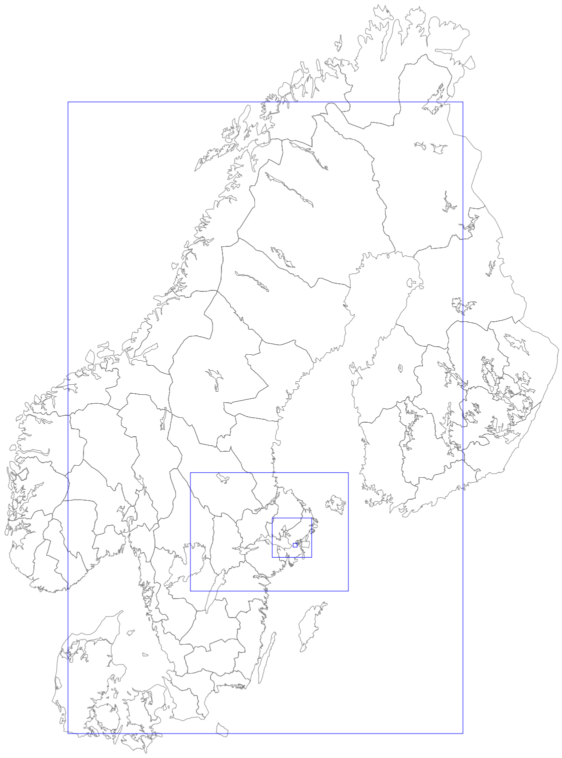


1000kmx100km frame | 100kmx100km frame | 10kmx10km frame

The frame delineates a collection of grids that are used for spatial analysis. The smallest frame recommended will be in the scale of 100 times the grid size in both directions[61]. It is important that the grid system admits professional work on all these levels as they coincide with existing and traditional practice.

[61] This is a consequence of the 100 by 100 rule. For a discussion here please see (Backer 2003) *Tandem II: WP 5: The Swedish contribution*

Figure 11 - The use of standard frame sizes on the Nordic region



The size of these frames does not have to be square but should be suited to users needs within the hierarchy of planning systems that is used within and between member nations.

Proposal

In all types of planning systems one talks about the need for information on different levels of resolution. Experience has shown that this is practically illustrated on the idea of a hierarchy of <u>frames</u>.

1. Frames for a system of Discrete Global grids
   - 10000 km frames (for1000 km grids) (The scale of *international regions*)
     The critical resolution of the objects used for analysis ca 100km
2. Frames for a system of Discrete Local Grids
   - 1000 km frames (for 100km grids) (The scale of *national regions*)
     (The scale of national regions) The critical resolution of the objects used for analysis ca 10km
   - 100 km frames (for 10km grids)
     (The scale of smaller towns or large urban districts) The critical resolution of the objects used for analysis ca 1km
   - 10 km frames (for 100m grids)
     (The scale of urban neighbourhoods) The critical resolution of the objects used for analysis ca 100m
3. Frames for a systems of Cartesian Grids
   - 1 km frames (for 10m grids)
     (The scale of urban blocks) The critical resolution of the objects used for analysis ca 10m
   - 100 m frames for 1m grids)
     (The scale of individual houses or house groups) The critical resolution of the objects used for analysis ca 1m
   - Etc.

A system of primary grids

In order to delineate clusters of things in these frames we have made the experience that the grids should on the average be spaced at distances of about framesize/100. Thus the grid size(resolution) needed for mapping in a 100km frame would have to be in the scale of 1km (or smaller), and the scale of objects to be clustered in a 10km frame be about 100m (or smaller). This would result in the use of a standard series of grids and frames;

- smaller (both grids and frames by powers of 10)
- 1m Grids for the 100m frame
- 10m Grids for the 1km frame
- 100m Grids for the 10km frame
- 1km Grids for the 100km frame
- 10km Grids for the 1000km frame
- 100km Grids for the 10000km frame
- and larger (both by powers of 10)

We assume that no larger frames than these are practical due to the limitations imposed by the UTM system[62].

A system of secondary grids (nestlings: a quadtree solution)

Further we suggest that a standard would have to contain a solution to the construction of quadtree cell structures. We believe here that the "frame" hierarchy suggested above reduces the need for a very "deep" solution. For most standard purposes a simple series of three (3) cell split tings will suffice.

1. A first division 100km gridsize/2
   (10km/2, 1km/2, 100m/2 etc.) = 50km grid (5km, 500m, 50m etc.)

2. A second division 100km gridsize/4
   (10km/4, 1km/4, 100m/4 etc.) =25km grid (2,5km, 250m, 25m)

3. A third division 100km gridsize/8
   (10km/8, 1km/8, 100m/8 etc.) =12,5km grid (1,25km, 125m, 12,5m)

The third division comes very close to the next level of grids (100km/10= 10km etc.) will probably become too small to be rendered effectively as an area in this frame.

In figure 12, the quadtree structure is used to map grids with population densities in the Stockholm region. The primary grid is divided by a power of two measuring equal to or below a given threshold. This gives a treelike structure. Although very few natural systems have treelike structures this method may be used for a quick analysis of simple patterns[63].For this 100km frame we have used a 1km grid according to the 1/100 rule. For a three level quadtree we get 500m grids for the first division, 250m grids in the second division, and 125m grids in the third division.

[62] Each UTM sector is relatively narrow (15 degrees) and allows for no grid system with larger grids than those discussed here.
[63] For a discussion of the limitations to use treelike structures in the planning and development of urban systems see (Alexander 1965) *A City is not a Tree*, 1965) *A City is not a Tree. Part 2.*

Figure 12 - Use of quadtree structure to discover data patterns within a 100x100km frame

