INSPIRE
Infrastructure for Spatial Information in Europe

D2.8.I.1 INSPIRE Specification on Coordinate Reference Systems - Guidelines

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Foreword
How to read the document?

This guideline describes the INSPIRE Specification on *Coordinate Reference Systems* developed by the Thematic Working Group Coordinate Reference Systems and Geographical Grid Systems (Thematic Working Group Reference System, TWG-RS).

The guideline contains detailed technical documentation highlighting the mandatory and the recommended elements related to the implementation of INSPIRE. The technical details are expected to be of prime interest to those organisations that are/will be responsible for implementing INSPIRE within the field of *Coordinate reference systems.*

At the beginning of the document, two executive summaries are included that provide a quick overview of the INSPIRE data specification process in general, and the content of the specification on *Coordinate reference systems* in particular. We highly recommend that managers, decision makers, and all those new to the INSPIRE process and/or information modelling should read these executive summaries first.

The document will be publicly available as a 'non-paper'. It does not represent an official position of the European Commission, and as such can not be invoked in the context of legal procedures.

Legal Notice

Interoperability of Spatial Data Sets and Services General Executive Summary

The challenges regarding the lack of availability, quality, organisation, accessibility, and sharing of spatial information are common to a large number of policies and activities and are experienced across the various levels of public authority in Europe. In order to solve these problems it is necessary to take measures of coordination between the users and providers of spatial information. The Directive 2007/2/EC of the European Parliament and of the Council adopted on 14 March 2007 aims at establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) for environmental policies, or policies and activities that have an impact on the environment.

INSPIRE will be based on the infrastructures for spatial information that are created and maintained by the Member States. To support the establishment of a European infrastructure, Implementing Rules addressing the following components of the infrastructure are being specified: metadata, interoperability of spatial data themes (as described in Annexes I, II, III of the Directive) and spatial data services, network services and technologies, data and service sharing, and monitoring and reporting procedures.

INSPIRE does not require collection of new data. However, after the period specified in the Directive[1] Member States have to make their data available according to the Implementing Rules.

Interoperability in INSPIRE means the possibility to combine spatial data and services from different sources across the European Community in a consistent way without involving specific efforts of humans or machines. It is important to note that “interoperability” is understood as providing access to spatial data sets through network services, typically via Internet. Interoperability may be achieved by either changing (harmonising) and storing existing data sets or transforming them via services for publication in the INSPIRE infrastructure. It is expected that users will spend less time and effort on understanding and integrating data when they build their applications based on data delivered within INSPIRE.

In order to benefit from the endeavours of international standardisation bodies and organisations established under international law their standards and technical means have been referenced, whenever possible.

To facilitate the implementation of INSPIRE, it is important that all stakeholders have the opportunity to participate its specification and development. For this reason, the Commission has put in place a consensus building process involving data users and providers together with representatives of industry, research, and government. These stakeholders, organised through Spatial Data Interest Communities (SDIC) and Legally Mandated Organisations (LMO)[2], have provided reference materials, participated in the user requirement and technical[3] surveys, proposed experts for the Data Specification Drafting Team[4] and Thematic Working Groups[5], expressed their views on the drafts of the technical documents of the data specification development framework[6]; they have reviewed and tested the draft data specifications and have been invited to comment the draft structure of the implementing rule on interoperability of spatial data sets and services.

1 For Annex I data: within two years of the adoption of the corresponding Implementing Rules for newly collected and extensively restructured data and within 5 years for other data in electronic format still in use

2 The number of SDICs and LMOs on 21/08/2009 was 301 and 176 respectively

3 Surveys on unique identifiers and usage of the elements of the spatial and temporal schema,

4 The Data Specification Drafting Team has been composed of experts from Austria, Belgium, Czech Republic, France, Germany, Greece, Italy, Netherlands, Norway, Poland, Switzerland, UK, and the European Environmental Agency

5 The Thematic Working Groups of Annex I themes have been composed of experts from Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Netherland, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, UK, the European Commission and the European Environmental Agency

6 Four documents describing common principles for data specifications across all spatial data themes. See further details in the text.

The development framework elaborated by the Data Specification Drafting Team aims at keeping the data specifications of the different themes coherent. It summarises the methodology to be used for the data specifications and provides a coherent set of requirements and recommendations to achieve interoperability. The pillars of the framework are four technical documents:

- The Definition of Annex Themes and Scope[7] describes in greater detail the spatial data themes defined in the Directive, and thus provides a sound starting point for the thematic aspects of the data specification development.

- The Generic Conceptual Model[8] defines the elements necessary for interoperability and data harmonisation including cross-theme issues. It specifies requirements and recommendations with regard to data specification elements of common use, like the spatial and temporal schema, unique identifier management, object referencing, a generic network model, some common code lists, etc. Those requirements of the Generic Conceptual Model that are directly implementable will be included in the Implementing Rule on Interoperability of Spatial Data Sets and Services.

- The Methodology for the Development of Data Specifications[9] defines a repeatable methodology, enabling to arrive from user requirements to a data specification through a number of steps including use-case development, initial specification development and analysis of analogies and gaps for further specification refinement.

- The “Guidelines for the Encoding of Spatial Data”[10] defines how geographic information can be encoded to enable transfer processes between the systems of the data providers in the Member States. Even though it does not specify a mandatory encoding rule it sets GML (ISO 19136) as the default encoding for INSPIRE.

