NAVIPAC 4

GEODETIC CONTROL

Contents

1 Introduction

This document gives a complete listing of the geodesy settings supported in NaviPac and in all other software modules.

Besides the full list, we do also support user-defined methods – so most should be covered.

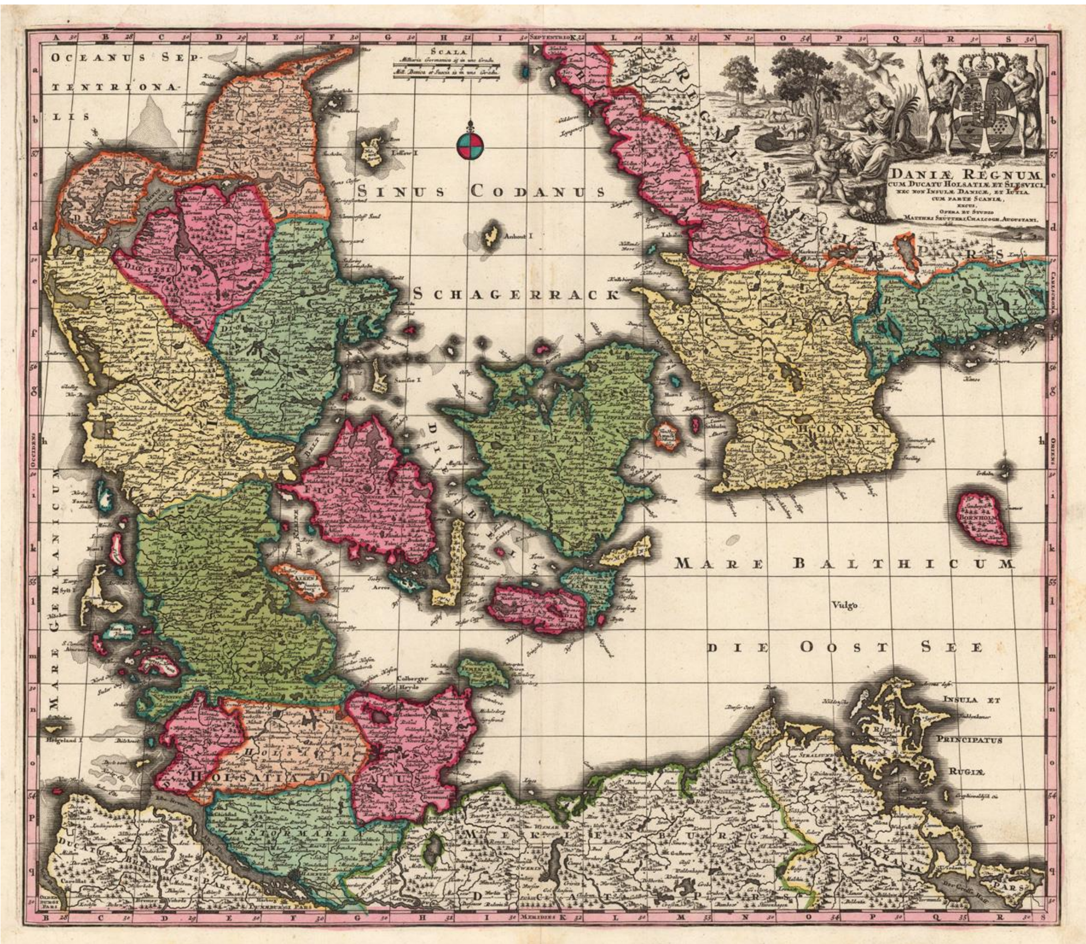


Figure 1 Denmark mapped a few years ago

2 Projections

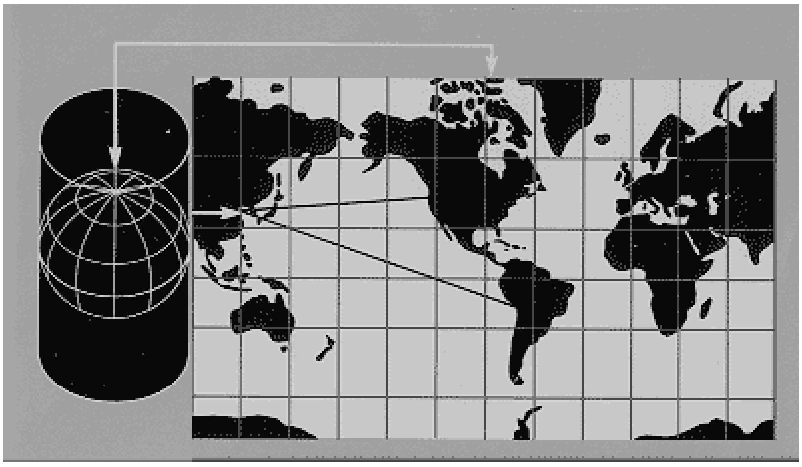


Figure 2 Mapping the globe onto a piece of paper

Projections are defined using the below-listed attributes:

Projection type
Type of projection. Select one from the list of available predefined projections.

Projection name
Name of the source reference projection that will be used, eg the Universal Transverse Mercator.

Origin scale factor
Point scale factor at origin of projection. That is, at the central meridian, at the pole, at the centre, etc.

NOTE: If you have selected a Polar Stereographic projection, the pole scale factor depends on the Latitude of true scale if this is not equal to degrees. Range: [0.000000000001 - 5]; default 1.

Origin longitude
Longitude at origin of projection, ie the central meridian, centre longitude, etc. Range: degrees; default 0 degrees.

Origin latitude
Latitude at origin of projection, ie the Latitude of true scale, centre latitude, etc. Range: degrees; default 0 degrees.

Origin east (False easting)
Range: metres; default 0 metres.

Origin north (False northing)
Range: metres; default 0 metres.

UTM zone
UTM zone number, using the Universal Transverse Mercator projection. Range: [1 - 60]; default 31.

A more detailed description of the individual projections follows:

- Projections in general
- Transverse Mercator
- UTM
- UTM north
- UTM south
- Gauss Krueger
- NGGB
- Gauss Boaga east
- Gauss Boaga west
- System SBF
- RT38/RT90
- Mercator
- Stereographic
- Polar Stereographic
- UPS north
- UPS south
- Equatorial Stereographic
- Oblique Stereographic
- RD
- Rectified Skew Orthomorphic
- New Zealand Map Grid
- American Polyconic

2.1 Projections in general

Coordinates from the projection plane are referred to as external coordinates. They are normally represented in metres or feet. Coordinates from the ellipsoid are referred to as geographical coordinates. On the maps, you may choose to display external and/or geographical coordinates.