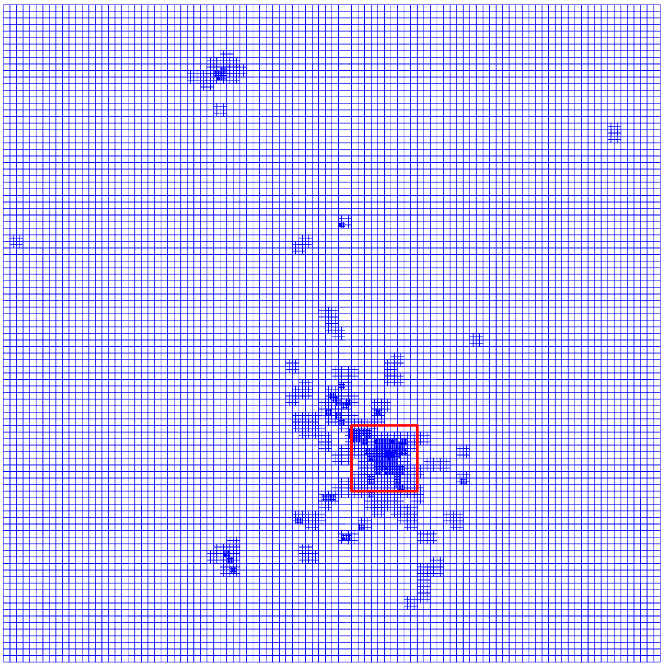
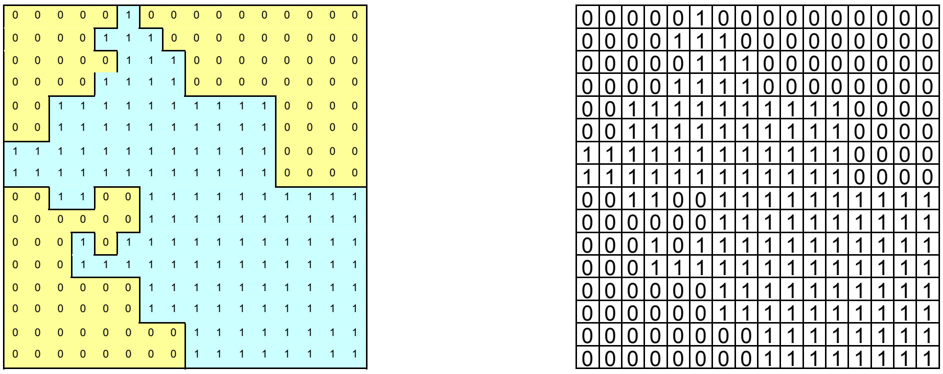
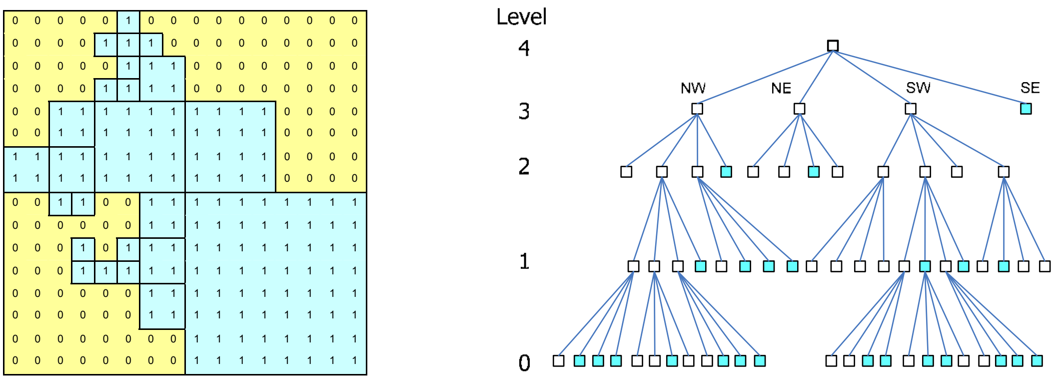


Figure 13 - Nestlings within a tiling of squares[64]



(a) A region such as a field or a forest

(b) A binary image of the region



[64] See (Catrell 1991) *Concepts of GIS and Geographical data*

A coordinate system (graticule)

The use of a graticule on maps should generally consist of a overlay of the latitude longitude grid generally using decimal fractions of degrees. This would give a pair of coordinates in float format. A pure metric system would suggest the use of an integer solution. This could use 7 or 8 digits to get down to a precision of 1m (7 digits) or 1 decimetre (8 digits) depending on the resolution needed. For most geo-statistical purposes 1m (7 digits) accuracy will suffice.

A set of standard projection(s)

If we are looking for a projection system well suited for the presentation of equal area grids, it seems that we have not so many choices, especially if it is important that the EUROGRID system should be compatible to grid systems used elsewhere. A Gauss Krueger projection might be a strong candidate here, but the issue should be decided after hearing expert advice. The main problem here is to decide on a standard projection for storing regular geographical features as grids, as they become distorted when translated into another projection.

However, in the case where point based geo-statistics is used, data are generally stored in alpha-numeric databases with their x,y,z coordinates. In this case the projection system is of no importance.

A Coding System

The coding system is very important for most calculations related to the use of grids. The problem is not so much connected to the calculation of areas etc. as these functions are processed by efficient computers. The problems seem to be closely connected to our ability to visualise important aspects as the size and/or position of a grid from the code that is assign to it for identification[65].

A standard coding system from grid coordinates

The construction of a grid structure is dependent of a series of issues related to mapping that, will have to be specified in a standard on the issue.

1. The first issues are related to the problem of the projection to be used in the system. Here we need a solution that renders the system of regular tessellations regular over the whole surface studied. One solution here is the UTM family of projections that in turn limits the scale to frame sizes below 10000km

2. The next issue is the question of coordinate system. Here it is important that we in both directions use false southing or false easting that will allow for a system of e.g. 7 digits to get down to 1m accuracy[66].

3. Further we assume that in the case of a square grid system we will need a system of codes that reflects the size and position of an individual grid cell. For this purpose it is practical to use the coordinates for the lower left corner. In a 7 digit system (having the coordinates for this corner 1234567,1234567) we could construct a code to denote the identity size and position of a single 100m grid by reducing the last two digits to get the coordinates for the lower left corner (1234500,1234500) and give it an integer or text id code (1234512345). The centre of this hypothetical cell would have the coordinates [(12345+Gridsize/2), (12345+gridsize/2)].

This type of coding system is ideal for the construction of a regular system of grids. For each row a grid can be generated from the digits presented in the code using standard GIS methods.

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[65] Please see (Tammilehto-Luode, Backer, and Rogstad 2000) *Grid data and area delimitation by definition towards a better European territorial statistical system* for a discussion on the construction of a code system along such lines.