Based on the data specification development framework, the Thematic Working Groups have created the INSPIRE data specification for each Annex I theme. The data specifications follow the structure of “ISO 19131 Geographic information - Data product specifications” standard. They include the technical documentation of the application schema, the spatial object types with their properties, and other specifics of the spatial data themes using natural language as well as a formal conceptual schema language[11].

A consolidated model repository, feature concept dictionary and glossary are being maintained to support the consistent specification development process and potential further reuse of specification elements. The consolidated model consists of the harmonised models of the relevant standards from the ISO 19100 series, the INSPIRE Generic Conceptual Model, and the application schemas[12] developed for each spatial data theme (the latest with two exceptions: the application schemas are not developed for the INSPIRE spatial data themes *Coordinate reference systems* and *Geographical grid systems*). The multilingual INSPIRE Feature Concept Dictionary contains the definition and description of the INSPIRE themes together with the definition of the spatial object types present in the specification. The INSPIRE Glossary defines all the terms (beyond the spatial object types) necessary for understanding the INSPIRE documentation including the terminology of other components (metadata, network services, data sharing, and monitoring).

By listing a number of requirements and making the necessary recommendations, the data specifications enable full system interoperability across the Member States, within the scope of the application areas targeted by the Directive. They are published as technical guidelines and provide the basis for the content of the Implementing Rule on Interoperability of Spatial Data Sets and Services for data themes included in Annex I of the Directive. The Implementing Rule will be

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7 http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/DataSpecifications/D2.3_Definition_of_Annex_Themes_and_scope_v3.0.pdf

8 http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/DataSpecifications/D2.5_v3.1.pdf

9 http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/DataSpecifications/D2.6_v3.0.pdf

10 http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/DataSpecifications/D2.7_v3.0.pdf

11 UML – Unified Modelling Language

12 Conceptual models related to specific areas (e.g. INSPIRE themes)

extracted from the data specifications keeping in mind the technical feasibility as well as cost-benefit considerations. The Implementing Rule will be legally binding for the Member States.

In addition to providing a basis for the interoperability of spatial data in INSPIRE, the data specification development framework and the thematic data specifications can be reused in other environments at local, regional, national and global level contributing to improvements in the coherence and interoperability of data in spatial data infrastructures.

Coordinate Reference Systems
Executive Summary

Coordinate reference systems are included in Annex I, which means that they are considered as reference data, i.e. data that constitute the spatial frame for linking and/or pointing to other information that belong to specific thematic fields as defined in the INSPIRE Annexes II and III.

The INSPIRE specification on *Coordinate reference systems* has been prepared following the participative principle of a consensus building process. The stakeholders, based on their registration as a Spatial Data Interest Community (SDIC) or a Legally Mandated Organisation (LMO) had the opportunity to bring forward user requirements and reference materials, propose experts for the specification development, and participate in the review of the data specifications. The Thematic Working Group responsible for the specification development was composed of geodetic and mapping experts coming from Portugal, Slovenia, France, Germany, Italy, Sweden, the UK and the Netherlands, all of them for many years involved in activities aiming to establish uniform geo-referencing within Europe. Due to the close links between and the special technical nature of the two themes of C*oordinate reference systems* and *Geographical grid systems*, the specifications of both themes were developed by one thematic working group.

Coordinate reference systems (hereafter: CRS) play a specific role that is quite different from the other themes in the Directive's annexes. Contrary to the other themes the *CRS* specification does <u>not</u> concern a downloadable or viewable thematic data set. Rather, it presents a basic functionality allowing the harmonised and interoperable geographic localisation of spatial objects defined by the other INSPIRE thematic data specifications. Therefore, the methodology developed by the Drafting Team Data Specifications is only partly applicable to the work of this Thematic Working Group.

The specific task of the definition of the CRS therefore consists in taking the right decisions on the choice of one (or a limited number of) coordinate reference systems and map projections that will ensure a common basis for the geographical harmonisation between all the other themes defined in the Annexes of the Directive. There are however themes for which in addition to linear systems (that are usually used for the horizontal component) parametric, or on non-length-based systems[13] are used for the vertical component.

There are also themes that may require temporal references. The referencing by parameters and temporal reference systems is not defined in general by the theme CRS. However, it is required that when data are exchanged using such reference systems, this is either specified using the ISO 19111-2 standard, or it is linked by reference to a document explaining the reference system.

There are specific parametric reference systems for the vertical component which are used by the atmospheric and oceanographic communities, and in the case of the atmospheric reference system, there is an existing ISO standard (ISO 2533:1975) which defines the International Standard Atmosphere. The definition of these reference systems will be refined by the respective thematic working groups for the INSPIRE annex II and III themes. The current understanding of the TWG CRS is the following:

"In the free ocean depths, observations of temperature, salinity etc. have no direct height measure. Pressure is the parametric reference system used and any measure of depth is an approximation or inferred value based on the vertical profile.

In the free atmosphere, aircraft use barometric pressure, scaled as heights and appropriately calibrated to a surface datum to ensure separation. Relative height differences measured by pressure are not appreciably affected by changes in the actual surface pressure. Here too, there are no direct height measurements.

