# GEO1003 - Shared Notes

Master Geomatics Students

2025-01-07

## Contents

# Introduction

This is the introduction to the notes.

# Example

## Introduction

The goal of this chapter is just to demonstrate how things should be organized. It will be removed from the notes in the end.

## Markdown Basics

### Resources and Helpers

A nice cheat sheet about Markdown can be found at this link: https://www.markdownguide.org/cheat-sheet/.

On VS Code, there are some nice extensions that can help you write Markdown files:

- Markdown All in One to provide useful shortcuts and commands
- markdownlint to properly format your Markdown files

Feel free to ask me if you have questions about Markdown.

### Comments

```
This <!--This is a comment.--> is
<!--
Comments are not rendered.
They can take multiple lines
-->
a
sentence.
```

This is a sentence.

### Headers

```
<!-- Comment the fist headers to avoid messing up the outline of this file -->
<!--
# Level 1

## Level 2

### Level 3
-->

#### Level 4

##### Level 5

###### Level 6
```

#### Level 4

##### Level 5

###### Level 6

### Bold and Italic

```
- Normal text
- **Bold text**
- _Italic text_
- **_Bold and italic text_**
```

- Normal text
- **Bold text**
- *Italic text*
- ***Bold and italic text***

### Lists

```
Unordered list:

- Unordered list item 1
- Unordered list item 2
  - Nested unordered list item

Ordered list:

1. Ordered list item 1
2. Ordered list item 2
   1. Nested ordered list item
```

Unordered list:

- Unordered list item 1
- Unordered list item 2
  - Nested unordered list item

Ordered list:

1. Ordered list item 1
2. Ordered list item 2

    1. Nested ordered list item

### Links

```
[Example link](https://www.example.com)
```

Example link

### Images

```
![Example image](../../../images/example.jpg){ width="250" }
```

Figure 1: Example image

### Blockquotes

```
> This is a blockquote.
```

> This is a blockquote.

### Code

```
Inline code: `print("Hello, World!")`

Code block:

```python
def hello_world():
    print("Hello, World!")
```
```

Inline code: `print("Hello, World!")`

Code block:

```python
def hello_world():
    print("Hello, World!")
```

### Tables

```
Table: A simple table

| Header 1 | Header 2 |
| -------- | -------- |
| Cell 1   | Cell 2   |
| Cell 3   | Cell 4   |
```

Table 1: A simple table

| Header 1 | Header 2 |
|---|---|
| Cell 1 | Cell 2 |
| Cell 3 | Cell 4 |

### Math

```
Inline math: $x^2$ is the square of $x$.

Block math:

$$
\int_0^\infty e^{-x^2} dx = \frac{\sqrt{\pi}}{2}
$$
```

Inline math: $x^2$ is the square of $x$.

Block math:

$$\int_0^\infty e^{-x^2} dx = \frac{\sqrt{\pi}}{2}$$

### Empty Section

This section gives more information about the empty section.

## How does GNSS work?

### Introduction

The Global Positioning System (**GPS**), also known as the NAVigation Satellite Time And Ranging (**NAVSTAR**) system had its first satellite launched back in February 1978. GPS is a *one-way* radio ranging system which provides realtime knowledge of one's Position and Velocity, and a very accurate Time reference as well (all together referred to as **PVT**).

### GPS segments

The GPS system consists of three segments:

1. The **space segment**, consisting of 24 or more satellites, with accurate atomic clocks on board, continuously transmitting ranging signals to Earth.
2. The **control segment**, consisting of a number of ground stations, which monitors the satellites, computes their orbits and clock offsets, and uploads this information to the satellites, which in turn encode this information on the ranging signal (the so-called navigation data).
3. The **user segment**, simply consisting of many GPS receivers, which each track four or more GPS satellites, and compute their own position.

### Radio Signal

The GPS radio signal contains:

- the **L-band carrier frequency** between 1 and 2 GHz
- the **Pseudo Random Noise** (PRN, also called the **spreading code**), unique to each satellite, publicly available
- the **navigation message** containing the satellite orbit and clock information

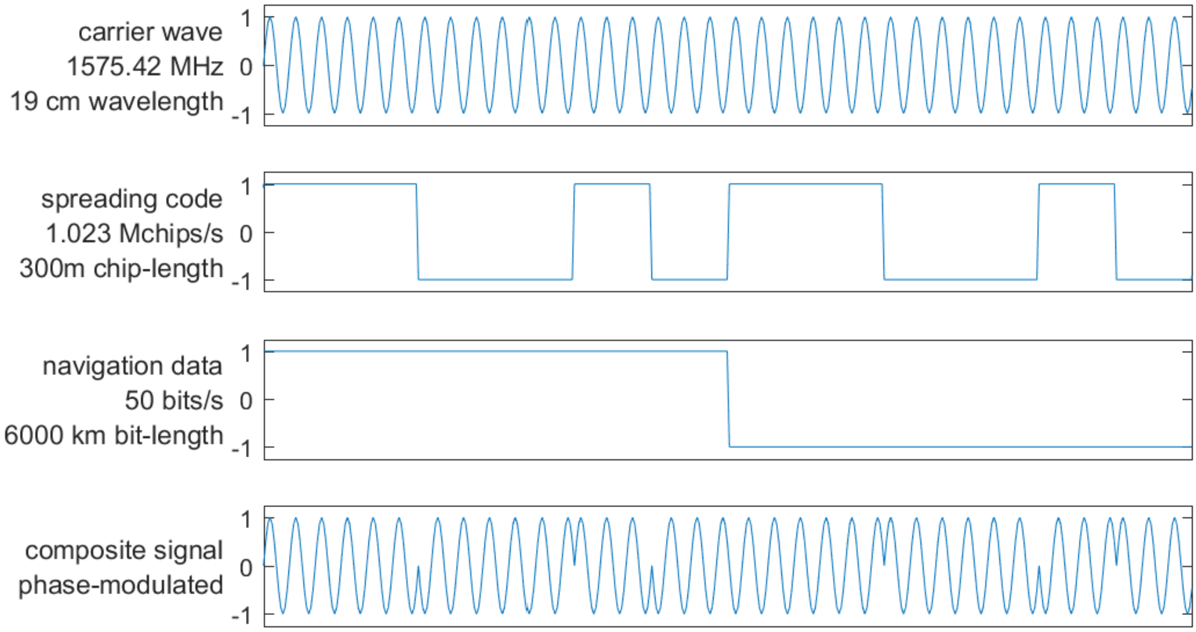



Figure 2: GPS L1 CA-signal (scale is not accurate)

### Initialisation

A GPS receiver typically consists of tens to hundreds of so-called **channels**, and will allocate each of these to a specific GPS (GNSS) satellite. When a GPS receiver first starts up, it will begin to *search for a particular GPS satellite on each of its channels*, by trying to scan for the corresponding **spreading codes** at different *Doppler offsets* and *time delays*. This is done by overlaying the received signal with a *local copy or replica of the same code* and then (time) shifting it until correlation shows a maximum (best fit, or match).

### Pseudorange Measurement

Once the receiver is locked on to a satellite's spreading code, it will continue to track it by *continuously adjusting the time delay and Doppler offset* to keep the correlation at a maximum. The time delay is then used to calculate the **pseudorange** $p_{r,s}$ to the satellite, which is (theoretically) the travel time $\tau_{r,s}$ multiplied by the speed of light $c$:

$$p_{r,s} = c \cdot \tau_{r,s} \text{ where } \tau_{r,s} = t_r - t_s$$

See Error Sources for more information on the errors in the pseudorange measurement.

### Carrier Phase Measurement

A GPS receiver may measure the **fractional phase difference** between the received *carrier wave* from the satellite and a locally generated copy (replica). The carrier wave measurement is a **very precise measure** of the distance between the satellite and the receiver, but the initial number of carrier wave cycles is *unknown*, and needs to be estimated before the carrier phase measurements can be effectively used.

The much better precision of the carrier phase measurement with respect to the pseudorange code measurement can be explained by **much smaller period** of the carrier compared to the code chip duration (for the L1 CAcode signal, 1540 periods of the carrier fit in one chip of the Pseudo Random Noise (PRN) spreading code).

### Jamming and Spoofing

#### GPS Jamming

#### GPS Spoofing

## GNSS performance

### Introduction

### Error Sources

There are a few issues with this calculation:

- the **satellite clock** has an **offset**, which is *known* (part of the navigation message)
- the **receiver clock** has an **offset**, which is *unknown*
- the **ionosphere** causes a delay (due to a lower speed of light), which is *unknown*
- there might be other errors, such as multipath, which are unknown

Any of these issues will cause the calculated pseudorange to be **inaccurate**. The calculation is very sensible since $c \approx 3 \times 10^8$ m/s, and a **1 µs** error will cause a **300 m** error in the calculated distance.

### Ionosphere Delay

One of the *major error sources* in GPS is due to the **ionosphere**, which contains *free electrons* that cause the speed of light to be lower than in vacuum.

The ionospheric delay may be **highly variable**, as a function of both **time** and **space**. In terms of distance ranging, it can go from *a few meter to hundreds of meters*, and is maximum round the geomagnetic equator around local noon, and during solar maxima.