[66] This is generally achieved with false easting and false northing when using UTM projections.

A system of discrete local grids for Europe

When doing spatial analysis using point based statistics with resolutions below the bifurcation or collapsing point that may be comparable across national borders an extended system of grids are needed that are suited for this purpose. A rudimental framework for a grid structure of this type should consist of:

1. A hierarchy of systems
   Here we believe that it is not possible to design one system that will scale from the very small to the very large.
    a. A Global system of discrete Grids
    b. A Local system of discrete grids
    c. A Cartesian system of discrete grids

2. A Tiling system
   This should contain conclusive information on the tiling system, and how the tiles are related to the coordinate system.
    a. Square tiling (primary)
    b. Hexagonal tiling (secondary)

3. Grid structure
   A suitable grid structure for instance generated from the coordinates of the lower left corner. This system should be suitable for easy generation of grids by reducing digits to 0 in both dimensions.
    a. Hierarchy of Perspectives (Frames)
        i. One global Frame (the European level)
        ii. Three local Frames (National, Regional and Local)
        iii. One sub-local Frame
    b. Hierarchy of primary grids
       A suitable hierarchy of grid sizes that are practical for most general purposes. For the purposes discussed in this paper this would require a series of main grid sizes with sides in the power of 10m (10^{-1}, 10^{0},10^{1}, 10^{2}, 10^{3} etc).
    c. Hierarchy of secondary grids (Quadtree structure)
       For each level a quadtree hierarchy would be needed that divides the “main” grid into powers of 2 (2^{1},2^{2},2^{3},etc.). For most purposes a system of 4 levels would suffice.

4. Projection system (standard projections)
   A suitable Gauss Krueger projection, (UTM or similar) that renders grids as same size, regular polygons also when comparing distant locations.

5. A coordinate system
   A suitable coordinate system that if possible offers a standard number of digits for both x and y coordinates. (This is generally accomplished using a system of false easting and northing in a Gauss Krueger projection to achieve a standard size of the coordinates in both directions) The coordinate system should preferably be an integer with 7 or 8 digits in both directions. The symmetry is important.

6. Coding system
   A coding system should be based on a integer based gradicule describing the coordinates of the lower left corner of a grid. To denote a 1mx1m grid would then require a code with 14 digits (2x7), a 100mx100m grid would require 10 digits (2x5) etc. For the quadtree system (the secondary grids) an additional digit would be required to suggest its depth.

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The modifiable areal unit problem in the context of a standard grid

Javier Gallego

Summary: Data associated to territorial units, such as socio-economic, demographic or epidemiological data, can lead to different conclusions if the territorial units change. For example the correlation between variables often increases when data are aggregated to larger units. Transforming data from an areal system to a different one often involves two steps: disaggregation into small units and re-aggregation. Disaggregation is always possible, but generally introduces a considerable inaccuracy. The quality of disaggregation depends above all on the quality of covariables used to guide the attribution of values to different units. If no covariables can be used, simple areal weighting is possible, but this option is not recommended in general.

Keywords: Modifiable areal units, data disaggregation, downscaling

The modifiable areal unit problem

The modifiable areal unit problem (MAUP) can be defined as the effect of the selection of areal units on the analysis of geographical data, or in other words "the set of phenomena arising from the imposition of artificial units of spatial reporting on continuous geographical phenomenon resulting in the generation of artificial spatial patterns" (Heywood, 1998). More specifically,

Openshaw and Alvanides (1999) warn that GIS users need to consider how the zones of analysis affect results. If relations between variables change with the selection of different areal units, results maybe unreliable.

Most socioeconomic or epidemiologic data are meaningless referred to a single point. They must be linked to a certain geographic area to be meaningful; we can mention for example population migration data or the percentage of population with a certain characteristic. Such areas are often administrative units: communes, regions, countries, etc. In the jargon of the European Commission (EC), standard administrative units are called NUTS (in French: Nomenclature des Unités Territoriales Statistiques), but for some applications it could be advantageous to use units defined with a geophysical criterion or simply cells of a grid with regular shape.

MAUP effects may be due to different scales of data: results or conclusions become unstable when the size of zones used changes. For example land cover data or landscape indicators obtained by measuring polygons or counting pixels in a land cover map can change significantly with the scale of the maps (Gallego, 2002).

Scale effects can come from aggregation or disaggregation processes. A typical aggregation effect, already observed in the 1940s is the increase of correlation when the reference units are aggregated (Robinson, 1950).

Results can also change significantly when the system of areal units changes, not necessarily to larger or smaller units, but to units defined with a different criterion. For example using administrative units or river catchments to map data can lead to different pictures of a phenomenon. In general the change from a reference areal system A to a system B can be decomposed into two steps: disaggregation from A to a system C with finer scale and re-aggregation from C to B. The system C must be defined in such a way that any areal unit in A or B can be expressed as different aggregations of (small) units in C.

However there is always a loss of information in such processes, and the result of transferring information from one geographic system to another one can be dramatically wrong (Vidal et al, 2001). Using as "C" a regular grid with a relatively fine resolution can be a practical solution for some types of data, especially data strongly linked to the territory: any large geographical unit can be approximately expressed as a set of cells in C, but accumulating disaggregation and aggregation processes should be avoided as much as possible. On of the basic rules to produce reliable data in different areal systems is stocking the original data at a level as detailed as possible. In many cases detailed data are confidential and can be managed only by a few authorized staff. Therefore it is essential to provide them with user-friendly tools to produce aggregated results for different areal systems.

Notice that the MAUP is linked with grids conceived as tessellations of a geographical area, but have very little relationship with grids of points that can be used for sampling and data collection.

Data disaggregation

The ideal system would stock detailed original data and would aggregate them into different systems according to the needs, but the real situation is often far from ideal: original data may have been lost or their location is not sufficiently precise to allow for aggregation into different areal systems.

Converting data from one areal system to another often has two steps: disaggregation to a finer resolution an re-aggregation into the new system. Re-aggregation is usually a straightforward sum or average (although the effects of re-aggregation are not obvious).

We focus here on the more delicate process of disaggregation (or downscaling). The problem can be stated in this way:

- we have values y_i of a variable Y for the units A_i, $i=1\ldots I$ of an areal system $\mathcal{A}$.
- we want to attribute values y_k to the units Ck, k=1…K of a new system C with smaller units.