In 1951, the International Civil Aviation Organisation (ICAO) incorporated the International Standard Atmosphere (ISA) into international law under Annex 8 of the Convention on International Civil Aviation (the Chicago Convention, 1947). ISO adopted the Standard

[13] like barometric, or other systems

Atmosphere as ISO 2533:1975 in the range 2km to 32km. (Manual of the ICAO Standard Atmosphere: Doc 7488/3). “

This document provides the result of the specification of the CRS. It contains elements that was proposed as part of the draft Implementing Rule on interoperability of spatial data sets and services. These elements are clearly indicated in the document as “requirements”. The other parts of the documents give clarification, background information and examples and are intended as part of the technical guidance documents accompanying the Implementing Rule.

The cornerstone of the specification development was the definition of the Directive on *Coordinate reference systems* as being *“*Systems for uniquely referencing spatial information in space as a set of coordinates (X, Y, Z) and/or latitude and longitude and height, based on a geodetic horizontal and vertical datum”.

For the three-dimensional and two-dimensional coordinate reference systems and the horizontal component of compound coordinate reference systems used for making available the INSPIRE spatial data sets available, the datum shall be the datum of the European Terrestrial Reference System 1989 (ETRS89) in areas within its geographical scope, or the datum of the International Terrestrial Reference System (ITRS) or other geodetic coordinate reference systems compliant with ITRS in areas that are outside the geographical scope of ETRS89. Compliant with the ITRS means that the system definition is based on the definition of the ITRS and there is a well documented relationship between both systems, according to EN ISO 19111.

For the vertical component on land, the European Vertical Reference System (EVRS) shall be used to express gravity-related heights within its geographical scope. Other vertical reference systems related to the Earth gravity field shall be used to express gravity-related heights in areas that are outside the geographical scope of EVRS.

For the vertical component in the free atmosphere, barometric pressure, converted to height using ISO 2533:1975 International Standard Atmosphere shall be used.

The vertical component in the free ocean is to be refined during the annex II and III data specifications. The TWG-CRS suggests the following formulations as starting point :

“For the vertical component measuring depths in the water column of the free ocean, depths inferred from barometric pressure shall be used.”

and

“*For depth values of the sea floor in marine areas with an appreciable tidal range, depths are usually referenced to the Lowest Astronomical Tide, as has already been mandated by Technical Resolution A2.5 of the International Hydrographic Organisation (IHO). Depths relative to LAT may be used as an exception in some themes. In marine areas without an appreciable tidal range, in open oceans and effectively in waters deeper than 200m tide is not measured since it has no significant impact on the accuracy of the sounding.*”

The requirements and recommendations Map projections are based on the results from the “Map Projections for Europe” workshop[14]. These are:

- Lambert Azimuthal Equal Area (ETRS89-LAEA) for pan-European spatial analysis and reporting, where true area representation is required;
- Lambert Conformal Conic (ETRS89-LCC) for conformal pan-European mapping at scales smaller than or equal to 1:500,000;
- Transverse Mercator (ETRS89-TMzn) for conformal pan-European mapping at scales larger than 1:500,000.

These projections shall be available in INSPIRE transformation services.

[14] The workshop took place on 15/12/2000. See proceedings on http://www.ec-gis.org/sdi/publist/pdfs/annoni-etal2003eur.pdf

For regions outside of continental Europe, for example for overseas MS territories, the MS shall define a map projection they consider most suitable for the purpose. Moreover, different INSPIRE themes or applications may use appropriate map projections, for example if the data characteristics require large scale mapping. In these cases the map projections shall be well documented to allow the conversion to geographic coordinates and an identifier shall be created, according to ISO 19111.

For the rendering of spatial information for INSPIRE View Services, and in case there is a need for plane coordinates, the "Plate-Carrée" projection is recommended for the non-polar regions. For the polar regions a Polar stereographic projection is recommended.

This document contains also the identifiers for the different types of coordinates that shall be used.

Acknowledgements

Many individuals and organisations have contributed to the development of these Guidelines.

The Thematic Working Group Coordinate Reference Systems and Geographical Grid Systems (TWG-RS) included:
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The Drafting Team Data Specifications included:
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The Consolidated UML repository has been set up by Michael Lutz, Anders Friis-Christensen, and Clemens Portele. The INSPIRE Registry has been developed by Angelo Quaglia and Michael Lutz. The INSPIRE Feature Concept Dictionary and Glossary has been consolidated by Darja Lihteneger. The data specification testing has been coordinated by Martin Tuchyna. The Testing Wiki has been set up by Loizos Bailas, Karen Fullerton and Nicole Ostländer. Web communication and tools for the consultations have been developed by Karen Fullerton and Hildegard Gerlach.

The stakeholders participated, as Spatial Data Interested Communities (SDIC) or Legally Mandated Organisations (LMO), in different steps of the development of the data specification development framework documents and the technical guidelines, providing information on questionnaires and user surveys, participating in the consultation process and workshops, testing the draft data specifications and supporting the work of their members in the Thematic Working Groups and Drafting Team Data Specifications.

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1 Scope

This document presents a specification for the spatial data theme *Coordinate reference systems* as defined in Annex I of the INSPIRE Directive.

This specification provides the basis for the drafting of Implementing Rules according to Article 7 (1) of the INSPIRE Directive [Directive 2007/2/EC]. The entire specification will be published as implementation guidelines accompanying these Implementing Rules.