The ionosphere delay scales, to a very good approximation, with the **inverse of the square of the radio frequency** of the signal, so using two different frequencies allows to create the so-called *ionosphere-free range measurements*. This is why GPS satellites were originally designed to transmit ranging signals on both the **L1** (1575.42 MHz) and **L2** (1227.60 MHz) frequency.

## Accuracy and Precision

The receiver can measure the received **signal strength**, through the so-called carrier-to-noise-density ratio $C/N_0$, which gives an indication of the **quality of the measurement** (larger signal strength yields more precise measurement).

The **pseudorange measurement** precision is typically at the *one or few meter* level for low-cost, mass-market equipment, and can get down to the *few decimeter level* for professional highend equipment.

The **carrier phase measurement** precision ranges from the *few centimeter to the millimeter level.* The carrier phase is an ambiguous measurement of distance, but it is more precise than the pseudorange, typically by **two orders of magnitude**.

### Dilution of Precision

### Availability, Continuity and Integrity

#### Availability

#### Continuity

#### Integrity

### PPP-RTK

#### PPP

#### RTK

### DGNSS

## GNSS in the built environment (outdoor, indoor and in between)

### Introduction

### Multipath

### Urban Canyon

### Shadow Matching

# CRS

### Introduction

### Coordinate Systems

#### Coordinate Reference Systems

According to the EPSG and ISO guidelines, four groups of CRSs can be distinguished:

- **Geographic CRSs** give geographic coordinates in degrees (2D latitude and longitude, and for 3D also height) relative to an ellipsoidal model of the Earth's surface. Examples include the European ETRS89, the global ITRF2020, and WGS 84. Geographic CRSs, such as ETRS89 and WGS 84, cannot be visualized on a flat plane without a map projection.
- **Projected CRSs** present geo-information on a flat surface in Cartesian (x and y) coordinates. A projected CRS is a derivative of a geographic CRS, where a map projection is used for the depiction on the flat surface. An example of this is the Dutch RD with the geographic CRS RD-Bessel as its basis.
- **Vertical CRSs** for recording height and depth relative to a reference plane. This reference plane is often based on the direction of gravity and normally does not coincide with the surface of an ellipsoid. With a reference plane based on the direction of gravity, no water flows between two points of equal height, but water usually does flow between two points of equal ellipsoidal height. Examples of vertical CRSs are the NAP and the LAT.

- **Compound CRSs** are composite CRSs, for example: RDNAP which is composed of the projected CRS RD and the vertical CRS NAP.

In this chapter of the summary, we will highlight two examples of Coordinate Reference Systems. Before doing so, here is an overview of some terminology and their examples:

**Geodetic terminology**

- Terrestrial Reference System (definition) (e.g. ETRS89, WGS84)
- Terrestrial Reference Frame (realisation) (e.g. ETRF2000, ITRF2020)
- Ellipsoid (e.g. GRS80, Bessel 1841)
- ‘Coordinate notation’ (e.g. axis, order, units)
- Map projection (optional) (e.g. UTM, LCC)
- Epoch (for time-dependent coordinates) (e.g. 2024.91 (27 November 2024)

NB: be aware of the difference between epoch and the year in names!

**Geo-spatial terminology**

- Datum ensemble ≠ Terrestrial Reference System
- Datum ≈ Terrestrial Reference Frame + ellipsoid
- Coordinate system ≈ Coordinate notation (+ map projection)
- CRS (= projection in some software) = datum + coordinate system

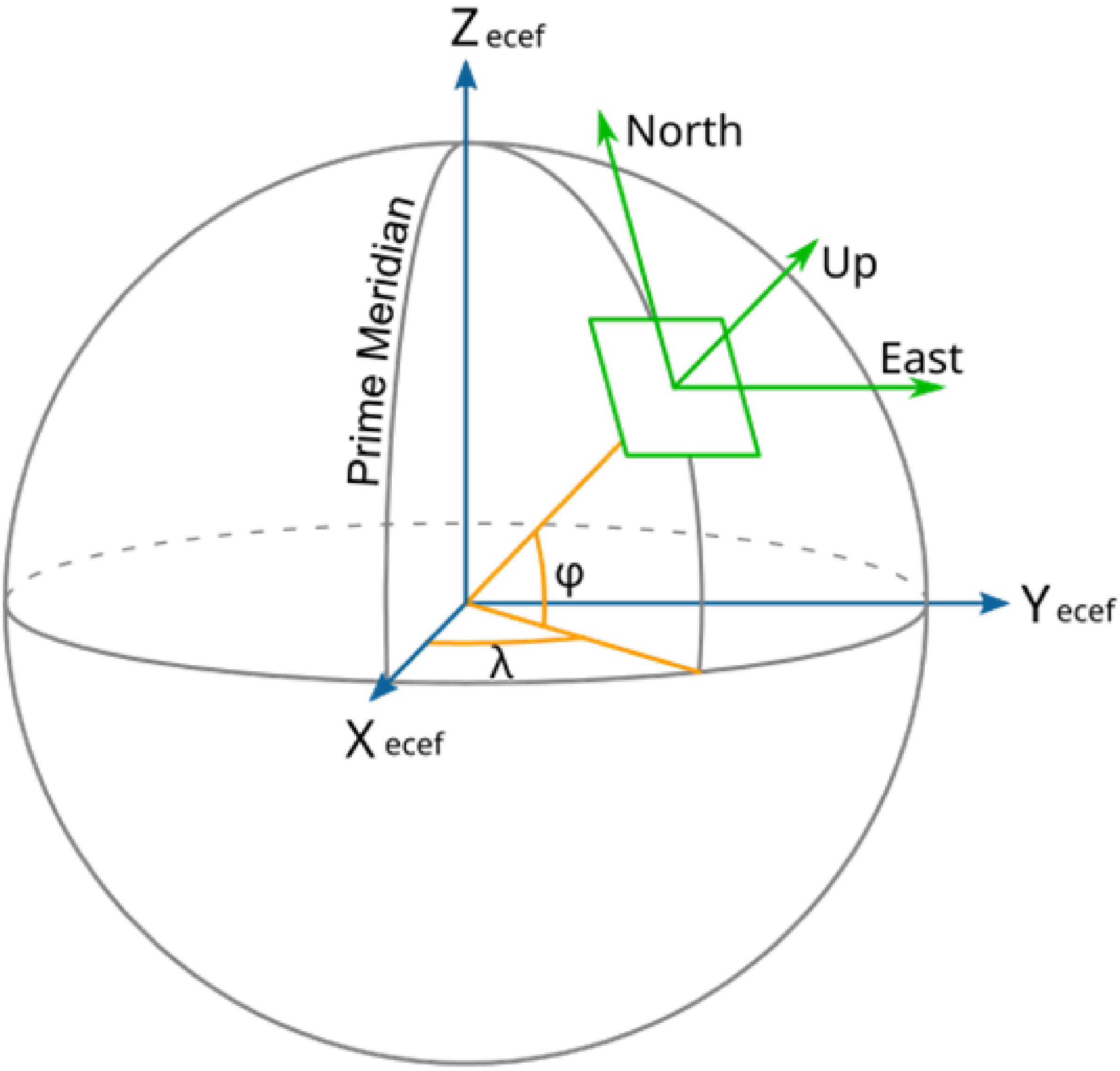
### Geographic Coordinate Reference Systems

The use of Geographic Coordinate Reference Systems is very common. They use degrees of latitude and longitude and sometimes also a height value to describe a location on the earth’s surface.

**Lines of latitude** run parallel to the equator and divide the earth into 180 equally spaced sections from North to South. The reference line for latitude is the equator and each **hemisphere** is divided into ninety sections, each representing one degree of latitude. Wherever you are on the earth’s surface, the distance between the lines of latitude is the same (60 nautical miles).

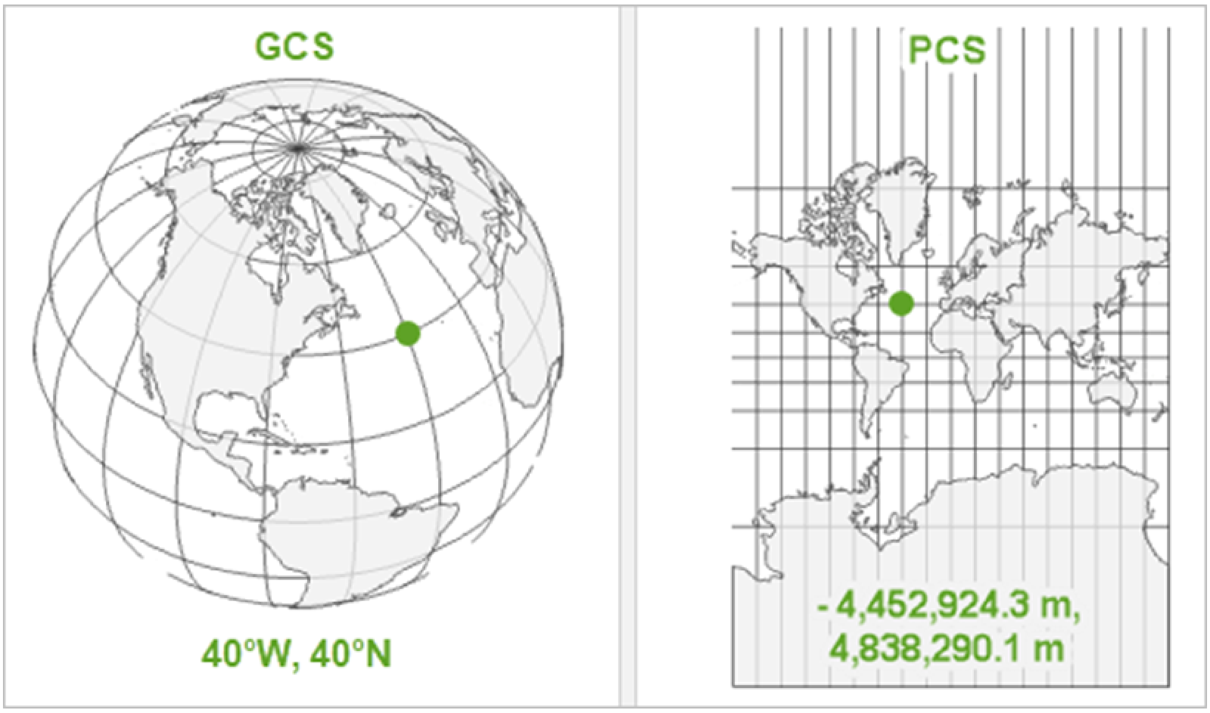
**Lines of longitude**, on the other hand, do not stand up so well to the standard of uniformity. Lines of longitude run perpendicular to the equator and converge at the poles. The reference line for longitude (the prime meridian) runs from the North Pole to the South Pole through Greenwich, England. At the equator, and only at the equator, the distance represented by one line of longitude is equal to the distance represented by one degree of latitude.

