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Infrastructure for Spatial Information in the European Community (INSPIRE) Zenith Tropospheric Delay (ZTD) UML model and implementation of the web application based on the ZTD model

Doctoral (Ph.D.) Thesis

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Acronyms

GNSS Global Navigation Satellite System

E-GVAP European EIG EUMETNET GNSS Water Vapour Programme

ZTD Zenith Tropospheric Delay

INSPIRE Infrastructure for Spatial Information in the European Community

UML Unified Modeling Language

GIS Geographic Information System

XML Extensible Markup Language

GPS Global Positioning System

NAVSTAR Navigation System Using Timing and Ranging

MCS Master Control Station

OCS Operational Control Segment

ZHD Zenith Hydrostatic Delay and Zenith Wet Delay

ZWD Zenith Wet Delay

SA Selective availability

SDI Spatial Data Infrastructure

NSDI National Spatial Data Infrastructure

ESDI European Spatial Data Infrastructure

MS Member States

TC Technical Committee

OGC Open Geospatial Consortium

HTTP HyperText Transfer Protocol

IR Implementation Rules

ITRS International Terrestrial Reference System

EA Enterprise Architect

GML Geography Markup Language

OM Observation and Measurement

GIN Generalized Inverted Indexes

BRIN Block Range Indexes

JSON JavaScript Object Notation

AC-MF Atmospheric Conditions and Metrological Geographical Features

DAL Data Access Layer

SRID Spatial Referencing System Identifier

DML Data Manipulation Language

DDL Data Definition Language

TCL Transaction Control Language

DCL Data Control Language

CRUD Create, Read, Update, Delete

CET Central European Time

POCO Plain Old Common Language runtime Object

IDW Inverse Distance Weighting

JPEG Joint Photographic Experts Group

HTML HyperText Markup Language

CSS Cascade Style Sheet

JS Java Script

DOM Document Object Model

URL Uniform Resource Locator

RGB Red Green Blue

1. Introduction

One of the purposes of the satellite measurement is to examine how the atmosphere affects the GNSS signals. This particular case pays attention to the signal delays due to the neutral atmosphere. However, this research started after finishing the European project ”HUSKROUA - Space Emergency System,” (http://meteognss.net/?action=prj_descript) in which Miskolc University participated with Romanian, Slovakian partners under Ukrainian leadership. The project has been expanded to the Western European EIG EUMETNET GNSS Water Vapour Programme (E-GVAP) network (http://egvap.dmi.dk).

The purpose of the E-GVAP project was to collect and control the global navigation satellite system (GNSS) products, which are operational for the Numerical Weather Prediction (NWP) in the whole of Europe.

Furthermore, the main objective of the E-GVAP project was to get GNSS derived Zenith Tropospheric Delay (ZTD) estimates in real-time for metrological purposes. During these observations, the E-GVAP network is also used to determine tropospheric vapour from satellite observation measurements of the ZTD. These measurements were calculated in the Central and Eastern European countries from 2012 until 2015. After finishing project E-GVAP, it was suggested to elaborate a ZTD data model according to Infrastructure for Spatial Information in the European Community (INSPIRE) Data Specification.

1.1. Research Objectives

The ZTD estimation has been calculated on the base of specific parameters. For this research, it was used ZTD_estimation.TRP file and GNSS-station.xlsx file. The ZTD_estimation.TRP file is an output of the Bernese software analysis. For the calculation of the ZTD data in the Bernese software, it should be selected input parameters, which are very important to get a correct measurement of the ZTD estimation. Input parameters determine many things for the data modelling and the attributes which are calculated on the base of these parameters. The Bernese software was used mainly to process measurements which were collected from the satellites. In this particular case, the measurements were done between satellite and receiver. For the receiver, it was used the metrological station.

The objectives of this thesis work are summarized in the six main theses:

1. Elaboration of the ZTD data attributes and comparison of the relevant INSPIRE Data Specification UML model;
2. Elaboration of the relevant INSPIRE Data Specification UML model and developing an INSPIRE ZTD UML Data model;
3. Creating a web application based on the ZTD data;
4. Development of a new web-based technique for the presentation of the ZTD observations on the maps;
5. Based on inverse distance weighting it has been developed a method for the interpolation of the attributes (stations) inside the ZTD web application;
6. Developing XML files based on the ZTD_estimation.TRP file and their validation;

1.2. Thesis structure

This thesis has been written in 9 chapters. I was starting from the introduction, presenting the purpose of the thesis and research work. There is also an explanation of the project on which is this scientific research was based. Chapters 2, 3, 4 describe the scientific background of this thesis work and which techniques are used for the proposed research.

Furthermore, Chapter 5 presents a short introduction to the experimental part of the thesis and what has been done in the following Chapters. Chapter 6 presents the practical part of the work, and it describes how the ZTD UML data model was created and which Annexes of the INSPIRE has been used for that. All package structures of the ZTD UML model are elaborated, and there is a suggestion of the extension Atmospheric Condition application schema.

Additionally, Chapter 7 represents the developed ZTD web application, which is based on the ZTD UML model. The database is created, and it has fulfilled all INSPIRE requirements. This application is presented like a mini Geographic Information System (GIS) with a few layers in which one we can see heatmaps with ZTD estimation parameters.

On the other hand, in Chapter 8, I have created several XML files based on the INSPIRE standards, and they describe all parameters of the ZTD_estimation.TRP file.

Finally, Chapter 9 summarizes the whole thesis work and gives some propositions for future research.

1.3. Author's contribution

Chapters 2, 3, 4 give a short overview of the scientific background of this work. In Chapter 4, it has been described programming techniques and notations which have been used for creating a ZTD UML model based on the INSPIRE standards and also a ZTD web application. The essential contribution of the author of this research is described in Chapters 6, 7 and 8.

In Chapter 6, I elaborated the first two theses of the research work. I elaborated on ZTD data attributes in the ZTD_estimation.TRP file and based on them, a comparison of the relevant INSPIRE Data Specification UML model is made. In this case, there is an overlap of the two Annexes in INSPIRE, between two application schemas. One is an application schema of the Geophysics (subtheme of the Geology, Annex II) and application schema of the Atmospheric Conditions (Annex III) which is based on the INSPIRE Observation and Measurements.

Furthermore, in Chapter 6, I suggested an extension of the Atmospheric Conditions application schema with the ZTD model. The details of the package structure have been described in this Chapter.

However, in Chapter 7 I suggested a very compact mini GIS system where have been elaborated these theses: creating a web application based on the ZTD data, development of a new web-based technique for the presentation of the ZTD observations on the maps, and based on inverse distance weighting, development of a method for interpolation of the attributes (stations) inside the ZTD web application.

The last thesis is elaborated in Chapter 8, and all XML files which have been made are my contribution. They are based on the ZTD estimation file, which was the input to the whole research together with the GNSS station coordinates.

2. Advanced satellite geodesy – Global Navigation Satellite Systems (GNSS)

The first developed GNSS based on satellite technology is the NAVSTAR Global Positioning System. Pentagon proposed the first global satellite navigation system in 1973. The reason for this proposal was the absence of the system which will be operational for the whole day. GPS was developed as a part of the satellite system, which has been used by the United States Department of Defence. The GPS was a part of the NAVSTAR (Navigation System Using Timing and Ranging) program, and it has highly accurate navigation using radio-based ranging (Havasi & Bartha, Introduction to GIS, 2011).

Launching of the satellites started in 1978, but the system was operational by 1993 and fully functional by 1995 (Parkinson & Spilker, (eds) 1996). Firstly, GPS was created to serve in military purposes. In the year 1983, it was open for civil users but just under some special requirements. It was declared fully operational for civilian purposes in 1994, and from then GPS was used for tracking delivery vehicles to the tracking of human beings.

Russia operates a GLONASS positioning satellite system. Member states of the European Union (EU) has developed its satellite system so-called Galileo. China was working on its satellite system in 2000, and they called him Beidou (Havasi, 2012). All these satellite navigation systems have the same positioning principles, and they are quite similar to the US GPS system. It applies the same GNSS theory and algorithms as above mentioned methods (Guochang & Yan, 2016).

In January 2006, the first experimental GIOVE-A satellite began to transmit Galileo signals. Aim of the project Galileo is a constellation of the 30 navigation satellites in orbit by 2020. The goal of the Chinese navigation system is to be a global system that will have 30 satellites in orbit by 2020 (DiBiase, Sloan II, Baxter, & Stroh, 2018).

2.1. Basics of the GPS

The fundamental technique of the GPS operation measures ranges between the receiver and at least four simultaneously observed satellites (Havasi & Bartha, 2011). If the positions of the observed satellites are known, and distances between the receiver and the satellites are measured, one can quickly determine the status of the receiver. The structure of the GPS is based on three segments: space, control, and user segment (Epa.gov, 2015).

The space segment consists of the constellation of the satellites, which transmit radio signals to the users. GPS constellation consists of at least 24 fully operational satellites in six orbital planes. These orbital planes surround the Earth, and each of them contains four slots that are occupied by the baseline. United States has committed to having 24 GPS operational satellites 95% of the time. During the past few years to ensure the commitment of the United States, the Air Force launched 31 GPS operational satellites. These satellites orbit in the Medium Earth Orbit (MEO) at an altitude of approximately 20,200 km. Each GPS satellite circles the Earth twice a day. There are more than 24 GPS satellites of the Air Force, which need to be operational whenever are the baseline satellites decommissioned (GPS.gov, 2019). The representation of the GPS satellite constellation has been represented in Figure 2.1.

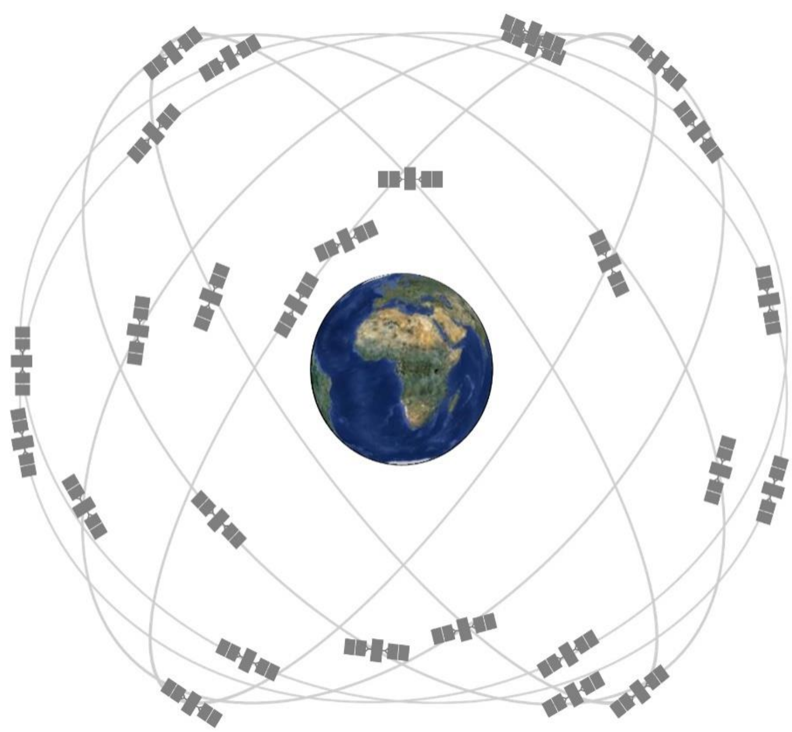

Figure 2.1. Presentation of the GPS satellite constellation (GPS.gov, National Coordination Office for Space-Based Positioning, 2019);

The GPS space segment has the primary function to transmit radio-navigation signals, and it operates on the L1, L2 and L5 frequencies. Also, the space segment has been used for storing and retransmitting the navigation message which has been sent from the control segment (Hoffmann-Wellenhof, Lichtenegger, & Wasle, 2008).

The control segment is focused more on the base task of the GPS. It is responsible for the proper functionality and operation of the system. The GPS control segment has a global network of the facilities which tracks GPS satellites, does the analysis and sends commands and data to the space segment.

It operates a master control station which is in Colorado Springs (North America), and there is also an alternate master control station which has been settling down in Vandenberg (California). There are also 10 more monitoring stations all over the world.

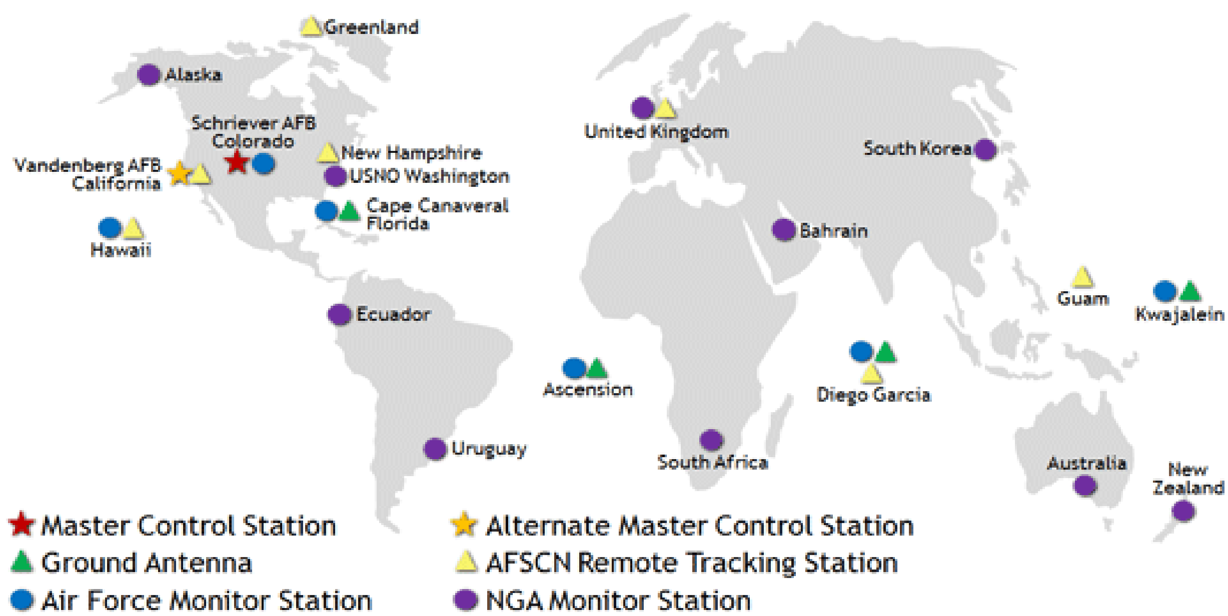

Figure 2.2. The map of the GPS control segment (GPS.gov, 2019);

In the Colorado Springs, there is a Master Control Station (MCS), where are data processed from the other monitoring stations. Master Control Station (MCS) is a part of the Operational Control Segment (OCS), and it also includes an alternate master control station, 11 command and control antennas, and 16 monitoring sites. In Figure 2.2. are illustrated the facilities of the GPS control segment with their locations.

The monitoring stations contain exact caesium clocks. They are used to determine broadcast ephemerides, define the GPS time scale, and put timestamps into GPS navigation message. As it has been known, GPS satellites emit signals on three frequencies L1 (1575.42 MHz), L2 (1227.60 MHz), and L5 (1227.60 MHz). The fundamental frequency (10.23 MHz) has been generated on each atomic clock aboard the satellite. Values of the L1, L2, and L5 rates are made from the fundamental frequency, which has been multiplying by 154, 120, and 115, respectively.

The satellite generates the same carrier frequencies along with satellite ephemerides, ionospheric models, and satellite clock corrections. Pseudorandom noise (PRN) codes modulate all of them. The codes which will be described in the further text serve to measure the transmission of the satellite clock signals to the receiver. These codes are C/A (coarse/acquisition) code, P (precision or protected) code, and navigation message.

The C/A-code repeats itself every millisecond, and it can be detected on the L1 channel. Necessary information which is carried by the C/A code contains the time according to the satellite clock (when the signal was transmitted).

The P-code is more precise and more accurate then C/A code. The total length of the code is approximately 266 days, which is 38 weeks. The one-week segment has been assigned to different satellites. The P-code unlike the C/A code can be encrypted by a process which is known as "anti-spoofing". The "anti-spoofing" or A/S process can be explained like encryption of the P-code. His chip length is 30 m and accuracy 1% of 30 m, when it has been calculated, it is 30 cm (Guochang & Yan, 2016, p. 3).

The navigation message is on the L1 channel, and it is being transmitted in a prolonged rate od the 50 bps. Parameters of the navigation message which has been used to calculate coordinates of the GPS satellites in the arbitrary moment (Blagojević, 2014, p. 123):

- Reference moment of the time satellite ephemerides which are related to Kepler elements – t_{0e};
- The square root of the large half-axis of the satellite orbit – $a^{1/2}$;
- The first numerical eccentricity of the satellite orbit – e;
- The inclination of the satellite orbit in the time reference frame – i_0;
- Longitude of the ascending node of the satellite orbit in the reference time frame which is related to the position of the Greenwich meridian at the beginning of the current GPS week – Ω_0;

- Satellite orbit perineum argument – ω;
- The middle anomaly of the GPS satellite in the time reference frame – M_0;
- The velocity of the change of the satellite orbit inclination – di/dt;
- The speed of the change right ascension of the ascending node of the satellite orbit - $\dot{\Omega}$;
- Correction of the middle satellite circulation – Δn;
- Harmonic coefficients for the calculation of the distance correction to the satellite – C_{rc}, C_{rs};
- Harmonic coefficients for the calculation of the latitude argument correction – C_{uc}, C_{us};
- Harmonic coefficients for the calculation of the satellite orbit inclination correction – C_{ic}, C_{is};

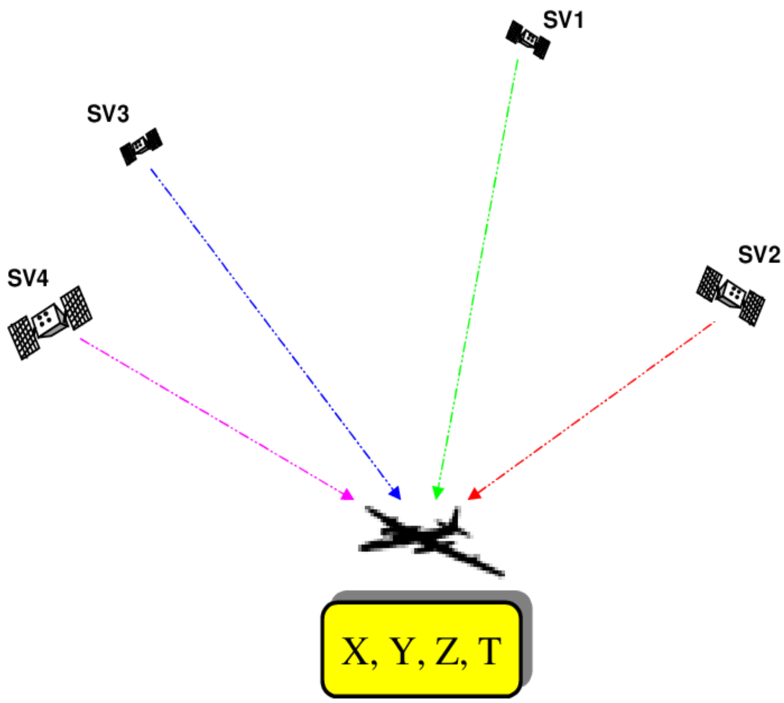

Figure 2.3. GPS Positioning – for unknown *X*, *Y*, *Z*, coordinate of receiver and GPS provided time (Young , 1999);

The navigation message bites are emitted on the frequency of 50 Hz, which means that the duration of the one navigation byte is 20 ms. It needs 12.5 minutes to eject the whole navigation message, but all data which are essential for the positioning and navigation are repeated every 30 s (Blagojević, 2014, p. 110).

2.2. GPS mathematical models

This part will describe mathematical expressions of the GPS measurements, namely, code pseudoranges, carrier phases, and also Doppler effect.

Code pseudoranges and carrier phases are used to measure the same distances, but between them, there are two significant differences. First, the accuracy of the code pseudoranges is on the meter level, while carrier phases are on the status of the millimetre. The second difference is that code pseudoranges are complete measurements of the distances between the receiver and a satellite. Still, the phase carrier is ambiguous because of the unknown number of the whole phase cycles (Blagojević, 2014, p. 13). The pesudorange measurements which are using the C/A code are the most commonly employed. They can obtain a higher level of the measurement precision using the measures of the received phase of the GPS, L1 or L2 carrier.

The code pseudorange, as has been mentioned, is the distance that is measured between satellite and the receiver's antenna. During the GPS signal transmission from the GPS satellite to the GPS antenna, there are a lot of physical influences. The GPS antenna's code, in this case, receiver, has been derived by the clock, which is in the GPS receiver. The satellite generates the GPS signal, which is created by the clock in the GPS satellite. Because of all these mentioned things, pseudorange, which has been measured, is different from the geometric distance between GPS satellite and GPS receiver's antenna.

During the GPS satellite emission of the signal, the time of the discharge has been labelled with t_e and the GPS signal reception of the receiver by the t_r. If we suppose that the electromagnetic wave travels through the vacuum medium in an error-free situation, then the pseudorange, which is measured, corresponds to the measured geometric distance, which is mathematically expressed as:

$$R_r^s\,(t_r, t_e) = (t_r - t_e)c, \qquad (2.1)$$

Where the subscript *r* and *s* represent receiver and satellite and *c* represents the speed of light on the same side (left-hand) t_r present the epoch in which is pseudorange measured and on the different hand (right-hand) the c represents the speed of light. As it has been mentioned, t_e and t_r are the emission and reception time of the GPS signal.

After introducing the receiver and satellite clock errors, the pseudorange expression develops into:

$$R_r^s(t_r, t_e) = (t_r - t_e)c - (\delta t_r - \delta t_s)c, \quad (2.2)$$

In this Eq. δt_r and δt_s represents the clock errors of the satellite and receiver.

The geometric distance (Eq. 2.1) can be calculated using the relation:

$$\rho_r^s(t_r, t_e) = \sqrt{(x_s - x_r)^2 + (y_s - y_r)^2 + (z_s - z_r)^2}, \quad (2.3)$$

As it has been explained, the t_r and t_e correspond to the timestamps of sending t_e and receiving t_r an electromagnetic wave. In the Eq. 2.3 the vector, which is a function of the time, in this case, t_e is the satellite coordinate vector (x_s, y_s, z_s), and the coordinate of the receiver (x_r, y_r, z_r) is in the function of the time t_r.

Furthermore, if we take into consideration: ionospheric effects, tropospheric effects, the Earth's tide effects, multipath and relativistic effects, and all other errors, the model of the pseudorange distances (Eq. 2.1) becomes:

$$R_r^s(t_r, t_e) = \rho_r^s(t_r, t_e) - (\delta t_r - \delta t_s)c + \delta_{ion} + \delta_{tro} + \delta_{tide} + \delta_{mul} + \delta_{rel} + \varepsilon. \quad (2.4)$$

The above equation represents the measured pseudorange, which is equal to the geometric distance from the satellite (at the time of the emission) to the receiver's antenna (at the time of the reception), minus or plus few corrections. The errors which are described in the pseudorange model (Eq. 2.4) are clock error corrections which are multiplied with a velocity of the light c, then δ_{ion} and δ_{tro} which are ionospheric and tropospheric effects, δ_{tide} Earth's tide and ocean loading tide effects, δ_{mul} represents multipath effects, and δ_{rel} is a relativistic effect. Everything else, which means all other errors is labelled with ε (Guochang & Yan, 2016, pp. 56-57).

The carrier phase is a measure of the satellite signal phase, which is received and relative to the receiver generated carrier phase in the time of the reception.