2 Definitions

- 'datum' means a parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system, in accordance with EN ISO 19111.
- 'geodetic datum' means a datum describing the relationship of a coordinate system to the Earth, in accordance with EN ISO 19111.
- 'coordinate system' means a set of mathematical rules for specifying how coordinates are to be assigned to points, in accordance with EN ISO 19111.
- 'coordinate reference system' means a coordinate system which is related to the real world by a datum, in accordance with EN ISO 19111. This definition includes coordinate systems based on geodetic or cartesian coordinates and coordinate systems based on map projections.
- 'map projection' means a change of coordinates, based on a one-to-one relationship, from a geodetic coordinate system to a plane, based on the same datum, in accordance with EN ISO 19111.
- 'compound coordinate reference system' means a coordinate reference system using two other independent coordinate reference systems, one for the horizontal component and one for the vertical component, to describe a position, in accordance with EN ISO 19111.
- 'geodetic coordinate system' means a coordinate system in which position is specified by geodetic latitude, geodetic longitude and (in the three-dimensional case) ellipsoidal height, in accordance with EN ISO 19111.

3 Overview

3.1 Name and acronyms

INSPIRE specification for the theme *Coordinate reference systems.*

3.2 Informal description

Definition:

Systems for uniquely referencing spatial information in space as a set of coordinates (X, Y, Z) and/or latitude, longitude and height, based on a geodetic horizontal and vertical datum. [Directive 2007/2/EC]

Description:

The scope of the theme *Coordinate reference systems* covers the Geodetic Coordinate Reference Systems (CRS) required for uniquely referencing spatial information in space as a set of coordinates (X, Y, Z) and/or latitude, longitude and height.

This is achieved by defining a geodetic datum to express the geographical coordinates latitude, longitude (horizontal component) and a vertical datum to express height (vertical component).

The set of coordinates (Latitude, Longitude, Ellipsoidal height) can be derived from the space set of coordinates (X,Y,Z) using a suitable reference ellipsoid. The GRS80 ellipsoid will be adopted for this purpose.

For the three-dimensional and two-dimensional coordinate reference systems and the horizontal component of compound coordinate reference systems used for making available the INSPIRE spatial data sets available, the datum shall be the datum of the European Terrestrial Reference System 1989 (ETRS89) in areas within its geographical scope, or the datum of the International Terrestrial Reference System (ITRS) or other geodetic coordinate reference systems compliant with ITRS in areas that are outside the geographical scope of ETRS89. Compliant with the ITRS means that the system definition is based on the definition of the ITRS and there is a well documented relationship between both systems, according to EN ISO 19111.

For the vertical component on land, the European Vertical Reference System (EVRS) shall be used to express gravity-related heights within its geographical scope. Other vertical reference systems related to the Earth gravity field shall be used to express gravity-related heights in areas that are outside the geographical scope of EVRS.

For the vertical component in the free atmosphere, barometric pressure, converted to height using ISO 2533:1975 International Standard Atmosphere shall be used.

The vertical component in the free ocean is to be refined during the annex II and III data specifications. The TWG-CRS suggests the following formulations as starting point :

"For the vertical component measuring depths in the water column of the free ocean, depths inferred from barometric pressure shall be used."

and

"*For depth values of the sea floor in marine areas with an appreciable tidal range, the Lowest Astronomical Tide is already mandated by Technical Resolution A2.5 of the International Hydrographic Organisation (IHO), and may be used as an exception in some themes. In marine areas without an appreciable tidal range, in open oceans and effectively in waters deeper than 200m tide is not measured since it has no significant impact on the accuracy of the sounding*."

Plane coordinates may be derived from latitude and longitude using suitable cartographic projections. Different cartographic projections are adopted and recommended for different purposes, covering the requirements of the INSPIRE transformation services and view services as well.
It is recognised that there is a need to enable CRS for regions outside of continental Europe, for example for overseas Member States (MS) territories.

Such MS defined CRS will be based on the International Terrestrial Reference System (ITRS), or other geodetic coordinate reference systems compliant with ITRS in areas that are outside the geographical scope of ETRS89, and on vertical systems related to the Earth gravity field.

For these regions, the MS shall define a map projection they consider most suitable for the purpose. Moreover, different INSPIRE themes or applications may use appropriate map projections, In these cases the map projections shall be well documented and an identifier shall be created, according to ISO 19111.

For the display of spatial data sets with the view network service as specified in Regulation No 976/2009[15], at least the coordinate reference systems for two-dimensional geodetic coordinates (latitude, longitude) shall be available.

This document contains also the identifiers for the different types of coordinates that shall be used.

In general the referencing by parameters and temporal reference systems are out of scope of the theme CRS.