The conversion between external and geographical coordinates is based on the defined source reference ellipsoid and source reference projection.

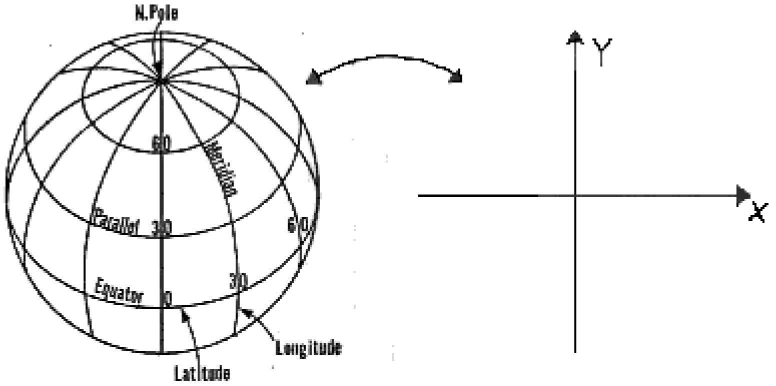


Figure 3 Meridians and parallels on an ellipsoid

2.2 Specific projections

The following subsections provide details on each type of projection.

2.2.1 Transverse Mercator

Parameters that must be specified for the Transverse Mercator projection:

- Scale factor
- Central meridian
- Origin latitude
- False easting
- False northing

The Transverse Mercator projection is a cylindrical and conform projection in which the cylinder is tangent to a meridian. This meridian is called the central meridian. In the tangent form, any latitude along the central meridian can be selected as projection centre; this latitude is called the Origin latitude or the Footpoint latitude; however, most often the Equator is selected as the Footpoint latitude.

Because significant scale errors occur at relatively short distances from the central meridian, the Transverse Mercator is used for mapping areas with small east-west and large north-south extent.

A scale factor must be defined at the central meridian.

A False easting and a False northing can be added to the external coordinates.

2.2.2 Universal Transverse Mercator

The Universal Transverse Mercator (UTM) projection is a specially defined poly-cylindrical Transverse Mercator projection used to cover the whole world. The projection is defined for zones of three degrees on each side of the central meridian. Each six-degree-wide area extends from -80 degrees to 84 degrees and is known as a zone. The result is 60 zones needed to cover the earth, starting with Zone 1 at 180 degrees west and progressing eastward. The greater latitudinal extent in the northern hemisphere was done to accommodate NATO requirements for mapping northern Greenland.

The scale factor at the central meridian is 0.9996.

Mathematically creating two standard meridians (secant lines) with scale factor 1 results in a margin of error of one metre or less per kilometre at the centre and at the limits of each zone (See Figure 4 below).

Origin latitude is the Equator.

False easting is 500,000 metres.

A False northing can be added to the external coordinates. In the northern hemisphere, False northing is 0 metres, while in the southern hemisphere, the value 10,000,000 metres is used. This serves to make the coordinates positive in the region where you work.

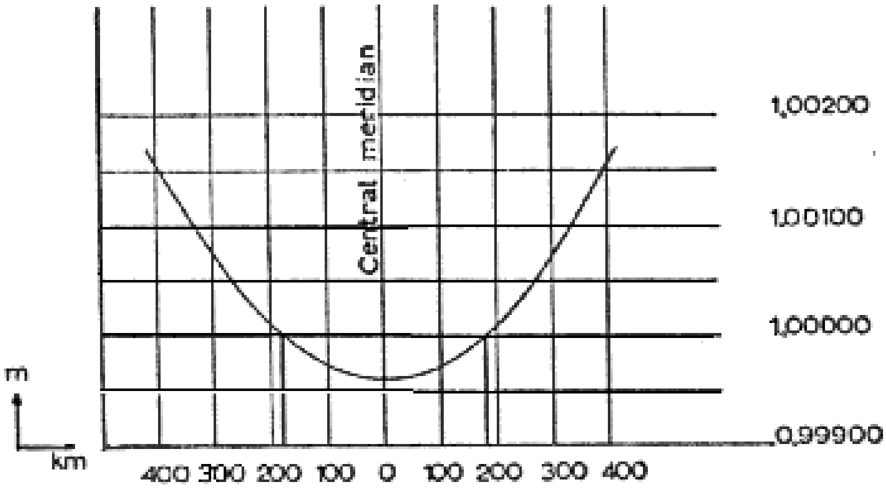


Figure 4 UTM definition

Zone	Central meridian	Range	Zone	Central meridian	Range
01	177W	180W-174W	31	3E	0E-06E
02	171W	174W-168W	32	9E	6E-12E
03	165W	168W-162W	33	15E	12E-18E
04	159W	162W-156W	34	21E	18E-24E
05	153W	156W-150W	35	27E	24E-30E
06	147W	150W-144W	36	33E	30E-36E
07	141W	144W-138W	37	39E	36E-42E
08	135W	138W-132W	38	45E	42E-48E
09	129W	132W-126W	39	51E	48E-54E
10	123W	126W-120W	40	57E	54E-60E
11	117W	120W-114W	41	63E	60E-66E
12	111W	114W-108W	42	69E	66E-72E
13	105W	108W-102W	43	75E	72E-78E
14	99W	102W- 96W	44	81E	78E-84E
15	93W	96W- 90W	45	87E	84E-90E
16	87W	90W- 84W	46	93E	90E-96E
17	81W	84W-78W	47	99E	96E-102E
18	75W	78W-72W	48	105E	102E-108E
19	69W	72W-66W	49	111E	108E-114E
20	63W	66W-60W	50	117E	114E-120E
21	57W	60W-54W	51	123E	120E-126E
22	51W	54W-48W	52	129E	126E-132E
23	45W	48W-42W	53	135E	132E-138E
24	39W	42W-36W	54	141E	138E-144E
25	33W	36W-30W	55	147E	144E-150E
26	27W	30W-24W	56	153E	150E-156E
27	21W	24W-18W	57	159E	156E-162E
28	15W	18W-12W	58	165E	162E-168E
29	9W	12W-6W	59	171E	168E-174E

30	3W	6W-0W	60	177E	174E-180E

Table 1 UTM zone definition

2.2.3 UTM north

The Universal Transverse Mercator north is used in the northern hemisphere.