Using the geographic coordinate system, we have a grid of lines dividing the earth into squares that cover approximately 12363.365 square kilometres at the equator — a good start, but not very useful for determining the location of anything within that square. To be truly useful, a map grid must be divided into small enough sections so that they can be used to describe (with an acceptable level of accuracy) the location of a point on the map. To accomplish this, degrees are divided into **minutes** (’) and **seconds** (“). There are sixty minutes in a degree, and sixty seconds in a minute (3600 seconds in a degree). So, at the equator, one second of latitude or longitude = 30.87624 meters.




**Projected Coordinate Reference Systems**

There is a difference between a geographic coordinate system (GCS) and a projected coordinate system (PCS). In short, a GCS defines **where** the data is located on the earth's surface; a PCS tells the data **how** to draw on a flat surface. A GCS is round, and so records locations in angular units (usually degrees). A PCS is flat, so it records locations in linear units (usually meters).




The GCS is what ties your coordinate values to real locations on the earth. Only knowing the latitude and longitude of a location is thus not good enough, as it only tells you where a location is within a GCS. To draw a graticule, you need a model of the earth that is at least a regular spheroid, if not a perfect sphere. There are many different models of the earth's surface, and therefore many different GCS!

Once you know where to draw something, you need to know how. The earth's surface — and your GCS — are round, but the map is flat. This is where the map projections come in. They tell you how to distort the earth so the parts that are most important to your map get the least distorted and are displayed best on the flat surface of the map. A **projected coordinate system** (PCS) is a GCS that has been flattened using a map projection.

Your data must have a GCS before it knows where it is on Earth. Projecting your data is optional, but projecting your map is not. Maps are flat, so your map must have a PCS to know how to draw.

Coordinates in a PCS are recorded in **a Linear Unit**, often meters. A PCS also contains a Geographic Coordinate System (e.g. WGS 1984)! Remember that a PCS is just a GCS that has been projected.

Coordinates in a GCS are recorded in an Angular Unit, usually degrees. The **Prime Meridian** is an arbitrary line of longitude that is defined as 0°. The **Datum** defines which model is used to represent the earth's surface and where that model is positioned relative to the surface. The **Spheroid** is the regular model of the irregular earth. It's part of the datum. **Semimajor Axis, Semiminor Axis**, and **Inverse Flattening** define the size of the spheroid.

### Linear Reference Systems

**Linear referencing** is the method to store and geographically locate data using relative positions along a measured line feature without the need to explicitly use x,y coordinates or an address. When data is linearly referenced, measure values are used to measure the distance along a line feature, allowing multiple sets of dynamically changing attribute data to be associated with any portion of an existing linear feature, independent of its beginning and end. Linear referencing is used for many reasons. The following are the two primary reasons:

- Many locations are recorded as events along linear features.

For example, locations of traffic accidents are recorded using a convention such as "27 meters east of reference mile marker 35 along State Highway 287." Many sensors record conditions using measures of distance or time along the lines—along pipelines, along roads, along streams, and so forth.

- Linear referencing is also used to associate multiple sets of attributes to portions of linear features without requiring that underlying lines be segmented (split) each time that attribute values change.

  For example, most road centreline feature classes are segmented where three or more road segments intersect and where the road names change.


Figure 3: img.png

Great examples of Linear Reference Systems are the Dutch **hectometre markers**. As the name suggests, Dutch hectometre markers are spaced at 100-metre intervals. In addition to showing the motorway number and location, they also bear a **carriageway identifier** – Li for Links (Left) and Re for Rechts (Right). The carriageways are identified as being left-hand and right-hand as viewed by somebody looking in the direction of increasing location numbers. By and large, Dutch location numbers increase as one moves away from Amsterdam, or in the case of roads that do not originate in Amsterdam, location numbers increase as one moves eastwards away from the North Sea.

**Dynamic segmentation** is the process of computing the map locations of events stored and managed in an event table and displaying them on a map using route features. The term dynamic segmentation is derived from the concept that line features need not be split (in other words, segmented) each time an attribute value changes; you can dynamically locate the segment.

Using dynamic segmentation, multiple sets of attributes can be associated with any portion of an existing linear feature independently of where it begins or ends. These attributes can be displayed, queried, edited, and analyzed without affecting the underlying linear feature's geometry.

### Terrestrial Reference Systems and Frames

In this chapter of the summary, we will highlight some examples of Coordinate Reference Systems and Frames:

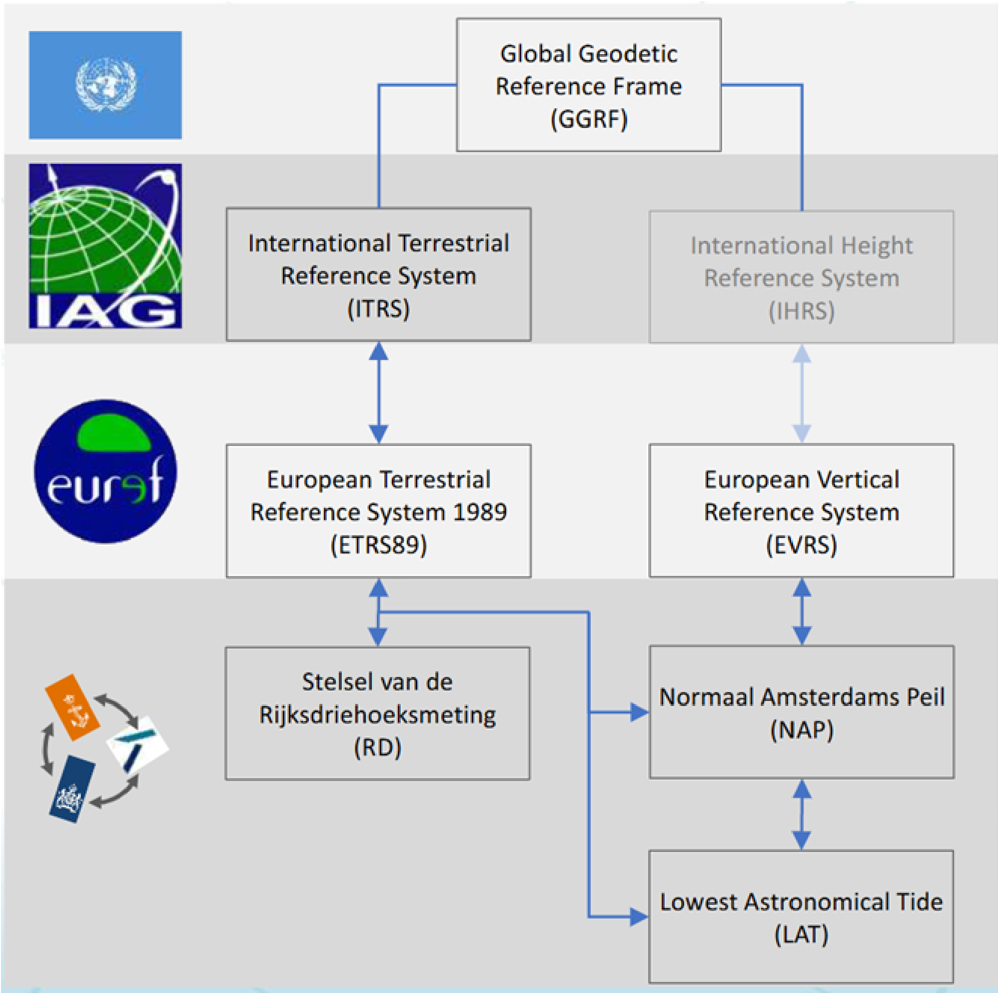



Figure 4: img_1.png

**ITRS: International Terrestrial Reference System** uses the GRS80 ellipsoid, with as its origin the centre of mass of the Earth. Greenwich (UK) is used as a meridian. When using time-dependent coordinates, you always need to specify the epoch (e.g. @2024.91).