3.3 Normative References

[Directive 2007/2/EC]	Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE)
[ISO 19111]	EN ISO 19111:2007 Geographic information - Spatial referencing by coordinates (ISO 19111:2007)
[ISO 19111-2]	EN ISO 19111:--[16] Geographic information - Spatial referencing by coordinates – Part 2: Extension for parametric values
[ISO 19115]	EN ISO 19115:2005, Geographic information – Metadata (ISO 19115:2003)
[ISO/TS 19127]	ISO/TS 19127:2005, Geographic information -- Geodetic codes and parameters
[ISO 2533]	ISO 2533:1975, International Standard Atmosphere
[ISO 6709]	ISO 6709:2008 (Standard representation of geographical point position by coordinates)
[IHO TRA2.5]	Datums and Benchmarks in IHO M3 Resolutions of the International Hydrographic Organization, version updated to September 2008
[IHO S32]	Hydrographic Dictionary, 5th edition, 1994
[IHO S44]	Standards for Hydrographic Surveys, 5th edition, February 2008

[15] OJ L 274, 20.10.2009, p. 9–18.
[16] to be published, currently in “Approval” stage

3.4 Information about the creation of the specification

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3.5 Terms and definitions

Terms and definitions necessary for understanding this document are defined in the INSPIRE Glossary:
http://inspire-registry.jrc.ec.europa.eu/registers/GLOSSARY .

3.6 Symbols and abbreviations

CRS	Coordinate reference system
EC	European Commission
ETRS89	European Terrestrial Reference System 1989
ETRS89/EVRS	Compound coordinate reference system ETRS89/EVRS
ETRS89-LAEA	Projection Lambert Azimuthal Equal Area
ETRS89-LCC	Projection Lambert Conformal Conic
ETRS89-TMzn	Projection Transverse Mercator
EUREF	Reference Frame Sub-commission for Europe of the IAG
EVRS	European Vertical Reference System
GCM	Generic Conceptual Model
GRS80	Geodetic Reference System 1980
IAG	International Association of Geodesy
ICAO	International Civil Aviation Organisation
IERS	International Earth Rotation and Reference Systems Service
IHO	International Hydrographic Organisation
ISA	International Standard Atmosphere
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
JRC	Joint Research Centre
LAT	Lowest Astronomical Tide
MS	Member States
MSL	Mean Sea Level
TRS	Terrestrial Reference System
TWG	Thematic Working Group
VFR	Visual Flying Rules

3.7 Notation of requirements and recommendations

To make it easier to identify the mandatory requirements and the recommendations for spatial data sets in the text, they are highlighted and numbered.

Requirement X Requirements are shown using this style.

Recommendation X Recommendations are shown using this style.

4 Introduction

The INSPIRE theme *Coordinate reference systems* (CRS) provides a harmonised specification for uniquely referencing spatial information.

This document also provides the specification for the map projections to be used for geo-referencing the spatial information in plane coordinates.

The mandated CRS can be used for any kind of information/resolution/accuracy; the resolution and accuracy of data are out of scope of the theme CRS.

For data sets with low positional accuracy, the original CRS of the data set can sometimes be considered equivalent to the mandated CRS. It is recommended that the data set provider consults the experts in the Member States (MS) to evaluate the need to transform the data sets from the original CRS to the mandated CRS.

The decision for the maintenance of the data sets in its original CRS or in the mandated CRS will be taken according to the MS and the INSPIRE regulations.

The accuracy of the data sets resulting from transformations and conversion formulas are out of scope of the theme CRS. The accuracy of the data sets must be documented by the data set provider according to all the aspects that contribute to it, namely the original data accuracy and the accuracy of the conversions, transformations and other aspects involved with the management of the data.

There are themes for which data are expressed in linear systems for the horizontal component or on non-length-based vertical systems like pressure, density, for the vertical component. This kind of referencing is parametric.

In general the referencing by parameters is out of scope of the theme CRS. It is recommended to associate the parameters with the specific data according to ISO 19111 (Part 2: Extension for parametric values).

However for data measured in the free atmosphere or free ocean, parametric references using barometric pressure converted to height are adopted for INSPIRE within the CRS.

Where more general parametric reference systems are used this is out of scope, but it is recommended that they should be appropriately specified and referenced.

There are themes that may require temporal references. Temporal reference systems are also out of scope of the theme CRS.

5 Coordinate Reference Systems

5.1 General description

Geodetic Coordinate Reference Systems (CRS) define the constants and parameters needed for Geodetic Datums, and are required for uniquely referencing spatial information in space as a set of coordinates (X, Y, Z) and/or latitude, longitude and height.

This is achieved by defining a geodetic datum to express the geographical coordinates latitude, longitude (horizontal component) and a vertical datum to express height (vertical component), to form a compound coordinate reference system.

The set of coordinates (Latitude, Longitude, Ellipsoidal height) can be derived from the space set of coordinates (X,Y,Z) using a suitable reference ellipsoid.

Plane coordinates may be derived from latitude and longitude using suitable cartographic projections.

5.2 Datums for three-dimensional and two-dimensional coordinate reference systems

5.2.1 Geodetic reference systems

The coordinate reference systems used in the majority of the European region are linked to the Eurasian tectonic plate. Since Directive 2007/2/EC affects areas that are not on the Eurasian tectonic plate, it is necessary that the rules concerning coordinate reference systems take also into account areas that are not considered to be on the Eurasian tectonic plate.

This kind of situation occurs, for example, in the European countries' overseas territories.

The International Terrestrial Reference System (ITRS) [IERS] is presently the recommended Terrestrial Reference System (TRS) for the whole geo-science community, through a resolution adopted by the International Union of Geodesy and Geophysics (IUGG) during its General Assembly of Perugia in 2007. The primary realisations of ITRS are created through an optimal combined use of space geodetic techniques; they are released to the international community and labelled International Terrestrial Reference Frames: (ITRFyy).

