Appendix H

Reference frame offsets for ground truth markers at Jammertest 2024

1. Introduction

Based on requests received at Jammertest 2023, the Norwegian Public Roads Administration and the Norwegian Mapping Authority plan to establish some ground truth markers for use at Jammertest 2024. Ground Truth (GT) markers are well marked points on ground (or tied to ground), for which accurate coordinates have been computed. We provide this document to inform the Jammertest participants about the differences between the most commonly used geodetic reference frames in Norway. The document also provides the necessary information to perform simple horizontal transformations between these reference frames, and some information about the differences between ellipsoidal heights ("GNSS heights") and physical heights ("heights above mean sea level") in the test areas.

2. Geodetic reference systems and reference frames

The terms "reference system" and "reference frame" are often used somewhat interchangeably, which might be confusing. The difference between these terms is that a reference **system** is the theoretical definition of a coordinate system and its relation to a geophysical or geometrical model of the earth, whereas a reference **frame** consists of a set of physical points with computed coordinates that indirectly defines the "invisible" reference system. Therefore, a reference frame is called a realization of a reference system. For example, ETRF89 (European Terrestrial Reference Frame 1989) is a realization of ETRS89 (European Terrestrial Reference System 1989).

3. EUREF89

EUREF89 is a Norwegian densification of ETRF89 and is the official reference frame for Norwegian maps. EUREF89 is considered a static 3D reference frame with reference epoch 1989 Jan. 1st. The term "static" means that the reference frame is tied to the stable part of the Eurasian tectonic plate, so that the horizontal coordinates of a point do not change with time (as a general rule). This differs from dynamic reference frames, ref. section 5.

The GT will be given as coordinates for a set of physically marked points, given in the reference frame EUREF89 (ETRF89) and coordinate differences to WGS84, known as the "GPS reference frame".

To ensure correctness of the GT, measurements and calculations will be performed independently by geodesists both at The Norwegian Mapping Authority (NMA) and The Norwegian Public Road Administration (NPRA).

4. Some coordinate forms in a reference frame

Coordinates for a point P at the surface of the Earth can be given in various forms, e.g.

- Cartesian coordinates X, Y, Z (Figure 1)
- Ellipsoidal coordinates φ (latitude), λ (longitude), h (height above ellipsoid) (Figure 1)
- In a map projection, e.g. UTM33 as North, East and height (above ellipsoid) (Figure 2)

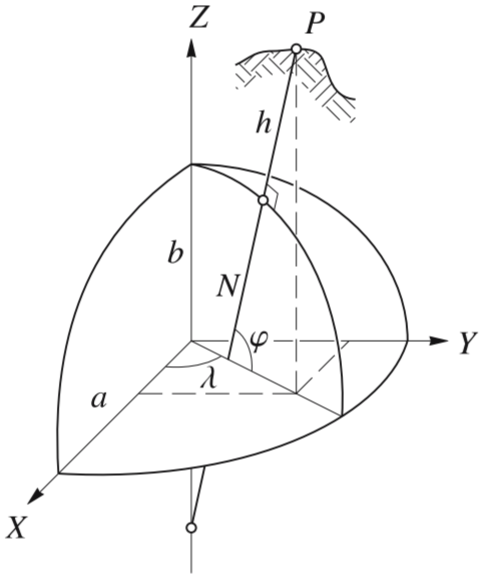

Figure 1: From [1] GNSS – Global Navigation Satellite Systems

Equations to convert between the coordinate forms, see e.g. [1].

The NMA operates a nationwide Network RTK service which is named CPOS. Coordinates for the permanent GNSS stations in CPOS refer to EUREF89.
Note: Coordinates computed by measurements to a GNSS rover unit refer to EUREF89 when using corrections from CPOS. More information in the NMA report [3]: *Norwegian reference frames and transformations.*

Approximate coordinates for one point representing the test area in EUREF89 UTM zone 33 is North N=7,690,000 and East E=540,000 or Latitude: 69.316631093° and Longitude: 16.014796031°.