Parameters that must be specified for the Universal Transverse Mercator north projection:

UTM zone: The central meridian is calculated from the UTM zone.

Predefined parameters:
Based on the International 1924 ellipsoid and the Transverse Mercator projection.
Semi major axis : 6,378,388 m
Inverse flattening : 297
Scale factor : 0.9996
Origin latitude : 0°
False easting : 500,000 m
False northing : 0 m

The Universal Transverse Mercator north projection is a standard UTM projection used in the northern hemisphere.

2.2.4 System 1934

NaviPac supports a non-conform variant of the UTM zone 32-based System 1934 projection. X and Y are first calculated in UTM and then transformed to System 34 using a third degree transformation, as given by Kai Borre in *Landmåling* (ISBN 87-984210-2-6), Chapters 5.10 and 5.11. The system has an accuracy of one decimetre.

2.2.5 UTM south

The Universal Transverse Mercator south is used in the southern hemisphere.

Parameters that must be specified for the Universal Transverse Mercator south projection:

UTM zone: The central meridian is calculated from the UTM zone.

Predefined parameters:
Based on the International 1924 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,378,388 m
Inverse flattening	: 297
Scale factor	: 0.9996
Origin latitude	: 0°
False easting	: 500,000 m
False northing	: 10,000,000 m

The Universal Transverse Mercator south projection is a standard UTM projection used in the southern hemisphere.

2.2.6 Gauss Krueger

Parameters that must be specified for the Gauss Krueger projection:

Central meridian: The central meridian is used in increments of three degrees. Used in the northern hemisphere (Europe).

Predefined parameters:
Based on the Bessel 1841 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,377,397.155 m
Inverse flattening	: 299.152813
Scale factor	: 1.0
Origin latitude	: 0°
False easting	: 500,000 m
False northing	: 0 m

The Gauss Krueger projection is a standard Transverse Mercator projection with predefined parameters.

2.2.7 NGGB

The NGGB (National Grid of Great Britain) projection is used in the United Kingdom.

Predefined parameters:
Based on the Airy 1830 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,378,563.396 m
Inverse flattening	: 299.324964
Scale factor	: 0.9996012717

Central meridian : -2°
Origin latitude : 49°
False easting : 400,000 m
False northing : -100,000 m

The NGGB projection is a standard Transverse Mercator projection with predefined parameters.

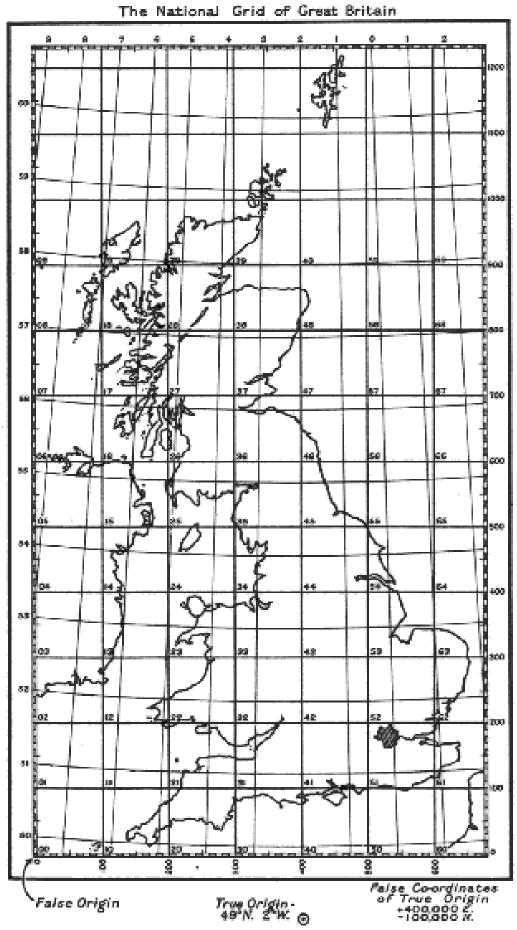


Figure 5 National Grid of Great Britain

2.2.8 Gauss Boaga east

The Gauss Boaga east projection is used in Italy.

Predefined parameters:
Based on the International 1924 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,378,388 m
Inverse flattening	: 297
Scale factor	: 0.9996
Central meridian	: 15°
Origin latitude	: 0°
False easting	: 2,520,000 m
False northing	: 0 m

The Gauss Boaga east projection is a standard Transverse Mercator projection with predefined parameters.

2.2.9 Gauss Boaga west

The Gauss Boaga west projection is used in Italy.

Predefined parameters:
Based on the International 1924 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,378,388 m
Inverse flattening	: 297
Scale factor	: 0.9996
Central meridian	: 9°
Origin latitude	: 0°
False easting	: 1,500,000 m
False northing	: 0 m

The Gauss Boaga west projection is a standard Transverse Mercator projection with predefined parameters.

2.2.10 System SBF

The System SBF projection is used in Storebælt (The Great Belt), Denmark.

Predefined parameters:
Based on the International 1924 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,378,388 m
Inverse flattening	: 297
Scale factor	: 0.999999
Central meridian	: 10.966666666666° (10°58’00”)

Origin latitude	: 0°
False easting	: 500,000 m
False northing	: 0 m

The System SBF projection is a standard Transverse Mercator projection with predefined parameters.

2.2.11 RT38/90

The RT38 projection is used in Sweden.

Predefined parameters:
Based on the Bessel 1841 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,377,397.155 m
Inverse flattening	: 299.1528128
Scale factor	: 1.0
Central meridian	: 15.808277777777° (15°48'29.8")
Origin latitude	: 0°
False easting	: 1,500,000 m
False northing	: 0 m

The RT38 projection is a standard Transverse Mercator projection with predefined parameters. The RT90 projection, created in 1990, is a slightly modified version of the RT38 projection. The parameters are identical for both projections.