These primary realisations are also densified and disseminated through regional, national and local terrestrial geodetic networks.The European Terrestrial Reference System 1989 (ETRS89) [EUREF] is related to the ITRS and its realisations are designated by European Terrestrial Reference Frames: (ETRFyy),

The WGS84 system designates a full set of geodetic standards, in which successive realisations of a unique TRS has been provided. The most recent WGS84 realisations are in agreement with the ITRF at the level of a few centimetres. In consequence, the WGS84 products (as concerning TRS issues) are considered as realisations of the ITRS. The WGS84 is linked to the ITRS.

The MS have extended the ETRS89 to their continental and neighbour territories through their own realisations that are linked to the ETRFyy solutions. The European continental and neighbour territories of the MS constitute the geographical scope of the ETRS89.

Requirement 1	For the three-dimensional and two-dimensional (horizontal component) coordinate reference systems, the European Terrestrial Reference System 1989 (ETRS89) shall be used for the areas within the geographical scope of ETRS89.

Requirement 2	The International Terrestrial Reference System (ITRS) or other geodetic coordinate reference systems compliant with ITRS shall be used in areas that are outside the geographical scope of ETRS89.

Requirement 3	For the computation of latitude, longitude and ellipsoidal height, and for the computation of plane coordinates using a suitable mapping projection, the parameters of the GRS80 ellipsoid shall be used.

5.2.2 Map projections

Map projections are used for geo-referencing spatial information in plane coordinates.

Map projections are required to make possible the data delivery and exchange in this type of coordinates at the Pan-European level.

In 14-15 December 2000 the “Map Projections for Europe” workshop was organised to propose the map projections to be used for representation of data in plane coordinates in general applications. The use of the following projections was recommended:

- Lambert Azimuthal Equal Area (ETRS89-LAEA) for spatial analysis and display;
- Lambert Conformal Conic (ETRS89-LCC) for conformal pan-European mapping at scales smaller or equal to 1:500,000;
- Transverse Mercator (ETRS89-TMzn) for conformal pan-European mapping at scales larger than 1:500,000.

In order to clarify the projected CRS identifiers, the datum parts of the designations given in the workshop are changed from ETRS to ETRS89.

These recommendations have been used by the European Commission (EC) for geo-referencing the data internally within the EC. For the representation of data in plane coordinates in general pan-European applications in continental Europe in the frame of INSPIRE, these projections are either mandated or recommended. For regions outside of continental Europe, for example for overseas MS territories, the MS shall define a map projection they consider most suitable for the application. The purpose of ETRS89-LAEA is changed to spatial analysis and reporting.

The formulas of the above mentioned map projections are published in the proceedings of the “Map Projections for Europe” workshop (Marne-La Vallee, 14-15 December 2000) and in the proceedings of the “European Reference Grids” workshop (Ispra, 27-29 October 2003). For other map projections, see Snyder, John P: Map Projections – A Working Manual (Snyder, 1987).
In case other map projections are used, they must be well documented to allow the conversion to geographic coordinates and an identifier will be created. The documentation shall be provided according to ISO 19111, which states how a projected coordinate reference system must be described.

The Transverse Mercator (ETRS89-TMzn) is identical to the Universal Transverse Mercator (UTM) grid system for the Northern hemisphere when applied to the ETRS89 geodetic datum and the GRS80 ellipsoid. The UTM system was developed for worldwide application between 80º S and 84º N.

Map projections for atmospheric and meteorological data cannot be restricted to European land areas. Typically a Polar stereographic projection is used for these purposes which include en-route weather forecasts across the Pole to America or Japan.

For navigation at sea, Mercator projections are used except in Polar regions.

Requirement 4	For representation with plane coordinates one of the Lambert Azimuthal Equal Area (ETRS89-LAEA), the Lambert Conformal Conic (ETRS89-LCC) or the Transverse Mercator (ETRS89-TMzn) projection shall be used.

Recommendation 1	For pan-European spatial analysis and reporting, where true area representation is required, the ETRS89-LAEA is recommended

Recommendation 2	For conformal pan-European mapping at scales smaller than or equal to 1:500,000, the ETRS89-LCC is recommended

Recommendation 3	For conformal pan-European mapping at scales larger than 1:500,000, the Transverse Mercator ETRS89-TMzn is recommended

Recommendation 4	It is recommended that the projections referred in Requirement 4, are available in INSPIRE transformation services.

Requirement 5	For regions outside of continental Europe, for example for overseas MS territories, the MS shall define a map projection they consider most suitable for the purpose.

For the display of spatial information on the screen the important feature is the ability of the application to give the pixel coordinates true projected coordinates and to facilitate the overlaying of different sources of spatial information when taking into account the economic aspects of putting online spatial information for MS.

The Mercator cylindrical spherical is the most interoperable in the field of view services. Several commercial services on the Internet use this CRS. It is fully compatible with good Internet practices. Parameters have to be defined once for the whole world (continental Europe and overseas territories).

For the rendering of spatial information for INSPIRE View Services, and in the case where there is a need to use projected coordinates, one of the most intuitive is the “Plate-Carrée” projection. Parameters have to be defined once for the whole world (continental Europe and overseas territories). This assumption does not exclude other map projections with similar features.