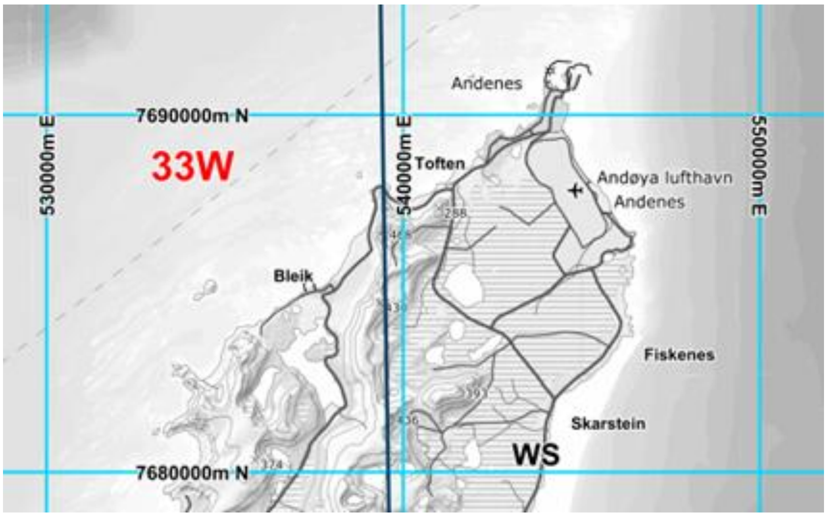

Figure 2: The UTM33 grid nearby Andøya

5. Dynamic or global 4D reference frames

In a global or a dynamic reference frame, the coordinates of a point change as a function of time, as the continents move mainly due to the plate tectonics. To achieve unambiguity in such a frame, the time (epoch) to which the data refer must be specified. ITRF2014, IGS14 and WGS84 are all dynamic and very similar reference frames.

Note: A single GPS unit without any corrections will refer to WGS84, current epoch of time (the moment of measurement).

6. Reference frame differences at Andøya, September 2024

A transformation with the NMA software SkTrans from EUREF89 to ITRF2014 (very similar to WGS84) UTM33 epoch 2024.69 (2024 Sep.) gives N= 7,690,000.6355, E= 540,000.4579 or Lat = 69.316636723° and Long = 16.014807912°.

Transformation equations from EUREF89 epoch 1989.00 to ITRF2014≈WGS84 epoch 2024.69 for all points the test area around Andøya around 2024 September 10th then become:

$N_{\ WGS84\ epoch2024.7} = N_{EUREF89UTM33_{epoch1989.0}} + \Delta N$ where ΔN=0.64m

$E_{\ WGS84\ epoch2024.7} = E_{EUREF89UTM33_{epoch1989.0}} + \Delta E$ where ΔE = 0.46m

$\varphi_{\ WGS84\ epoch2024.7} = \varphi_{EUREF89UTM33_{epoch1989.0}} + \Delta Lat$ where ΔLat =0.0000056°

$\lambda_{\ WGS84\ epoch2024.7} = \lambda_{EUREF89UTM33_{epoch1989.0}} + \Delta Long$ where $\Delta Long$= 0.0000119

Seven significant decimal digits for latitude and longitude will ensure cm-precision.

7. Vertical coordinates (heights)

Vertical coordinates (heights) computed by GNSS receivers refer to a rotational ellipsoid which is a simplified model of the earth. These heights are called ellipsoidal heights, or heights above ellipsoid. On the other hand, the mean sea level roughly aligns to the geoid, which is an equipotential surface in the earth's gravity field. In order to translate ellipsoidal heights into physical heights (heights above mean sea level), a geoid model must be applied. Geoid models originate from gravimetric measurements. If high accuracy of the physical heights is required, height reference models (which are geoid models adjusted by a combination of GNSS measurements and levelling) must be used. Many GNSS receivers have built-in geoid models or height reference models.

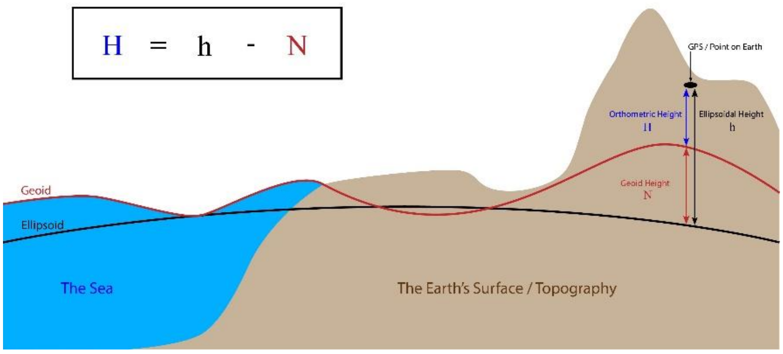

Figure 3: Ellipsoid and geoid. Credit: https://support.virtual-surveyor.com/

The differences [ellipsoidal heights minus physical heights] (N in Figure 3) in the Jammertest areas vary from about +35.6 meters at Andenes to about +36.2 meters at Nordmela just south of test area 3.

8. References

[1] GNSS – Global Navigation Satellite Systems, Hofmann-Wellenhof, Lichtenegger and Wasle
ISBN 978-3-211-73012-6 SpringerWienNewYork 2008

[2] Geodetisk grunnlag [Geodetic datum] (in Norwegian language only)

[3] Referanserammer og transformasjoner [Reference frames and transformations](in Norwegian language only)
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