2.2.12 Mercator

Parameters that must be specified for the Mercator projection:

- Central meridian
- Latitude of true scale
- False easting
- False northing

The Mercator projection is most commonly used for navigational maps of oceans. The projection is a cylindrical and conform projection in which the cylinder is tangent to a parallel (Latitude of true scale), normally the Equator. Thus, the Equator may be called the standard parallel. It is also possible to have, instead, another parallel (actually up to two) as standard, with true scale. Such a projection is most commonly used for navigational mapping of a part of an ocean, such as the North Atlantic Ocean. Small areas retain their true shapes, chart angles or directions are true to the real world angles, and at any point the point scale factor is the same in all directions. Both meridians and parallels are expanded at the same ratio with increased latitude. The expansion is equivalent to the secant of the latitude, with a small correction due to the earth's elliptical shape. Since the secant of 90 degrees is infinite, the Mercator projection is not defined at the North Pole or the South Pole. (See figure below)

A False easting and a False northing can be added to the external coordinates.

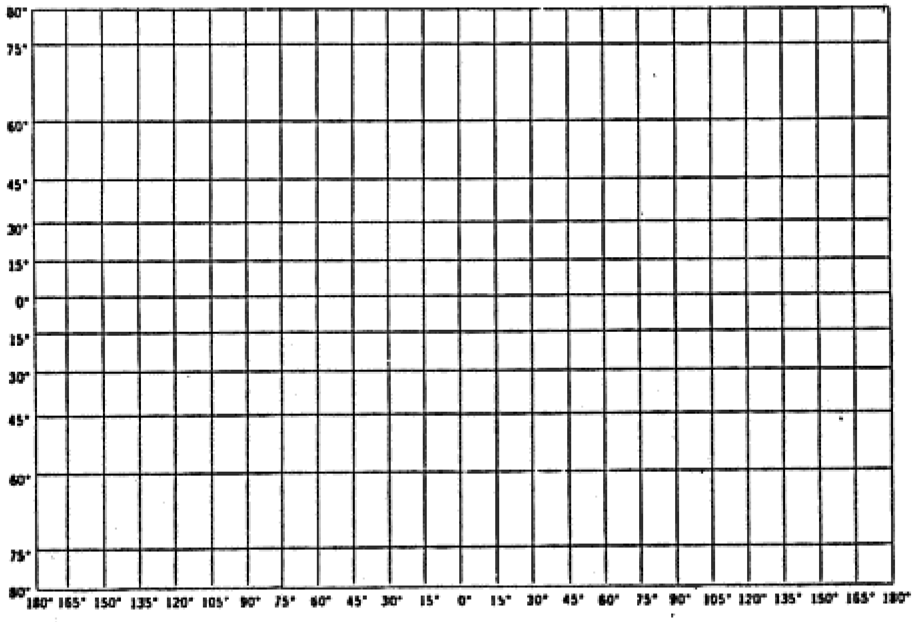


Figure 6 Mercator projection grid map

2.2.13 Stereographic

Some general characteristics of the Stereographic projection:

- It is azimuth based
- It is conform
- It is used in three different aspects (polar aspect, equatorial aspect and oblique aspect)
- The central meridian and a particular parallel (equatorial aspect) are straight lines
- All meridians on the polar aspect and the Equator on the equatorial aspect are straight lines
- All other meridians and parallels are arcs of circles
- Directions from the centre of the projection in the polar aspect are true
- Scale increases away from the centre of the projection
- Distortions of shapes and areas increase away from the centre of the projection
- It is mainly used for nautical and bathymetric charts of the polar regions and stellar charts

- For geodesic purposes, it has been introduced in countries of circular shape
- The national coordinate systems of Poland, Hungary and Holland are based on this projection in its oblique aspect

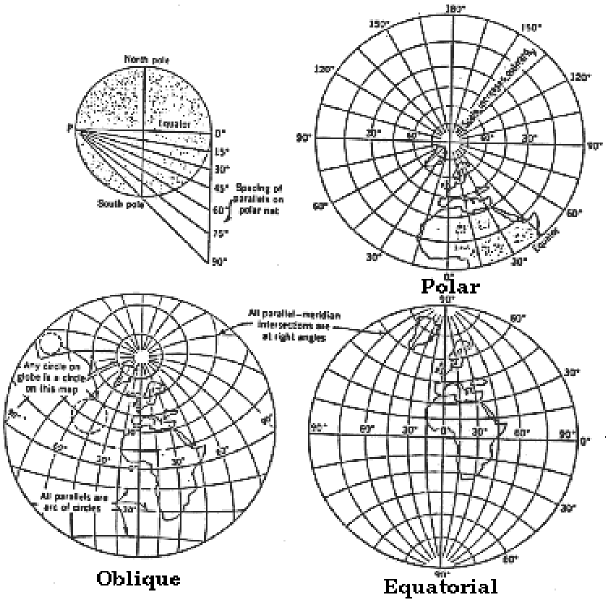


Figure 7 The Stereographic projection in the different aspects

2.2.14 Polar Stereographic

The Polar Stereographic projection can be used at both poles.

Parameters that must be specified for the Polar Stereographic projection:

- Scale factor at pole
- Longitude from pole
- Latitude of true scale
- False easting
- False northing

The polar aspect somewhat resembles other polar azimuths, with straight radiating meridians and concentric circles for parallels. The parallels are spaced at increasingly wide distances the farther the latitude is from the pole (the Orthographic has the opposite feature). Due to the conformality of the projection, a stereographic map may be given as a standard parallel with an appropriate radius from the centre (the pole), balancing the scale error through the map. This parallel is the Latitude of true scale; the point scale factor is 1 along this parallel. The USGS has most often used the Stereographic in the polar aspect and ellipsoidal form for maps of Antarctica. For 1:500,000 sketch maps, the standard parallel is -71 degrees; for its 1:250,000-scale series between -80 degrees and the South Pole, the standard parallel is -80 degrees, 14 minutes. The Universal Transverse Mercator (UTM) grid employs the Universal Polar Stereographic (UPS) from the North Pole to 84 degrees, and from the South Pole to -80 degrees. For the UPS, the scale at each pole is reduced to 0.994, resulting in a standard parallel of about +/- 81 degrees, 7 minutes. The UPS central meridian is the Greenwich meridian, with False eastings and False northings of 2,000,000 metres at each pole. The reference ellipsoid for all these Polar Stereographic projections is the International 1924.

2.2.15 UPS north

The Universal Polar Stereographic north is used at the North Pole.

Parameters that must be specified for the Universal Polar Stereographic north projection:

Longitude out from pole: The origin meridian out from the North Pole.

Predefined parameters:
Based on the International 1924 ellipsoid and the Polar Stereographic projection.