**ITRF: International Terrestrial Reference Frames** are realisations of the ITRS. They publish updates every ~1-6 years. Due to the movement of tectonic plates, the differences between each iteration can be multiple centimetres to decimetres. Two examples are ITRF2014 and ITRF2020 (NB: Frame ≠ epoch, e.g. ITRF2014@2022.90). These updates reflect:

- Improved precision of the station positions $r(t_0)$ and velocities $r$ due to the availability of a longer period of observations, which is particularly important for the velocities,
- Improved datum definition due to the availability of more observations and better models,
- Discontinuities in the time series due to earthquakes and other geophysical events,
- Newly added and discontinued stations,
- Occasionally a new reference epoch $t_0$.

**WGS 84** is aligned with ITRS (WGS 84-G2296 (2024) = ITRF2020). For time-dependent coordinates, however, it has limited precision. The realisations (frames) often have differences between m – cm. The ensemble code (± 2m): EPSG:4326 for 2D (often used as unknown latlon).

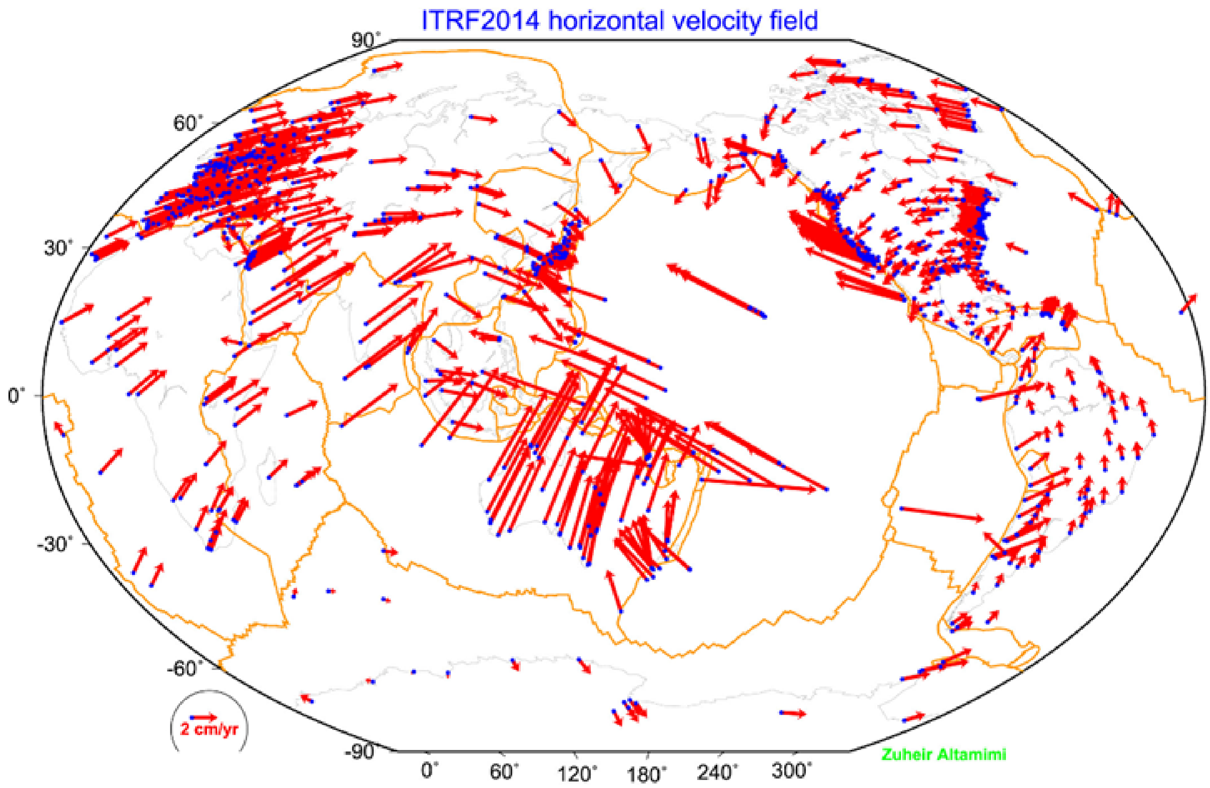



Figure 5: img.png

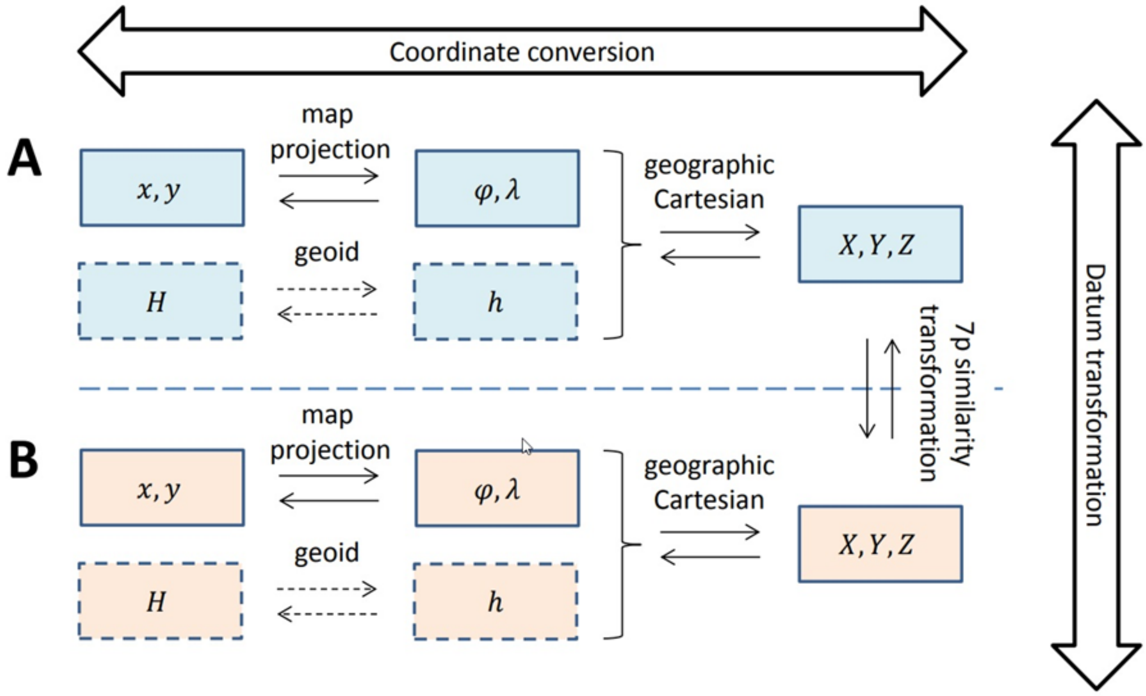
**ETRS89: European Terrestrial Reference System 1989** is ITRF89 at epoch 1989.00. It moves with a stable part of Europe, "no" time-dependency. A new realisation (frame) comes with every ITRF. ETRF2000 is recommended for mapping and the ensemble code has an accuracy of ± 0.1m.

A transformation from ETRS89 to ITRS (and WGS84) is an example of a **Time-dependent transformation** (2.4 cm/year), but a specification of realisation and epoch is needed and most software does not include this transformation. A **Null transformation** is possible, simple and the current practice, but it is not future-proof, since the difference is growing (now 0.9m).

## Datum and Transformations

### Transformations and conversions

The International Association of Oil and Gas Producers (EPSG) used a *de facto* standard instead of an ISO standard. The EPSG collects all the different reference systems and their transformations. There are two different steps when working with 3D data. First, the coordinates need to be converted to a new coordinate system, after which the height values are transformed.




Note, that a geoid is a stochastic height transformation and not a conversion. It uses in total 14 parameters: * 7 parameters;

3 Translations [m];

3 Rotations [“];

1 Scale factor [ppm];

- 7 rates and reference epoch (t0).

These parameters can be given (by an official source), user-estimated (empirical) and/or conventional (by definition). A correction grid can be used as an alternative transformation or an additional conversion.

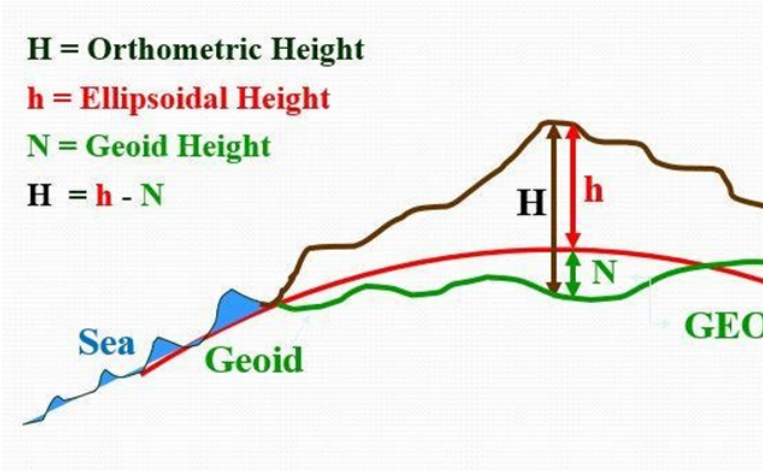
A big difference between datum transformations and coordinate conversions is that the parameters for the datum transformation are often empirically determined and thus subject to measurement errors, whereas coordinate conversions are fully deterministic. More specific, three possibilities need to be distinguished for the datum transformation parameters:

1. **The datum transformation parameters are conventional**. This means they are chosen and therefore not stochastic. The datum transformation is then just some sort of coordinate conversion (which is also not stochastic).
2. **The datum transformation parameters are given but have been derived by a third party through measurements**. This third party often does new measurements and updates the transformation parameters occasionally or at regular intervals. This is also related to the concepts of reference systems and reference frames. Reference frames are considered (different) realisations of the same reference system, with different numerical values assigned to the coordinates of the points in the reference frame, and often with different realisations of the transformation parameters. The station coordinates and transformation parameters are stochastic, so new measurements, mean new estimates that are different from previous estimates.
3. **There is no third party that has determined the transformation parameters, and you as a user, have to estimate them using at least three common points in both systems**. In this case you will need coordinates from the other reference system. Keep in mind that the coordinates from the external reference system should all come from the same realization, or, reference frame.