If Y is an additive variable, we should have

$$y_i = \sum_{C_k \subset A_i} y_k \ .$$

We try here to discuss different possible situations.

Attribution proportional to area

It may happen that only Y is known, and we do not have any other information suggesting that the density of Y may be not homogeneous inside each unit A_i. In this case one option is attribution proportional to area:

$$y_k = \frac{y_i \times S(C_k)}{S(A_i)}$$

Smoothing techniques can be considered if some type of continuity is a reasonable assumption for the data. A usually requested property is that the smoothing is voume-preserving (Goodchild and Lam, 1980), i.e. that the value y_i estimated by integration of the smoothed surface coincides with the known value.

An example of such technique is the Tobler's pycnophylatic interpolation (Tobler, 1979).

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From National Square Grids to a European Standard- The Nordic Grid Project

Hans Ravnkjær Larsen

Summary: Setting off from the annual meetings in the Nordic Forum for Geo-Statistics a joint project is being initiated to establish a common Nordic Grid, following experiences from the Nordic countries. Whereas many national grid approaches are tried successfully in the whole of Europe, experiences with cross-border grids are sparse. There are, however, huge benefits from international grid solutions. The Nordic Forum for Geo-Statistics therefore suggests that GEOMATIC be pioneer and tender for a Nordic Grid Project. GEOMATIC will be working closely together with the NFGS under supervision from chairman Erik Sommer, Statistics Denmark. The Nordic Grid Project aims to establish a fully operational Nordic community for exchanging ideas, experiences, best practises and even data on a grid basis. The project elements and notions are elaborated in the present paper. Economic funding is crucial. For this reason, The Nordic Forum for GeoStatistics applies for economic funding of the Nordic Grid Project. Any contributions will be welcome.

The Nordic Grid Project at a glance

In this section the Nordic Grid Project (NGP) will be described conceptually, in order to motivate and inspire for further reading.

Motivation

Within the whole of EU, and more locally in the Nordic countries, attention is focussed on the need for facilities in aggregation and presentation of data across frontiers, i.e. across different national bases for registration. Work has been initiated to develop a Nordic cooperation toward establishing a Nordic Square Grid for joint data compilations and visualisations. This work has been fulfilled with focus also on the European level, as to how to meet the future challenges that lie within the collection of commensurable data from all parts of the expanding Union. The need for standardized geostatistics will increase further, especially for areas close to and even crossing national borders.

The notion of a Nordic Grid

For quite some years there has been a desire to set up a system enabling datasets with different origin and in different form, to be aggregated and analysed via some kind of common data structure. Instead of viewing different geodata as they originally appear geographically (form, format, etc.), a common grid should be generated on which data be divided into the grid cells and thus compiled and presented.

Consequently, the cells may be bearers of different information depending on the use and may represent different collections of data in primitive formats. These cells will therefore be named Information Bearing Cells (IBC) for the remains of this paper.

The notion of square grids is simple, the range is immense

The overall advantages with IBC is in brief that they form static, non-administrative and, non-political, but instead universal units that are easily created, maintained and referenced within any geographical area.

Background – the Nordic Grid Project initiative

Every single country within the Nordic Region has established national square grid solutions to some extent and has its own set of specifications.

On the initiative of the Nordic Statistics Agencies an annual ”Nordic Forum for GeoStatistics” meeting is held. The Nordic Forum for GeoStatistics (NFGS) is membered by representatives from Finland, Norway, Sweden and Denmark. The NFGS hosts a working group, the Nordic Grid Task Force (NGTF), that will take active part of the Nordic Grid Project.

Therefore Statistics Denmark and GEOMATIC[67] in cooperation have been asked to initiate the establishment of a Nordic Grid Project, primarily to facilitate a common Nordic framework for IBC.

European aspects

Internationally, several initiatives have been taken which aim at setting up guidelines for how to conduct the collection of data in order to enable data comparability among countries e.g. the LUCAS project (Land Use/Cover Area frame statistical Survey). Where the attention of LUCAS is focussed on a common sample design, there is also a general interest in the underlying issue of formulating standards for presenting data in a comparable manner.

The ISO (the International Organization for Standardization) is in the process of preparing a standard for handling ‘gridded data’ (the standard will become part of the ISO 19100 suite of standards). However, the time before the standard will be implemented in general, will be considerable.

Within the EUROSTAT organisation the subject also has often been debated, but so forth with no specific conventions, iniatives nor actions taken. Also the EUROGI, the European umbrella organisation for users of geographical data, states that a common strategy for all the European countries in such matters will be crucial in the future.

Project scope

The Nordic Grid Project will prove it feasible and highly useful to form common specifications for the establishment and use of square grids and IBC. During the Nordic Grid Project the NFGS will coordinate and encourage the Nordic countries in the joint work towards the fulfilment of the shared/common needs. When the establishment of a Nordic Grid proves to be successful, generalisation towards large-scale European solutions will open for a wide range of applications.

The Nordic Grid Project should be considered adjacent to e.g. the EUROGRID project, NGP being only the first step towards a unified solution for the entire Union.

Status- Fall 2003

Since the NFGS 2003 meeting a complete Nordic Grid has been preliminarily created by GEOMATIC.

Such a common grid framework has for long been wanted/wished for in order to facilitate commensurable statistical areas for visualizing and analyzing of data, the so called Small Area Market Statistics (SAMS) crossing frontiers

The Small Area Market Statistics (SAMS) is now operational in the Nordic Region.

[67] GEOMATIC – Centre for Geomatics is a private vendor that acts as the No. 1 Danish expert on grid based analyses.

With the first common IBC product, “The population of Denmark, Finland, Norway and Sweden”, the Nordic Grid has come closer, and comparable SAMS is proven to be within reach.

Figure 1 - Population of the Nordic Countries based on a common 1 km square grid

Towards international solutions on a larger scale

The objectives of the Nordic Grid Project that will be elaborated and examplified in the following, is to improve the set of tools for aggregation and standardized representation of data that are taken from different environments/countries and, in doing so, to facilitate commensurable analysis and reporting thereof.