Semi major axis	: 6,378,388 m
Inverse flattening	: 297
Scale factor at pole	: 0.994
Latitude of true scale	: 81.116666666666° (81°07'00.000")
False easting	: 2,000,000 m
False northing	: 2,000,000 m

The Universal Polar Stereographic north projection is a standard Polar Stereographic projection used at the North Pole.

2.2.16 UPS south

The Universal Polar Stereographic south is used at the South Pole.

Parameters that must be specified for the Universal Polar Stereographic south projection:

Longitude out from pole: The origin meridian out from the South Pole.

Predefined parameters:
Based on the International 1924 ellipsoid and the Polar Stereographic projection.
Semi major axis : 6,378,388 m
Inverse flattening : 297
Scale factor at pole : 0.994
Latitude of true scale : -81.116666666666° (-81°07’00.000”)
False easting : 2,000,000 m
False northing : 2,000,000 m

The Universal Polar Stereographic south projection is a standard Polar Stereographic projection used at the South Pole.

2.2.17 Equatorial Stereographic

Parameters that must be specified for the Equatorial Stereographic projection:

- Scale factor at the Equator
- Central meridian
- False easting
- False northing

Predefined parameters:
Centre latitude : 0°

In the equatorial and oblique aspects, the distinctive appearance of the Stereographic projection becomes more evident. All meridians and parallels, except for two, are shown as circles, and the meridians intersect the parallels at right angles. The central meridian is shown straight, as the parallel of the same numerical value, but opposite in sign to the central parallel. For example, if latitude 40 degrees is the central parallel, then latitude -40 degrees is shown as a straight line. For the equatorial aspect with latitude 0 degrees as the central parallel, the Equator, which is of course also its own negative counterpart, is shown straight. Circles for parallels are centred along the central meridian; circles for meridians are centred along the straight parallel. The meridian 90 degrees from the central meridian on the equatorial aspect is shown as a circle bounding the hemisphere. This circle is centred on the projection centre and is equidistantly marked for parallels of latitude. As an azimuthal projection, directions from the centre are shown correctly in the spherical form. In the ellipsoidal form, only the polar aspect is truly azimuthal, but it is not perspective, in order to retain conformality. The oblique and equatorial aspects of the Ellipsoidal Stereographic, in order to be conformal, are neither azimuthal nor perspective. As with other azimuthal projections, there is no distortion at the centre, which may be made the standard point true to scale in all directions. Because of the conformality of the projection, there is a 'standard circle' with an appropriate radius from the centre, balancing the scale error throughout the map. In ellipsoidal oblique or equatorial aspects, the lines of constant are not perfect circles.

2.2.18 Oblique Stereographic

Parameters that must be specified for the Oblique Stereographic projection:

- Scale factor at centre
- Centre longitude
- Centre latitude
- False easting
- False northing

In the equatorial and oblique aspects, the distinctive appearance of the Stereographic projection becomes more evident. All meridians and parallels, except for two, are shown as circles, and the meridians intersect the parallels at right angles. The central meridian is shown straight, as the parallel of the same numerical value, but opposite in sign to the central parallel. For example, if latitude 40 degrees is the central parallel, then latitude -40 degrees is shown as a straight line. For the equatorial aspect with latitude 0 degrees as the central parallel, the Equator, which is of course also its own negative counterpart, is shown straight. Circles for parallels are centred along the central meridian; circles for meridians are centred along the straight parallel. The meridian 90 degrees from the central meridian on the equatorial aspect is shown as a circle bounding the hemisphere. This circle is centred on the projection centre and is equidistantly marked for parallels of latitude. As an azimuthal projection, directions from the centre are shown correctly in the spherical form. In the ellipsoidal form, only the polar aspect is truly azimuthal, but it is not perspective, in order to retain conformality. The oblique and equatorial aspects of the Ellipsoidal Stereographic, in order to be conformal, are neither azimuthal nor perspective. As with other azimuthal projections, there is no distortion at the centre, which may be made the standard point true to scale in all directions. Because of the conformality of the projection, there is a 'standard circle' with an appropriate radius from the centre, balancing the scale error throughout the map. In ellipsoidal oblique or equatorial aspects, the lines of constant are not perfect circles.

2.2.19 RD projection

The RD projection is used in Holland.

Predefined parameters:
Based on the Bessel 1841 ellipsoid and the Transverse Mercator projection.

Semi major axis	: 6,377,397.155 m
Inverse flattening	: 299.152813
Centre scale factor	: 0.9999079
Centre longitude	: 5.3876388888888° (5°23’15.5’’)
Centre latitude	: 52.156160555556° (52°9’22.178’’)
False easting	: 155,000 m
False northing	: 463,000 m

The RD projection is a polynomial version of the Oblique Stereographic projection with predefined parameters.

2.2.20 Rectified Skew Orthomorphic

The RSO method is mostly used in Indonesia and Malaysia (Borneo), but also sometimes in Alaska, Hungary and Madagascar.

It has been noted that the Transverse Mercator projection is employed for the topographical mapping of longitudinal bands of territories, limiting the amount of scale distortion by limiting the extent of the projection on either side of the central meridian. Sometimes the shape, general trend and extent of some countries make it preferable to apply a single zone of the same kind of projection, but with its central line aligned with the trend of the territory concerned, rather than with a meridian. So, instead of a meridian forming this true scale central line for one of the various forms of the Transverse Mercator, or the Equator forming the line for the Mercator, a line with a particular azimuth traversing the territory is chosen, and the same principles of construction are applied to derive what is now an Oblique Mercator.