### Datums

When people in the field of Geomatics are talking about height, they can reference multiple different definitions of height:

- **Geometric**: Ellipsoidal height (max. MSL deviation ±150m)
- **Physical**: Height above the geoid ≈ Mean Sea Level (MSL)
- **Relative**: Height above ground level (DTM)




- **Water depth**: Lowest Astronomical Tide (LAT)
  There are multiple physical height standards depending on where you want to know the height:
- **International Height Reference Systems** (IHRS) – No realisation yet
- **European Vertical Reference System** (EVRS) – Realisations available, but not widely used yet (dm – cm)
- **Earth Gravitation Model** (EGM84, 96, 2008, 2020) – By USA like WGS84 (m – dm)
- National Height Systems – Based on local MSL

### Map Projection

**Map projections** try to portray the surface of the earth or a portion of the earth, on a flat piece of paper or computer screen.They try to transform the earth from its spherical shape (3D) to a planar shape (2D).

**A coordinate reference system** (CRS) then defines how the two-dimensional, projected map relates to real places on Earth. The decision of which map projection and CRS to use depends on the regional extent of the area you want to work in, on the analysis you want to do, and often on the availability of data.

When viewed at close range the earth appears to be relatively flat. Maps are representations of reality: they are designed to not only represent features but also their shape and spatial arrangement. Each map projection has **advantages** and **disadvantages**.

The best projection for a map depends on the **scale** of the map, and on the purposes for which it will be used. For example, a projection may have unacceptable distortions if used to map the entire African continent but may be an excellent choice for a **large-scale (detailed) map** of your country.

Different projection methods can be produced by surrounding the globe in a **cylindrical** fashion, as a **cone**, or even as a **flat surface**. Each of these methods produces what is called a **map projection family**. Therefore, there is a family of **planar/azimuthal projections (c)**, a family of **cylindrical projections (a)**, and another called **conical projections (b).**

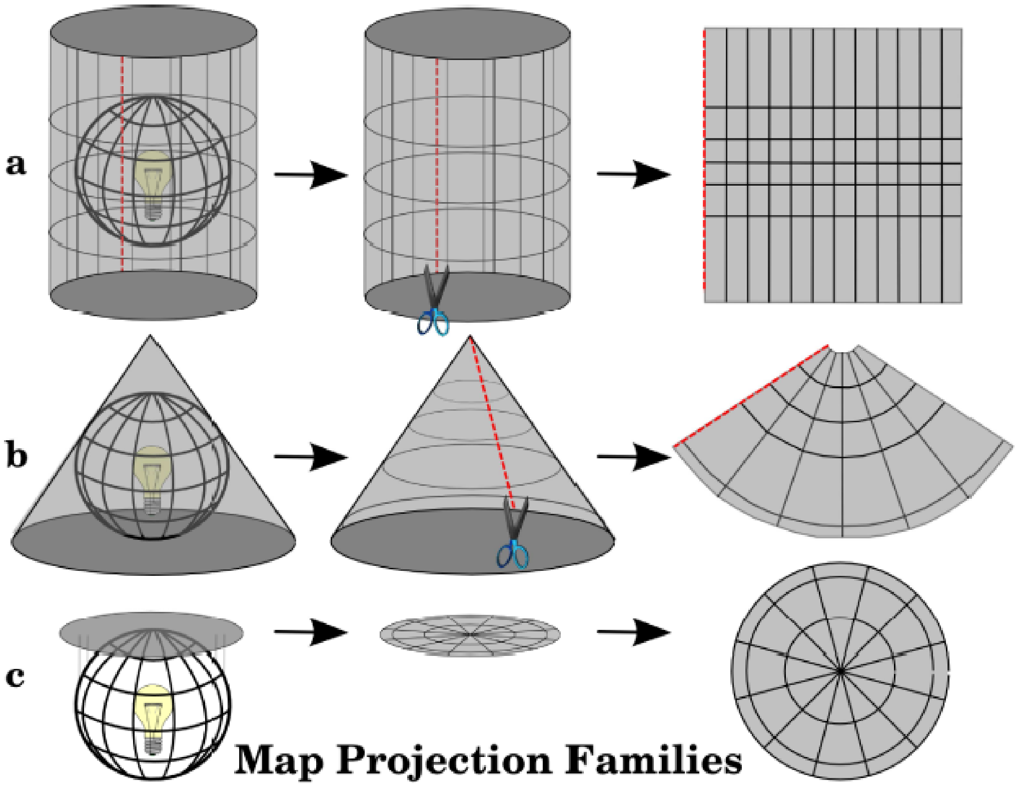



Figure 6: img.png

Map projections are never absolutely accurate representations of the spherical Earth. As a result of the map projection process, every map shows **distortions of angular conformity, distance and/or area**. It is usually impossible to preserve all characteristics at the same time in a map projection. This means that when you want to carry out accurate analytical operations, you need to use a map projection that provides the best characteristics for your analyses.

When working with a globe, the main directions of the compass (North, East, South and West) will always occur at 90 degrees to one another. In other words, the East will always occur at a 90-degree angle to the North. Maintaining correct **angular properties** can be preserved on a map projection as well. A map projection that retains this property of angular conformity is called a **conformal** or **orthomorphic projection**. These projections are used when the **preservation of angular relationships** is important. They are commonly used for navigational or meteorological tasks.

If your goal in projecting a map is to accurately measure distances, you should select a projection that is designed to preserve distances well. Such projections, called **equidistant projections**, require that the **scale** of the map is **kept constant**. A map is equidistant when it correctly represents distances from the centre of the projection to any other place on the map.**Equidistant projections** maintain accurate distances from the centre of the projection or along given lines. These projections are used for radio and seismic mapping, and navigation.