On the other hand, if we compare code and phase measurements, the phase is more precise then the code measurement. This statement can be proved very easy, by measuring the fractional carrier phase by electronics with outstanding precision of the wavelength, which is on the millimetre level. If it has been considered that the signal is travelling through the vacuum and error-free medium, the measured phase can be formulated as:

$$\Phi_r^s(t_r) = \Phi_r(t_r) - \Phi^s(t_r) + N_r^s, \tag{2.5}$$

In (Eq. 2.5) Φ_r^s presents the receiver and satellite carrier phase, t_r is the time of the GPS signal reception by the receiver. Φ_r represents the phase of the receiver's oscillator, and Φ^s is the signal phase that is received from the satellite. The last parameter in the Eq. 2.5 is the N_r^s integer ambiguity.

If we consider that the received phase of the satellite signal at the time of the reception is the same as the phase of the emitted satellite signal during the time of the emission, the transmission of the signal phase can be expressed as (Remondi, 1984) and (Leick, 1995):

$$\Phi^s(t_r) = \Phi_e^s(t_r - \Delta t), \tag{2.6}$$

where Φ_e^s represents the emitted phase of the satellite, and Δt is labelled as the GPS signal transmission time. Time difference Δt is defined as:

$$\Delta t = \frac{\rho_r^s(t_r, t_e)}{c}, \tag{2.7}$$

The $\rho_r^s(t_r, t_s)$ represents geometric distance, which is measured between a satellite at the time of emission t_e and a GPS antenna during the time of the reception t_r. c represents the speed of light. If we suppose that the initial time is zero and the two signals are in phase, then the received satellite signal and the reference carrier of the receiver have the nominal frequency f. The speed of the light has a relation with the frequency and the wavelength, and it is defined by the (Eq. 2.8):

$$c = f\lambda \tag{2.8}$$

As it has been mentioned, the reference carrier of the receiver has nominal frequency f, then

$$\Phi_r(t_r) = f(t_r), \tag{2.9}$$

$$\Phi_e^s(t_r - \Delta t) = f(t_r - \Delta t). \tag{2.10}$$

If we take into consideration ionospheric effects, tropospheric effects, Earth's tide and loading tide effects, multipath and relativistic effects, and also other errors, the carrier phase model can be defined using the expression:

$$\Phi_r^s(t_r) = \frac{\rho_r^s(t_r, t_e)}{\lambda} - f(\delta t_r - \delta t_s) + N_r^s - \frac{\delta_{ion}}{\lambda} + \frac{\delta_{tro}}{\lambda} + \frac{\delta_{tide}}{\lambda} + \frac{\delta_{mul}}{\lambda} + \frac{\delta_{rel}}{\lambda} + \frac{\varepsilon}{\lambda} \tag{2.11}$$

Development of (Eq. 2.11) yields to;

$$\lambda\Phi_r^s(t_r) = \rho_r^s(t_r, t_e) - (\delta t_r - \delta t_s)c + \lambda N_r^s - \delta_{ion} + \delta_{tro} + \delta_{tide} + \delta_{mul} + \delta_{rel} + \varepsilon. \tag{2.12}$$

In the (Eq. 2.12), on the left-hand side, the wavelength λ equals the measured phase of the geometric distance between the satellite during the emission time and the antenna during the reception time. The carrier phase model also describes several corrections which are defined like, δ_{ion} and δ_{tro} which are ionospheric and tropospheric effects, δ_{tide} Earth's tide and ocean loading tide effects, δ_{mul} represents multipath effects, and δ_{rel} is a relativistic effect. Everything else, which means all other errors is labelled with ε. The errors of the clock multiply with c, which is the speed of the light (Guochang & Yan, 2016, pp. 55-59).

The Doppler effect can be described with the phenomena of electromagnetic waves. Their wavelength and frequency change when the source of the stream moves relative to the receiver. This phenomenon is a characteristic of all types of waves, not just electromagnetic. The wonder of the Doppler effect got a name by the Austrian physicist Christian Doppler who has first described it in 1842 (Blagojević, 2014, p. 61).

2.3. Delay in the troposphere

The troposphere is an area of the atmosphere that extends from the physical surface of the Earth to an altitude of about 40 km. The difference between the ionosphere and the troposphere is in that the troposphere is not a dispersive medium for radio waves within the frequency range of 100 MHz to 15 GHz. The troposphere is a dispersive medium for electromagnetic waves within the visible light spectrum (Blagojević, 2014, p. 67).

The data which has been collected from the various number of satellites during the specific period can generate an atmospheric delay and also clock errors and phase uncertainties. As mentioned earlier, the upper layers of the ionosphere have a dispersive nature, and it affects all GPS frequencies. The mathematical combination of L1 and L2 signals defines the same way of the influence and L3, which is called an ionosphere-free linear combination, can be made. In that way, the first-order ionospheric delays can be eliminated. The second-order effects are also present, but the purpose of this scientific background is not essential. The L3 ionospheric-free linear combination can be described with the mathematical expression:

$$L_3 = \frac{f_1^2}{f_1^2 - f_2^2} L_1 - \frac{f_2^2}{f_1^2 - f_2^2} L_{2.} \tag{2.13}$$

Concerning the GPS receiver, the local atmosphere is assumed to be horizontally homogenous, and based on this scientific presumption, and slant path delays can be mapped into the vertical and unknown numbers can be more reduced. In this thesis, the focus is put on the tropospheric zenith delay so that the slant path delay will be ignored.

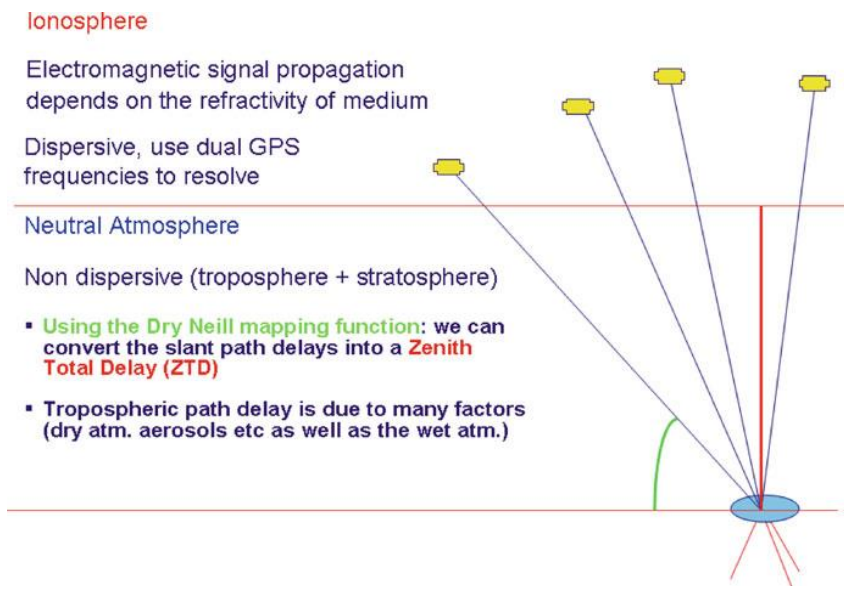

Figure 2.4. Travelling of the satellite signal through the atmosphere (Jones et al., 2019, p. 10);

The delay in the troposphere can be expressed with:

$$\Delta^T = \int_s n ds - \int_g dg \tag{2.14}$$

where n is the refractive index, s is the actual signal path, and g is the hydro-technical geometric path. The zenith angles are very high only in the situations when geometric path length cause changes in the refractivity index. Today in the current use, most GPS receivers are set on the elevation cut off angles of either 5° or 10° which can minimize the multipath effect and also eliminates the geometric delay of the signals which have been reflected off the Earth's surface. By the (Smith & Weintraub, 1953) and (Thomson, Moran, & Swenson, 1986, p. 720) the refractivity N is defined as $N = 10^6(n\text{-}1)$. The refractivity in the microwave range has been related to the atmospheric parameters. This relation has been expressed by:

$$N = k_1 \frac{p_d}{T} Z_d^{-1} + k_2 \frac{e}{T} Z_w^{-1} + k_3 \frac{e}{T^2} Z_w^{-1}. \tag{2.15}$$

The following parameters are labelled as p_d what represents the pressure of the dry air, e is the water pressure, T is temperature, Z_d and Z_w are the factors of the dry air and water vapour, respectively, and finally, k_1, k_2 and k_3 are thermodynamic coefficients. By (Thayer, 1974, pp. 803-807), the values of these coefficients are 77.6 KhPa^{-1}, 70.4 KhPa$^{-1,}$ and 373900 K2hPa^{-1}, respectively.

2.4. The physical phenomena of the Zenith Tropospheric Delay

During the software processing of a large number of GPS measurements, one of the standard outputs is ZTD. The ZTD is based on the phase measurement from the network of the GPS receivers on the ground, and it has two constituent parts: Zenith Hydrostatic Delay (ZHD) and Zenith Wet Delay (ZWD). These terms are in the most common use in the GPS meteorology. For the vast majority of the ZTD delay is responsible ZHD: around 90%. The ZWD is often used in meteorology, and it can be changed rapidly in time and space. Using the parameters from the (Eq. 2.15), Z_d and $Z_{w,}$ and if it is assumed that they are ideal gases, then these parameters are equal to 1 by the (Bevis, et al., 1992, pp. 15787-15801). If we assume this they can be eliminated, we can separate dry and wet component into the dry and wet partial pressures and they can be expressed with:

$$\rho_d = \frac{p_d}{R_d T} \tag{2.16}$$

$$\rho_w = \frac{e}{R_w T} \tag{2.17}$$

In equations 2.16 and 2.17, R_d and R_w are the gas constants of the dry and wet vapour. The air density can be defined as $\rho_d + \rho_w$ so the refractivity can be formulated as:

$$N = k_1 \frac{p_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2} \tag{2.18}$$

Furthermore, the path has been predicted to be zenithal, so the ZTD is equal to the Δ^T so that ZTD between the receiver altitude z_r and infinity is defined like:

$$ZTD = 10^{-6} \int_{z_r}^{\infty} N dz$$

(2.19)

Then from the (Eq. 2.19), the ZTD can be further presented as:

$$ZTD = 10^{-6} \int_{z_r}^{\infty} k_1 \rho R_d \, dz + 10^{-6} \int_{z_r}^{\infty} (k_2 R_w - k_1 R_d) \, \rho_w dz + 10^{-6} \int_{z_r}^{\infty} \frac{k_3 \rho_w R_w}{T} \, dz.$$

(2.20)

2.5. The program of the GPS modernization

During the time, there are many initiatives to upgrade GPS with new capabilities, which will serve better in the military, civil and commercial needs (GPS.gov, National Coordination Office for Space-Based Positioning, 2019). By (Shaw, 2011), this program should consider consecutive satellite acquisitions. GPS modernization includes the following initiatives: ending selective availability, new civil signals, new GPS satellites, and the control segment upgrades.

Firstly, the modernization started when the use of selective availability SA was finished. That occurred in May 2000. After turning off SA, civil GPS accuracy was improved immediately. The new satellite generation released in 2007, and they did not have the SA feature.

Secondly, the main focus of the GPS modernization was on the navigation signals in addition to the satellite constellation. In the future, the legacy civil signals will continue to broadcast. The most significant number of the new signals will be limited to broadcast from 18 to 24 satellites.

Finally, the most essential GPS control segment program has been updated continuously. The original master control station was upgraded with a new one in September 2007. The new master control station is entirely operated and can command and control a constellation of up to 32 satellites (Guochang & Yan, 2016, pp. 5-6).

3. INSPIRE (Infrastructure for Spatial Information in the European Community)

The term infrastructure, as a mechanism of support for spatial data, has been used for the first time in the early 1990s in Canada. Today, the concept of spatial data infrastructure (SDI) has become a worldwide new paradigm for the collection, use, exchange, and distribution of spatial data and information. Spatial data infrastructure has joint throughout sets of spatial data, metadata, agreements for everyday spatial data use and distribution, network services, and related coordination activities. SDI is always present in a specific form, but the level of implementation varies according to current demand and technological readiness. Subjects can be classified at several basic levels – from personal and corporative, through local and county, to national, regional, and finally, global. Today, the most fundamental level is the national one, i.e., the National Spatial Data Infrastructure (NSDI) project (OG 16/2007) and INSPIRE Directive (Infrastructure for Spatial Information in the European Community - 2007/2/EC) (Mijic & Sestic, 2018). Without spatial data and related services, it would be impossible to manage space effectively, plan city development and infrastructure networks, monitor situations on the ground, or carry out many other activities.

This chapter gives an overview of what has been happening throughout the time with the INSPIRE Directive starting in 2007. including legislative regulations, technical requirements, assumed standards, scientific methodologies, developed data specifications, and, finally, resulting in software tools and services. The assessment also describes overall country-wise alignment to INSPIRE standards and services implementation throughout EU member states, thus their readiness for fully standardized data acquisition, representation, and exchange on national and regional levels. As a result of this, it represents country-specific implementation assessment including the following indicators: (a) legislative conformance with imposed INSPIRE regulations, (b) technical SDI conformance with set standards and data specifications, and (c) implemented INSPIRE-compliant systems, services, and datasets.

3.1. Introduction to the INSPIRE Directive (Infrastructure for Spatial Information in the European Community

The INSPIRE Directive aims to create a European Union spatial data infrastructure. Spatial data infrastructures (SDI) exist for quite a long time, actually from the moment when the first spatial data were collected and presented in maps and plans (Groot & Mc Laughlin, 2000). With the rapid development of spatial data collecting and communication technologies, spatial data infrastructure is becoming a more and more critical factor in the way of spatial data usage at the level of private and public sector, or state, and ultimately at the global level. President Clinton's Executive Order No. 12906 from 1994 played an important role and a stimulus for the creation of national spatial data infrastructures (Executive order 12906, 1994). Besides national spatial data infrastructures, different initiatives at regional (EUROGI, PCGIAP…) and global level (GSDI) were also included (Phillips, Rajagopalan, & Rosenzweig, 1999). Sets of essential spatial data also vary from country to country, and each national spatial data infrastructure is different concerning social needs, sociological evolution, economic reality, and national ambitions and priorities. The efficient land management with sustainable development, and the planning of all land operations, demands for spatial files arrangement and modernization, and establishment of national spatial data infrastructure. Its establishment demands for full coordination and cooperation between the provider and the spatial data user, as well as between public and state institutions (Messer, 2000). The aim of national SDI is precise: 1) to share data evaluation and eliminate duplicated efforts in data evaluation; 2) to make geographic-based data worldwide easily accessible; 3) to support the seamless integration of geographic data from different sources. Unfortunately, spatial information in Europe can be described as fragmentations of datasets and sources, gaps in availability, lack of interoperability, or harmonization between datasets at different geographical scales and duplication of information collection. Therefore, several SDI initiatives in Europe can lack a coherent, Europe full framework.

For instance, which standards should be used, how to formulate data sharing policies, and more critical, which generally feature models (i.e., for example, attribute names, standard spatial reference models, etc.) to follow. The multilingual nature of the European Union further increases this complexity. However, awareness was growing at national and at EU level about the need for quality georeferenced information to support understanding of the complexity and interactions between human activities and environmental pressures and impacts. Thanks to this awareness, in September 2001, an E-ESDI Expert group, representing geoinformation experts of the European Commission, the European Environmental Agency, and Member States' environmental and national mapping bodies started elaboration a proposal for European directive to establish a European Spatial Data Infrastructure (ESDI).

The adoption of the proposal for a directive on establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) by the European Commission in July 2004 marked the first important step on the way to a European-wide legislative framework to achieve a European Spatial Data Infrastructure. The first overview of an organizational and a process model for INSPIRE was elaborated in a preparatory phase (2005-06). Five drafting teams have been nominated, and each been mandated to draft implement rules according to the next five components of INSPIRE:

- Interoperability of Spatial Data Sets and Services - enlisting 34 data topics that shall be made available in the final infrastructure (see later ISO 19100 series).
- Metadata - to allow the discovery and evaluation of INSPIRE relevant data sets and services in Europe (see later provision for Metadata).
- Network Services - to make it possible to discover, transform, view, and download spatial data and to invoke spatial data and e-commerce services (see later provision for Network Services).
- Data Sharing - to allow secure possible data exchange between public bodies and to allow third parties, especially citizens, to have as much as possible free and easy access to spatial information covered by INSPIRE (see later provision for data policy).
- Coordination and Complementary Measures – to monitor the organizational and management aspects of the INSPIRE implementation. In March 2007, the INSPIRE proposal was adopted as Directive 2007/2/EC of the European Parliament and the Council; the Directive was published in the Official Journal on the 25th April 2007 (Directive INSPIRE, 2007). The overall implementation may take more than ten years, thus by 2019, and INSPIRE can be expected to be fully implemented.

3.2. Components of the INSPIRE

Interoperability is the base of standardization. Standardization has three-level in EU member states (MS). There is an internationally accepted level that is adopted at the European level and finally implemented at the national level. In the case of INSPIRE, the ISO 19100 series was selected as an international standard for the technical base (Bartha & Kocsis, 2011).

The standards are summarized in (www.inspire.ec.europa.eu, 2017). ISO Technical Committee has elaborated this series (TC) 211 as Geographic information/Geomatics standard based on the proposals of Open Geospatial Consortium (OGC), World Wide Web Consortium (W3C), Object Management Group (OMG), Organization for the Advancement of Structured Information Standards (OASIS) (ISO/TC 211 Advisory Group on Outreach, 2009:Standards Guide ISO/TC 211, 2009). The standardization has been started in 2001 and still is in process. The standards specify the IT and the Geographic aspects of Spatial Data Infrastructure and fall into five categories:

- Standards that specify the infrastructure for geospatial standardization.
- Standards that describe data models for geographic information.
- Standards for geographic information management.
- Standards for geographic information services.
- Standards for the encoding of geographic information.
- The standard for a specific thematic.

ISO 19100 series of standards was adopted as the technical base of INSPIRE by the European standardization organization Comité Européen Normalisation - CEN TC/211. Their implementation was included in 34 themes. The themes are subdivided into three groups and included in the INSPIRE directive in three Appendices.

Member States should make the metadata available for the themes in Appendices I and II in 2010, and the themes in Appendices III in 2013 can be seen on the following web page (http://inspire.ec.europa.eu/search?search_api_views_fulltext=apex+3+2013, 2017).

Metadata contains details about the owner of the geographic data, quality, validity, etc., and how it can be traced and used. The ISO 19115 International Standards defines metadata elements, provides a schema, and establishes a standard set of metadata terminology, definitions, and extension procedures. This International Standard specifies the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data. This International Standard is accomplished with two other ones, namely ISO 19118 and ISO/TS 19139, concerning metadata encoding. International standard ISO 19118 describes the requirements for creating encoding rules based on Unified Modeling Language (UML) schemas. At the same time, ISO/TS 19139 defines Extensible Markup Language (XML) as selected encoding language for geographic metadata. The INSPIRE Metadata Regulation entered into force on 24 December 2008 (European Commission 2008). The member states must provide the metadata for data sets and services listed in Annex I and II of the Directive. A revised version of the TG to implement the Regulation using EN ISO 19115 Metadata and EN ISO 19119 Services was also published on the INSPIRE web site in June 2010 (http://inspire.jrc.ec.europa.eu, 2017).

Metadata regulation ISO 19115 is explained better in the Technical Specifications shown in (http://inspire.ec.europa.eu/search?search_api_views_fulltext=ISO+19115, 2017).

Network services are required from Member States (MS), and they are better explained in the (http://inspire.ec.europa.eu/search?search_api_views_fulltext=ISO+19115, 2017) INSPIRE Directive as follows:

- Discovery services making it possible to search for spatial data sets and services based on the content of the corresponding metadata and to display the content of the metadata;
- View services making it possible, as a minimum, to communicate, navigate, zoom in/out, pan, or overlay viewable spatial data sets and to display legend information and any relevant content of metadata;
- Download services, enabling copies of spatial data sets, or parts of such locations, to be downloaded and, where practicable, accessed directly;
- Transformation services, enabling spatial data sets to be transformed to achieve interoperability;

- Invoke services allows a user or client application to run them without requiring the availability of GIS services allowing spatial data services to be invoked;
- The registry is not a standard service, but obviously, all INSPIRE based services should provide a kind of record for the stored data.

The INSPIRE networks are web-based services; therefore, they use HTTP (HyperText Transfer Protocol). The data are structured according to the rules of UML (Unified Modeling Language). UML is a graphical planning frame to establish the structure of problem-solving, or datasets, respectively. The data are described in XML (extensible Markup Language). XML an object-oriented, generalized markup language. The XML datasets are accessed in the SOAP (Simple Object Access Protocol) frame.

The characteristic features of INSPIRE network services and data management are summarized in (http://inspire.ec.europa.eu/search?search, 2017). Data sharing - legal and administrative measures to allow an as easy possible data exchange between public bodies and to allow third parties, especially citizens. Commission Regulation guarantees it No 1089/2010 based on the reports (European, Commission, 2010b) and (European, Commission, 2011) of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and the Council as regards the interoperability of spatial data sets and services. Monitoring and reporting On 5 June 2009, the Commission Decision implementing Directive 2007/2/EC of the European Parliament and the Council as regards monitoring and reporting were adopted (European, Commission, 2009b).

3.3. INSPIRE Development

The implementation, development, and research done in MS published in country fiche template documents, reporting information providing together with a comprehensive view. The template consists of several components:

- Information extracted from the report on the status of implementation and operation of the infrastructure (State of Play);
- Information extracted from the monitoring data on the status of implementation (automatically generated content from INSPIRE Dashboard);

- MS action plan info: MS objectives, actions and roadmap to reach INSPIRE implementation objectives;
- Summary (based on overall information including bilateral meetings);
- Specific recommendation (optional).

Country fiche template contains all legally binding information given in INSPIRE Directive, Article 21 (http://inspire.ec.europa.eu/legislation-details/directive-20072ec-article-21, 2017):

- The Member States shall monitor the implementation and use of their infrastructures for spatial information. They shall make the results of this monitoring access to the Commission and the public permanently.
- No later than 15 May 2010 Member States shall send the Commission a report including summary descriptions of:
  a) how public sector providers and users of spatial data sets and services and intermediary bodies are coordinated, and of the relationship with the third parties and the organization of quality assurance;
  b) the contribution made by public authorities or third parties to the functioning and coordination of the infrastructure for spatial information;
  c) information on the use of the infrastructure for spatial information;
  d) data-sharing agreements between public authorities;
  e) the costs and benefits of implementing this Directive.
- Every three years, and starting no later than 15 May 2013, Member States shall send to the Commission a report providing updated information concerning the items referred to in paragraph 2.
- Detailed rules for the implementation of this Article shall be adopted following the regulatory procedure referred to in Article 22(2).

Maintenance and Implementation Framework (MIF) is an informal collaboration between the EU level partners (namely the European Commission, mainly Directorate-General for Environment (DG ENV) and Joint Research Center of the European Commission (JRC), and the European Environment Agency (EEA), short the EU Coordination Team “CT”) and the Member State competent authorities responsible for the INSPIRE implementation (Villa, Di Matteo, Lucchi, Millot, & Kanellopoulos, 2008).

It has built on the work of the consultative process to prepare the numerous Implementing Acts (https://ies-svn.jrc.ec.europa.eu/projects/mig-p/wiki/5th_MIG-P, 2017) for the INSPIRE Directive and is now maintaining them. It also made useful guidance documents and exchanged acceptable practices, even with the help of EU-funded projects.