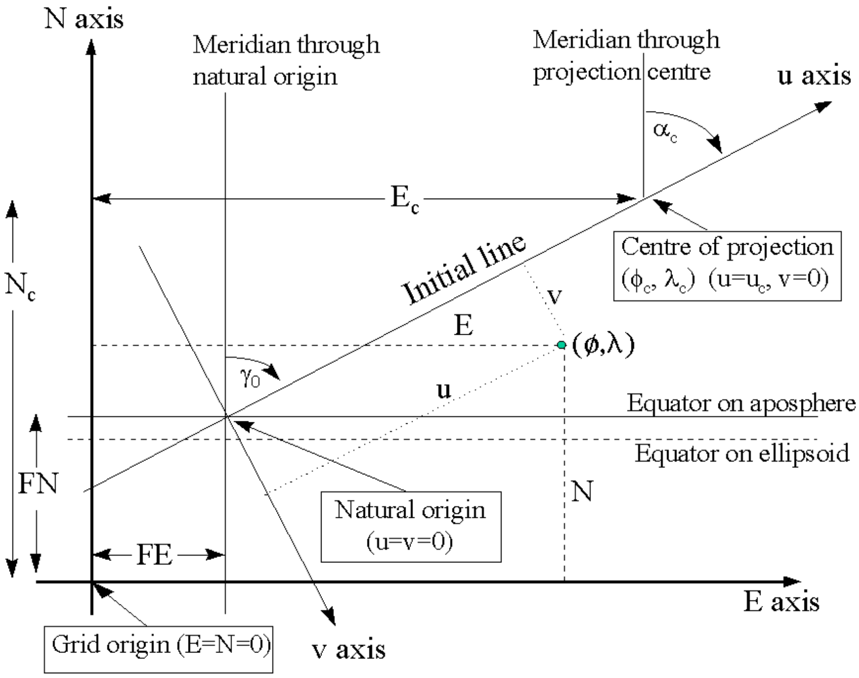


Figure 8 Skewed projection

Learn more at:
http://www.posc.org/Epicentre.2_2/DataModel/ExamplesofUsage/eu_cs34i.html

In the EIVA geodesy library, one RSO item is defined – but more can be added manually by defining the appropriate parameters:

Name	: 'R.S.O. Borneo'
Scale	: 0.99984
Azimuth of central line	: 53°18'56.9537"
Rectified to skew grid	: 53°07'48.3685"
Longitude	: 115°
Latitude	: 4°
Easting	: 0
Northing	: 0

2.2.21 New Zealand Map Grid

The New Zealand Map Grid (NZMG) is a projection that is used to convert latitudes and longitudes to easting and northing coordinates for most mapping of New Zealand. The projection is unique to New Zealand. It was designed by Dr W. I. Reilly (1973) to minimize the scale error over the land area of the country; it cannot sensibly be used elsewhere. The conversion is calculated using a complex polynomial formula. Familiarity with complex arithmetic is assumed in this description.

Note that the projection applies to latitudes and longitudes referenced to the New Zealand Geodetic Datum 1949 (NZGD49). Coordinates from other datums, such as the WGS84 datum commonly used by GPS receivers, must be converted to NZGD49 before these formulae can be applied.

Learn more at: http://www.linz.govt.nz

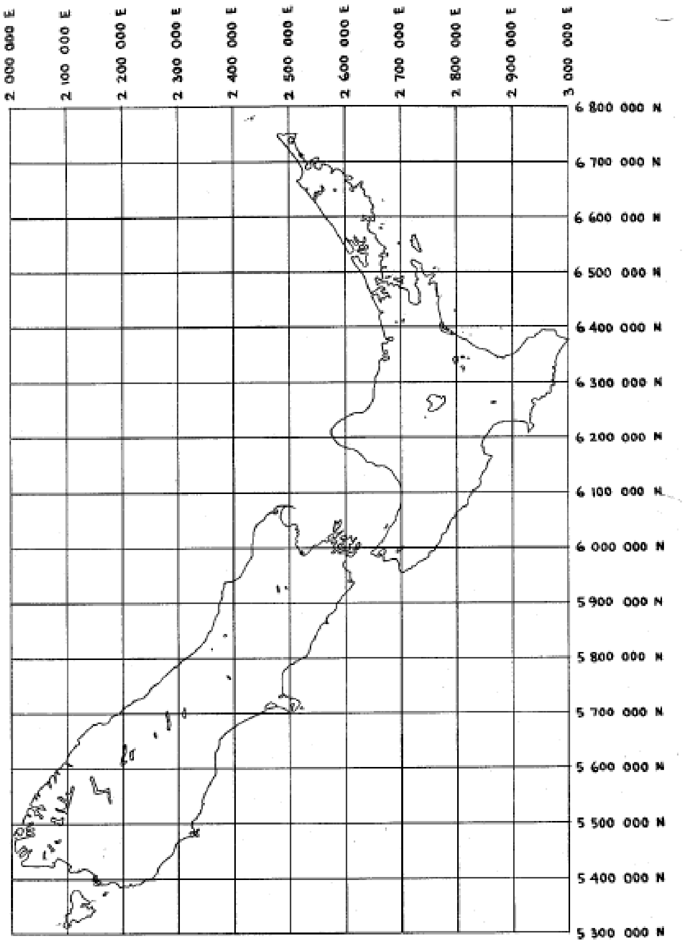


Figure 9 New Zealand Map Grid

Name	: 'New Zealand Map Grid'
Scale	: 1.000
Longitude	: 173°
Latitude	: -41°
Easting	: 2,510,000 m
Northing	: 6,023,150 m

2.2.22 American Polyconic

As a specific projection, the American Polyconic is conceptualised as ‘rolling’ a cone tangent to the Earth at all parallels of latitude, instead of a single cone as in a normal conic projection. Each parallel is a circular arc of true scale. The scale is also true on the central meridian of the projection. The projection was in common use by many map-making agencies of the United States from the time of its proposal by Ferdinand Rudolph Hassler in 1825 until the middle of the 20th century.

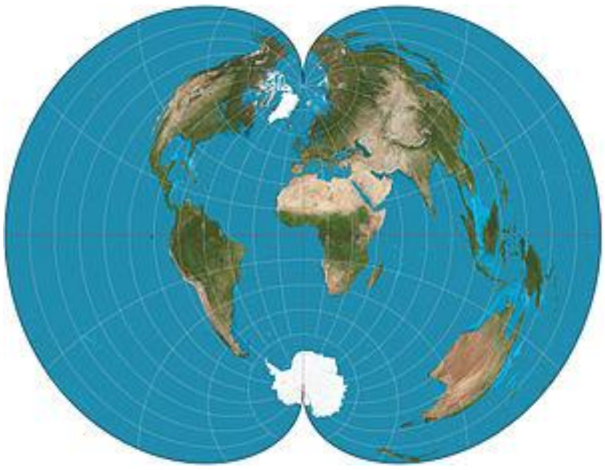


Figure 10 American Polyconic world map

Name	: ‘American Polyconic’
Scale	: 1.000
Longitude	: 54°W
Latitude	: 0°
Easting	: 5,000,000 m
Northing	: 10,000,000 m

3 Ellipsoid

Ellipsoids are defined using the below-listed attributes:

Ellipsoid name
Name of the source reference ellipsoid that will be used. You can select one from the list of the predefined ellipsoids, eg International 1924.