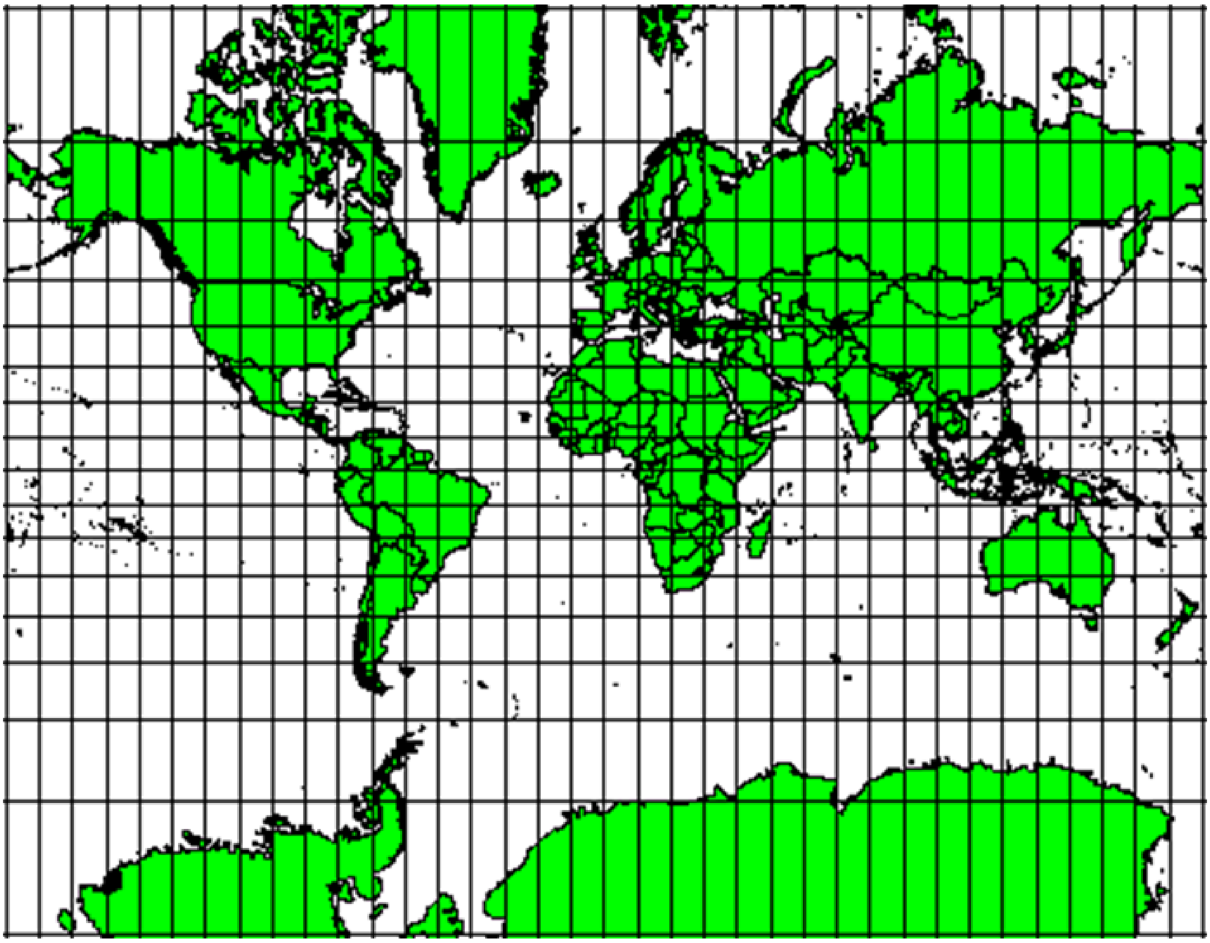
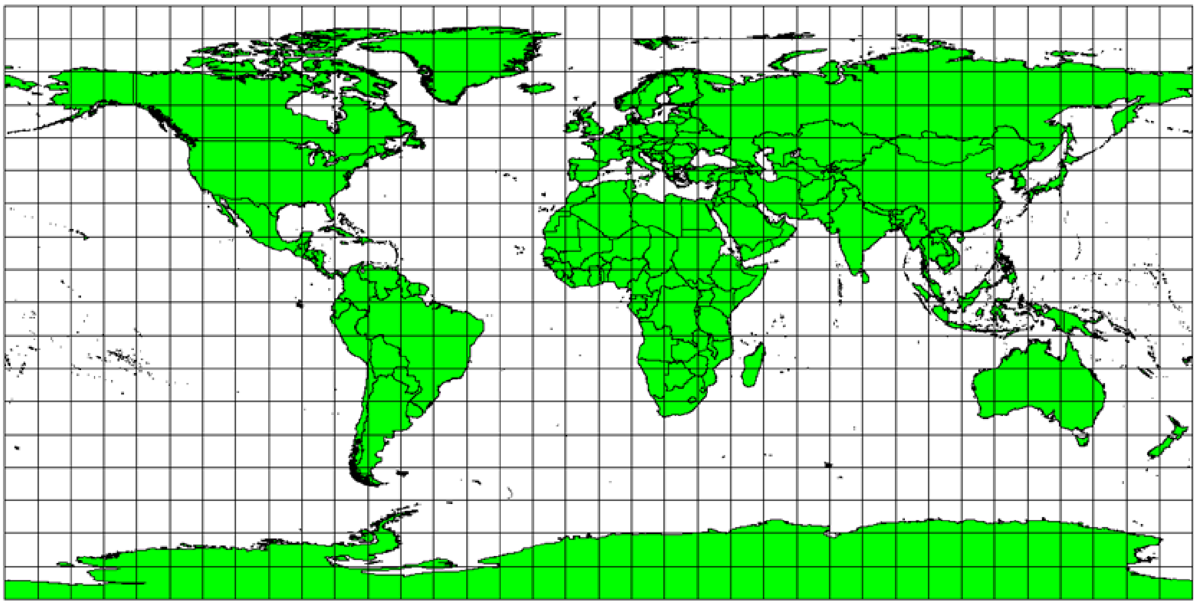
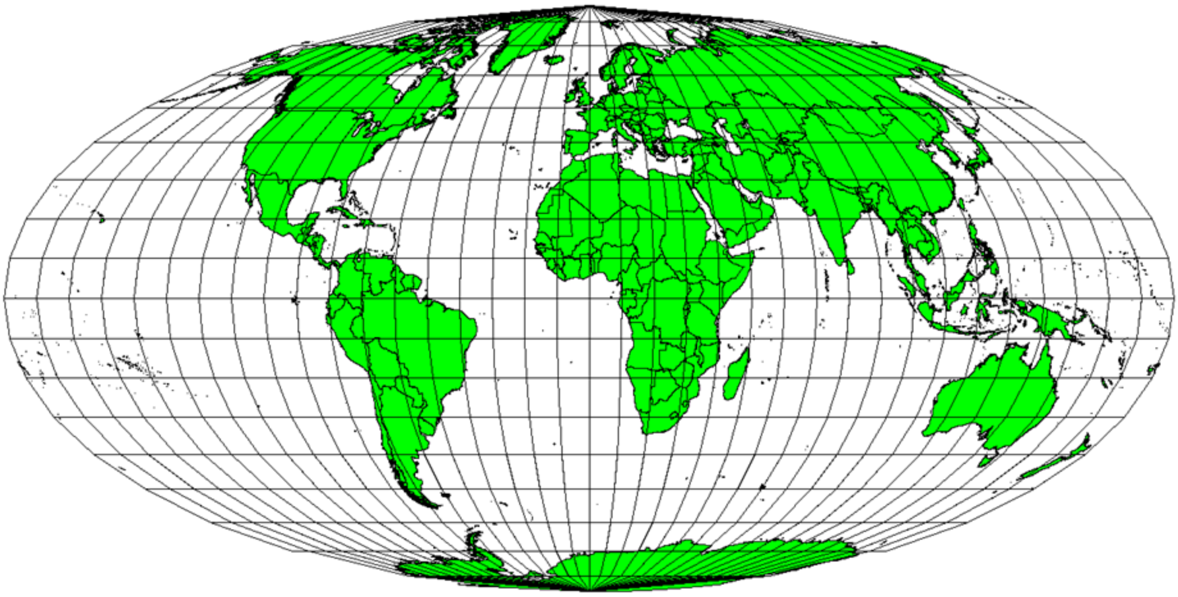


Figure 7: img.png



When a map portrays areas over the entire map, so that all mapped areas have the same proportional relationship to the areas on the Earth that they represent, the map is an **equal area map**. As the name implies, these maps are best used when calculations of area are the dominant calculations you will perform. If, for example, you are trying to analyse a particular area in your town to find out whether it is large enough for a new shopping mall, **equal area projections** are the best choice. On the one hand, the larger the area you are analysing, the more precise your area measures will be, if you use an equal area projection rather than another type. On the other hand, an equal area projection results in **distortions of angular conformity** when dealing with large areas.



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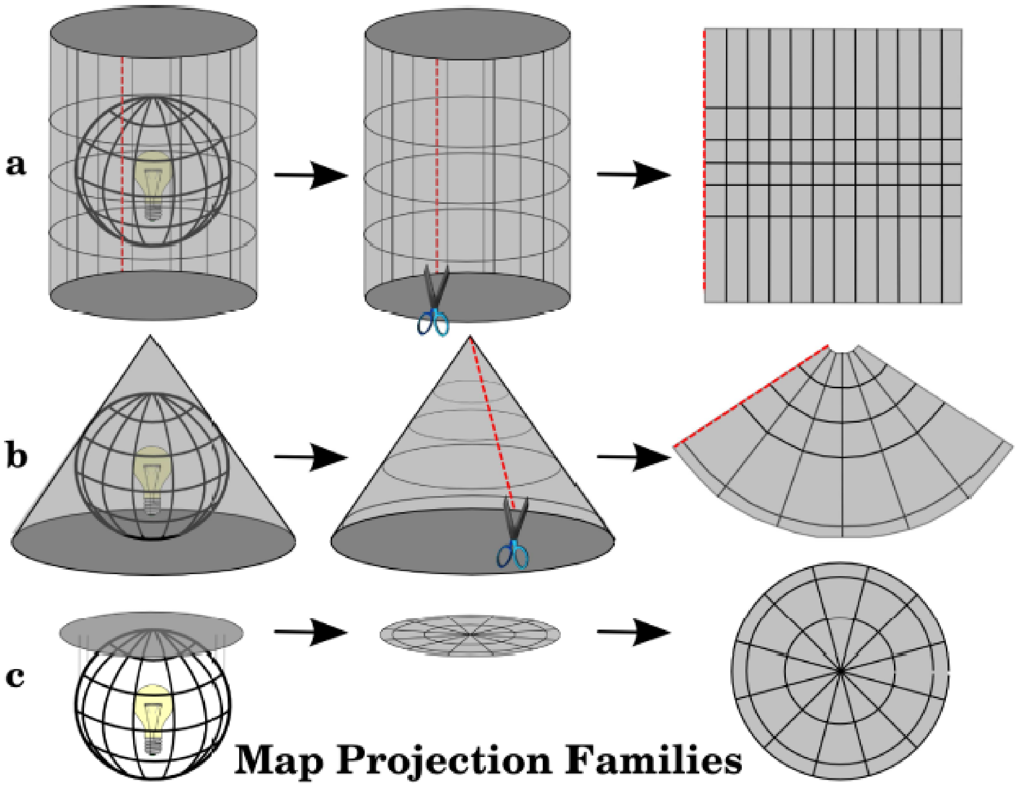



Figure 8: img.png

Map projections are never absolutely accurate representations of the spherical Earth. As a result of the map projection process, every map shows **distortions of angular conformity, distance and/or area**. It is usually impossible to preserve all characteristics at the same time in a map projection. This means that when you want to carry out accurate analytical operations, you need to use a map projection that provides the best characteristics for your analyses.