The equirectangular projection allows overlaying the existing view services in “Plate-Carrée” while being conformal. Whereas the cost of re-projecting into equirectangular is lower than for the Mercator cylindrical spherical, parameters have to be defined separately for continental Europe and overseas territories.

However, if the data are stored in geographic coordinates there is no need for re-projecting.

Requirement 6	For the display of spatial data sets with the view network service as specified in Regulation No 976/2009[17], at least the coordinate reference systems for two-dimensional geodetic coordinates (latitude, longitude) shall be available.

GIS applications may use INSPIRE download and transformation services to get and re-project datasets for the end-users aims. Moreover, different INSPIRE themes or applications may use appropriate map projections, for example if the data characteristics require large scale mapping.

[17] OJ L 274, 20.10.2009, p. 9–18.

Requirement 7	In the case the map projections are defined internally, they shall be well documented to allow the conversion to geographic coordinates and an identifier shall be created, according to ISO 19111 and ISO 19127.

5.3 One-dimensional coordinate reference systems

The European Vertical Reference System (EVRS) [EUREF] is the vertical reference system recommended for Europe on land to express gravity-related heights. The most recent realisation of the EVRS is labelled European Vertical Reference Frame 2007 (EVRF2007). The definition of EVRS is described in the EVRS Conventions 2007.

The vertical reference systems for land existing in the MS can be expressed in the EVRS in their continental territories through their own realisations that are linked to the EVRF2007 solution. Future solutions of the EVRF will constitute an improvement and are considered realisations of the EVRS. The European continental territories of the MS constitute the geographical scope of the EVRS.

Since not all the vertical datums in use can be connected to the European vertical datum, it is necessary that the rules concerning the vertical datum also take into account areas that are not in the European continental territories. In this case, a locally or globally defined vertical reference system related to the Earth gravity field will be used to express gravity-related heights.

Requirement 8	For the vertical component on land, the European Vertical Reference System (EVRS) shall be used to express gravity-related heights for the areas within the geographical scope of EVRS.

Requirement 9	Other vertical reference systems related to the Earth gravity field shall be used to express gravity-related heights in areas that are outside the geographical scope of EVRS.

For the free ocean, the profile in the deep ocean is typically measured by sounding buoys. These use pressure as a vertical measure and the datum is the actual ocean surface. When these buoys surface and transmit the measurements, the depths are usually supplied already converted by a calibration mechanism which also includes corrections for the temperature and salinity profiles, and for the compressional effects of water under high pressure.

Otherwise depths are estimated using a hydrostatic approximation. For anything other than ocean modelling this is likely to be sufficient. Divers, submarines and tethered buoys only operate at shallow depths compared to deep oceans where the approximations become unacceptable.
The specification of the ocean surface datum too has problems. Although there are projects to use satellite measurements of the oceanic geoid, these are not universally available or used. Ocean modellers also have to consider diurnal variations in temperature in the immediate ocean surface.

For depth values of the sea floor in marine areas with an appreciable tidal range, depths are usually referenced to the Lowest Astronomical Tide, as has already been mandated by Technical Resolution A2.5 of the International Hydrographic Organisation (IHO). Depths relative to LAT may be used as an exception in some themes. In marine areas without an appreciable tidal range, in open oceans and effectively in waters deeper than 200m tide is not measured since it has no significant impact on the accuracy of the sounding.

The vertical component in the free ocean is to be refined during the annex II and III data specifications. The TWG-CRS suggests the following formulations as starting point :

"For the vertical component measuring depths in the water column of the free ocean, depths inferred from barometric pressure shall be used. Where other parametric reference systems are used (e.g. density) a full specification should be available either directly or linked by reference."

and

"For depth values of the sea floor in marine areas with an appreciable tidal range, depths are usually referenced to the Lowest Astronomical Tide, as has already been mandated by Technical Resolution A2.5 of the International Hydrographic Organisation (IHO). Depths relative to LAT may be used as an exception in some themes. In marine areas without an appreciable tidal range, in open oceans and effectively in waters deeper than 200m tide is not measured since it has no significant impact on the accuracy of the sounding."

In the free atmosphere, aircraft use barometric pressure, scaled as heights and appropriately calibrated to a surface datum to ensure separation. Atmospheric observations and measurements from aircraft therefore have the vertical coordinate measured as a barometric pressure.

Barometric pressure decreases monotonically with height, and to measure the exact height the full temperature profile in the vertical below the measurement must be known. This is seldom available directly, and indirect measurement of height requires estimation of this profile using numerical atmospheric models. At sufficiently elevated levels, an approximate conversion to height is used. The International Standard Atmosphere (ISA) [ISO 2533] is calibrated in both thousands of feet and in metres (aviation, by law, uses kilofeet). It measures approximate geopotential height because the datum ignores the variation of the atmospheric temperature and pressure near the bottom of the atmosphere. Heights are named as flight levels (e.g. FL320 is nominally 32 thousand feet). Even if a true height measure is available in an aircraft (e.g. through radar or GPS) the readings must be converted to ISA flight levels – unless the pilot is flying under Visual Flying Rules (VFR) near the ground.

The datum is set at mean sea level pressure in the standard atmosphere at 1013.25 hectoPascals (hPa) (the non-SI unit is identical: millibars (mb))

Requirement 10	For the vertical component in the free atmosphere, barometric pressure, converted to height using ISO 2533:1975 International Standard Atmosphere shall be used.