Moreover, stakeholder engagement was part of the activities from the outset. Besides, the main achievements over the past years are, in particular:

- Guiding the Member States by developing technical guidelines;
- Corrective maintenance of the INSPIRE framework by managing and resolving issues in technical guidelines and preparing proposals for change for Implementing Acts;
- Adaptive maintenance of the INSPIRE framework;
- Development of tools supporting implementation;
- Building capacity in the Member States for INSPIRE implementation; Maintenance and Implementation Group (MIG) is a formal body to monitor the performance and development. Their Working Program (MIWP) for 2017-2020 contains:
- The Digital Single Market initiatives with particular relevance for the INSPIRE Directive, namely the free flow of data initiative, the e-Government Action Plan and the European Interoperability Framework, where synergies can be created;
- The Better Regulation agenda driving efficiency and effectiveness whereby the INSPIRE Directive can help reducing administrative burden while enhancing the access to evidence for policymaking and implementation;
- The Environment policy plan based on the 7th Environment Action Programme with a strong emphasis on implementation;
- The link to EU policies and other international initiatives, in particular, Copernicus, the HORIZON 2020 list, the United Nations Committee of Experts on Global Geospatial Information Management (UN GGIM), and GEO where INSPIRE already plays an important role;
- Agenda 2030 and the need for geospatial data in achieving and monitoring the SDGs. Also, the Census 2021 will be a driver for NSIs to modernize their statistical production and use addresses, buildings, or cadastral parcels to link to analytical data;

- The national eGovernment and Open Data initiatives, where the convergence of efforts and alignment of implementation rules would partially address the omnipresent resource issues;
- On all these and other initiatives not explicitly listed here, the MIWP 2017- 2020 can play an essential role in contributing and can act as a platform to explore and exploit synergies to the maximum extent in a collaborative and consultative spirit that dominated in the INSPIRE implementation from the outset.

3.4. INSPIRE Perspectives

Vision for a European spatial data infrastructure for EU's environmental policies and policies or activities which have an impact on the environment (http://inspire.ec.europa.eu/legislation-details/directive-20072ec-article-1, 2017), is to put in place easy-to-use, transparent, interoperable spatial data services which are used in the daily work of environmental policymakers and implementers across the EU at all levels of governance as well as businesses, science and citizens to help to improve the quality of the environment and to lead to effectiveness gains and more simplification. When talking about users, it is clear that public authorities dealing with the situation (e.g., from EU policy-making to national implementation to local enforcement) are the initial primary beneficiary of the INSPIRE implementation.
Nevertheless, just about any public authority that uses spatial data can benefit, such as an agriculture department or the transport authorities. In particular, the collaboration between the INSPIRE implementation and the eGovernment initiatives in many countries has widened the potential user base. Eventually, academics, researchers, non-governmental organizations, businesses, and citizens are also expected to benefit. The industry will most likely be encouraged to develop new electronic applications for markets interested in (quality) geospatial information - for example, providing shoppers with the locations of bank machines, insurance companies with details on flooding hazards, or cyclists with cycling shop locations, delivered through personal mobile phones.

- Therefore, user demands will become more critical in the strategic direction as a basis for this work program, in addition to the continued "support for implementation". The main other working areas are:
- to assess the fitness for the INSPIRE framework and promote simplification "Fitness for purpose": Making INSPIRE “fit for purpose” supporting solution-oriented end-user perspective;
- to deliver short term results (quick win applications) including helping to streamline reporting (which is one use case but not the only one) "End-user applications" for environmental reporting and implementation;
- to ensure alignment and synergies with EU emerging policies and initiatives "Alignment with EU policies/initiatives," creating a platform for cooperation.

The new strategic direction will guide the MIWP 2017-2020 and result in immediate actions so that we demonstrate that the INSPIRE Directive can be implemented in a proportionate, faster, and pragmatic way. This strategy is the centrepiece of the new MIWP 2017-2020. Given the significant scope and ambition of the INSPIRE Directive, the implementation process overall would benefit from stricter EU priority setting. This would allocate the limited resources on those issues with the highest priority and where tangible benefits for environment policy can be expected. It would also strengthen the cross-border and EU dimension of the INSPIRE Directive implementation because interoperability can only be successful if all partners (EU, national, regional and local administrations) share the same priorities so that we all “pull in the same direction.” Hence, when defining new actions for the MIWP, the following criteria for priority setting should be considered (which would replace the prioritization template currently used):

1. Engage users!
2. Addressing emerging priorities (EC and MSs);
3. Demonstrate short term benefits of current investment;
4. Make the INSPIRE framework more productive and better exploitable;
5. Facilitate implementation (e.g., through appropriate simplification measures);
6. Ensure sustainability of INSPIRE;

7. Adapt to changes (e.g., driven by the Digital Single Market or Better Regulation).

As regards priority setting concerning spatial data covered by the INSPIRE Directive, the following approach, from the EU (reporting) perspective, has been introduced for discussion. They do not neglect user needs for planning, running and monitoring environmental infrastructures. Any priority-setting approach has its intrinsic logic that one area is prioritized over another but that ultimately, step-by-step, all issues get addressed systematically and efficiently. Any EU priorities complement any national and other preferences which are set elsewhere and do not alter in any way the legal obligations set out by the Directive.

3.5. INSPIRE digital data models

The basic of the environmental policies lay down in all public authorities from the aspect of the Infrastructure for spatial information in the European Community. The institutions and bodies in the Community need to integrate spatial data for all MS (Member States). The INSPIRE recognizes that it needs to be able to gain access to spatial data and services and use it following harmonized conditions. Directly in the Directive, there are concrete measures on how to implement data, and this is the responsibility of each MS. The regulations for adopting INSPIRE Data and Service Sharing was started on the 29th of March 2010. The implementing rules in INSPIRE are based on the spatial data sets and services; also, there is data specification guidance, which is based on the UML models created by the INSPIRE Thematic Working Groups. The rules of the implementation were adopted as Commission Decision and Regulations, and they are binding in their entity (MIG-T, 2016). The INSPIRE is based on the infrastructures of the spatial information which is established and operated by the 28 MS of the European Union. The key of this Directive is 34 spatial data themes that are needed for the environmental applications with the critical component which has been specified through implementing rules.

This Directive requires standard implementation rules (IR), and they are adopted in these areas:

- Metadata;

- The interoperability and harmonization of spatial data and services for selected themes (as described in Annexes I, II, III of the Directive);
- Network Services;
- Measures on sharing spatial data and services;
- Co-ordination and monitoring measures.

In the INSPIRE directive, data specification is based on the UML data models, XML schemas, and Feature Catalogue, which has been developed by the INSPIRE Thematic Working Groups (Inspire, 2017).

3.5.1. Data and service sharing

The process of sharing data and services is related to the provision of a sustainable structure to develop, facilitate, and streamline. For the sharing activities, the essential step is the coordination, and it enables access and use of the spatial data sets. These structures often include secure, accessible view services for the stakeholders and the general public, which has been defined under Article 14 and other critical operational capacities for the SDI such as data harmonization and research of the development efforts. The excellent structure for coordination of the data sharing should provide:

- A clear view of the roles of the various stakeholders and their respective responsibilities;
- A clear view of the processes involved. The methods should provide for vertical and horizontal communication, information to potential participants on how to be included in the data sharing, and how to solve problems and conflicts.
- Planning should include practical administrative and technical infrastructure support, for example, template licenses, repositories, registries, and frontline assistance such as helpdesk, hotline, and consultancy.
- Central access point to spatial data sets and services that provides all the relevant information for access and use.

The policy also should take into consideration who is the stakeholder because it is not necessary to be an individual institution. The responsibilities of the stakeholders must include planning, monitoring, problem-solving, and settlement of disputes. If it is considered in the context of the INSPIRE data and service sharing, transparency on the data is about the Member States and their public authorities. It should be clear what kind of data and services are available and how they can be obtained and used. The most important thing about data transparency and, also, the benefits is that the user can evaluate the data whatever they are available, and they meet his needs and requirements. The information can be known as metadata, but some other additional information should also be possible if it is requested to allow an assessment of fitness for the purpose to be made. The multilingual transformation can offer transparency without delay to all MS and their public authorities as well as to the European Community. The most important criteria for achieving transparency are:

- Metadata is up-to-date and available;
- Additional technical information can be readily made available to allow assessment for fitness for purpose;
- All conditions of use are specific, complete, published online and available for the public;
- Precise contact details and speedy process for acquiring further information about all aspects of the data;
- Multilingual information is made available if needed (e.g., European level);
- Metadata is up-to-date and available;
- Metadata is being kept up-to-date frequently and is available via the network services;
- Additional technical information can be readily made available to allow assessment for fitness for purpose.

The data which are quite often are used for different purposes from those for which it was collected. Much information is available in metadata, additional technical information on source and quality should be provided to allow decisions that the data can be used for different purposes (Drafting Team – Data and Service Sharing, 2013).

3.5.2. Requirements for spatial data themes

Definitions of the coordinate reference system which has been set out in Article 2 and that should be applied:

- ‘datum’ means a parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system, following EN ISO 19111;
- ‘geodetic datum’ means a datum describing the relationship of a coordinate system to the Earth, following EN ISO 19111;
- ‘coordinate system’ means a set of mathematical rules for specifying how coordinates are to be assigned to points, under EN ISO 19111;
- ‘coordinate reference system’ means a coordinate system that is related to the real world by a datum, following 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, per 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, under 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, under EN ISO 19111.

The datum of the European Terrestrial Reference System 1989 (ETRS89) is defined for the three dimensional and two dimensions coordinate reference system and the horizontal component of the compound coordinate reference systems which have been used for making data sets available. The ETRS89 is defined in the areas within its geographical scope or the datum of the International Terrestrial Reference System (ITRS) or the other geodetic coordinate reference system which is compliant with ITRS in areas that are outside the geographical scope of ETRS89. The system which is compliant with ITRS means that the system definition is based on the meaning of the ITRS and there is a relationship between both systems due to the EN ISO 19111 (Commission regulation, 2010).

3.5.3. INSPIRE implementing rules

The purpose of the INSPIRE Directive was to enable the formulation, implementation monitoring activities, and evaluation of Community environmental policies on all levels. All levels consider European global and local standards to provide public information. The MS has created an infrastructure for spatial information called INSPIRE. Those infrastructures have several components and they include metadata, spatial data themes (Annex I, II, and III), network services and technologies. There are also agreements on data sharing, access and use, coordination and monitoring mechanisms, processes, and procedures. The main principles of the INSPIRE are:

- that the infrastructures for spatial information in the Member States should be designed to ensure that spatial data are stored, made available and maintained at the most appropriate level;
- that it is possible to combine spatial data from different sources across the Community in a consistent way and share them between several users and applications;
- that it is possible for spatial data collected at one level and they should be shareable between different levels of all public authorities;
- that spatial data are made available under conditions that do not restrict their extensive use; and,
- that it is easy to discover available spatial data, to evaluate their fitness for purpose and to know the conditions applicable to their use.

Figure 3.1. shows the relationship between INSPIRE implementation rules and Technical Guidance.

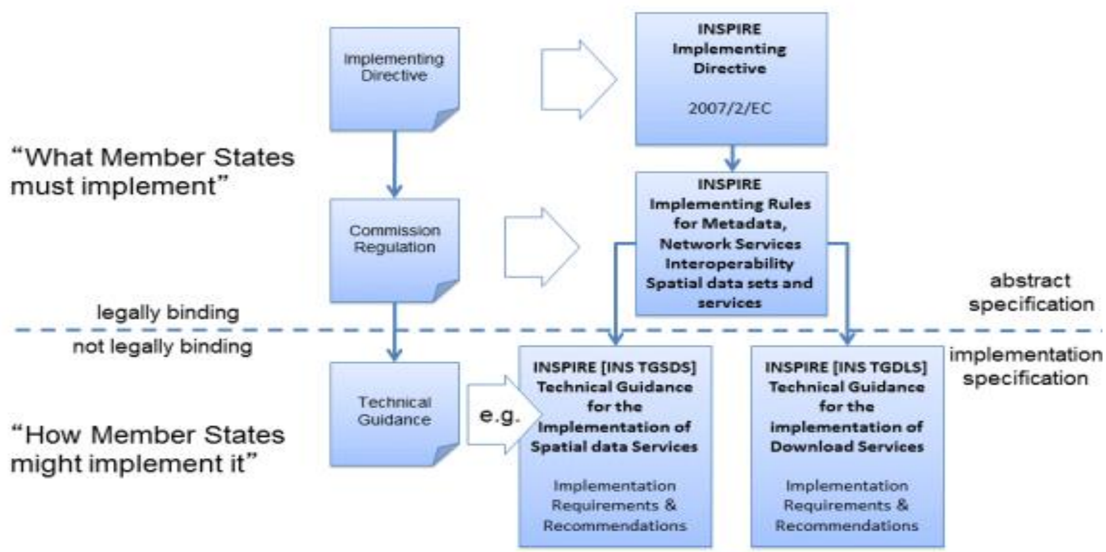

Figure 3.1. The relation between INSPIRE implementing rules and TG (MIG-T, 2016);

Technical documentation should be used to facilitate the implementation of the Directive 2007/2/EC. All reading, which is regarding the law, should be derived from Directive 2007/2/EC and other applicable texts and principles, and also all related Implementing Rules (MIG-T, 2016).

3.5.4. Data models in INSPIRE

The data models in INSPIRE are those models existing in the amendment to the Implementing Rules for Annex II + III themes, including some updates of the Annex I data themes. It will be described as a feature catalogue, HTML view of UML models, UML models for Enterprise Architect (EAP, XMI), UML models for Enterprise Architect (SVN), GML application schemas and code list dictionaries, and a Schema repository.

- **Feature catalogue**

  An informative overview of the spatial object types and data types defined in the INSPIRE data specifications, which provides a natural entry point to the INSPIRE data models and data specifications for implementers and decision-makers. Figure 3.2. has been shown a Feature catalogue for the conceptual data model according to INSPIRE data specifications.

	Feature class	Attribute
1	Buoy	InspireID
2	Beacon	InspireID
3	FairwayArea	InspireID
4	Ferry Crossing	ferryUse InspireID
5	Marine Waterway	deepWaterRoute InspireID
6	PortArea	conditionOfFacility InspireID
7	PortNode	conditionOfFacility InspireID
8	WaterLink Sequence	waterTrafficFlowDirection restrictionForVehicles InspireID
9	WaterLink	waterTrafficFlowDirection restrictionForVehicles InspireID
10	Waterway Node	formOfWaterwayNode InspireID
11	Shoreline Construction	levelOfDetail conditionOfFacility InspireID
12	Shoreline	waterLevel segment InspireID
13	InterTidal Area	highWaterLevel lowWaterLevel InspireID
14	Buildings	name conditionOfConstruction currentUse InspireID
15	ContourLine BreakLine IsolatedArea SpotElevation	(These Feature classes are part of bathymetry dataset, and each have own attributes)

Figure 3.2. Feature catalogue for conceptual data model according to INSPIRE data specifications (Hećimović , Rašić, & Ciceli, 2013);

- **HTML view of UML models**

  The HTML is an interactive view of the complete UML data models. This view includes detailed definitions of spatial object types, data types, enumerations and code lists, and UML class diagrams. Figure 3.3. shows the HTML view of the UML models.

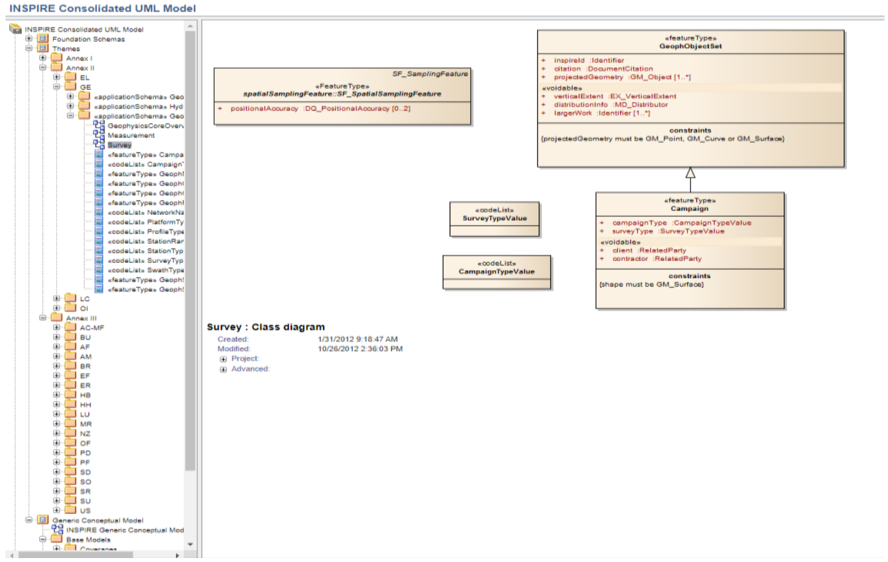

Figure 3.3. HTML view of the UML model (www.inspire.ec.europa.eu, 2017);

- **UML models for Enterprise Architect (EAP, XMI)**

  Zip archive containing the INSPIRE UML models as an EA project file and XMI exports. Developers can use them for the importing to INSPIRE data models in Enterprise Architect (EA) or other modelling tools.

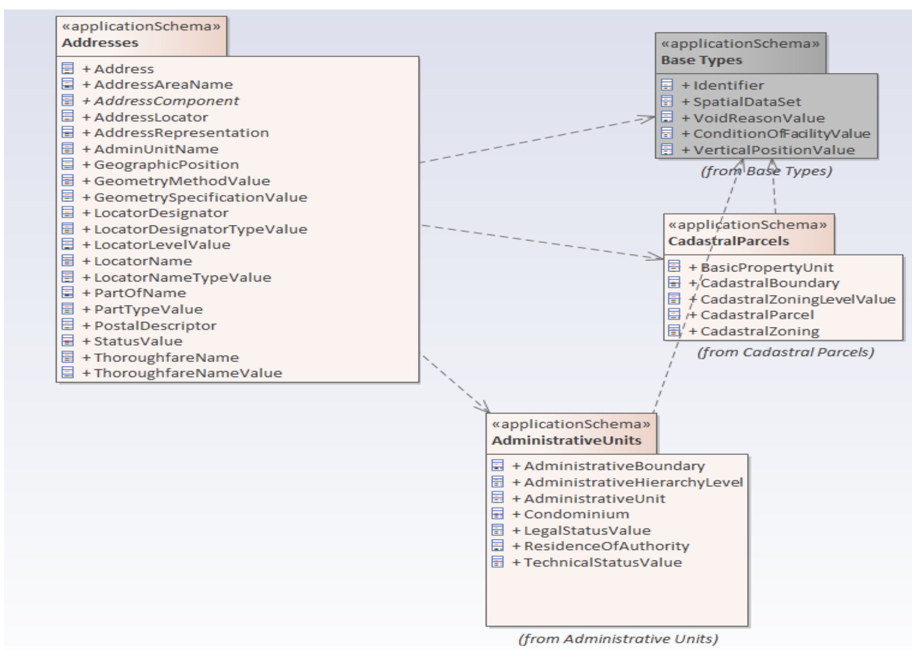

Figure 3.4. The UML package structure for Addresses under the Annex I (www.inspire.ec.europa.eu, 2017);

- **UML models for Enterprise Architect (SVN)**

  Alternatively, developers using EA can link to the INSPIRE UML models using one of the public branches in the svn repository. Before connecting, please read them for how to connect to the pools from EA and download the UML profile used in the INSPIRE data specification development.
- **GML application schemas and code list dictionaries**

  The GML application schemas (XML schema documents) and code list dictionaries generated from the UML application schemas based on the default encoding rule).
- **Schema repository**

  The GML application schemas are also available through the INSPIRE schema repository at (https://inspire.ec.europa.eu, 2016) which are approved schemas or (www.inspire.ec.europa.eu, 2017) – draft schemas.

This distribution combines the data models contained in the amendment to the Implementing Rules (see above) and the extended data models listed in the data specification Technical Guidelines (but not in the IRs). Please note that the comprehensive data models not included in the IRs should be considered as a draft and therefore be used with caution (Lutz, 2011).

The central aspect of the Infrastructure for spatial information in the European Community, like an essential for all public authorities, is to access spatial data and services. A necessary thing in INSPIRE during the implementation issue is to use Feature Catalogue, HTML view of the UML models, UML models for Enterprise Architect and GML application schemas, and code list dictionaries. During the implementation, these data models are fundamental, and they should be used.

3.6. INSPIRE Observation and measurement (OM) introduction

Several themes of Annex II and III are very specified in addition to the necessary spatial information, which includes measured, modelled, or simulated data about the real world. The International Standard on Observations and Measurement (OM) ISO 19156:2011 was designed for specific purposes, and it is intended to be used in INSPIRE to cover all these requirements. This paragraph will be explained the main scopes of the Observation and

Measurement standard for the better understanding INSPIRE specific design. The Observation and Measurement should be used firstly for the quality of property values, which should be provided with the data. If it is considered the data structure of the OM standard, it has defined the OM_Observation type. On the following Figure 3.5., there is a diagram that shows the essential OM_Observation type with all attributes, associations, and constraints.

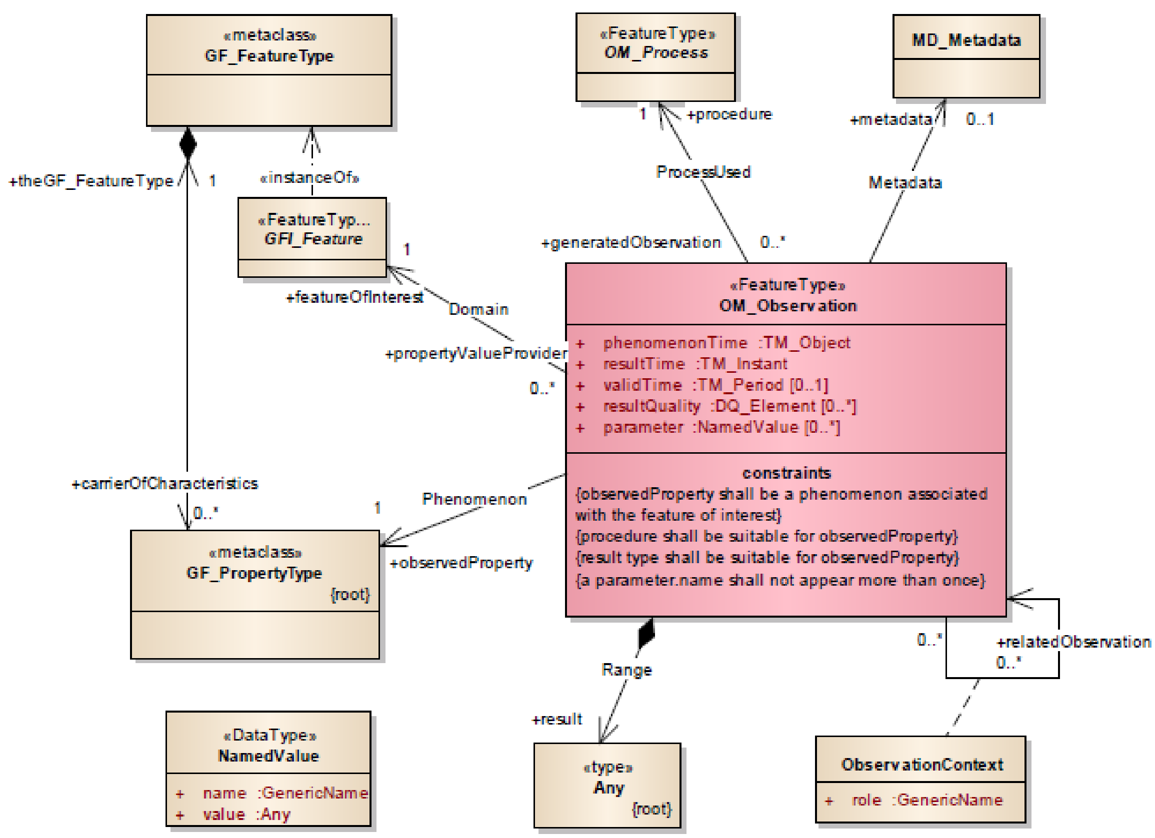

Figure 3.5. The UML diagram of the primary Observation type
(https://inspire.ec.europa.eu, 2016);

The UML diagram in Figure 3.5. can be evaluated like that the Observation is an apparition in which the result is estimated like a value of some property that has feature-of-interest, in the specific point of time under the particular procedure.