Hearings within the Nordic Forum for Geo-Statistics

The phases within the Nordic Grid Project (and what is suggested herein) will seek to examine the specific need from the contributing Nordic countries in order to establish a knowledge base on square grid structures.

A organisational and technical model for what is needed on a Nordic scale will be formulated, leading to a proposal for a website that will house a common Nordic Grid Community. On such a website users will be introduced to the Nordic Grid Project, the Nordic Grid itself, and to the uses of it. When the Nordic Grid Project proves successful, a long-term solution on a European scale should be considered.

Project timeline

At present an exact timeline for the project is not given, but the formulation of the conceptual specifications of the Nordic Grid is anticipated to be ended by winter 2003-2004.

A presentation of the Nordic Grid Project will be given on several occasions, at meetings and conferences, in order to invite for participation and funding:

October 2003	EUROSTAT annual NMA/statistics meeting, Luxembourg
	JRC/Inspire workshop on European Grids, ISPRA\Italy
November 2003	The Nordic GIS conference (GI Norden), Oslo\Norway
March 2004	NFGS annual meeting, Copenhagen\Denmark

By March 2004 technical discussions and clarifications is expected to be concluded and the establishment of the Nordic Grid itself commenced.

The Nordic Grid Project in detail

In this section the partial tasks and objectives within the Nordic Grid Project (NGP) will be elaborated, in order to clarify the how’s and what’s.

The Nordic Grid Project outcomes

In rough, the project phases seek to bring the Nordic Grid community closer together by:

1. Making inquiries to establish a knowledge base within the Nordic countries on what regards the needs for and experiences with square grid structures.
2. Via the feedback from the members of NFGS formulating a model that covers organisational as well as technical aspects, that is the framework for the specifications of the Nordic Grid. At this point the technical requirements will be clarified and debated.

3. Formulating a proposal for a website that will house/accommodate a common Nordic Grid Portal or Community. On such a website users will be introduced to the Nordic Grid Project, the Nordic Grid itself, and to the uses of it.
4. Establishing and launching a Nordic Grid Portal website with whatever support and fundation will be obtainable.
5. Formulating a proposal for the long-term (permanent) solution on a European scale.

For instance, the examination process among the NFGS members concerning common as well as specific needs and requirements will inevitably lead to closer communication and cooperation on related areas. Also, taking up joint initiatives will prove to result in stronger applicable analysis frameworks within the statistics offices of the Nordic Region. GEOMATIC will be the key holder of the project in all technical aspects, referring to the NGTF chairman. GEOMATIC will strongly depend on the support from the NFGS, in what regards formulating and approving the specifications for the Nordic Grid.

The Nordic Grid website – home of the Grid community

The overall objective of launching a Nordic Grid website is to show users, primarily from the Nordic Region, but secondarily from all over the EU, how to cost-effectively benefit from working with grid based SAMS – the so-called IBC. The site will invite users to dialogue, and it shall contribute to the process of clarifying the political and juridical aspects of working with geostatistics cross-border.

On the long run, market forces will ensure for the payoff. The results from Denmark show that the public administration needed 2½ year to define the specifications for a Danish grid framework (The National Square Grid – Denmark, refer to p. 16) where the private market only needed a couple of months to adopt and implement it. Today, one year later, the public as well as the private market all benefit from it.

On behalf of Statistics Denmark, GEOMATIC has developed the non-commercial Internet site www.conzoom.net (in Danish). www.conzoom.net was developed to show the countries how a grid based solution could easily be reached. www.conzoom.net shows different geostatistical datasets – for Denmark based on the National Square Grid (100 × 100 meters) and for Norway and Finland, a prototype of a Nordic Grid (1000 ×1000 meters).

As a service from GEOMATIC, and to show market interest, GEOMATIC offers the www.conzoom.net framework as a starting-point for the Nordic Grid Project. On the NFGS meeting 2003 there was a general consensus that this particular website could form a efficient starting-point for visualising the Nordic Grid Project and show examples of uses of IBC.

The Nordic Grid website should ideally become the home of the society or community of grid based data users from the Nordic Region. As shown in Figure 2 (a preliminary website architechture diagramme), The Nordic Grid website is planned to consist of two separate sites, one being non-commercial as the home of formal Nordic Grid documentation, the other being commercial as the home of grid data merchants, distributors and users.

A central part of the website will be the Nordic Grid data related Who’s who that will enable visitors to locate whatever contact information that may be relevant. Also, the Nordic Grid data themselves will be accessible, either for download or for construction online. Also, the collection of and access to datasets needed on the Nordic Grid website will be crucial.

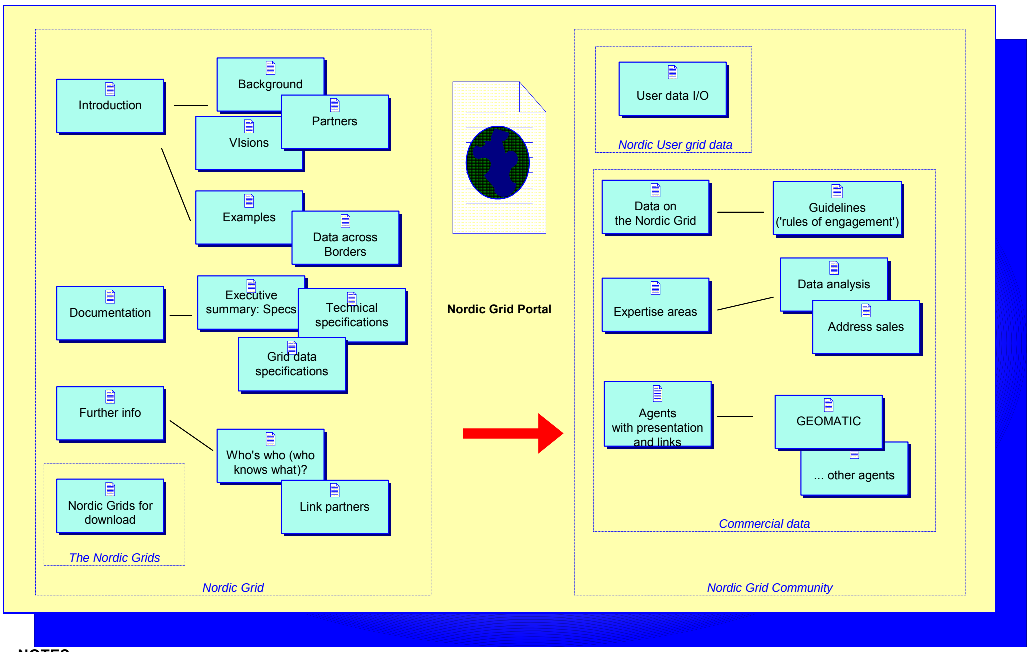
On the non-commercial part of the website there also will be free access to a wide range of grid based statistical and demographical data. Special attention or focus should be given example data from areas close to, or even crossing, national borderlines. For instance example data from the Øresund/Öresund Region, areas on the Norwegian/Swedish and the Swedish/Finnish frontiers would make excellent case studies. In such areas, aspects regarding differences in map projections, data registration methodology or administrative or cadastral conditions inevitably should inspire politicians and decision makers, scientists or others to give notice to the Nordic Region.