When working with a globe, the main directions of the compass (North, East, South and West) will always occur at 90 degrees to one another. In other words, the East will always occur at a 90-degree angle to the North. Maintaining correct **angular properties** can be preserved on a map projection as well. A map projection that retains this property of angular conformity is called a **conformal** or **orthomorphic projection**. These projections are used when the **preservation of angular relationships** is important. They are commonly used for navigational or meteorological tasks.

If your goal in projecting a map is to accurately measure distances, you should select a projection that is designed to preserve distances well. Such projections, called **equidistant projections**, require that the **scale** of the map is **kept constant**. A map is equidistant when it correctly represents distances from the centre of the projection to any other place on the map.**Equidistant projections** maintain accurate distances from the centre of the projection or along given lines. These projections are used for radio and seismic mapping, and navigation.

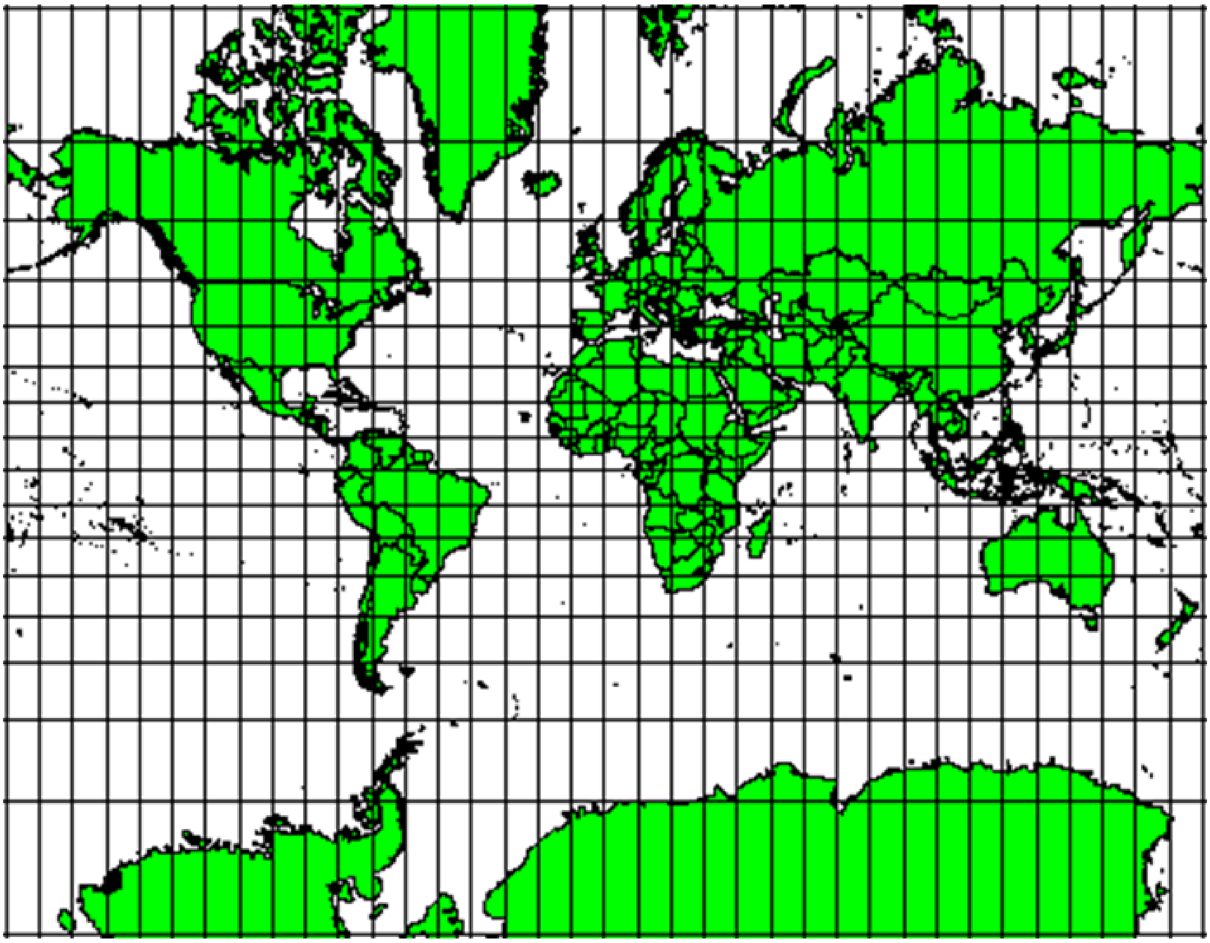
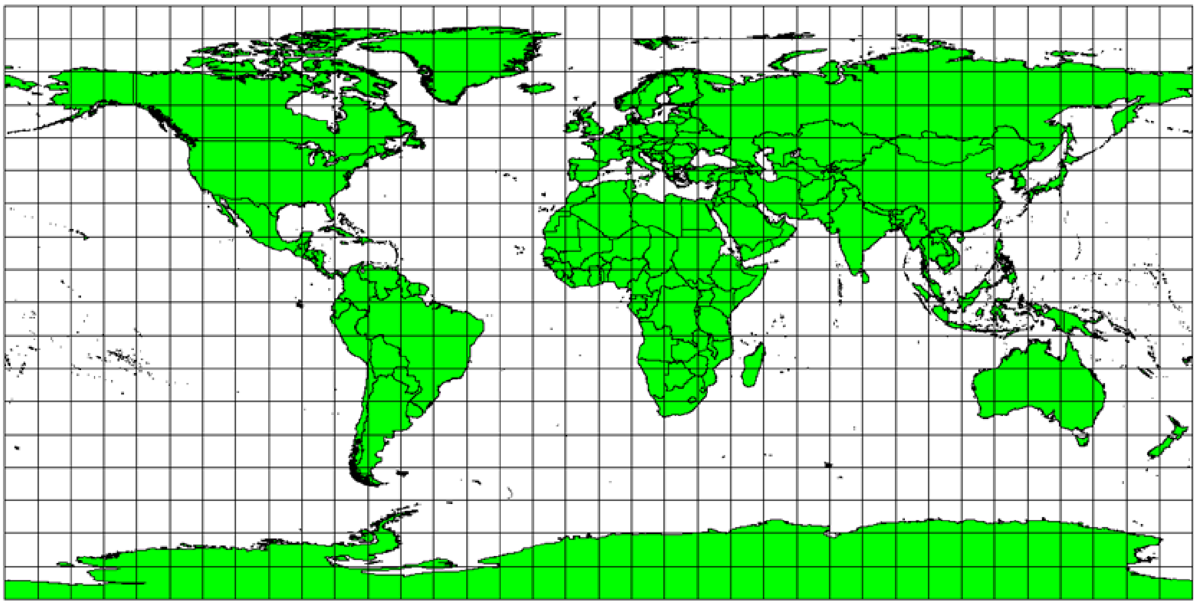
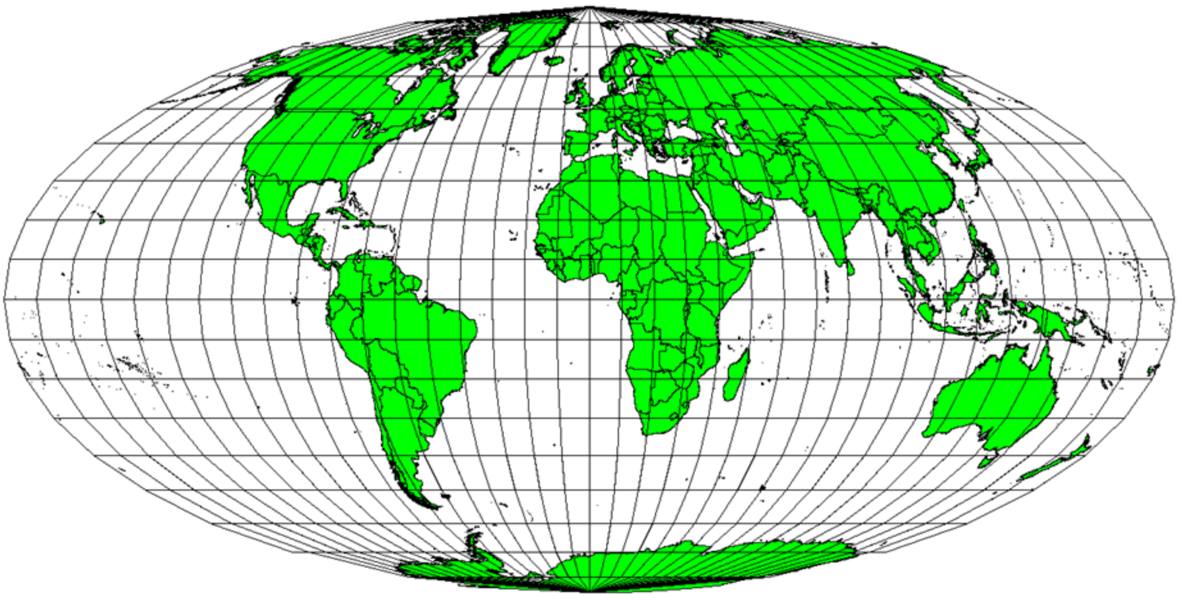


Figure 9: img.png



When a map portrays areas over the entire map, so that all mapped areas have the same proportional relationship to the areas on the Earth that they represent, the map is an **equal area map**. As the name implies, these maps are best used when calculations of area are the dominant calculations you will perform. If, for example, you are trying to analyse a particular area in your town to find out whether it is large enough for a new shopping mall, **equal area projections** are the best choice. On the one hand, the larger the area you are analysing, the more precise your area measures will be, if you use an equal area projection rather than another type. On the other hand, an equal area projection results in **distortions of angular conformity** when dealing with large areas.