Firstly, there is a problem to understand the meaning of the observation because it is essential for a specific and accurate understanding of the domain of word and feature-of-interest. The

OM standard does not provide a formal facility or station concept, so there are requirements to provide information on specific locations that will be used for multiple observations.

The modelling of stations is suggested with Observation and Measurement standard in the form of the SamplingPoint, and this can cause some difficulties if someone wants to include remote sensing or measurements from the satellites, which are the basic concept of this thesis. Also, it cannot provide support for the mobile facilities and then it cannot be used within the INSPIRE context.

The OM standard will be discussed more in the next chapters, and during the model creation, all explanations will be given in the following chapters.

4. Programming techniques

This chapter will give a short overview of all programming techniques which have been used for the experimental part of the thesis. It will describe all methods of the programming which are needed to create a model that is aligned with INSPIRE Directive rules.

Furthermore, notations, technologies, formats of the data which have been used for the implementation of the practical part of the experiment are described in this chapter.

4.1. The Unified Modeling Language (UML)

The unified language for modelling (UML) is a congregation of the graphic notations which are based on the unique metamodel, and it serves for the describing and projecting of the software systems, especially those which are designed by applying object-oriented technologies. The previous definition is a base of the UML. The UML is not a programming language, and it is more a language for the visualization. This language is not intended to be a visual programming language in the concept of having all visual and semantic support to replace programming languages. As it is mentioned above, UML is not a programming language, but these tools can be used to generate code in different styles using UML diagrams. The UML has a direct relation with object-oriented analysis and after standardization, has become Object Management Standard (OMG) (ISO/IEC, 2005, pp. 13-20).

Diagrams that are created in UML are not made just for developers but also for business users, for people familiar with UML modelling and all users who want to understand the system.
To follow the concept of the experimental part of the thesis and INSPIRE Directive implementing rules, the short overview in this chapter will be on the UML class and object diagrams.

4.1.1. UML conceptual model and object-oriented concepts

The concepts and their relationships define the UML conceptual model. Before drawing a UML diagram, a theoretical model should be made. This model helps to understand entities and their functionalities with each other in the real world. The three major elements are the basis of the UML conceptual model: UML building blocks, the basic rules on how to connect the building blocks, and the shared mechanism of UML.
The concepts of the UML exist in object-oriented analysis, and UML is good enough to represent it. Before start modelling, it is essential to understand object-oriented concepts. The basic object-oriented concepts are Object (it is a necessary entity for building block), Class (represents object blueprint), Abstraction (shows the behaviour of a real-world entity), Encapsulation (this is a mechanism for binding data together and hide them), Inheritance (making new classes from the existing one) and Polymorphism (defines the means to exist in different forms).
The object-oriented concept is the most important for the analysis to identify objects of a system that has been designed.

4.1.2. The UML Diagrams

The UML diagrams are the output of the entire system. For the creation of the UML diagram, it is essential to identify its elements and relationships. The complete UML diagram represents a system. There are two types of UML diagrams: behavioural and structural UML diagrams.
The types of behavioural UML diagrams are:

- Timing Diagram;

- Use Case Diagram;
- State Diagram;
- Activity Diagram;
- Interaction Overview Diagram;
- Sequence Diagram;

The types of structural UML diagrams are:

- Object Diagram;
- Component Diagram;
- Composite Structure Diagram;
- Class Diagram;
- Package Diagram;

The focus of this chapter will be put on the package and class diagrams, as was previously mentioned.

4.1.2.1. The UML class diagram

The class diagram has the purpose of modelling an application. This diagram is the only one which can be mapped with object-oriented languages and is widely used for the construction of the model. It describes the classes in the system and the relations between them. The UML class diagram has all object-oriented concepts: associations, aggregation and inheritance.

Furthermore, the class diagram is an essential UML diagram for the creation of software applications. It is crucial to consider the class diagram during the drawing from the top-level view. The different aspects of the application are represented with the class diagram, and this is the best graphical presentation.

To present the whole static system, it has needed to have a collection of the class diagrams (https://www.tutorialspoint.com/uml/index.htm, 2018, pp. 26-28). During the creation of the UML class diagram, there are some rules which should be kept in mind:

- The class diagram should have an appropriate name that needs to describe the real aspect of the system.

- During the modelling, relations between each element should be defined in advance.
- Each class should have an identified responsibility.
- Every class should have a minimum number of properties.
- The notes should be included to define a diagram. After the drawing, it should be understandable for the development team.
- In the end, the diagram should be reworked until it is ready for the final presentation.

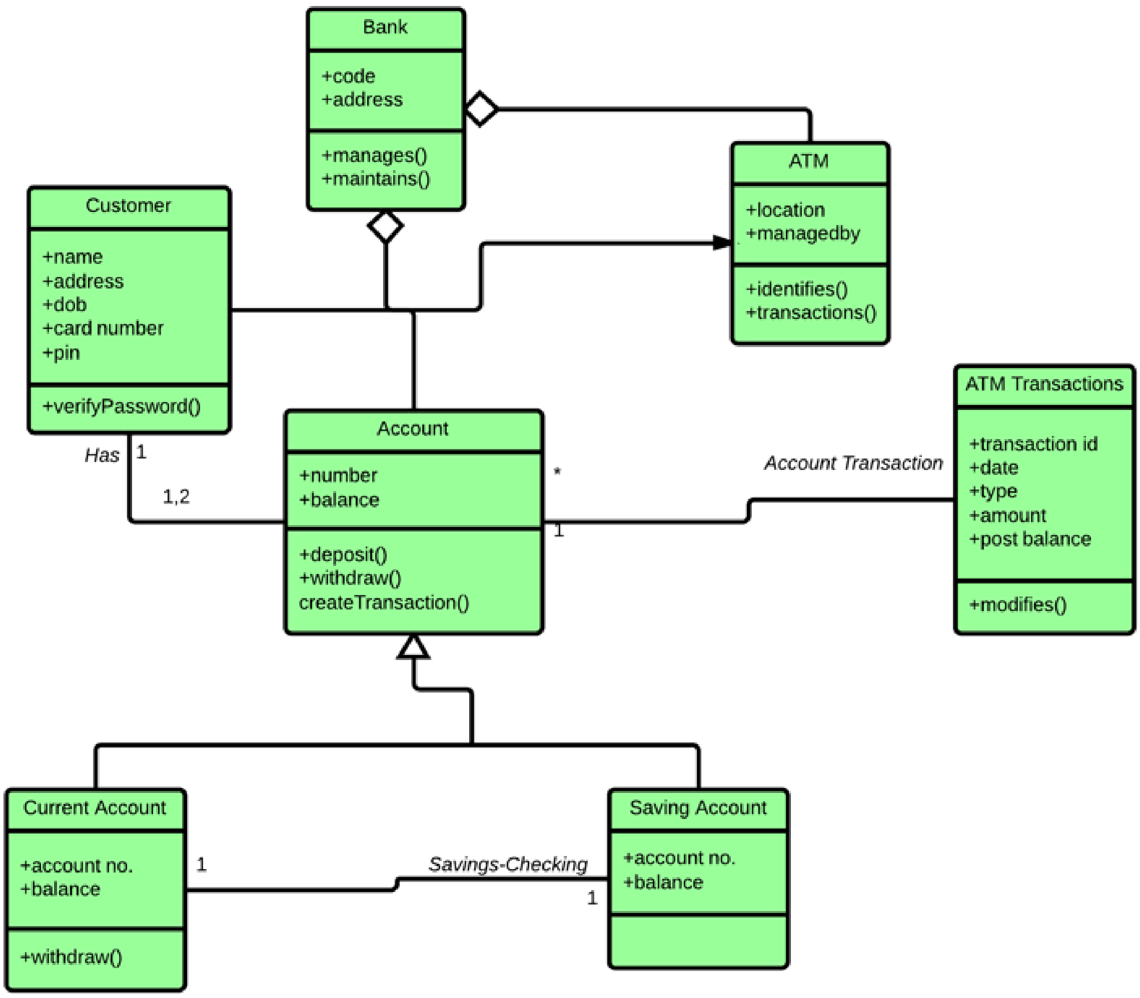

Figure 4.1. The example of the UML class diagram (https://www.guru99.com/uml-class-diagram.html#7, 2019);

This UML class diagram explains the ATM systems. It describes that ATM is straightforward for use. In this case, customers need to press a button to get some cash. There are some security layers that all ATMs need to have. All these functionalities are useful for preventing fraud and provide money for customers.

In the end, the UML class diagram describes the system in which there are some types of objects and different kinds of relationships between them. The most critical elements of the UML class diagram are classes, attributes, and relationships. This UML class diagram is handy to map programming languages like Java, C++, Python, etc.

4.1.2.2. The UML object diagram

The UML object diagrams are created from the class diagrams. The object diagram is dependent on the class diagram. If it has been considered the concept of the object diagram, it can be said that it is very similar to the UML class diagram. An object diagram is a snapshot of the static view of the whole system but in a specific moment.

In order to present the data, the class diagram illustrates an abstract model that is created from the classes and their relationships. The object diagram is an instance of the class diagram, and that means that it has the same thing which is used in the class diagram. In the object diagram, all the elements are strictly specified, and they have formed to represent the real-world object. Figure 4.2. depicts the object diagram example.

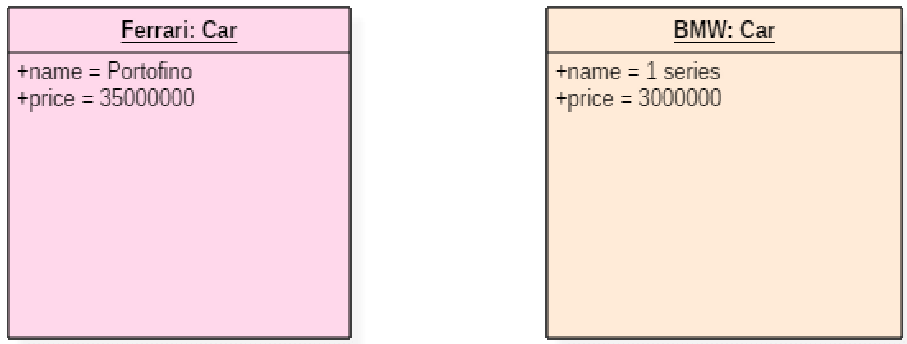

Figure 4.2. Example of the UML object diagram (https://www.guru99.com/uml-object-diagram.html, 2019);

The example from Figure 4.2. shows the created UML object diagram, which contains two objects. The name of the objects are Ferrari and BMW, and they belong to the class Car. In this object diagram, the entities that are in the real world are the instances of the class.

Furthermore, one can conclude that UML object diagrams are used for the modelling of the classes, data and provide other information as a set. The UML object diagrams can be used for visualization and also for analyzing online or offline systems. Also, they are suitable for understanding a practical part of the plan (https://www.tutorialspoint.com/uml/index.htm, 2018, pp. 30-31).

4.2. The Extensible Markup Language (XML)

The Extensible Markup Language (XML) is a text-based language, defining a set of the rules in a specific format. Firstly, this language is used to describe data, and it has a textual data format with a strong background through the Unicode for the different styles. The XML is one of the most significant IT standards when it has been considered to build the Spatial Data Infrastructures (SDI's). In INSPIRE, the XML schema is fundamental for data transfer purposes.

Furthermore, this chapter will describe the basic concepts of the XML, which are very important for the INSPIRE, and they are XML syntax, elements, and attributes (https://inspire.ec.europa.eu/training/basic-concepts-xml-and-gml, 2018).

4.2.1. The XML syntax, elements, and attributes

In order to explain XML functionalities, each part of the XML document will be described. Each XML document should contain, in the first line, the declaration stating that it is an XML document, also the version of the XML, which has been used. In the following example, XML syntax, attributes, and elements will be explained.

To create an XML document and describe all the content of the following document, a relational database table will be made. The relational database table will have the name ”Student”, and this table will have some attributes.

Student-ID	LastName	FirstName
210422	Smith	Ed
220422	Zhao	Lu

Figure 4.3. Relational database table (”Student”) (https://inspire.ec.europa.eu/training/basic-concepts-xml-and-gml, 2018, p. 4);

Data from Table 1 can be expressed as an XML file and it looks like this:

```
<?xml version="1.0"encoding="utf-8"?>
<MyDatabase>
<Student>
<Student-ID>210422</Student-ID>
<LastName>Smith</LastName>
<FirstName>Ed</FirstName>
</Student>
<Student>
<Student-ID>220422</Student-ID>
<LastName>Zhao</LastName>
<FirstName>Lu</FirstName>
</Student>
</MyDatabase>
```

The first line of the XML file which has been created should be the declaration of the XML version which has been used. This XML file, also, includes a statement of encoding together with the version which has been used. The most important content of the file is the XML elements, and usually, they consist of the start and the end tag. Between the start and the end tag, there is a content of the XML elements. In this XML file, the start tag is `<Student>` and the end tag has the form `</Student>`.

The XML file also has other root elements that contain all other aspects besides the start and the end tag. Attributes in the XML file can be confused with the features. Sometimes, its characteristics can be described and explained like metadata, and elements describe just data. When the attributes are used, there are some problems because attributes cannot have multiple values. They are not expandable, and they cannot describe structures.

Finally, the best solution is that metadata should be stored like attributes, and the data should be stored like elements (https://inspire.ec.europa.eu/training/basic-concepts-xml-and-gml, 2018, pp. 7-8).

4.3. Enterprise Architect (EA)

Sparx Systems has developed the Enterprise Architect software. It is a visual modelling and design tool based on the Object Management Group (OMG) and Unified Modeling Language (UML). The EA platform has many functionalities and supports design and construction systems, business process modelling, and modelling in the industry domains. Using UML modelling as a basis provides a unique organizational architecture and provides a reasonable basis for the creation and implementation of the new systems, additionally changing the existing ones. The EA has a wide range of users, from the programmers and business analysts to enterprise architects, which are situated in the small developer companies, big corporations, and governmental organizations (Cox & Ardlie, 2007,2009).

In the EA software, there is a wide range of standards for designing and modelling different systems. Some of the most important standards are:

- UML 2.5
- SysML 1.5
- BPMN 2.0
- DMN
- BMM
- MARTE 1.2
- BPEL
- SoaML
- SPEM
- WSDL
- XSD
- DDS
- ArchiMate 3.0
- ArcGIS
- IFML
- CMMN
- Geography Markup Language (GML)

- ODM, OWL, and RDF
- VDML 1.0

The EA has integrated functionality for working with a different version control system. However, since EA stores its models in a binary form, Microsoft Access file cannot be used directly in the EA repository. But the EA repositories can interact with MS Access using the linked tables. Setting up a repository and checking out/inversions is not wholly straightforward. Since the EA file by itself is binary, it will allow import/export of each package in XML in the Metadata Interchange format (which is an ASCII-file) that will then be checked out/in of EA. The packages by themselves are version controlled, but the EA file is not (Lutz, 2011).

4.4. PostgreSQL

PostgreSQL was developed as a part of the project at the University of California, Berkley. The phase of the development started in the 1980s and continues until now. Furthermore, during the project in which PostgreSQL has been developed, one of the team leaders left the project and wanted to create his version of the part of the project called Ingres.

However, he returned to the Berkley and started a post-Ingres project with a specific objective to develop a system that will resolve the problems of the databases (Stonebraker, 2011).

This database is also known as Postgres, and it is a free, open-source relational database that has many functionalities in compliance with a lot of technical standards. During the creation of this database, the development team takes into consideration handling work with a wide range of the workload and also supporting many users/customers from one single workplace.

In order to explain this relational database, indexes, schemas, and data types that can be used in PostgreSQL will be considered. All these elements will be used in the experimental part during the implementation.

The indexes supported in PostgreSQL are B-tree and hash table indexes. Still, there are some other index methods for the access, namely: generalized search trees (GiST), generalized

inverted indexes (GIN), Space-Partitioned GiST (SP-GiST) and Block Range Indexes (BRIN) (Bartunov & Sigaev, SP-GiST - a new indexing framework for PostgreSQL , 2011).
Furthermore, there are even more significant indexes, like expression indexes, partial indexes and k-nearest neighbours indexing. Each of these indexes has appropriate definitions:

- An index, which is an expression of the function instead of the actual value of the chain is an expression index.
- An index, which is just a simple part of the table is partial.
- The indexing which is specified to find the closes values, which is also useful for finding similar words or some close objects or locations with specific coordinates (using geospatial data) is called k-nearest neighbours (Bartunov & Sigaev, K-nearest neighbour search for PostgreSQL, 2010)

PostgreSQL defines schemas containing all objects except tablespaces. The schemas have the purpose of allowing an object to exist in the same database as namespaces and act like them. All schemas which are created in the new databases are called public, but it can be added other schemas. Furthermore, there are a lot of data types which are supported by PostgreSQL: Boolean, Arbitrary precision numerics, Character BinaryDate/time MoneyEnumBit strings, Text search type, Composite, HStore is a valuable extension, (https://www.linuxjournal.com/content/postgresql-nosql-database, 2019) Arrays, Geometric primitives, IPv4 and IPv6 addresses, Classless Inter-Domain Routing (CIDR) blocks and MAC addresses, XML supporting XPath queries, Universally unique identifier (UUID), JavaSript Object Notation (JSON) and JSONB (Geoghegan, 2014).
Finally, the users can create their datasets and types which can support indexable PostgreSQL's indexing infrastructures. These data types include examples of the geographic information system (GIS) data types from the PostGIS, which is a project of the PostgreSQL. The PostGIS will be discussed in the following chapters.

4.5. PostGIS

This paragraph will shortly introduce PostGIS. It will explain the history, features and users of the PostGIS. However, more about PostGIS and its functionalities will be described in detail in the implementation part of the application.

Firstly, PostGIS is open-source software, and it has functionalities that support geographical objects and also a PostgreSQL database. The features of the PostGIS comply with the rules of the SQL specification of the Open Geospatial Consortium (OGC).

Implementation of the PostGIS was designed to be a PostgreSQL external extension (https://www.postgresql.org/docs/current/external-extensions.html, 2019). The Refraction Research released the first version of the PostGIS under the GNU General Public License. PostGIS was registered in the OGC, like implementing the specific standard for the Simple Features for SQL (http://refractions.net/, 2019). The software using a PostGIS like a backend database are ArcGIS, Cadcorp SIS, CartoDB, CitySurf Globe, GeoMedia, GeoServer, GeoNetwork, GRASS GIS, gvSIG, Kosmo, Manifold System, MapInfo Professional, Mapnik, MapServer, Maptitude, MapGuide, OpenJUMP, OpenStreetMap, QGIS, SAGA GIS, TerraLib, TerraView, and uDig.

Finally, PostGIS has many functionalities that are very different. These functionalities or features are geometry types, spatial predicates for determining interactions between geometry, spatial operators for the regulation of geospatial measurement, spatial operators for the rule of the geospatial operations, R-tree, index selectivity support. For raster data, it is PostGIS WKT Raster (https://www.opengeospatial.org/resource/products/details/?pid=509, 2019).

4.6. .NET Core

.NET Core represents a free and open-source cross computer framework, and it can be used on the Windows, Linux, and macOS operating systems (https://dotnet.microsoft.com/download, 2017). This open-source computer framework is defined as an added platform to .NET Framework (https://betanews.com/2019/05/07/future-of-dotnet/, 2019). The .NET Core supports C# and F#, and it helps but just partially Visual Basic .NET.

Microsoft has developed the project called .NET Core but under the MIT license has released (https://github.com/dotnet/core/blob/master/LICENSE.TXT, 2018).
Finally, the platforms which support .NET Core are ASP.NET Core web apps, command-line apps. Libraries, and Universal Windows Platform apps.

4.7. The Hypertext Markup Language (HTML) and Cascading Style Sheets (CSS)

The HTML (Hypertext Markup Language) and CSS (Cascading Style Sheets) are fundamental technologies for creating Web pages. They are not programming languages, and they represent page structure and style. The HTML presents the system of the page, and CSS provides the visual layout for different devices. If we consider graphics and scripting, these two technologies are fundamental for creating Web pages and Web Applications. The HTML describes the structure of the Web pages, as was previously mentioned. The authors who are creating Web pages can publish online documents with their attributes, using hypertext links at the click on the button can retrieve online information and include video and sound clips directly in their compositions.

The HTML is very convenient to add headings, make lists, create unique characters, insert images, create tables, and many more (https://blog.hubspot.com/marketing/web-design-html-css-javascript, 2019).

The CSS is an acronym for Cascading Style Sheets, and it has been used for the description and presentation of elements of the HTML. It can be said that the HTML gives a basic structure of the website, and CSS gives the entire website its style.

Furthermore, CSS is significant because it affects the entire look of the webpage, and it is a powerful tool. Separation of the HTML and CSS makes it easier to share style sheets and tailor pages for different environments. However, CSS is independent of HTML, and it can be used with any XML language (https://www.w3.org/standards/webdesign/htmlcss.html, 2019).

5. Experimental Research

This experimental research is based on INSPIRE directive data specifications. The input for creating a UML ZTD model was a ZTD_estimation.TRP file. This file has been processed in the Bernese software. It contains input parameters which have been defined by the software, and these parameters are a-priori model gradient model, mapping function, min Elevation and tabular interval from and to. The explanation of these input parameters in the Bernese software will be given in Chapter 6. Furthermore, the output parameters of the software were correction, correction East, correction North, correction Sigma, model, sigma East, sigma North.

Based on these parameters, which are held in ZTD_estimation.TRP file, a ZTD UML model, was created, It is based on the INSPIRE Data Specification. For the creation of the ZTD UML model, Enterprise Architect (EA) has been used. During the creation of the ZTD UML model, there was the overlap of the two themes of the INSPIRE; Geology (sub-theme Geophysics) and Atmospheric Conditions.

On the other hand, a web application of the mini GIS system is created. It was developed as a software system for showing observation figures. The database has been created using PostgreSQL and PostGIS. In the backend of the web application, an ASP.NET Core framework is used, then data format JSON, web service REST, and HTTP protocol. The frontend was based on the programming language JavaScript, markup language HTML and styling language CSS.

Furthermore, because of the flexibility, Google Maps were used, and vector layers are overlays which are placed on top of the Google Maps raster. Additionally, the implementation of the ZTD web application will be discussed in Chapter 7.

Finally, in this Chapter, I will explain a higher context of the extension of the Atmospheric conditions model and creation of the ZTD web application. During the research of INSPIRE themes and regulations, I have realized that in the Atmospheric conditions theme, there are a lot of gaps and unfinished work. In AC theme there is no any Style Design Layer (SLD’s) which should be created or Web Feature Service or Web Map Service. Even the maps which are presented as a part of this theme just shows the snow land coverage. Just to have on our mind, these maps are available only for several countries. The extension of the AC theme, in this case, ZTD model will be handy for the entire INSPIRE community. Besides the ZTD model, the web application, which is created on the base of the model, can be beneficial for further work and creating an SLD's for the AC theme. This research is just a base for the new development of the INSPIRE services for the AC theme. One of them is also to create WFS and WMS publishable services. The application which is made in this research can also be used by INSPIRE community for the weather forecast and climate changes. There is a lot of advantages of this research work which can be used and modelled by INSPIRE community.

6. The UML ZTD (Zenith Tropospheric Delay) model

6.1. Introduction

In this chapter, the whole procedure for creating a ZTD UML model will be explained, which is based on the INSPIRE standards. The input for creating a ZTD UML model was a ZTD_estimation.TRP file. This file has been output from the Bernese software, which is used for data processing which has been collected from the metrological stations. The main goal of the data processing file was to determine troposphere vapour from satellite observation measurements of ZTD. The input and output parameters in the Bernese software on which is based the ZTD UML model will be described in the following subchapters.

Additionally, the tool which has been used for creating the ZTD UML model is Enterprise Architect (EA), which is also one of the tools suggested by the INSPIRE implementation rules.