On the commercial part of the website distributors like GEOMATIC and others will be given room for presentations of grid based products, links and more. Above all, a collection of best practises will be presented. Furthermore, on this specific part of the website visitors will be given an opportunity to upload and thus share own grid based data; data that will contribute to an improved sharing of data, the basis of knowledge, all over the Nordic Region.

As has been stated above, designing the Nordic Grid website infrastructure is an ongoing process and GEOMATIC will welcome all ideas and contributions whatsoever.

Figure 2 - Preliminary website architecture for the Nordic Grid Community

Nordic Grid Website - preliminary draft 01, hrl



NOTES

1. Whereas the 'Nordic Grid' part of the site is non-commercial and thus meant to present and document the notion and specifications of the Nordic Grid, the 'Nordic Grid Community' contains descriptions of and links to commercial agents on the direct marketing and geoanalysing field.

2. The possibilty for different login profiles (eg. citizens, private agents, NGOs or even governmental institutions) is yet to be considered.

3. Hosting, webmastering and administration is yet to be clarified and discussed.

4. Every partner and agent should be given substantial space on the commercial site to be able to present own products and thus add value to the community.

Budget – economic needs for the Nordic Grid Project

From the present description of the Nordic Grid Project it should be clear that GEOMATIC and the NGTF have commenced the work with great seriousness and of a genuine interest in the large-scale Nordic aspects.

On the other hand, it is evident that GEOMATIC cannot undertake this project, let alone to establish nor run the Nordic Grid website without substantial economic funding. On behalf of the NGTF and NFGS, GEOMATIC therefore will apply for economic funding of any kind to ensure a stable service/enterprise of the Nordic Grid Project.

Any contributors who may be willing to support the project with data, resources, personnel or other are most welcome to make contact with the project partners.

Estimates for the different tasks in connection to the creation and operation of the Nordic Grid website are presented below. The estimated work needed is in general limited due to the fact that GEOMATIC offers to contribute with existing scripting code and more. Furthermore, the hosting of the website is limited.

Costs of development

The costs of developing the website in question will be kept at a minimum. The mathematical methods forming the base of the common square grid methodology are already developed by GEOMATIC, and GEOMATIC will offer the NFGS to use scripts and more free of charge. The cost of developing the website is therefore reduced to the cost of designing the site and building the underlying databases.

Process	Hours	Price per hour (in €)	Total price (in €)
Graphical design of GUI	120	120	14,400
Usability test	30	120	3,600
Database design	30	120	3,600
Data preparation	90	120	10,800
Data import	60	120	7,200
Project Management	50	120	6,000
Total cost of development	380	120	45,600

The budget includes all technical details of developing the website. However, it does not include domain name registration and travel costs which will be added. The need for travelling is expected to be minimum one visit per country for one or two individuals. The budget presented here is based on the assumption that the individual countries deliver data needed free of charge and that each country will allocate a (named) representative available for the project.

Cost of operation

First the site a developed the NFGS needs to have a server running and to have data maintained and updated dynamically. The server is offered to be hosted by GEOMATIC or by a GEOMATIC partner. As long as the server is hosted by GEOMATIC or one of the participating countries, no expenses to cover the server maintenance are expected.

Process	Unit price (in €)	Units	Total price (in €)
Data import per country	1,800	4	7,200
Server operation per month	250	12	3,000
Total operation cost per year			10,200

The budget is based on assumptions identical to the above (development). The budget includes all technical details of operating the website; however, it does not cover annual domain name fee. Furthermore, the budget does not include any possible fee to National Mapping Agencies supporting the website with background map data.

Participation and sponsorship model

So far the estimates given above do not explicitly clarify how a group of project members or financial contributors/sponsors will share the costs and equivalently the benefits. A model is presently considered that operates with differentiated prices as to whether the participation regards all or a certain part of the project.

Nordic Grid Project Partners

Below is a brief description of the different parties within the Nordic Grid Project.

The Nordic Forum for Geo-Statistics

The Nordic Forum for GeoStatistics (NFGS) is a forum for key accounts working with geostatistics in the national agencies for geostatistics. On the formal level the key accounts meet once a year to discuss issues of common interest. The role of chairman and host follow a one year turn. The NFGS meeting 2003 was held in Helsinki in March. The next official meeting will be in Copenhagen in the winter 2004, chaired by Erik Sommer, Statistics Denmark.

The NFGS consists of:

- Danmarks Statistik (www.dst.dk)
- Statistics Finland (www.stat.fi)
- Statistisk sentralbyrå (www.ssb.no)
- Statistiska centralbyrån AB (www.scb.se)

GEOMATIC

GEOMATIC – Centre of Geoinformatics is leading in Denmark in the field of providing addresses, carrying out demographic analyses and geostatistics for the market branch. In co-operation with the Statistics Denmark and Taylor Nelson Sofres (Gallup) GEOMATIC has developed a commercial IBC product called conzoom®, which has been a success for business purpose as well as research and public administration. The National Square Grid – Denmark forms the underlying basic structure of conzoom®. GEOMATIC also supervises the Statistics Denmark in matters concerning geostatistics and cluster techniques. GEOMATIC is an authorised dealer of official statistics and is specialised in SAMS, IBC and cluster techniques.