## RDNAP

The national height system in the Netherlands is called **Normaal Amsterdams Peil (NAP)** and is based on the average summer flood in 1683-1684. Maintenance is based on point stability and it uses the NLGEO2018 geoid for GNSS measurements. Values range between 39.1 – 48.7m.

For parts of the Noordzee however, the NAP cannot be used. Instead, they use the **Lowest Astronomical Tide** (LAT), which is the water depth in Worst-case astronomical conditions and average meteorological conditions.

The **Stelsel van de Rijksdriehoeksmeting (RD)** was created using triangulation from church spires and stone markers (historical), but nowadays is derived from ETRS89 with RDNAPTRANS. It has no time dependence; the differences are <1cm since 2000. It uses one EPSG-code (EPSG:28992 (RD New) for 2D and EPSG:7415 for compound CRS with NAP). The RD projection has its origin in Amersfoort in the middle of the Netherlands, it uses conformal stereographic projection (angles are preserved) and the north of the map is not equal to the true north. Unlike what you might think, the highest accuracy is not in Amersfoort itself, but rather in a circle ~100km around it.

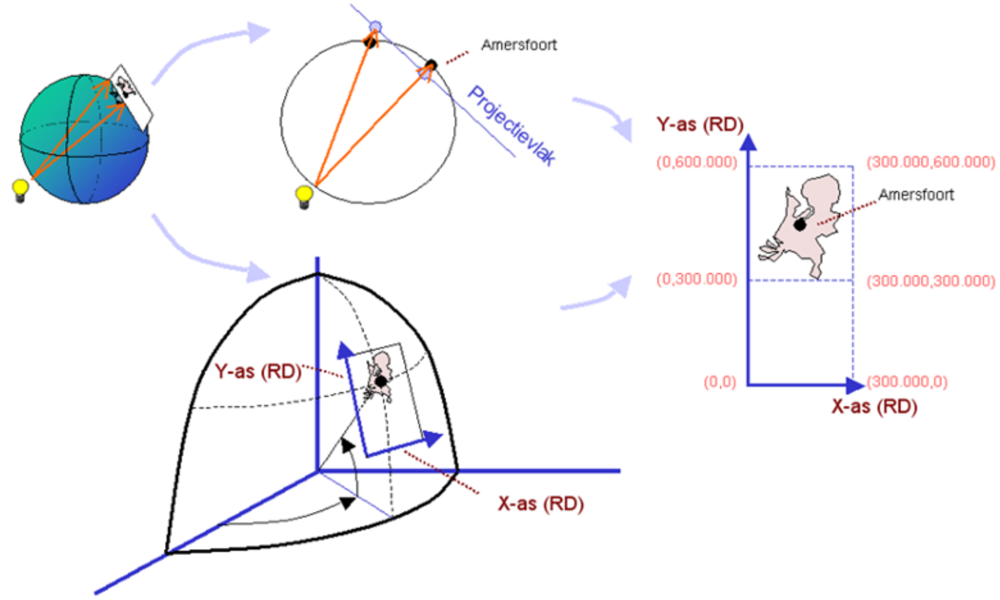



Figure 10: img.png

To prevent confusion between the x-coordinates and y-coordinates, and to obtain always positive coordinates, the origin of the coordinates was shifted 155 km to the West and 463 km to the South (**False Easting and Northing**). This resulted in only positive x- and y-coordinates, where the y-coordinates are always larger than the x-coordinates.

**RDNAPTRANS** is the transformation between ETRS89 and RD NAP. It uses a Datum transformation and a correction grid (see fig.) in combination with the map projection to transform the values. The height of the transformation is determined by a quasi-geoid.

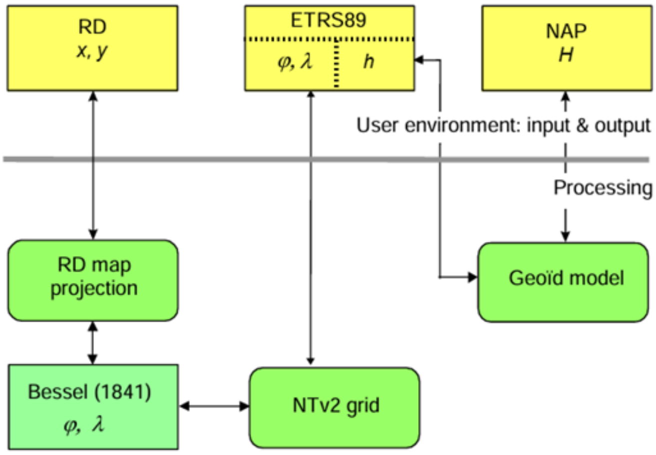
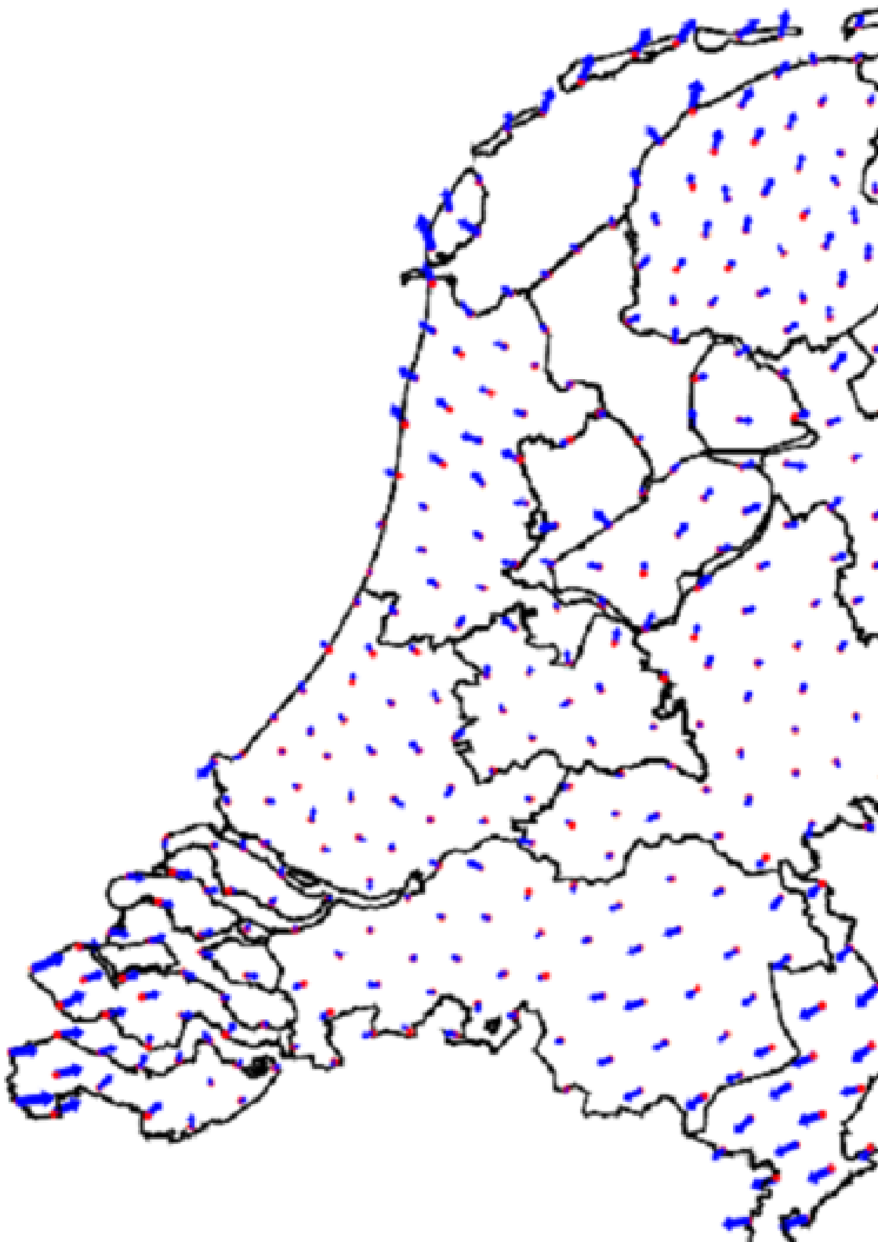



Figure 10.5: NTv2 transformation procedure used by RDNAPTRANS™2018. The figure outlines the relationships and transformations between ETRS89, RD2000 and NAP using the proposed NTv2 procedure, in variant 2 of RDNAPTRANS™2018 where the datum transformation is included in the correction grid. The coordinates below the line are used only for computational purposes and should never be published or distributed to other users.

Figure 11: img_1.png



# Wi-Fi-monitoring / Fingerprinting

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## Wi-Fi-Based Approaches

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### Wi-Fi Fingerprinting

## Radio Signal Based Techniques

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# Location awareness and privacy

## Introduction