Finally, the ZTD UML model was created, and during the creation, the two themes are overlapped: the Atmospheric Conditions and Geology (sub-theme Geophysics). This model was suggested as an extension of the Atmospheric Conditions application schema and also is based on the Package for observations (this package extends ISO 19156). The model which has been created is an extension of the Atmospheric Conditions schema. This model is built on the theoretical base respecting all INSPIRE standards. Also, just to take into consideration this model is theoretically correct.

In this research, as it was previously mentioned, there is an overlap with the Geology theme of INSPIRE. Even it was more suitable and more comfortable to create an extension of the Geology theme because all features are available, I have decided to make an extension of the AC theme. My decision was because it was more logical that Zenith Troposhepric Delay should be part of Atmospheric Conditions (because of the output parameters from the Bernese software) than Geology, sub-theme Geophysics.

The explanation of the proposed ZTD UML model extension will be described in the details in the following subchapters.

6.2. Description of the Annex II theme Geology and Annex III theme Atmospheric Conditions

In this experimental research, there is an overlap between the two themes. These themes are in the different Annexes of INSPIRE. The theme Geology is in Annex II of the INSPIRE. This theme has three sub-themes: Geology, Hydrology, and Geophysics. This research has been used as a part of the UML model, an application schema of the sub-theme Geophysics.
Furthermore, it will be explained what does the term Geophysical Station mean and also how it is presented in an application schema of the Geophysics sub-theme. By the terms and definitions in INSPIRE (https://inspire.ec.europa.eu/file/1519, 2013, p. 5) the Geophysical Station represents a geophysical measurement, which is referenced in space to a single point location. In Figure 6.1. UML class diagram of the Geophysics Measurement is presented.

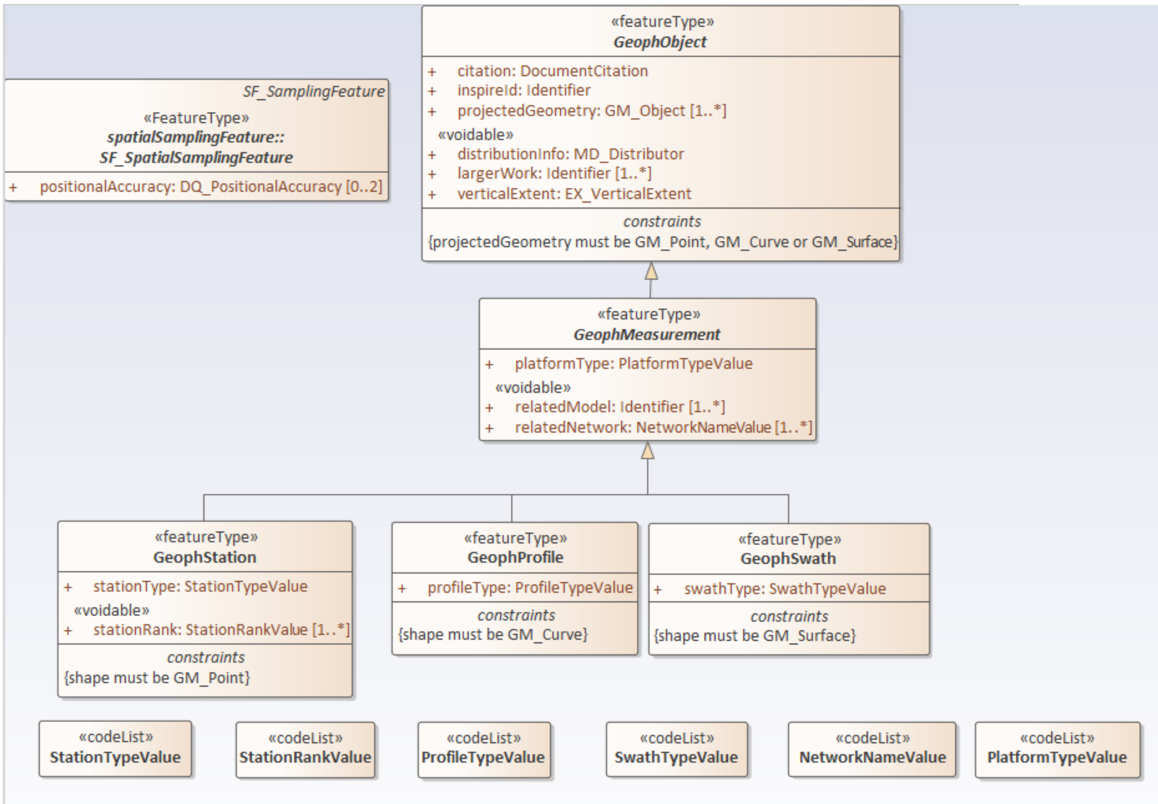

Figure 6.1. The UML class diagram of the Geophysics Measurement;

Additionally, in this UML class diagram, an essential feature type for this research is GeophStation. GeophStation is defined as the geophysical measurement, which is referenced to a single point location in space. They are used to collect data from an only place, and the collected data are spatially referenced to a single point. The GeophStation can be Gravity station, Magnetic station, and in this case, it is referred to a ground-based GNSS station. The UML application schema of the Atmospheric Conditions is shown in Figure 6.2.

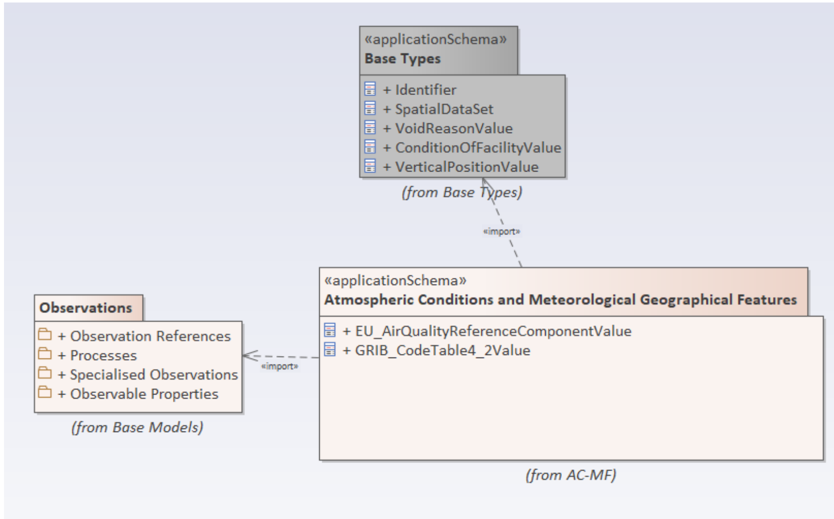

Figure 6.2. The package structure of the Atmospheric Conditions;

On the other hand, the theme Atmospheric Conditions data specifications are based on the Observation and Measurement conceptual model, which has been defined with ISO 19156:2011 (https://inspire.ec.europa.eu/file/1532, 2013, p. 21). The overview of the conceptual model of the Observations is shown in Figure 6.3.

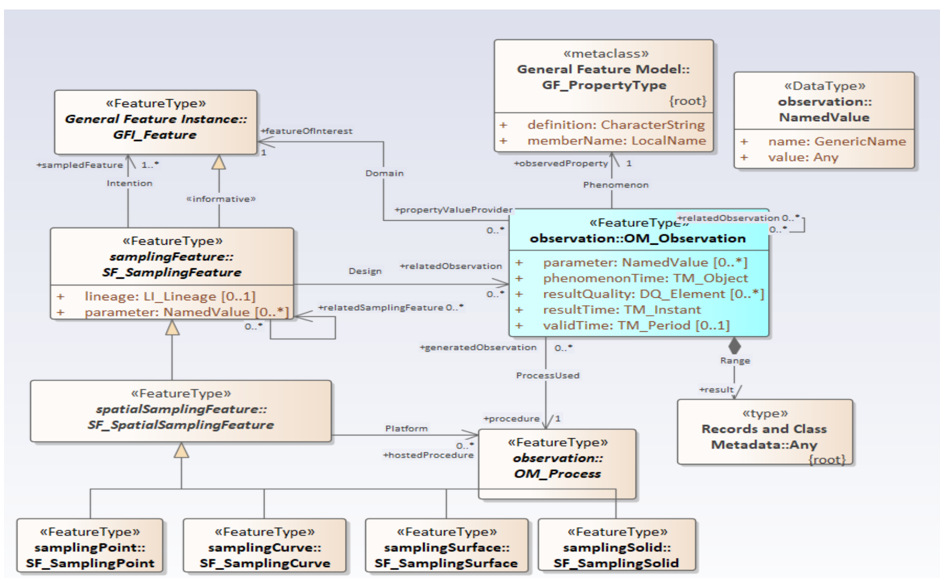

Figure 6.3. The overview of the Observation concept;

Finally, the Observations package from the base model can import application schema for the Specialised Observations and also introduce leaf Point Observations, which are from Specialised Observations.

6.3. Input parameters from ZTD_estimation.TRP file

The input for creating the ZTD UML data model was ZTD_estimation.TRP file. This file was the output of the processed data with Bernese software, as it was mentioned in the previous subchapters. In Figure 6.4. there is a ZTD_estimation.TRP file with its values and input and output parameters.

```
SGO NRT ZTD estimation                                       18-SEP-14 02:30
------------------------------------------------------------------------------------------------------------------------------------
 A PRIORI MODEL:  -15   MAPPING FUNCTION:    4   GRADIENT MODEL:    1   MIN. ELEVATION:    5   TABULAR INTERVAL:  1800 / 43200

 STATION NAME     FLG   YYYY MM DD HH MM SS   YYYY MM DD HH MM SS   MOD_U   CORR_U  SIGMA_U TOTAL_U  CORR_N  SIGMA_N  CORR_E  SIGMA_E

 ANKR 20805M002    A    2014 09 17 14 00 00                         2.0534  0.15193 0.00134 2.20529 -0.00016 0.00012 -0.00088 0.00009
 ANKR 20805M002    A    2014 09 17 14 30 00                         2.0534  0.15725 0.00089 2.21061 -0.00015 0.00011 -0.00081 0.00009
 ANKR 20805M002    A    2014 09 17 15 00 00                         2.0534  0.15505 0.00090 2.20841 -0.00014 0.00010 -0.00073 0.00008
 ANKR 20805M002    A    2014 09 17 15 30 00                         2.0534  0.15912 0.00098 2.21248 -0.00012 0.00009 -0.00066 0.00007
 ANKR 20805M002    A    2014 09 17 16 00 00                         2.0534  0.16490 0.00078 2.21826 -0.00011 0.00009 -0.00058 0.00007
 ANKR 20805M002    A    2014 09 17 16 30 00                         2.0534  0.16662 0.00095 2.21998 -0.00009 0.00008 -0.00051 0.00006
 ANKR 20805M002    A    2014 09 17 17 00 00                         2.0534  0.16420 0.00077 2.21756 -0.00008 0.00007 -0.00043 0.00006
 ANKR 20805M002    A    2014 09 17 17 30 00                         2.0534  0.15839 0.00083 2.21175 -0.00006 0.00007 -0.00036 0.00006
 ANKR 20805M002    A    2014 09 17 18 00 00                         2.0534  0.16271 0.00070 2.21606 -0.00005 0.00006 -0.00028 0.00005
 ANKR 20805M002    A    2014 09 17 18 30 00                         2.0534  0.16071 0.00087 2.21407 -0.00003 0.00006 -0.00021 0.00005
 ANKR 20805M002    A    2014 09 17 19 00 00                         2.0534  0.16700 0.00077 2.22036 -0.00002 0.00006 -0.00013 0.00005
 ANKR 20805M002    A    2014 09 17 19 30 00                         2.0534  0.16450 0.00083 2.21786 -0.00000 0.00006 -0.00006 0.00005
 ANKR 20805M002    A    2014 09 17 20 00 00                         2.0534  0.16999 0.00078 2.22335  0.00001 0.00005  0.00002 0.00006
 ANKR 20805M002    A    2014 09 17 20 30 00                         2.0534  0.16858 0.00102 2.22194  0.00003 0.00006  0.00009 0.00006
 ANKR 20805M002    A    2014 09 17 21 00 00                         2.0534  0.16933 0.00081 2.22269  0.00004 0.00006  0.00017 0.00006
 ANKR 20805M002    A    2014 09 17 21 30 00                         2.0534  0.16750 0.00092 2.22086  0.00006 0.00006  0.00024 0.00007
 ANKR 20805M002    A    2014 09 17 22 00 00                         2.0534  0.16564 0.00078 2.21900  0.00007 0.00007  0.00032 0.00007
 ANKR 20805M002    A    2014 09 17 22 30 00                         2.0534  0.16620 0.00070 2.21955  0.00009 0.00007  0.00039 0.00008
 ANKR 20805M002    A    2014 09 17 23 00 00                         2.0534  0.16814 0.00067 2.22150  0.00010 0.00008  0.00047 0.00008
 ANKR 20805M002    A    2014 09 17 23 30 00                         2.0534  0.17340 0.00094 2.22676  0.00012 0.00009  0.00054 0.00009
 ANKR 20805M002    A    2014 09 18 00 00 00                         2.0534  0.17250 0.00099 2.22585  0.00013 0.00009  0.00062 0.00010
 ANKR 20805M002    A    2014 09 18 00 30 00                         2.0534  0.16531 0.00105 2.21867  0.00059 0.00008  0.00060 0.00008
 ANKR 20805M002    A    2014 09 18 01 00 00                         2.0534  0.16107 0.00089 2.21443  0.00105 0.00011  0.00059 0.00010
 ANKR 20805M002    A    2014 09 18 01 30 00                         2.0534  0.15825 0.00101 2.21161  0.00151 0.00017  0.00058 0.00014
 ANKR 20805M002    A    2014 09 18 02 00 00                         2.0534  0.16495 0.00143 2.21831  0.00197 0.00022  0.00056 0.00019
```

Figure 6.4. The ZTD_estimation.TRP file;

The input parameters and explanation of them in the Bernese software are the following:

- A PRIORI MODEL: -15: The number -15 means that was used Saastamoinen tropospheric model with Neil dry model. The Bernese software has obtained the modelling of the tropospheric delay, which is calculated between the satellite and the receiver. The user chooses the a-priori model; it can be NEIL or DRY_NEIL. These models are dominated by the formula of the Saastamoinen in which one the a priori tropospheric path delay model is using pressure, temperature and relative humidity surface observations. The a-priori model (input values) - traditionally derived from a standard atmospheric model.

- MAPPING FUNCTION: 4: The number 4 means - Wet Neil mapping function, based on the simple 1/sinε. Mapping function - Bernese software is used to check the plausibility of the standard deviations.
- GRADIENT MODEL: 1: The number 1 means Tilting. Definition: The way to represent azimuthal asymmetries is a tilting of the zenith the mapping function. The troposphere gradient parameters then comply with the fact that the direction to the so-called tropospheric zenith (i.e., the direction with minimal tropospheric delay) and the corresponding tropospheric zenith distance might not be identical to the angular (or ellipsoidal) zenith distances.
- MIN. ELEVATION: 5: This is a cut-off angle in degrees.
- TABULAR INTERVAL: 1800/43200 means: It is for zenith parameters and gradient parameters, and it is calculated in seconds.

Additionally, another data has been calculated on the base of the input parameters, and they are structured in the groups of 12.5 hours for the period of 49 stations. The measurements from each station have 11 attributes and according to the ZTD_estimation.TRP file.

Station name with a code	e.g. ANKR 20805M02
Flag of status (operating, not operating)	e.g. A
Date (year, month, day, hour, min, s)	e.g. 2009 09 17 13 00 00
Model value	e.g. 2.0534
Correction	e.g. 0.15197
Correction Standard dev.	e.g. 0.00154
Total (Model+Correction)	e.g. 2.20533
NorthCorrection	e.g. 0.00005
North Standard dev.	e.g. 0.00012
EastCorrection	e.g. 0.00085
East Standard deviation	e.g. 0.00009

Figure 6.5. The processed data from the metrological stations according to the ZTD_estimation.TRP file;

The previous Figure 6.5. shows the output parameters from the Bernese software. During the measurement and like output parameters, we have 11 Time Series, and each of them contains 25 data because the samples (taken each second) are averaged for 30 minutes periods. The INSPIRE ZTD UML model will be elaborated for one group of the processed data. As we have data from the 49 metrological stations, and measurements were done for each station 12.5 hours, so the data for each station will be stored in 49 identical INSPIRE ZTD UML model.

6.4. INSPIRE ZTD UML data model

The proposition of the extension of the INSPIRE ZTD UML data model was based on the part of the application schema of the Geophysics (this is a subtheme of the Geology) and application schema Atmospheric Conditions which are based on the Observations. In the package structure AC-MF, the application schema ZTD Observations (AC-MF) was imported from the ZTD model. The proposed application schema ZTD Observations (AC-MF) is shown in Figure 6.6.

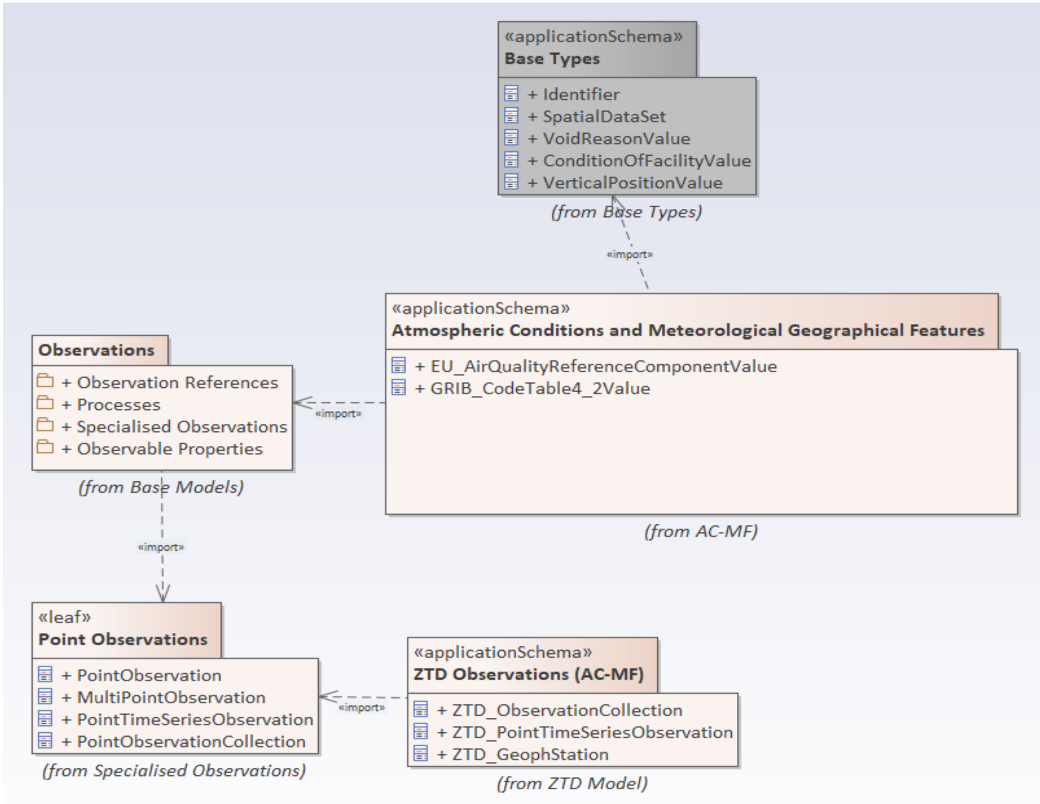

Figure 6.6. The package structure of the application schema ZTD Observations (AC-MF);

The Observation package is imported from the base model, and the leaf Point Observations belong to the Specialised Observations as it was previously mentioned. Still, PointTimeSeriesObservation will be used, because it is an observation that represents a time-series measurement of a property at the fixed location in the space and time.

Furthermore, three classes for the ZTD Observations (AC-MF) are made as to the proposition of extension of the model, and they are extensions of the exciting classes. Each class that has been made will be described. The first performed class for the creation of the model is ZTD_GeophStation. It is shown in Figure 6.7.

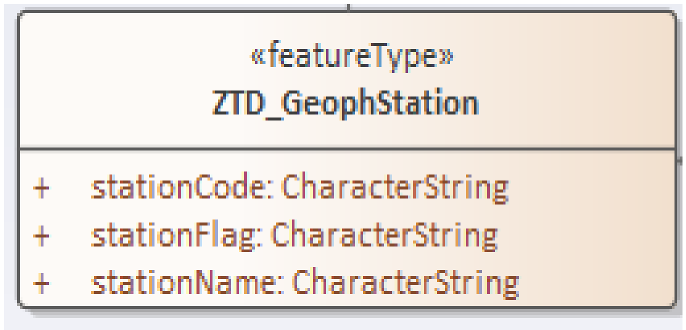

Figure 6.7. The first created class ZTD_GeophStation;

The first class, ZTD_GeophStation, was made based on the GeophStation from the application schema of the Geophysics, under the package GeophMeasurement. ZTD_GeophStation is defined as a single geophysical measurement station where ZTD measurement is made. So, this class describes the station, and in this case, it is a ground-based GNSS station with unique attributes like a code (20805M02), flag (A) and name (ANKR).

The second extended class is ZTD_PointTimeSeriesObservation, defined as the single station generated ZTD measurement samples, which are taken each second, averaged per period of 30 minutes. Figure 6.8. shows the extended class ZTD_PointTimeSeriesObservation.

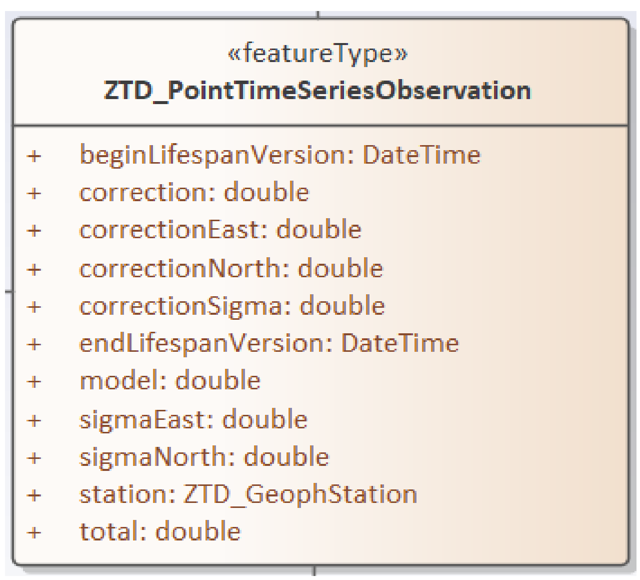

Figure 6.8. The second created class ZTD_PointTimeSeriesObservation;

In the second class, there are all attributes of the measured ZTD estimation from the TRP file. The extended third class is ZTD_ObservationCollection. This class is defined as a ZTD measurement collection based on specified process parameters. So, the third class is shown in Figure 6.9.

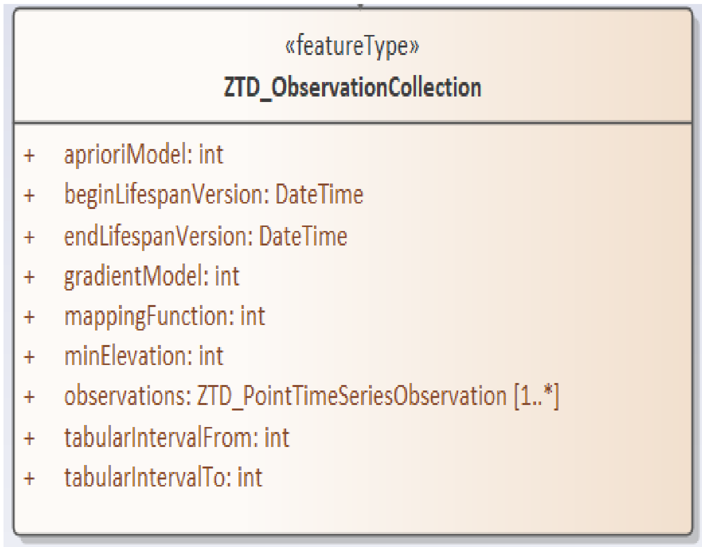

Figure 6.9. The third created class ZTD_ObservationCollection;

Furthermore, this class provides the input parameters of the Bernese software, on which calculations are based.