Danish experiences

As has been stated above, the foundation of the National Square Grid – Denmark was the result of an thorough examination of previous Nordic experiences as well as an investigation of Danish needs and possibilities. In the following sections the technical aspects of the square grid notion will be elaborated, the National Square Grid – Denmark presented in depth and finally a range of successful applications of grid based statistics documented.

In the establishment of the Nordic Grid, experiences that stem from the other Nordic countries will contribute to ensure a genuine Nordic solution that fulfils the requirements from all over the Nordic Region.

The notion of square grids – an immense application range

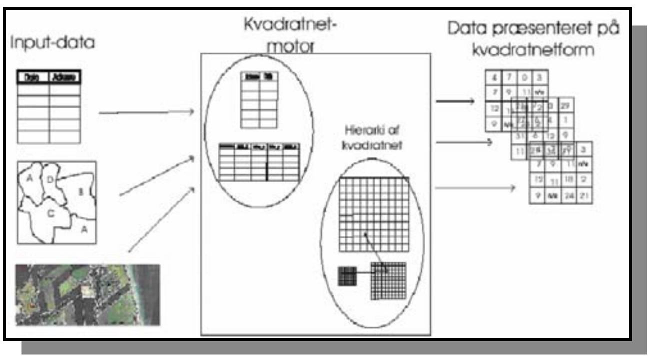
In brief, the process of using square grid cells for Information Bearers is as follows: A square grids is constructed. Each quadratic cell constitutes a geographic region; all addresses or other georeferenced objects within the region concerned are linked to the particular cell in which they belong – such a transformation can be formulated in tabular form.

Any dataset to which a geographic reference is attached, can subsequently be linked to the square grid by assigning a subset of cells to the objects or items in the dataset.

Different datasets can then be aggregated and used in various spatial analyses. Figure 3 illustrates this process.

The elements in grid based SAMS. Even if the principle of discretion differs between countries, the clustering will solve it and the data in the specific cell will therefore still be comparable.

Figure 3 - The grid base notion in brief



The advantages of grid based analyses are in rough the following: Cells are static over time (as opposed to traditional domains of analyses) and they do not depend on any predetermined division or regionalisation when the data are collected. The greatest advantage of accessibility to the square grid is that different datasets, irrespective of the distributors, can be aggregated and used in a spatial analysis of a given issue. Consequently, data can advantageously be compiled in square grids for the following generic ranges of use:

- In data compilations where greater importance is attached to being able to provide differentiated information about minor observation units (e.g. quadratic cells), than to enable comparisons of administrative units (postal district, municipality).
- When changes are made to the administrative divisions, and different data from before and after the changes are to be made comparable.
- When aggregating geodata whose origin differs to such a degree that the different datasets cannot directly be aggregated in their original form.
- To solve the problems of discretion, as data that may not be presented on the level of individuals can be aggregated or summed up within neighbouring cells in lieu of administrative references, such as postal code, municipality code, etc.

In addition to the above, it should be stressed that also when a fullscale GIS is not available grid based geo-analyses are feasible with simple spreadsheet or desktop mapping software.

In comparison to the current administrative divisions, a square grid structure is far more detailed. Even the detail of a relatively rough square grid is greater in relation to most administrative units (e.g. counties), and will make it possible to access data compilations of regional differences within the individual county. The square grids are constructed as basic grids of 100 × 100 metres, but alternative grids are also constructed e.g. city grids of 250 × 250 meters cells and regional grids of 1 ×1 km grids.

Working with Information Bearing Cells (IBC)

Specific guidelines are required when heterogeneous datasets are aggregated in grid form. Data compiled in grid form frequently consist of populations comprising individuals that are counted together within each cell, irrespective of whether they are persons, business units, occurrences of an event, etc. However, in some situations the data distributor has imposed restrictions as to how the data may be published.

When the individual square grids have been constructed, the tabulated data are attached. The grid cells are now enriched, hence the notion of Information Bearing Cells (IBC). The datasets in question are entered in a GIS, and a linkage is undertaken, which defines the relationship between e.g. a staircase address (Nørregade 13A in Sønderborg) and the cell in which the address is comprised. In cases where the underlying data are sensitive, the tables entered consist of summed-up values that have been calculated within each individual cell, thus ensuring that the cell does not comprise any data that should not be made publicly available.

The work on Information Bearing Cells in Denmark is subjected to set of discretionary requirements from Statistics Denmark. There must be a sufficient number of households in the combined cells before statistical data can be released. For example, key figures (average figures) are released when there is at least 20 households in an area or in a cell. Statistics Denmark releases a dataset with the number of persons and households on 100 x 100 m cells, which form the basis for the work performed by the data user in combining the cells.

The sensitivity of the data depend both on the discretion requirements, and on the lineage (registration method). The use of cluster techniques meets the often different principles of descretion by aggregating cells into greater areas. While each country often has different principles of descretion, thus the cells need to be handled in different ways depending on the policy of the respective countries.

Masking or smoothing data

Sensitive data that for instance cannot be shown in sparsely populated cells, can be subject to certain masking processes that will allow for visualization and distribution: GEOMATIC has refined a variety of methods for such handling of sensitive data, in order to deliver data even when the requirements for a minimal population within the cells are not originally met:

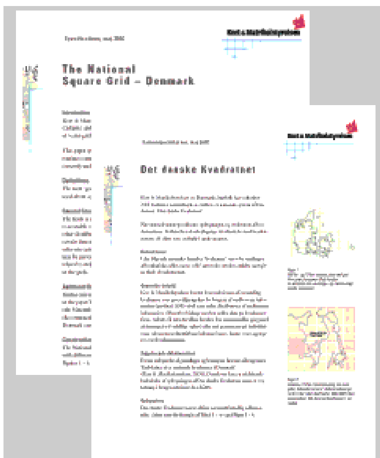
- **Suppression**: This method is being used in Sweden for the moment. Instead of clustering data, cells for which data can not be shown due to the level of discretion, is being given the attribute value 'zero or near', that is not the precise value.
- **Mowing Weighted Average**: As part of standard GIS toolboxes there are many different spatial interpolation models. The one mostly applied is the socalled 'Mowing Weighted Average' which calculates weighted information from the individual cells and their surrounding neighbours.
- **Clustering**: The individual cells are being clustered together. Clusters could be one or more neighbour cells with or without physical interaction. If there is not a sufficient number of households in the cell and a process of smoothing or aggregated values for cells are not applied, the cells must be combined into clusters. There are differences in how each individual cluster is generated, partly depending on the hypothesis put forward for the data analysis in question, the underlying method of registration and partly for reasons of the discretionary requirements. For example, if an analysis of spatial patterns in crimes is to be conducted, one could want the clusters to consist of neighbouring cells (hypothesis: patterns in crime are related to specific areas). Another example is as follows: In the case of a Direct Marketing (DM) campaign, one could make attempts to ensure that all clustered cells are significant with respect to a number of background variables related to the customers in questions. This would imply that they need not be neighbours. Finally, data owners or users may have their own administrative divisions of data, and consequently cells across these administrative distinctions may not be combined.