5.4 Compound coordinate reference systems

A compound CRS is a coordinate reference system that combines one two-dimensional CRS with one one-dimensional CRS:

EXAMPLE Geodetic coordinates in ETRS89 using the GRS80 ellipsoid combined with heights in EVRS form a compound CRS

A compound CRS allows unambiguous 3D geo-referencing.

Requirement 11	Where Requirements 2 and 8 apply, Member States shall make available information as to which system they use. The geodetic codes and parameters shall be documented according to ISO 19111:2007 and ISO 19127:2005.

Recommendation 5	Where more general parametric reference systems are used, it is recommended that they should be appropriately specified and referenced.

5.4.1 Identifiers

The following types of coordinates and their combinations are considered to comply with of the requirements:

- In 3 dimensions (3D):
- Cartesian coordinates in ETRS89 in space (X,Y,Z)
- Geodetic (geographic) coordinates and ellipsoidal height in ETRS89 on the GRS80 ellipsoid (Latitude, Longitude, Ellipsoidal height)

- In 2 dimensions (2D):
- Geodetic (geographic) coordinates in ETRS89 on the GRS80 ellipsoid (Latitude, Longitude)
- Plane coordinates converted from geodetic (geographic) coordinates in ETRS89 using a cartographic projection (N,E) or (Y,X)

- Compound CRS (2D+1D); one of the 2D types is combined with one of the following 1 dimension (1D) types:
- Height in EVRS (H)
- Pressure coordinate in the free atmosphere converted to height using ISO 2533:1975 International Standard Atmosphere (H).
- Pressure coordinate in the free ocean converted to depth (D).

Recommendation 6 For referring the coordinate reference systems adopted by INSPIRE, identifiers presented in the table 1 are recommended.

Recommendation 7 For referring a compound CRS, one 2D and one 1D system combined together, the respective identifier shall be created by appending the identifiers of the 2D and 1D CRS with a slash between both.

EXAMPLE When both ETRS89-GRS80 and EVRS the CRS used the identifier shall be ETRS89-GRS80/EVRS.

Identifier	Type of coordinates
ETRS89-XYZ	Cartesian coordinates in ETRS89 in space (X,Y,Z)
ETRS89-GRS80h	Geodetic (geographic) coordinates and ellipsoidal height in ETRS89 on the GRS80 ellipsoid (Latitude, Longitude, Ellipsoidal height)
ETRS89-GRS80	Geodetic (geographic) coordinates in ETRS89 on the GRS80 (Latitude, Longitude)
EVRS	Height in EVRS (H)
LAT	Depth of the sea floor, where there is an appreciable tidal range (D)
MSL	Depth of the sea floor, in marine areas without an appreciable tidal range, in open oceans and effectively in waters that are deeper than 200m (D)
ISA	Pressure coordinate in the free atmosphere (P)
PFO	Pressure coordinate in the free ocean (P)
ETRS89-LAEA	ETRS89 coordinates projected into plane coordinates by the Lambert Azimuthal Equal Area projection (Y,X)
ETRS89-LCC	ETRS89 coordinates projected into plane coordinates by the Lambert Conformal Conic projection (N,E)
ETRS89-TMzn[18]	ETRS89 coordinates projected into plane coordinates by the Transverse Mercator projection (N,E)

[18] »zn« denotes the projection zone

Table 1 - Identifiers

6 Bibliography and References

[EUR 19575 EN] Spatial Reference Systems in Europe – EUR Report 19575 EN. Proceedings of the “Spatial Reference Systems in Europe” workshop, Marne-La Vallee, 29-30 November 1999

[EUR 20120 EN] Map Projections for Europe – EUR Report 20120 EN. Proceedings of the “Map Projections for Europe” workshop, Marne-La Vallee, 14-15 December 2000 [19]

[EUR 21494 EN] European Reference Grids – EUR Report 21494 EN. Proceedings of the “European Reference Grids” workshop, Ispra, 27-29 October 2003 [20]

[Snyder, 1987] Map Projections – A Working Manual – Snyder, John P., Professional Paper 1395, U.S. Geological Survey, 1987

[IERS] www.iers.org – IERS website for information on the ITRS

[EUREF] www.euref.eu or www.euref-iag.net – EUREF website for information on the ETRS89 and the EVRS

[IHO] www.iho.int – IHO website for information on Hydrography

[WMO] www.wmo.int – World Meteorological Organization

[ICAO] www.icao.int http://www.wmo.int/ – International Civil Aviation Organization

[IOC] ioc-unesco.org http://www.wmo.int/ – Intergovernmental Oceanographic Commission

[GRIB] (GRIdded Binary) – WMO operational open data standard for multiple-dimensioned array data, exchanged daily by WMO, ICAO and IOC, http://www.wmo.ch/pages/prog/www/WMOCodes/OperationalCodes.html

[NetCDF] (Network Common Data Form) - Data Exchange Standard of the Climate and Forecasting community, http://www.unidata.ucar.edu/software/netcdf/

[19] http://www.ec-gis.org/sdi/publist/pdfs/annoni-etal2003eur.pdf
[20] http://www.ec-gis.org/sdi/publist/pdfs/annoni2005eurgrids.pdf