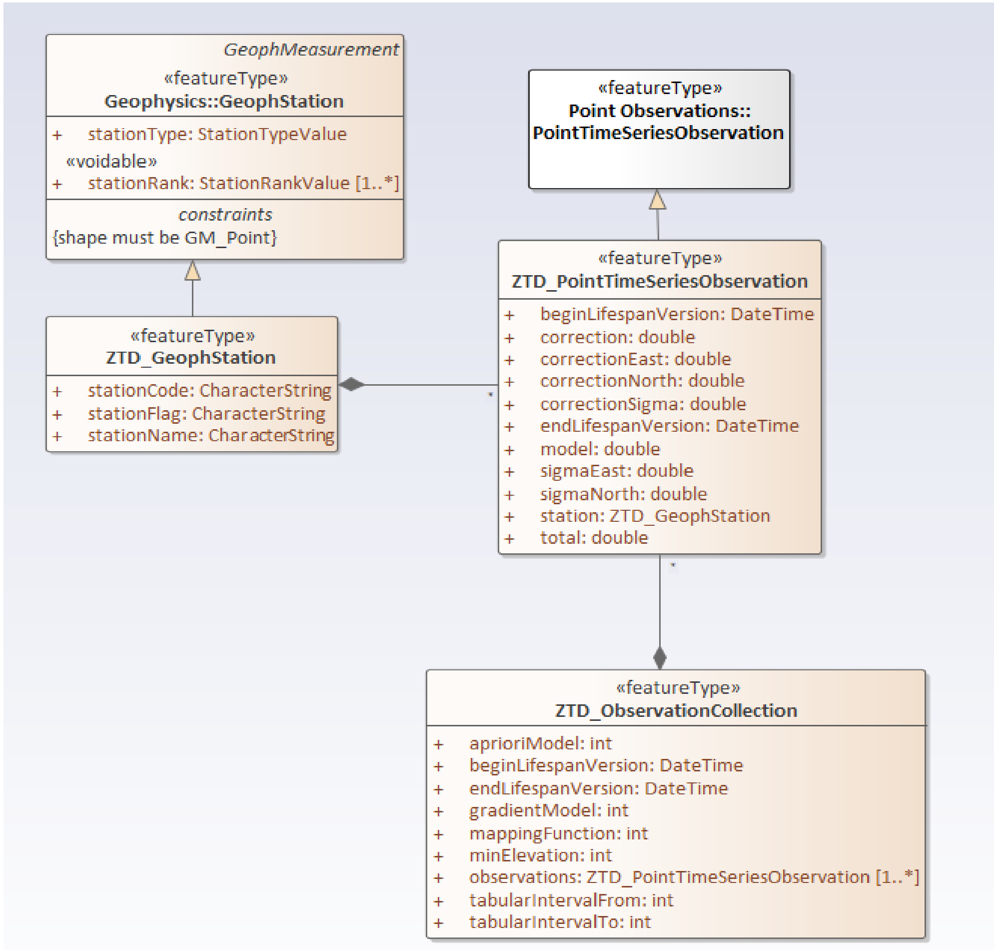

Figure 6.10. The proposed extension of the Atmospheric Conditions (AC-MF) INSPIRE ZTD UML data model;

The extension of the proposed model is based on these relationships between them, and they are generalization and aggregation. The relation between classes ZTD_GeophStation and Geophysics:: GeophStation is a generalization which means that ZTD_GeophStation is a single station which has a series of measurement with the specific type of geometry which is the 2D point. The station beside their characteristics has code, flag and name properties, too.

However, the relation between the ZTD_GeophStation and ZTD_PointTimeSeriesObservation is aggregation, which means that one station comprises several measurements. Each measurement which has been done on this station has its own station from which one was done. So, that is confirmed with this type of relation.

Additionally, ZTD_PointTimeSeriesObservation class inherits the Observation and Measurement class in this case PointObservations::PointTimeSeriesObservations. The relationship between them is a generalization, which means that the measurements have a specific time series.

In the end, the relation between classes ZTD_PointTimeSeriesObservation and ZTD_ObservationColection is aggregation and that means that objects of the ZTD_PointTimeSeriesObservation class can access to the objects of another class in this case ZTD_ObservationCollection.

In this relation, the dependent object is ZTD_PointTimeSeriesObservation because the ZTD_ObservationCollection contains parameters (input parameters of the Bernese software) on which basis are calculated all attributes of the ZTD_PointTimeSeriesObservation.

7. Zenith Tropospheric Delay (ZTD) Web Application

7.1. Introduction

This chapter describes the implementation of the ZTD web application, which has been made through this research. From Google Maps, raster base and vector layers are used, which enables viewing different values of the ZTD_estimation.TRP file and GNNS-station.xlsx file. The attributes or observation figures of the ZTD_estimation.TRP file and GNNS-station.xlsx file are shown in the application in the form of a mini Geographic Information System (GIS) (Havasi & Bartha, Introduction to GIS, 2011).

Furthermore, the first input parameters in the system are the observation figures of the ZTD_estimation.TRP file and they are apriori models, gradient model, mapping function, min elevation, the tabular interval from/to, correction, correction East, correction North, correction Sigma, sigma East and sigma North. The second input parameter of this mini GIS system is time. The output of the web application is the heatmaps with different layers, which are showing all these observation figures.

Finally, this web application was created by the INSPIRE standards. The ZTD model, which is presented in Chapter 6, was used for the modelling of the database of the web application. The web application has been published on the server (http://ztd.bladventure.net/), and it has a variety of functions. Some of them are heatmaps which are created on the base of the standard deviations, corrections, based on the model and finally correction for the model. It has different functions and results which are depending on the time for the other metrological stations. For future work, this application can be used to provide WFS and WMS services, and also offer metadata descriptions to fulfil all requirements of INSPIRE.

7.2. Software Architecture

The developed software system represents a 3-tier application consisting of:

- Presentation layer;
- Business logic layer;
- Data access layer – DAL (in the further text);

Additionally, there is a database that holds data in an appropriate format. The developed system is a web application that is usually divided into two parts, frontend, and backend. Figure, 7.1, represents the 3-tier application.

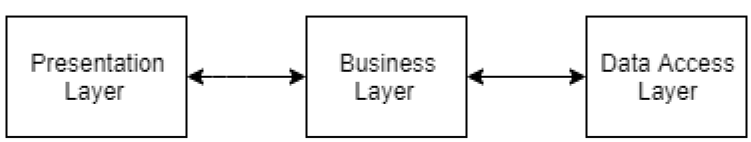

Figure 7.1. The presentation of the 3-tier architecture;

The frontend is a presentation layer, which is executed in the web browser on the user's machine. The backend contains business logic and DAL.

Furthermore, in the component diagram, it is described as the components of the system. The UML component diagram is different from the other UML diagrams and it does not represent the system functionality, but rather just elements that are used to make those functionalities. Figure 7.2. describes the components used to make the functionalities of the system, in this case, web application.

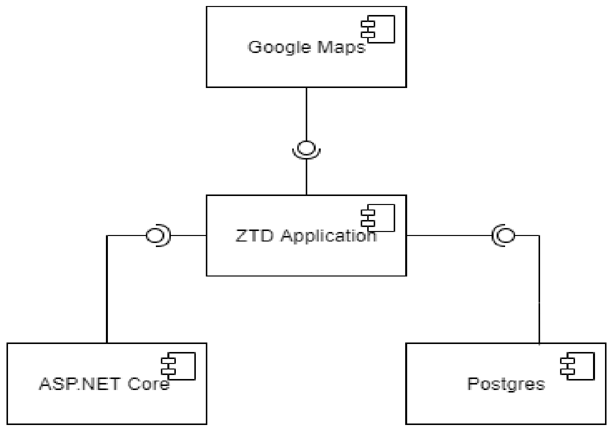

Figure 7.2. The UML component diagram of the ZTD application;

The component diagram has described the components which have been used to make the functionalities of the system; in this case, this is the ZTD Application. This application, which has been created for this experimental research, uses external libraries and services. Google Maps has been used as a raster. PostgreSQL and PostGIS have been used for data storage. The ASP.NET Core is a framework for developing a server-side of the web application. More explanation of these components will be given in the next subchapters.

7.3. The database aspects

The PostGIS supports a GIS object, and they are specified by the OpenGIS Consortium (OGC). This standard PostGIS extend with 3DZ, 3DM, and 4D coordinates. The Well-Known Text (WKT) form and the Well-Known Binary (WKB) form are the two possibilities to express spatial objects which are defined by the OpenGIS specification. These forms include information about the type of object and coordinates which form the object. Text is represented by the spatial objects: point, linestring, polygon, multipoint, multilinestring, multipolygon, and geometrycollection.

Furthermore, the spatial referencing system identifier (SRID) has been included in the internal storage of the format of the spatial object by the OpenGIS specification. The SRID integer has different values and represents a specific map projection, which means that all calculations are done by using a particular projection.

There are two types of data, and they are geography and geometry. The geography type represents the spatial features based on geographic coordinates. These coordinates are spherical, and their unit of measurement is degrees. The sphere is a basis for the PostGIS geography type, and that means all calculations on geographies which is reference surface for the PostGIS in this case, must be calculated on the sphere.

On the other hand, the geometry type has a plane basis, and that means that all calculations on the geometry type can be calculated using cartesian mathematics and straight-line vectors.

Additionally, geography type can store data in longitude and latitude coordinates. Some functions are defined on Geography and also in Geometry, but these functions which have been defined need more Central Processing Unit (CPU) time to be processed (https://postgis.net/docs/manual-2.5/using_postgis_dbmanagement.html#RefObject, 2019).

If we consider applicability, the spatial analysis functionalities are straightforward to understand, but the problem can be caused while choosing a wrong coordinate system. So, special attention should be paid to coordinate systems. If the longitude, latitude coordinate systems are used, the best option is to use a geography data type to be sure to get correct calculated measurements (Mikiewicz, Mackiewicz, & Nycz, 2017, pp. 105-106).

Geography and geometry are only types for specific columns in a relational database such as PostgreSQL. Relational databases consist of tables that have multiple columns. Their name and type represent columns. Foreign keys connect the tables. Every table has a set of columns that have to be unique for every record or row, and they are called the primary key. To be able to search forms based on some columns efficiently, indexes are used.

A standardized query language for the relational databases is SQL, which consists of several sublanguages: DML (Data Manipulation Language), DDL (Data Definition Language), TCL (Transaction Control Language) and DCL (Data Control Language). For this experimental work, DML and DDL are used.

The DML is used, among other things, for executing CRUD (Create, Read, Update, Delete) commands. The DDL is used to create the structure or metadata of the database. That means DDL is used to create or alter: tables, columns, foreign keys, indexes, etc. Figure 7.3. represents the database schema.

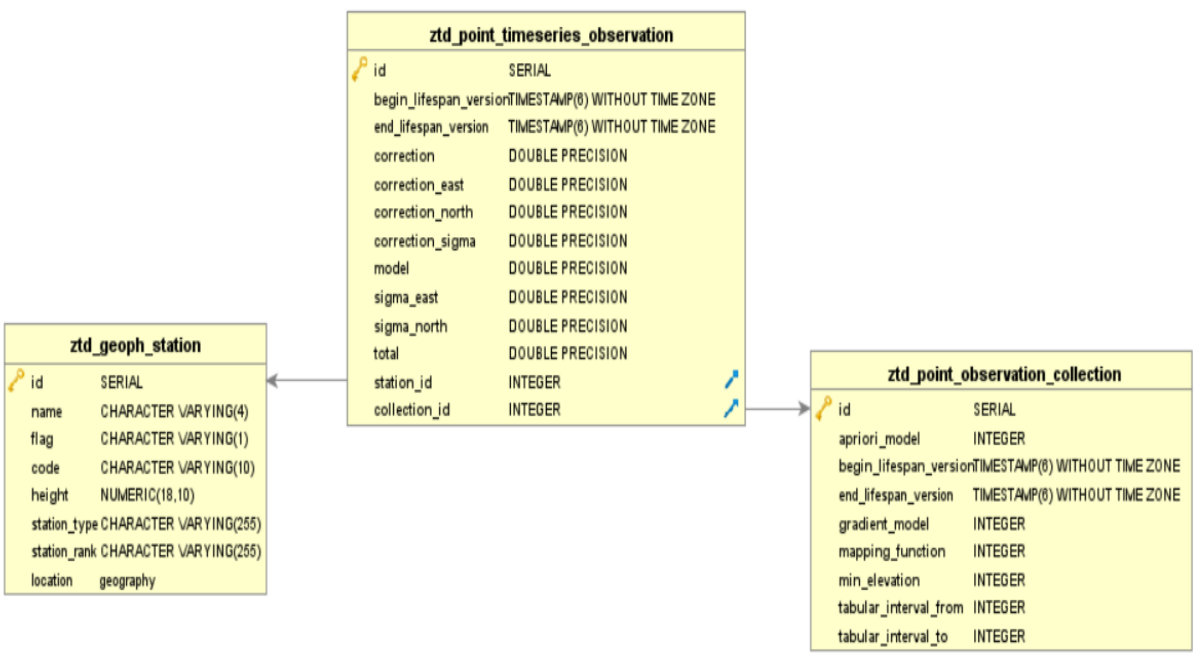

Figure 7.3. The schema of the database;

PostgreSQL relational database uses underscore notation, which is different from the Camel case used in the UML model as can be seen in Figure 7.3. there are three tables.

The tables are equivalent to the classes in the UML model. The first one is *ztd_geoph_station*, which represents a geophysical station with its accompanying columns. The location of the *ztd_geoph_station*is is represented by PostGIS based geography type point with the WGS84 coordinate system (SRID 4326). The table *ztd_point_timeseries_observation* describes the parameters that have been analyzed in the ZTD_estimation.TRP file. These parameters are the output measurements of the Bernese software from where it is generated.TRP file. The table *ztd_point_observation_collection* is based on the input parameters in the Bernese software. These parameters are apriori model, gradient model, mapping function, min elevation, and tabular interval. Also, the station_ID and collection_ID are the foreign keys, which means that they are linking to the other two columns.

DDL queries used to create presented tables are:

```
CREATE TABLE ztd_geoph_station (
  id SERIAL PRIMARY KEY,
  name VARCHAR (4) UNIQUE NOT NULL,
  flag VARCHAR(1) NOT NULL,
  code VARCHAR(10) UNIQUE NOT NULL,
  height NUMERIC(18,10) NOT NULL,
  station_type VARCHAR(255) NULL,
  station_rank VARCHAR(255) NULL,
  location GEOGRAPHY(POINT, 4326)
);

CREATE TABLE ztd_point_observation_collection (
  id SERIAL PRIMARY KEY,
  apriori_model INTEGER NOT NULL,
  begin_lifespan_version TIMESTAMP NOT NULL,
  end_lifespan_version TIMESTAMP,
  gradient_model INTEGER NOT NULL,
  mapping_function INTEGER NOT NULL,
  min_elevation INTEGER NOT NULL,
  tabular_interval_from  INTEGER NOT NULL,
  tabular_interval_to  INTEGER NOT NULL
);

CREATE TABLE ztd_point_timeseries_observation (
```

```
  id SERIAL PRIMARY KEY,
  begin_lifespan_version TIMESTAMP NOT NULL,
  end_lifespan_version TIMESTAMP,
  correction DOUBLE PRECISION NOT NULL,
  correction_east DOUBLE PRECISION NOT NULL,
  correction_north DOUBLE PRECISION NOT NULL,
  correction_sigma DOUBLE PRECISION NOT NULL,
  model DOUBLE PRECISION NOT NULL,
  sigma_east DOUBLE PRECISION NOT NULL,
  sigma_north DOUBLE PRECISION NOT NULL,
  total DOUBLE PRECISION NOT NULL,
  station_id INTEGER NOT NULL REFERENCES ztd_geoph_station(id),
  collection_id INTEGER NOT NULL REFERENCES ztd_point_observation_collection(id)
);
```

To create an index of location column in *ztd_geoph_station* table, the following query is executed:

```
CREATE INDEX station_geolocation_index
ON public.ztd_geoph_station
USING GIST (location);
```

In order to update the statistics that the database uses to select a query plan, we must run the following command.

```
VACUUM ANALYZE public.ztd_geoph_station;
```

PostGIS extension, apart from specific types such as geometry and geography, also enables usage of particular functions for manipulating and analyzing spatial data. Those functions are part of OGC SFS for SQL standards. For this thesis, the following procedures were used:

- ST_X(geometry), ST_Y(geometry) – Extraction of longitude and latitude coordinates from geometry type, respectively.
- ST_GeomFromEWKT(text) - Constructs a PostGIS ST_Geometry object from the OGC Extended Well-Known text (EWKT) representation (https://postgis.net/docs/ST_GeomFromEWKT.html, 2019).
- ST_AsText(geometry or geography) - Returns the Well-Known Text representation of the geometry/geography (https://postgis.net/docs/ST_AsText.html, 2019).

- ST_SetSRID(geometry, srid) - Sets the SRID metadata on a geometry to a particular integer value (https://postgis.net/docs/ST_SetSRID.html, 2019).
- ST_MakePoint(float, float) – Creates point geometry from x, y parameters.

The reason for using these functions is the ability to extract longitude and latitude from geography since ST_X, and ST_Y function only supports geometry so that the following statement: ST_X(ST_GeomFromEWKT(ST_AsText(geography))) can extract longitude from geography type. ST_SetSRID and ST_MakePoint are used for importing the data.

For the research purposes, two files were provided: ZTD_estimation.TRP file and GNSS-station.xlsx file. They contain station and observation data used for the practical implementation of the application. They had to be imported into the specially created "ztd" database, which includes a single "public" schema with three already mentioned tables. The *ztd_geoph_station* was populated by GNSS-station.xlsx file going through and inserting every single row as a record by using the following query:

INSERT INTO public.ztd_geoph_station(name, flag, code, height, station_type, station_rank, location) VALUES (@name, @flag, @code, @height, @station_type, @station_rank, ST_SetSRID(ST_MakePoint(@longitude, @latitude), 4326))

Additionally, for populating *ztd_point_timeseries_observation*, the following query was used:

INSERT INTO public.ztd_point_timeseries_observation (begin_lifespan_version, end_lifespan_version, correction, correction_east, correction_north, correction_sigma, model, sigma_east, sigma_north, total, station_id, collection_id) VALUES (@begin, @end, @corr, @corr_east, @corr_north, @corr_sigma, @model, @sigma_east, @sigma_north, @total, @station_id, @coll_id).

And for *ztd_point_observation_collection*, and the only single line was inserted by executing the following query:

INSERT INTO ztd_point_observation_collection (apriori_model, begin_lifespan_version, end_lifespan_version, gradient_model, mapping_function, min_elevation, tabular_interval_from, tabular_interval_to) VALUES (-15, '2014-09-18 02:30:00', NULL, 1, 4, 5, 1800, 43200).

The presented timestamp data as *begin_lifespan_version* and *end_lifespan_version* columns represent the Central European Time (CET) timezone.

7.4. The web application backend

For backend or server-side development of the ZTD web application, C# as a programming language and ASP.NET Core v3 as a framework were used. ASP.NET Core represents an open-source multi-platform framework for the development of web applications, developed by Microsoft. C# is an object-oriented programming language; thus, usage of classes and packages or namespaces is enabled. Server-side or backend of the web application is usually exposed and run by utilizing programs called web servers. For ASP.NET Core applications, IIS (Internet Information Services) is used as a web server. Web server catches HTTP (HyperText Transfer Protocol) requests, serves content, parses requests, and passes extracted data to programs or server-sides of web applications. Figure 7.4. shows the dataflow backend diagram.

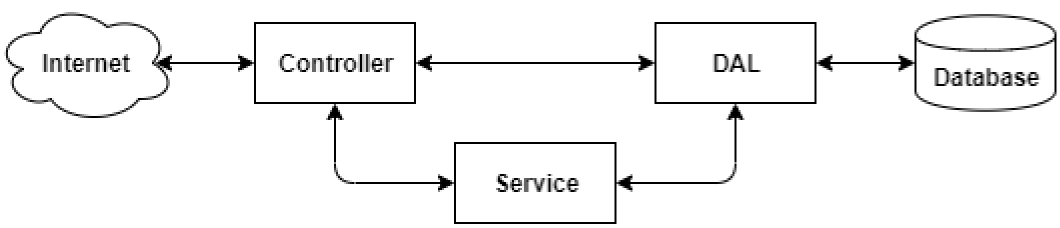

Figure 7.4. The dataflow backend diagram;

ASP.NET Core web application consists of packages or namespaces containing classes. The classes whose methods or action items handle HTTP requests are called Controllers. They return different result formats (JSON, XML, HTML, etc.) in the form of REST (Representational State Transfer) web services. They can use service classes that are responsible for special purpose data processing. Controllers and services together represent the business logic layer. They both use DAL as an interface towards the database. Figure 7.5. illustrates the package diagram of the backend of ZTD web application

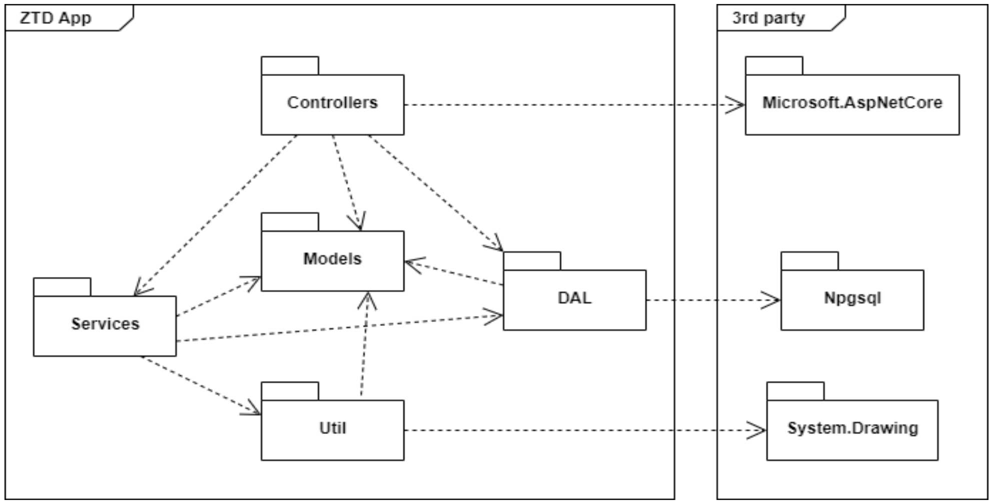

Figure 7.5. The package diagram of the backend of ZTD web application;

The ZTD application contains five packages, each containing the classes responsible for the package’s general purpose. Controllers incorporate or use Services, Models, DAL, and an external third-party package called Microsoft.AspNetCore for inherited functionalities. Controller calls services, and they use Models, DAL, and Util. Util package for utility classes uses Models and external package System. Drawing. DAL uses Models and Npgsql for accessing the PostgreSQL database. Models are the only package used by the others, who does not have any usages. The models' package class diagram is shown in the Figure 7.6.