In Denmark a company like GEOMATIC – Centre for Geoinformatics offers specialised skills in clustering cells and working within this discipline.

Scientists and researchers all over Europe would benefit of an EU standard for geostatistics. The Nordic Grid Project would make out a perfect foundation for also including any new members of the EU. At the NFGS 2003 meeting the Baltic countries all asked for advice as how to build SAMS. There was general consensus that a common grid framework be the best and most cost effective solution.

The National Square Grid - Denmark

(Det danske Kvadratnet)



In Denmark a project unit membered by representative from the National Mapping Agencie, Statistics Denmark, National Environmental Research Institute and the National Board of Health worked to examine Danish needs and possibilities. Resulting from that particular analysis the National Square Grid – Denmark was established during October 2002. The National Square Grid – Denmark consists of a hierarchy of five square grids of decreasing cell size. Eversince GEOMATIC has worked intensively and in close cooperation with Statistics Denmark to facilitate solutions for the private/corporate as well as the governmental market. This was the origin of the IBC notion.

Formal and technical documentation on the National Square Grid – Denmark is accessible on the National Survey and Cadastre website, www.kms.dk, following the path via: 'Mest til arbejde' > 'Kort & geodatagrundlag' > 'Det danske Kvadratnet'. Also, examples of use can be found.

Experience from the use of grid based statistics in Denmark

Throughout the last year grid based statistics have been widely taken up in many private companies as well as in the public administration. In this section some examples will clarify how effective the grid based SAMS prove to be.

Group 4 Falck – Rescue and Safety Services Planning

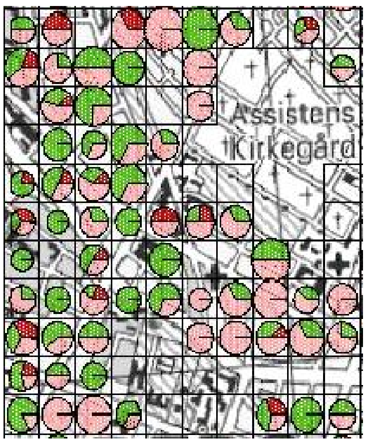
Safety services originally formed the basis of Falck's activities in Denmark. Safety as a business area has been expanded to the other Nordic countries and Poland. The services include activities within traditional public services such as fire and ambulance services. In addition, Group 4 Falck offers auto assistance, patient transport and other services to public authorities, private households and corporate customers.

Group 4 Falck provides patient transportation for private household subscribers as well as public authorities. Patient transport comprises transport between home and hospital or any other treatment location. Falck uses the National Square Grid – Denmark in the economic as well as operational planning of the patient transport. The National Square Grid – Denmark gives the public authorities the best tool to forecast the healthcare situation and provides decision support for the politicians.

By mapping the different cases of illness or accidents and comparing with other socio-economic variables and infrastructural elements (such as transportation time from each cell to each hospital), the square grid is actually a prophylactic treatment that offers to the planners a prophetic warning if the politicians tend to close down vital healthcare offers on selected hospitals.

The company Group 4 Falck uses the National Square Grid – Denmark in many ways; this chosen example merely is meant to show how effective grids can be also in decision making. Group 4 Falck operates in many countries throughout Europe, thus is in need for comparable geostatistics.

Nordea Bank – Risk Modeling



One of the biggest financial companies of Scandinavia is Nordea Bank. Nordea efforts of the National Square Grid – Denmark by building its analytical risk models based on the individual cells. While postal or municipal areas differ from time to time, the cells in the National Square Grid – Denmark are static. It is therefore easier for the Risk Managers to build and trim their models over time grid-wise, which again gives the local assistants a better decision support when giving advice to customers.

Nordea Bank have activities throughout Scandinavia, thus is in need for comparable geostatistics.

Codan insurance company – Tariff Policy

One of the biggest insurance companies in Scandinavia, in Denmark named Codan, is using the National Square Grid – Denmark to form and maintain tariff policy. Insurance companies throughout Europe are traditionally building their tariff policy depending on wery large statistical areas instead of SAMS. Therefore the actual tariffs for many households are unfair comparing to the actual risk for example burglary.

Codan owns insurance companies in Norway, Sweden, Lithuania and Latvia. The lack of geostatistics has been an obstacle for the company to enter its new markets. Specially Codan has been asking for IBC in Sweden, where Codan is the owner of TrygHansa insurance AB. With the same geostatistical reference it will be easier to work in the new EU market, from which many companies would benefit.

Save the Children – Fundraising

Save the Children Denmark uses the National Square Grid – Denmark to give a demographic profile of its members, in order to operate fundraising more effective. Knowing how to give which people a certain communication, that is in the right form and right timing, will reduce marketing expenses and benefit the children in need. To reduce even more expenses, statistical models developed in Denmark could be used in other countries if similar grids were accessible.

Department of Planning and Development – Social Sciences

The Department of Planning and Development at the University of Aalborg uses the National Square Grid – Denmark as the fundamental statistical tool for most geostatistics tasks. To mention just a few examples a Master in GeoInformatics used grids to build a crime-prevention model in co-operation with the Nordic Centre of Crime Prevention, National authorities of Denmark, Danish Police and the Danish Crime Prevention Council. A Ph.D. has been using the National Square Grid – Denmark for a historical analysis of the infrastructural influence from the freeways on the habitation and development in working places: How, when and why are some regions growing when others are depopulated.

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