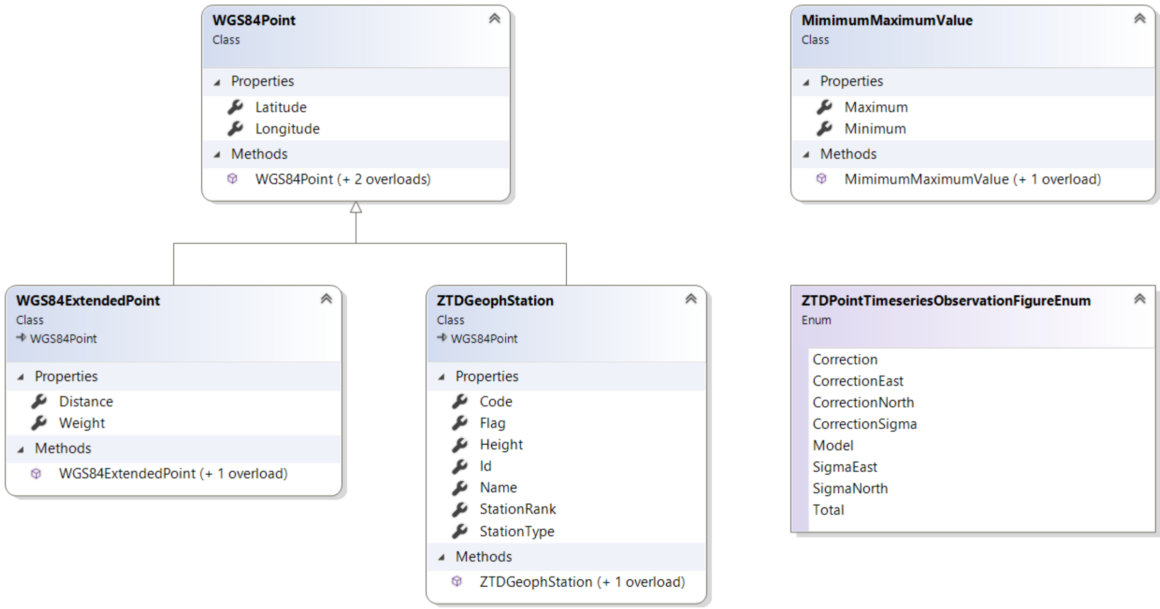

Figure 7.6. Models package class diagram;

Models package or namespace represents POCO classes (Plain Old Common language runtime Objects). Those classes are data transfer objects between Controllers, Services, and DAL. There is an enumeration or code list for different figures from the ZTDPointTimeseriesObservation model class. MinimumMaximumValue is used for extracting minimum and maximum values for a specific figure which is used for particular calculations in the application. WGS84Point is classic longitude, latitude attributed point class which is inherited by WGS84ExtendedPoint (having extra distance and weight) and ZTDGeophStation.

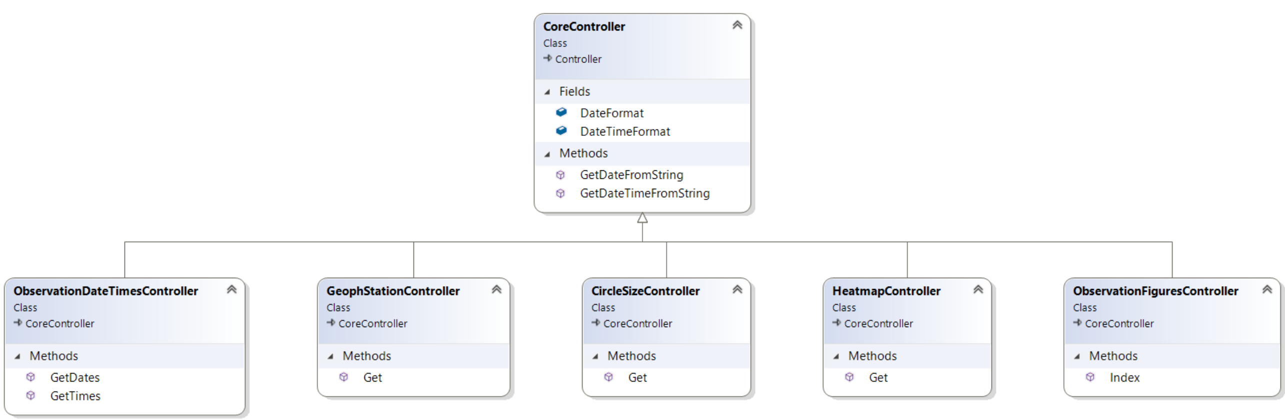

Figure 7.7. Controllers’ package class diagram;

All exposed Controllers inherit CoreController which provides Date and DateTime formats used in the application, to avoid duplication. The controllers' package class diagram is represented in the Figure 7.7. ObservationDateTimesController provides the exposure of dates and times which are attached to specific observations. The GeophStationController returns a list of geophysical stations along with attributes. Then the CircleSizeController is used for the particular layer in the application, showing a circle size diagram on the map. The HeatmapController is responsible for the heatmap layer on the map.

Furthermore, ObservationFiguresController returns a list of figures available in ZTDPointTimeseriesObservationFigureEnum. The DAL package diagram is represented in the Figure 7.8.

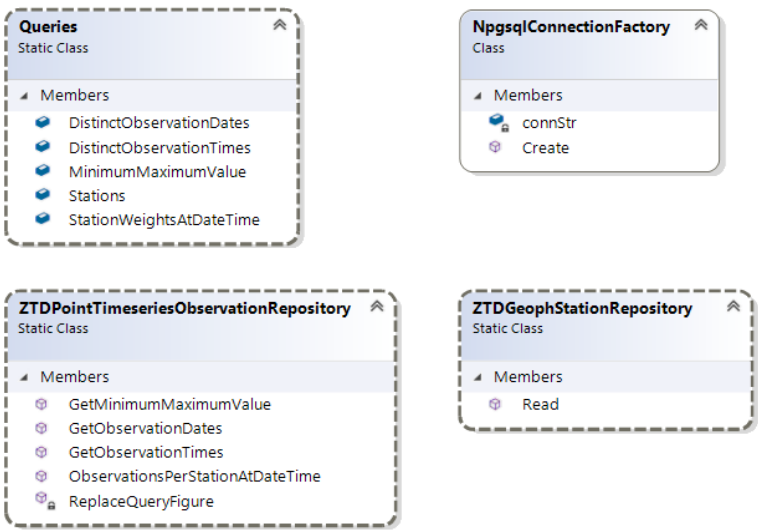

Figure 7.8. DAL package class diagram;

DAL represents an interface towards a data store or database. In this case, it is PostgreSQL with PostGIS plugin for GIS functionalities. DAL is implemented as a repository or DAO (Data Access Object) pattern. Software module or library used for handling queries and their execution is called a connector. For the ZTD Web application, the connector is Npgsql. It enables the usage of NpgsqlConnection, NpgsqlCommand, and NpgsqlDataReader classes. NpgsqlConnection is there for creating a direct connection with database service and its authentication and authorization. NpgsqlCommand is responsible for query execution on a specific relationship. When a query is executed, NpgsqlDataReader returns a relation or table containing data and metadata.

NpgsqlConnectionFactory creates new instances of NpgsqlConnection class based on connection string containing authentication data. It is called a “factory” because it implements a Factory pattern for creating new instances of objects. Queries are stored in Queries class, for purposes of this application. Names of 5 queries can be seen in the picture. ZTDPointTimeseriesObservationRepository and ZTDGeophStationRepository represent classes for executing special database-related calls or queries. For every call, they create a new NpgsqlConnection instance over NpgsqlConnectionFactory and then create a NpgsqlCommand instance by setting which particular SQL query is going to be executed.

In the end, NpgsqlDataReader is being emphasized through to extract data used for specific object creation.

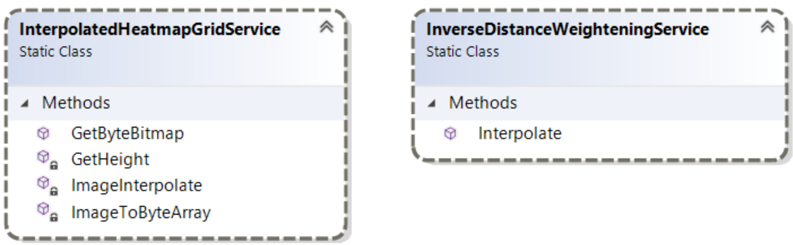

Figure 7.9. Services package class diagram;

Services package or namespace contains two classes: InterpolatedHeatmapGridService and InverseDistanceWeighteningService, and they are shown in the previous Figure 7.8. InverseDistanceWeighteningService implements IDW (Inverse Distance Weighting) interpolation by using the list of station locations and their corresponding figures or weights at a provided time, and this has been shown in Figure 7.9. The algorithm takes k-nearest neighbours to calculate the weight at an arbitrary point, as it can be seen in the picture. The philosophy of IDW interpolation is that the influence of a particular point’s weight is inversely proportional to the distance. Distances are calculated by using the SphericalDistanceUtil class, as it has been shown in Figure 7.10.

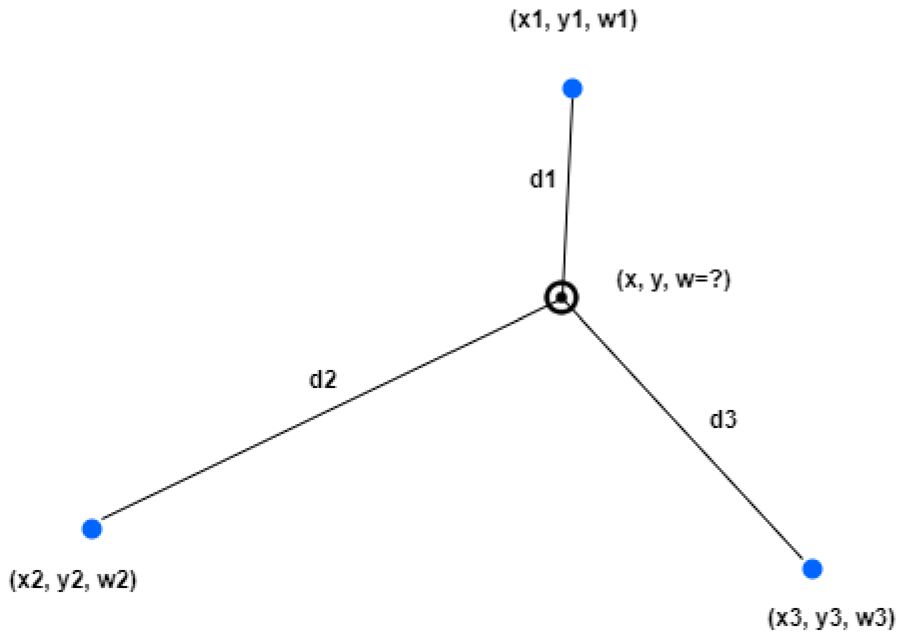

Figure 7.10. Inverse distance weighting calculation example for 3 points;

The formula for the calculation of the arbitrary weight for *n* points and their respective weights and distances is:

$$W_p = \frac{\sum_{i=1}^{n} \frac{w_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}} \tag{7.1}$$

The *p* parameter influences the formula so that it makes near points more critical if it is higher. For the ZTD application, *p* equals 1. Since the majority of figures are similar for different observations, interpolation is done based on two nearest points.

InterpolatedHeatmapGridService returns a bitmap of the heatmap by calculating the green-red gradient for every pixel based on the south-west and north-east boundaries. It goes through pixels and determines the same coordinate projection of pixels on the underlying raster. Then it interpolates the nearest stations and gets the figure which is recalculated to the percentage of the difference of minimum and maximum value of the constitution. As a result, heatmap has a shading effect in the form of a green-red gradient, which was described earlier in this paper. The image provided is at the end compressed to JPEG (Joint Photographic Experts Group) format, converted to bytes and passed further to frontend. Figure 7.11. presented until package diagram, and in the further work, this diagram will be described.

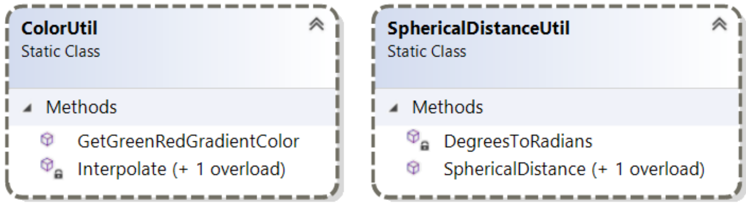

Figure 7.11. Util package class diagram;

There are two classes in the Util package: ColorUtil and SphericalDistanceUtil. ColorUtil calculates the green-red gradient from percentage. It sets RGB (red, green, blue) values from a single percentage value by setting offsets going from red over yellow to green. SphericalDistanceUtil calculates the distance between two points (using longitude and latitude coordinates) by utilizing the Haversine formula.

7.5. The web application frontend

The frontend part of the web application is executed in the web browser. It collects data from the server-side or backend and shows it on the web page. Modularly it is decoupled to:

- HTML (HyperText Markup Language) – web page structure
- CSS (Cascade Style Sheet) – web page styling
- JS (JavaScript) – web page functionality

ZTD represents a single page web application, and it has three files in the frontend part: index.html, main.css, and main.js. HTML page structure is hierarchically organized, containing structural elements which can include other components. A model with the hierarchical organization of web pages is called DOM (Document Object Model). It uses the jQuery library for DOM manipulation or changing parts of the web page on the user’s actions. Functionalities or user’s operations are handled by JavaScript code in the main.js file. It also initializes the Google Maps component and calls backend for data. Backend data is fetched by using AJAX (Asynchronous JavaScript + XML) technology. Data can be transferred in XML or JSON formats, but in this case, JSON is used because of its compatibility with Java Script.

On page load, the map is initialized by setting the map's central point, zoom and satellite image type. Google Map satellite imagery or raster is automatically loaded from Google Map service. The map is initialized by using google.maps.Map Java Script class or prototype. After that, dates and figures, drop-down selection components are populated with data that came from the server-side.

Apart from Google Maps raster base, there are three additional layers:

- Stations – shows stations names and respective geolocations
- Circles – shows a location-based circle-size diagram for selected figure and time
- Heatmap – shows green-red gradient heatmap over the map for selected figure and time

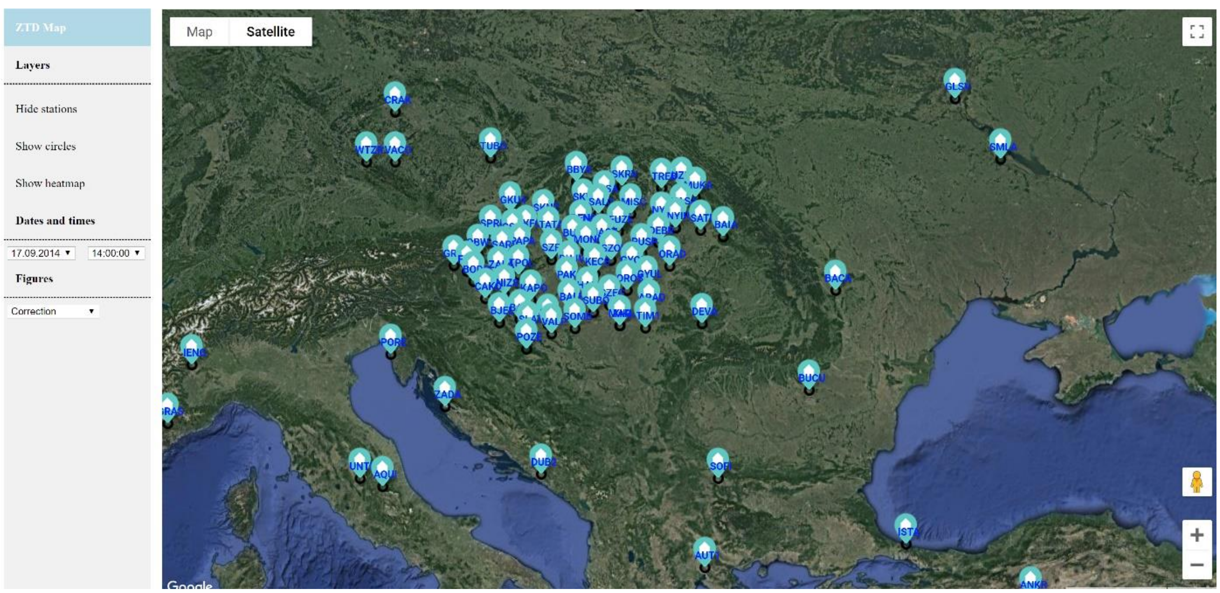

Figure 7.12. Stations layer;

The station's layer represents a simple marker map of stations along with their names. Station data is read from the *ztd_geoph_station* table on the server-side and rendered on the frontend. For the representation of markers, google.maps.Marker Java Script class or prototype is used. It receives parameters for coordinates, name, marker icon, and text style.

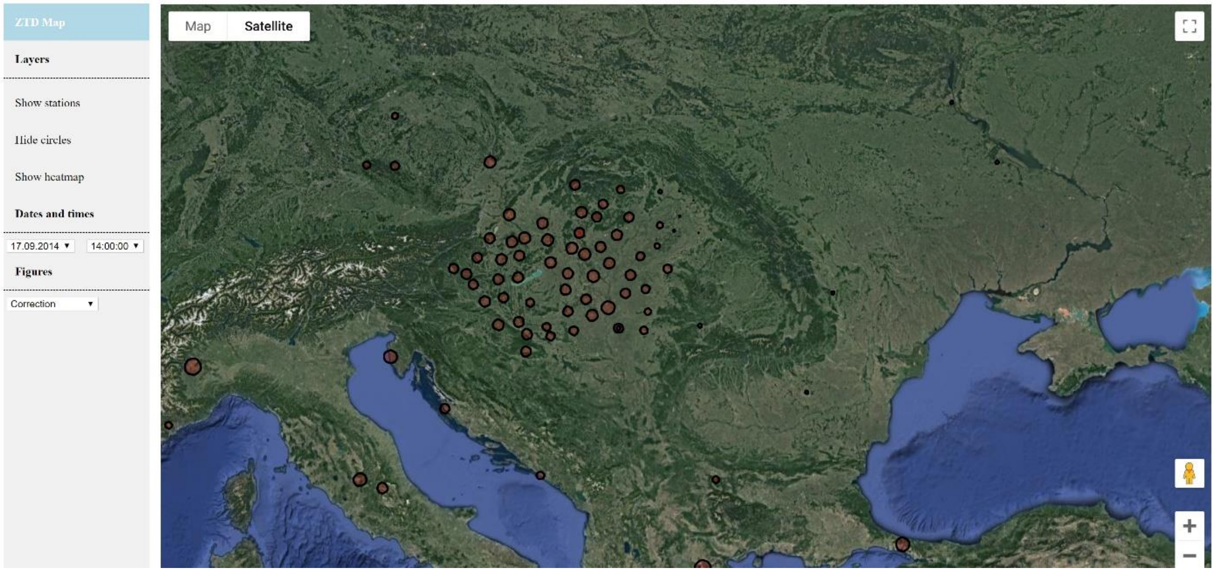

Figure 7.13. Circle-size layer;

The circle-size layer shows circles whose respective radius is calculated based on selected figures and time. For every circle, google.maps.Circle Java Script class or prototype is utilized. It receives the following parameters: centre location, radius and colour.

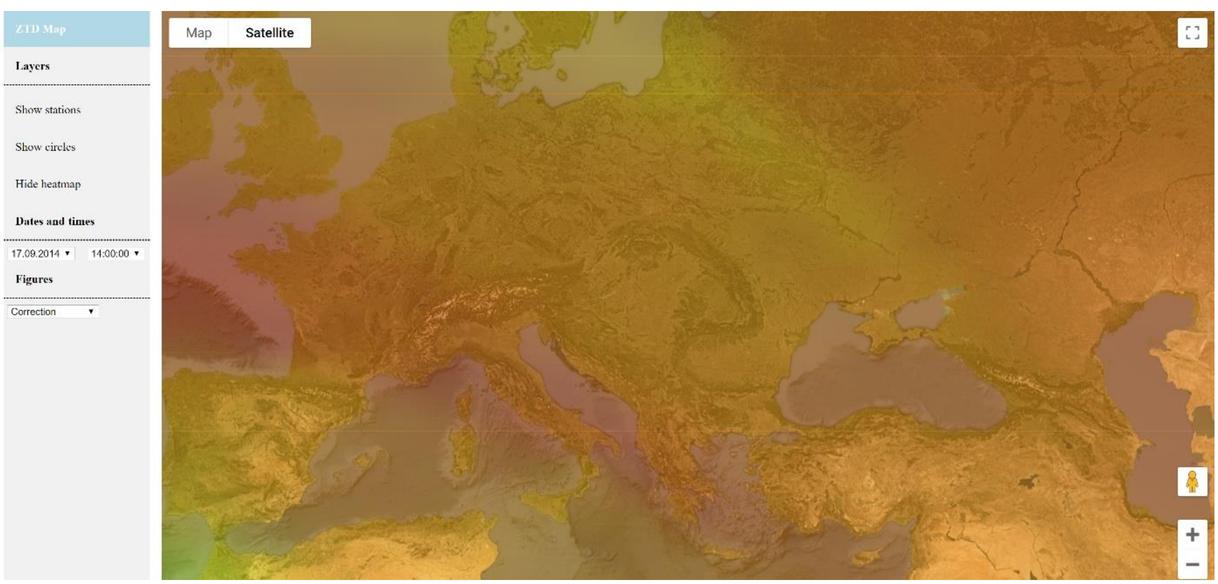

Figure 7.14. Heatmap layer;

The heatmap layer is different from Circle-size and Station layers because it is based on raster data, not vector data. Heatmap represents an RGB bitmap put over Google Maps satellite imagery raster with a setting of transparency or opacity. It uses google.maps.GroundOverlay class which receives an image URL (Uniform Resource Locator) and image bounds where the image should be "glued." Image bounds represent the whole map visible on the screen. URL of the image is a heatmap, which points to HeatmapController on the server-side which generates the image with Service package help.

8. Resulting ZTD XML files based on the consolidated UML model

During this experimental research four XML files were created from the consolidated UML model. The first XML file ZTD_ProcessParameters.xml file describes the input parameters of the Bernese software. Figure 8.1. shows this XML file.

```
<?xml version="1.0" encoding="UTF-8"?>
<ompr:Process
xmlns:base="http://inspire.ec.europa.eu/schemas/base/3.3"
xmlns:base2="http://inspire.ec.europa.eu/schemas/base2/2.0"
xmlns:ompr="http://inspire.ec.europa.eu/schemas/ompr/3.0"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://inspire.ec.europa.eu/schemas/ompr/3.0
https://inspire.ec.europa.eu/schemas/ompr/3.0/Processes.xsd">
	<ompr:inspireId>
		<base:Identifier>
			<base:localId/>
			<base:namespace/>
		</base:Identifier>
	</ompr:inspireId>
	<ompr:type/>
	<ompr:processParameter xsi:nil="false">
		<ompr:ProcessParameter>
			<ompr:name
xlink:href="ZTD_ProcessParameters.xml#aprioryModel"/>
			<ompr:description>Saastamoinen a priori hydrostatic
model</ompr:description>
		</ompr:ProcessParameter>
	</ompr:processParameter>
	<ompr:processParameter xsi:nil="false">
		<ompr:ProcessParameter>
			<ompr:name
xlink:href="ZTD_ProcessParameters.xml#mappingFunction"/>
```

```
                <ompr:description>Wet Neil mapping function based on
the simple 1/sinÎµ mapping function</ompr:description>
            </ompr:ProcessParameter>
        </ompr:processParameter>
        <ompr:processParameter xsi:nil="false">
            <ompr:ProcessParameter>
                <ompr:name
xlink:href="ZTD_ProcessParameters.xml#gradientModel"/>
                <ompr:description>The way to represent azimuthal
asymmetries is a tilting of the zenith the mapping
function</ompr:description>
            </ompr:ProcessParameter>
        </ompr:processParameter>
        <ompr:processParameter xsi:nil="false">
            <ompr:ProcessParameter>
                <ompr:name
xlink:href="ZTD_ProcessParameters.xml#minElevation"/>
                <ompr:description>Cut off angle calculated in
degrees</ompr:description>
            </ompr:ProcessParameter>
        </ompr:processParameter>
        <ompr:processParameter xsi:nil="false">
            <ompr:ProcessParameter>
                <ompr:name
xlink:href="ZTD_ProcessParameters.xml#tabularIntervalZenith"/>
                <ompr:description>Tabular interval for zenith
parameters</ompr:description>
            </ompr:ProcessParameter>
        </ompr:processParameter>
        <ompr:processParameter xsi:nil="false">
            <ompr:ProcessParameter>
                <ompr:name
xlink:href="ZTD_ProcessParameters.xml#tabularIntervalGradient"/>
                <ompr:description>Tabular interval for gradient
parameters</ompr:description>
            </ompr:ProcessParameter>
        </ompr:processParameter>
        <ompr:responsibleParty>
            <base2:RelatedParty/>
        </ompr:responsibleParty>
</ompr:Process>
```


Figure 8.1. The ZTD_ProcessParameters.xml file;

The second XML file is ZTD_Record.xml which contains all the output parameters of the ZTD_estimation. TRP file and they are: model, correction, correctionSigma, total, correctionNorth, sigmaNorth, correctionEast and sigmaEast. Figure 8.2. shows the following XML.

```
<?xml version="1.0" encoding="UTF-8"?>
<swe:DataRecord xmlns:gml="http://www.opengis.net/gml/3.2"
xmlns:swe="http://www.opengis.net/swe/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xlink="http://www.w3.org/1999/xlink"
xsi:schemaLocation="http://www.opengis.net/swe/2.0
http://schemas.opengis.net/sweCommon/2.0/swe.xsd">
	<swe:field name="model">
		<swe:Count definition="ZTD_Dictionary.xml#model"/>
	</swe:field>
	<swe:field name="correction">
		<swe:Count definition="ZTD_Dictionary.xml#correction"/>
	</swe:field>
	<swe:field name="correctionSigma">
		<swe:Count
definition="ZTD_Dictionary.xml#correctionSigma"/>
	</swe:field>
	<swe:field name="total">
		<swe:Count definition="ZTD_Dictionary.xml#total"/>
	</swe:field>
	<swe:field name="correctionNorth">
		<swe:Count
definition="ZTD_Dictionary.xml#correctionNorth"/>
	</swe:field>
	<swe:field name="sigmaNorth">
		<swe:Count definition="ZTD_Dictionary.xml#sigmaNorth"/>
	</swe:field>
	<swe:field name="correctionEast">
		<swe:Count
definition="ZTD_Dictionary.xml#correctionEast"/>
	</swe:field>
	<swe:field name="sigmaEast">
		<swe:Count definition="ZTD_Dictionary.xml#sigmaEast"/>
	</swe:field>
</swe:DataRecord>
```

Figure 8.2. The ZTD_Record.xml file;

The third XML is ZTD_Station_ANKR.1. This XML is generated from the ZTD_estimation.TRP file and it should be one XML for each station. This .xml is strongly connected with ZTD_Observations_ANKR-20805M002.1.xml because each station references the one ZTD_Observations_ANKR-20805M002.1.xml file. Figure 8.3. describes the ZTD_Station_ANKR.1.xml file.

```
<?xml version="1.0" encoding="UTF-8"?>
<ge_gp:GeophStation
xmlns:base="http://inspire.ec.europa.eu/schemas/base/3.3"
xmlns:gco="http://www.isotc211.org/2005/gco"
xmlns:gmd="http://www.isotc211.org/2005/gmd"
xmlns:sams="http://www.opengis.net/samplingSpatial/2.0"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:sam="http://www.opengis.net/sampling/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:ge_gp="http://inspire.ec.europa.eu/schemas/ge_gp/3.0"
xmlns:gph-ext="http://inspire.jrc.ec.europa.eu/schemas/gph-ext/3.0"
xmlns:gml="http://www.opengis.net/gml/3.2"
xmlns:base2="http://inspire.ec.europa.eu/schemas/base2/1.0"
gml:id="gst1"
xsi:schemaLocation="http://inspire.ec.europa.eu/schemas/ge_gp/3.0
http://inspire.ec.europa.eu/schemas/ge_gp/3.0/GeophysicsCore.xsd">
      <sam:sampledFeature xsi:nil="false"
xlink:href="http://sweet.jpl.nasa.gov/2.1/realmEarthReference.owl#Ear
thLithosphere"/>
      <sam:relatedObservation xlink:href="ZTD_Observation_ANKR-
20805M002.1" />
      <!--
      There could be more observations here, for example one
Observation for each month or year, as convenient

      <sam:relatedObservation xlink:href="ZTD_Observation_ANKR-
20805M002.2.xml"/>
      <sam:relatedObservation xlink:href="ZTD_Observation_ANKR-
20805M002.3.xml"/>
      <sam:relatedObservation xlink:href="ZTD_Observation_ANKR-
20805M002.4.xml"/>
      -->
      <sams:shape>
            <gml:Point gml:id="stn-1" srsDimension="3"
srsName="EPSG:4326">
                  <gml:pos>32.75848172 39.88775953
975.5345245</gml:pos>
            </gml:Point>
      </sams:shape>
      <ge_gp:inspireId>
            <base:Identifier>
                  <base:localId>ZTD_ANKR</base:localId>

      <base:namespace>http://mfgi.hu/inspire</base:namespace>
            </base:Identifier>
      </ge_gp:inspireId>
      <ge_gp:citation>
            <base2:DocumentCitation gml:id="ZTD_ANKR-ds1">
```

```
                <base2:name>ZTD_ANKR</base2:name>
                <base2:date xsi:nil="false">
                     <gmd:CI_Date>
                          <gmd:date>
                               <gco:Date>2010-12-14</gco:Date>
                          </gmd:date>
                          <gmd:dateType>
                               <gmd:CI_DateTypeCode
codeListValue="creation"
codeList="http://schemas.opengis.net/iso/19139/20070417/resources/cod
elist/gmxCodelists.xml#CI_DateTypeCode"/>
                          </gmd:dateType>
                     </gmd:CI_Date>
                </base2:date>
                <base2:link xsi:nil="true"/>
           </base2:DocumentCitation>
      </ge_gp:citation>
      <ge_gp:projectedGeometry>
           <gml:Point gml:id="ZTD_ANKR-gm-1" srsDimension="2"
srsName="EPSG:4326">
                <gml:pos>32.75848172 39.88775953</gml:pos>
           </gml:Point>
      </ge_gp:projectedGeometry>
      <ge_gp:verticalExtent xsi:nil="true" nilReason="unknown"/>
      <ge_gp:distributionInfo>
           <gmd:MD_Distributor>
                <gmd:distributorContact xlink:href=""
xlink:title="Nikolina Mijic"/>
           </gmd:MD_Distributor>
      </ge_gp:distributionInfo>
      <ge_gp:largerWork xsi:nil="true" nilReason="unknown"/>
      <ge_gp:relatedModel nilReason="missing" xsi:nil="true"/>
      <ge_gp:platformType
xlink:href="http://inspire.ec.europa.eu/codeList/PlatformTypeValue/sa
tellite"/>
      <ge_gp:relatedNetwork xsi:nil="true" nilReason="unknown"/>
      <ge_gp:stationType
xlink:href="http://inspire.ec.europa.eu/codeList/StationTypeValue/ztd
Station"/>
      <ge_gp:stationRank xsi:nil="true" nilReason="unknown"/>
</ge_gp:GeophStation>
```


Figure 8.3. The ZTD_Station_ANKR.1.xml file;

The last .xml file which has been created is ZTD_ANKR-2005M002-20805M002.1. The ZTD_ANKR-2005M002-20805M002.1.xml file has been generated from the ZTD_estimation.TRP file generating one file for each station. It contains 25 data samples which are referenced back to the ZTD_Station_ANKR.1.xml file. Figure 8.4. represents the ZTD_ANKR-2005M002-20805M002.1.xml file.

```
<?xml version="1.0" encoding="UTF-8"?>
<om:OM_Observation gml:id="OBS_ANKR-20805M002.1"
xmlns:swe="http://www.opengis.net/swe/2.0"
xmlns:cv="http://www.opengis.net/cv/0.2/gml32"
xmlns:om="http://www.opengis.net/om/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:gml="http://www.opengis.net/gml/3.2"
xsi:schemaLocation="http://www.opengis.net/om/2.0
http://schemas.opengis.net/om/2.0/observation.xsd
http://www.opengis.net/cv/0.2/gml32 http://bp.schemas.opengis.net/06-
188r2/cv/0.2.2_gml32/cv.xsd
http://www.opengis.net/swe/2.0
http://schemas.opengis.net/sweCommon/2.0/swe.xsd">
      <gml:description>SGO NRT ZTD estimation (18-SEP-14
02:30)</gml:description>
      <gml:name>ANKR-20805M002.1</gml:name>
      <om:type
xlink:href="http://www.opengis.net/def/observationType/OGC-
OM/2.0/OM_DiscreteTimeSeriesObservation"/>
      <!--
      Satellite time
      -->
      <om:phenomenonTime>
            <gml:TimePeriod gml:id="ts1t">
                  <gml:beginPosition>2014-09-
17T14:00:00</gml:beginPosition>
                  <gml:endPosition>2014-09-
18T02:00:00</gml:endPosition>
            </gml:TimePeriod>
      </om:phenomenonTime>
      <om:resultTime>
            <gml:TimeInstant gml:id="etslt">
                  <gml:timePosition>2014-09-
18T02:00:00</gml:timePosition>
            </gml:TimeInstant>
      </om:resultTime>
      <!--
      Here is the reference to the ZTD observation Procedure
      -->
      <om:procedure xlink:href="ZTD_Process.xml"/>
      <!--
      ZTD Process Parameters
      -->
      <om:parameter>
```

```
            <om:NamedValue>
                  <om:name
xlink:href="ZTD_Dictionary.xml#aprioryModel"/>
                  <om:value xsi:type="swe:CountType">
                        <swe:value>-15</swe:value>
                  </om:value>
            </om:NamedValue>
      </om:parameter>
      <om:parameter>
            <om:NamedValue>
                  <om:name
xlink:href="ZTD_Dictionary.xml#mappingFunction"/>
                  <om:value xsi:type="swe:CountType">
                        <swe:value>4</swe:value>
                  </om:value>
            </om:NamedValue>
      </om:parameter>
      <om:parameter>
            <om:NamedValue>
                  <om:name
xlink:href="ZTD_Dictionary.xml#gradientModel"/>
                  <om:value xsi:type="swe:CountType">
                        <swe:value>1</swe:value>
                  </om:value>
            </om:NamedValue>
      </om:parameter>
      <om:parameter>
            <om:NamedValue>
                  <om:name
xlink:href="ZTD_Dictionary.xml#minElevation"/>
                  <om:value xsi:type="swe:CountType">
                        <swe:value>5</swe:value>
                  </om:value>
            </om:NamedValue>
      </om:parameter>
      <om:parameter>
            <om:NamedValue>
                  <om:name
xlink:href="ZTD_Dictionary.xml#tabularIntervalZenith"/>
                  <om:value xsi:type="swe:CountType">
                        <swe:value>1800</swe:value>
                  </om:value>
            </om:NamedValue>
      </om:parameter>
      <om:parameter>
            <om:NamedValue>
                  <om:name
xlink:href="ZTD_Dictionary.xml#tabularIntervalGradient"/>
                  <om:value xsi:type="swe:CountType">
                        <swe:value>43200</swe:value>
```

```
                </om:value>
            </om:NamedValue>
        </om:parameter>
        <!--
        Obderved properties are listed in ZTD_Record.xml
        -->
        <om:observedProperty xlink:href="ZTD_Record.xml"/>
        <om:featureOfInterest
xlink:role="urn:ogc:def:featureType:OGC:Station"
xlink:href="ZTD_Station_ANKR.1.xml"/>
        <om:result
xsi:type="cv:CV_AbstractDiscreteCoveragePropertyType">
            <cv:CompactDiscreteTimeCoverage gml:id="CT5523525">
                <cv:domainExtent
xlink:href="http://my.example.org/feature?type=station%26name=st1#xpo
inter(./boundedBy)"/>
                <cv:rangeType xlink:href="ZTD_Record.xml"/>
                <cv:element>
                    <cv:CompactTimeValuePair>
                        <cv:geometry>2014-09-
17T14:00:00</cv:geometry>
                        <cv:value xsi:type="swe:DataRecordType">
                            <swe:field name="model">
                                <swe:Quantity
definition="ZTD_Dictionary.xml#model">
                                    <swe:uom code="m"
xlink:href="http://codes.wmo.int/common/unit/m"/>

        <swe:value>2.0534</swe:value>
                                </swe:Quantity>
                            </swe:field>
                            <swe:field name="correction">
                                <swe:Quantity
definition="ZTD_Dictionary.xml#correction">
                                    <swe:uom code="m"
xlink:href="http://codes.wmo.int/common/unit/m"/>

        <swe:value>0.15193</swe:value>
                                </swe:Quantity>
                            </swe:field>
                            <swe:field name="correctionSigma">
                                <swe:Quantity
definition="ZTD_Dictionary.xml#correctionSigma">
                                    <swe:uom code="m"
xlink:href="http://codes.wmo.int/common/unit/m"/>

        <swe:value>0.00134</swe:value>
                                </swe:Quantity>
                            </swe:field>
                            <swe:field name="total">
```

```
                                        <swe:Quantity
definition="ZTD_Dictionary.xml#total">
                                                <swe:uom code="m"
xlink:href="http://codes.wmo.int/common/unit/m"/>

        <swe:value>2.20529</swe:value>
                                        </swe:Quantity>
                                </swe:field>
                                <swe:field name="correctionNorth">
                                        <swe:Quantity
definition="ZTD_Dictionary.xml#correctionNorth">
                                                <swe:uom code="deg"
xlink:href="http://codes.wmo.int/common/unit/degree_(angle)"/>
                                                <swe:value>-
0.00016</swe:value>
                                        </swe:Quantity>
                                </swe:field>
                                <swe:field name="sigmaNorth">
                                        <swe:Quantity
definition="ZTD_Dictionary.xml#sigmaNorth">
                                                <swe:uom code="deg"
xlink:href="http://codes.wmo.int/common/unit/degree_(angle)"/>

        <swe:value>0.00012</swe:value>
                                        </swe:Quantity>
                                </swe:field>
                                <swe:field name="correctionEast">
                                        <swe:Quantity
definition="ZTD_Dictionary.xml#correctionEast">
                                                <swe:uom code="deg"
xlink:href="http://codes.wmo.int/common/unit/degree_(angle)"/>
                                                <swe:value>-
0.00088</swe:value>
                                        </swe:Quantity>
                                </swe:field>
                                <swe:field name="sigmaEast">
                                        <swe:Quantity
definition="ZTD_Dictionary.xml#sigmaEast">
                                                <swe:uom code="deg"
xlink:href="http://codes.wmo.int/common/unit/degree_(angle)"/>

        <swe:value>0.00009</swe:value>
                                        </swe:Quantity>
                                </swe:field>
                        </cv:value>
                </cv:CompactTimeValuePair>
        </cv:element>
        <!--
        Continue adding ANKR 20805M002 elements
        -->
```

```
            </cv:CompactDiscreteTimeCoverage>
      </om:result>
</om:OM_Observation>
```


Figure 8.4. ZTD_ANKR-2005M002-20805M002.1.xml file.

Additionally, all these .xml files together represent a unique, transformed ZTD_estimation.TRP file according to ZTD UML model.

Finally, it has been used as a tool to validate XML documents that have been created. All the .xml files have been approved without any errors.

9. Conclusion and Future work

9.1. Conclusion

This thesis elaborates the Zenith Tropospheric Delay (ZTD) data, which are the result of the satellite measurements. The ZTD estimation TRP file data where the input for this research. These data are processed data from the Bernese software. Based on the INSPIRE Directive and its Data Specification, a ZTD UML model is developed, This model is suggested to be an extension of the Atmospheric Conditions model, which is under the Annex III of the INSPIRE. Based on ZTD data, it should also need to define a station with its attributes and this class was created on the base of the Geophysics Station. All classes which are made in the ZTD UML model are described in the details, and each of them has their definitions. Relations between the classes are significant and they represent the relevant ZTD_estimation.TRP file and its parameters.

However, based on the model, the ZTD application has been developed, and it has a function of the mini GIS system. For the first time, visualization of the ZTD measurement attributes is proposed, based on Google Maps. Based on the coordinates of the GNNS stations in the whole of Europe, a method based on inverse distance weighting for the interpolation of the attributes (stations) inside the ZTD web application is developed. This ZTD web application shows the heatmaps with parameters from the ZTD_observation.TRP file on the specific reference station in Europe.

Finally, XML files are created on the base of the INSPIRE standards. They are describing the parameters of the ZTD_estimation.TRP file.

9.2. Future work

During this work, a few more possibilities were considered to build up this ZTD UML model. However, the propositions are the followings:

- Mapping ZTD data structure to the O&M standard with particular regard to complex time series data representation, observed properties, and process parameters.
- Taking into consideration and demonstrating use cases for individual satellite observations and interpolated surface coverages (ZTD_Station.xml and surface grid coverage prototypes).
- The positioning of ZTD features in the INSPIRE model using a cross-domain approach between Annex II/GE and Annex III/EF themes. (EMF XML prototypes).
- Developing RDF SKOS dictionaries for ZTD process parameters observed properties and process names.
- Creating an open source-based WFS/WMS service, and also provide metadata description to fulfil all INSPIRE requirements.

On the other hand, for future work, more attention should be paid on the elaboration of SLD (Style Design Layer) of the Atmospheric Conditions UML model.

List of Publications

Chapter of a Book

1. Borisov M., Mijić N., Bugarin T., Petrović V.M., Sabo F. (2020) The Concept and Application of the 3D Model Based on the Satellite Images. In: Avdaković S., Mujčić A., Mujezinović A., Uzunović T., Volić I. (eds) Advanced Technologies, Systems, and Applications IV -Proceedings of the International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies (IAT 2019). IAT 2019. Lecture Notes in Networks and Systems, vol 83. Springer, Cham, https://doi.org/10.1007/978-3-030-24986-1_23
2. Mijić N., Bartha G. (2019) Infrastructure for Spatial Information in European Community (INSPIRE) Through the Time from 2007. Until 2017. In: Avdaković S. (eds) Advanced Technologies, Systems, and Applications III. IAT 2018. Lecture Notes in Networks and Systems, vol 60. Springer, Cham, https://doi.org/10.1007/978-3-030-02577-9_5
3. Mijić N. (2019) Application of the Airborne LIDAR Technology on the Quarry Using AutoCAD Civil 3D Software. In: Avdaković S. (eds) Advanced Technologies, Systems, and Applications III. IAT 2018. Lecture Notes in Networks and Systems, vol 60. Springer, Cham, https://doi.org/10.1007/978-3-030-02577-9_6
4. Borisov M., Mijic N., Ilic Z., Petrovic V.M. (2019) Analysis and Visualization of the 3D Model – Case Study Municipality of Aleksandrovac (Serbia). In: Avdaković S. (eds) Advanced Technologies, Systems, and Applications III. IAT 2018. Lecture Notes in Networks and Systems, vol 60. Springer, Cham, https://doi.org/10.1007/978-3-030-02577-9_10
5. Mijic N., Ateljevic J. (2018) Demographic Analysis Using Modern GIS Software Tools—Case Study of the Republic of Srpska (Bosnia and Herzegovina). In: Hadžikadić M., Avdaković S. (eds) Advanced Technologies, Systems, and

Applications II. IAT 2017. Lecture Notes in Networks and Systems, vol 28. Springer, Cham, https://doi.org/10.1007/978-3-319-71321-2_51

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Journal Articles

1. Mijić N., Šestić M., Future development of NSDI based on European INSPIRE Directive – A case study of a Bosnian and Herzegovinian geoportal, International Journal of Spatial Data Infrastructure Research, 2018, Vol. 13, 315-338, Joint Research Centre, European Commission, DOI:10.2902/1725-0463.2018.13art19, http://ijsdir.jrc.ec.europa.eu/index.php/ijsdir/article/view/472
2. Davidovic M., Mijic N., ANALYSIS OF THE INFLUENCE OF SATELLITES CONSTELLATION IN GNSS POSITIONING ACCURACY, ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering Tome XV 2017, page 141-148.
3. Mijić N., VOLUME CALCULATION FROM DIGITAL TERRAIN MODEL**,** Journal Ekscentar Vol.18, December 2015, Zagreb, Croatia, page 62-63, ISSN (print version) 1331-4939, ISSN (online version) 1848-6398, UDK 378 528.

Conference Papers

1. Mijić N., Šestić M., ECONOMIC IMPACT ASSESSMENT OF THE INFRASTRUCTURE REQUIRED BY THE INSPIRE DIRECTIVE, 6th REDETE Conference - RESEARCHING ECONOMIC DEVELOPMENT AND ENTREPRENEURSHIP IN TRANSITION ECONOMIES, April 2018, Banja Luka, Bosnia and Herzegovina, pp 236-246, ISBN 978-99938-46-80-2, http://www.redete.org/

2. Mijić N., Bartha G., Vujičić M. T., INSPIRE CONCEPT AND DIGITAL DATA MODELS, 6th INTERNATIONAL CONFERENCE CONTEMPORARY ACHIEVEMENTS IN CIVIL ENGINEERING 2018, page 673-683, April, Subotica, Serbia.
3. Mijic N., Bartha G., INSPIRE INFRASTRUCTURE FOR SPATIAL DATA - MAIN ASPECTS OF FUTURE DEVELOPMENT, MultiScience – XXXI. MicroCAD International Multidisciplinary Scientific Conference, University of Miskolc, Miskolc, Hungary, 20-21 April 2017. ISBN 978-963-358-132-2

4. Mijic, N. QUARRY SURVEYING AND ANALYSIS USING DRONE-MOUNTED LiDAR & AutoCAD CIVIL 3D, 20th HU and 9th HR-HU Geo-mathematical Congress, Pecs, Hungary, 11-13. May 2017.

5. Mijic N, Preradovic D, Sestic M, STRATEGIC DEVELOPMENT OF INFRASTRUCTURE FOR SPATIAL INFORMATION BASED ON EUROPEAN INSPIRE DIRECTIVE, 5TH REDETE Conference, 28 – 30 October 2016, Belgrade, Serbia, http://www.redete.org, pp 301-317

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7. Davidovic M, Mijic N, COMPARISON OF TWO DIFFERENT TECHNOLOGIES OF SURVEYING AN OBJECT IN POLYGONAL NETWORK, Conference STES 2016, 23 -25.11. 2016., Banja Luka, Bosnia and Herzegovina.

8. Mijić, N., CALIBRATION OF TERRESTRIAL LASER SCANNER, 10th International Conference on Production Engineering - RIM 2015, 4th to 5th, October,

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10. Mijic, N., DETERMINATION OF GEODETIC INSTRUMENTS CENTERING ERROR ON THE PILLARS, 24th International Electrotechnical and Computer Science Conference - ERK, 21st to 23rd, April, pp. 301-304, Portoroz, Slovenia, 2015, ISSN 1581-4572, UDC 621.3 (082) 004 (082), http://www.ieee.si/erk/

11. Janic, M. Djukanovic, G., Grujovic, D. Mijic, N., EARTH VOLUME CALCULATION FROM DIGITAL TERRAIN MODELS, Journal of industrial design and engineering graphics, Vol. 10, pp 27-30, Special issue ICEGD, June 2015, Brasov, Romania, ISSN (online version) 2344-4681, ISSN (print version) 1843-3766. www.sorging.ro

12. Mijic, N., DETERMINATION OF THE MEASUREMENT UNCERTAINTY OF 3D LASER SCANNER, 38th International Convention - MIPRO 2015, 25th-29th May 2015, Opatija - Adriatic Coast, Croatia, p. 1345-1350, CTS, ISSN 1847-3946. www.mipro.hr

13. Mijić, N. Janić, M., CALCULATED QUANTITIES BASED ON 3D MODEL OF CHANNEL – RAČUNANJE KUBATURA MASA IZ 3D MODELA KANALA, 11th International Scientific-Technical Conference, Contemporary Theory and Practice in Building Development, 14th-15th of May, p. 503-510, 2015.

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