Semi_major axis
Semi major axis of the ellipsoid that will be used, in metres. Range: [1 – 30,000,000]; default 6,378,388 metres.

Inverse flattening (1/flattening)
Inverse flattening of the ellipsoid that will be used. Eccentricity is calculated from the entered inverse flattening. Range: [4 – 99,000,000]; default 297.

Eccentricity
Eccentricity of the ellipsoid that will be used. Inverse flattening is calculated from the entered eccentricity. Range: [0.001 - 0.9999].
Eccentricity = SQRT (flattening * (2 - flattening))

Some predefined ellipsoid/datum definitions:

Ellipsoid	Semi major axis (m)	Inverse flattening
Airy 1830	6,377,563.396	299.324964
Bessel 1841	6,377,397.155	299.1528128
Clarke 1866	6,378,206.4	294.978698
Clarke 1878	6,378,316	293.46
Clarke 1880	6,378,249.145	293.465
Clarke 1880 (M)	6,378,249.145	293.4663
Everest 1830	6,377,276.345	300.8017
Everest 1830)	6,377,298.56	300.8017
Helmert 1906 (Egypt)	6,378,200	298.3
International 1909	6,378,388	297
International 1924	6,378,388	297
International 1980	6,378,137	298.257
Hayford 1909	6,378,388	297
ED 50	6,378,388	297.00
Krassovski 1940	6,378,245	298.3
Pulkova 1942	6,378,140	298.257
NGO 1948	6,377,492.0176	299.1528
GRS 1967	6,378,160	298.2471674273

GRS 1980	6,378,137	298.257222101
Mercury 1960	6,378,166	298.3
Mercury 1968	6,378,150	298.3
Australian National	6,378,160	298.25
South America 1969	6,378,160	298.25
Int. Assoc. 1975	6,378,140	298.257
Int. Assoc. 1979	6,378,137	298.257223563
Int. Assoc. 1983	6,378,136	298.257
NWL9D (PE datum)	6,378,145	298.25
NWL10D (BE datum)	6,378,135	298.26
WGS 72	6,378,135	298.26
WGS 84 (GPS datum)	6,378,137	298.257223563
EUREF89	6,378,137	298.257223563
Clarke 1881 IGN	6,378,249.2	293.466

Table 2 Available ellipsoids in NaviPac

4 Datum shift

NaviPac supports datum shift using the ordinary 7-parameter method.

NaviPac (and all the EIVA software) is using the 'Position Vector transformation' method ((EPSG dataset coordinate operation method code 1033) for the 3D Helmert transformation (Bursa Wolf Method).

A variation of this formula is based on a different definition of the rotation parameters. This is known as the 'Coordinate Frame Rotation' convention (EPSG dataset coordinate operation method code 1032).

Conversion between the two methods can be conducted by changing the sign of each of the three rotations.

Normal Bursa-Wolff 7-parameter (NGO):

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} Tx \\ Ty \\ Tz \end{pmatrix} + \begin{pmatrix} PPM & -Rz & Ry \\ Rz & PPM & -Rx \\ -Ry & Rx & PPM \end{pmatrix} \times \begin{pmatrix} X0 \\ Y0 \\ Z0 \end{pmatrix} + \begin{pmatrix} X0 \\ Y0 \\ Z0 \end{pmatrix}$$

Modified Bursa-Wolff:

From WGS84 to user datum

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} Tx \\ Ty \\ Tz \end{pmatrix} + \left(1/(1-PPM)\right) * \begin{pmatrix} 1 & -Rz & Ry \\ Rz & 1 & -Rx \\ -Ry & Rx & 1 \end{pmatrix} \times \begin{pmatrix} X0 \\ Y0 \\ Z0 \end{pmatrix}$$

North Sea:

This is a multi-step operation that is commonly used in the Norwegian sector of the North Sea.

Transform from WGS84 to ED87 using a normal 7-parameter (NGO) transformation.

If the resulting latitude is below 62 degrees, use the dedicated algorithm to get from ED87 to ED50.

If the resulting latitude is above 65 degrees, use the dedicated 7-parameter transformation from ED87 to ED50:
Tx = 1.51 m
Ty = 0.84 m
Tz = 3.50 m
Rx = 1.893E-6 radians
Ry = 6.870E-7 radians
Rz = 2,764E-6 radians
PPM = -6.090E-7

If the resulting latitude is between 62 and 65 degrees, use a weighted average of the algorithm and the dedicated 7-parameter transformation.

One thing must be observed. Calculation of the Cartesian coordinates differs for the two methods. The Bursa-Wolf method uses the WGS84 height if available, as this gives the most correct result. The online shift (from GPS receivers) will use the GPS height, only if it's in RTK mode.

Please note: The result of the shift is two-dimensional, ie height is not calculated by the transformation.

4.1 US NADCON datum shift

If NaviPac is defined to use the US NADCON datum shift method (between NAD83 and NAD27 – learn more at http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.shtml), then the operator must select two grid separation files, one for latitude and one for longitude.

The files must be organised as ASCII grid files:

NADCON EXTRACTED REGION   NADGRD

273 121   1 -131.00000   .25000   20.00000   .25000   .00000

.864138   .868198   .872259   .876318   .880375   .884429

etc

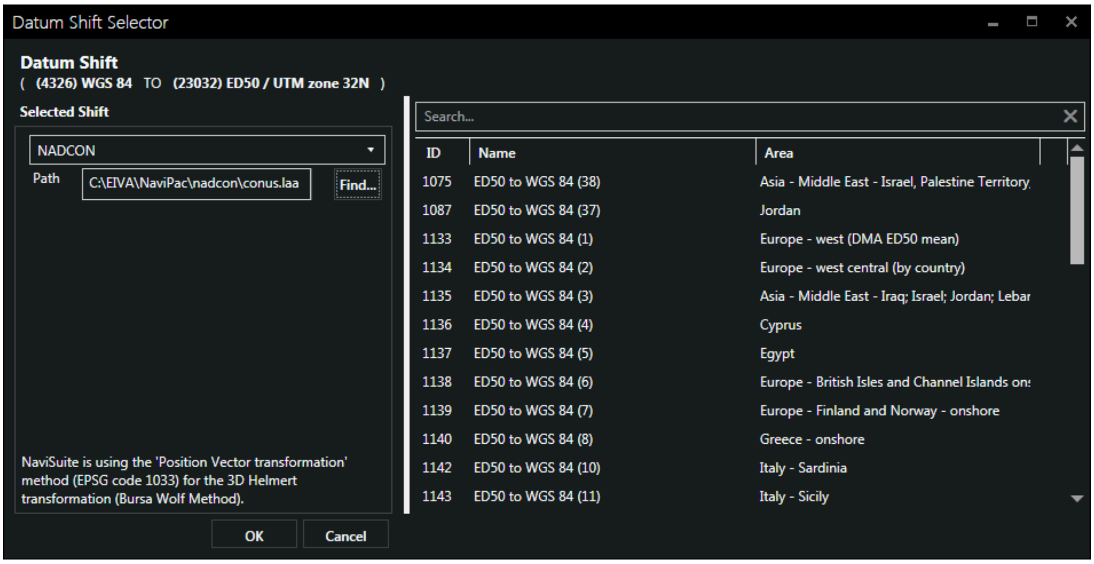


Figure 11 Set datum shift method to NADCON

The first header line is ignored. The second line gives number of longitudes, number of latitudes, ignored, start longitude, delta longitude, start latitude and delta latitude. Below, a point follows for each grid cell, as the order is starting from the lower left corner, moving eastward (longitude) and northward. The two files must have same name, one with extension *.laa (Latitude ASCII) and one with extension *.loa (Longitude ASCII). Official files can be retrieved from http://www.cs.arizona.edu/icon/ftp/data/nadcon/.

The NADCON file is selected by clicking the **Find** button in the datum shift dialogue box.

First of all you must select the grid files, which is done by selecting the Latitude ASCII file:

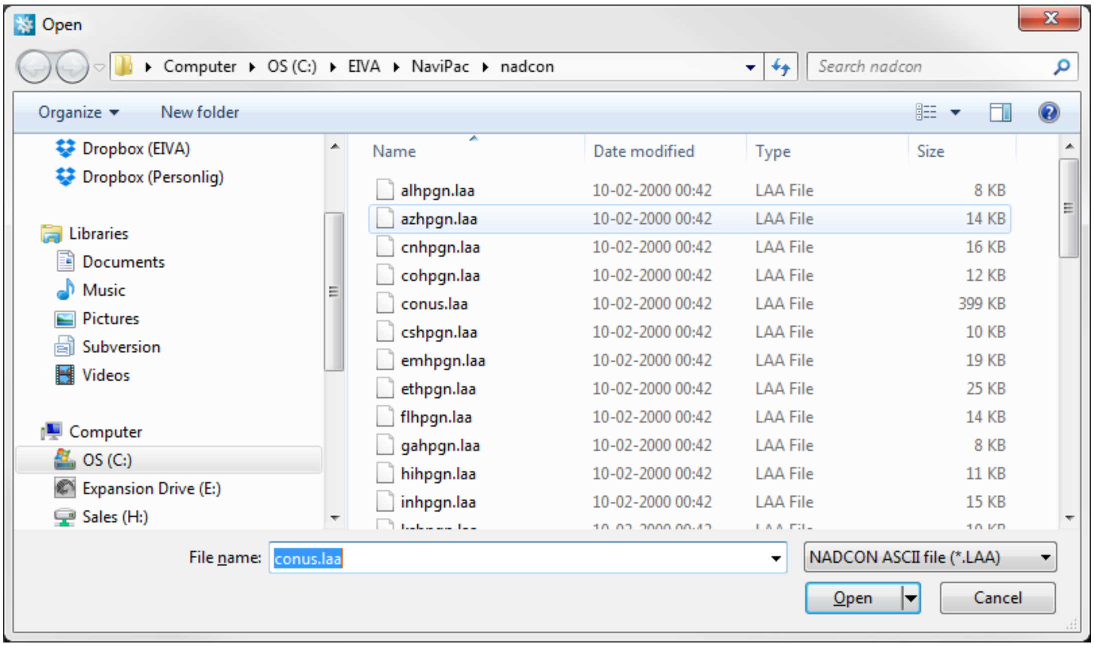


Figure 12 Selecting grid file

The dialogue box remembers where you selected a file last time, but it will NOT show the last selection.

5 Geoidal separation

If you are using NaviPac with GPS RTK to calculate exact height of the vessel (eg together with EIVA NaviScan), you need to specify the distance between GPS geoidal height and your local zero.

The vessel height will hereafter be defined as:

- height from GPS
- moved to local zero by subtracting geoidal separation
- corrected for 3D antenna offsets (after R/P correction)

The entire setup is performed via the in the **Height Reduction** entry in the **Geodesy Settings** in the **Project**:

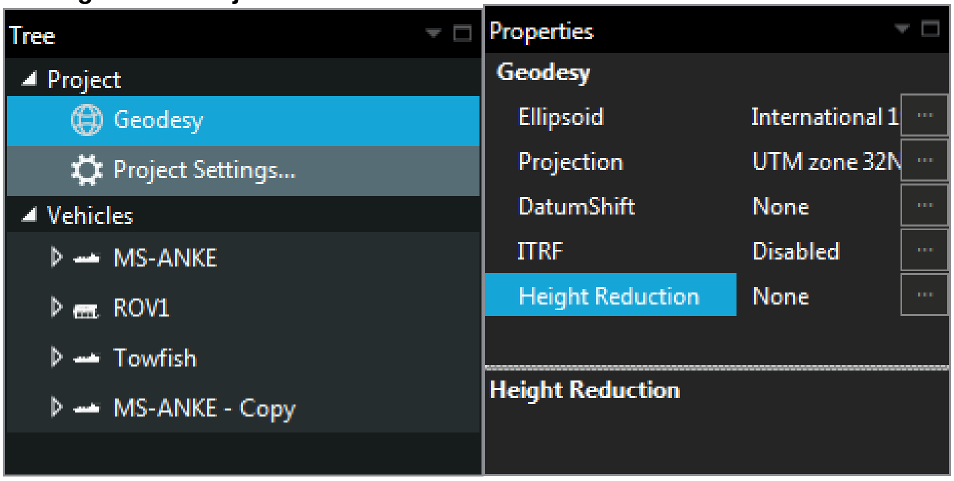


Figure 13 Defining height reference

5.1 Constant separation

If you are operating in ‘flat’ areas, the geoidal separation value can be specified as a constant for the entire area:

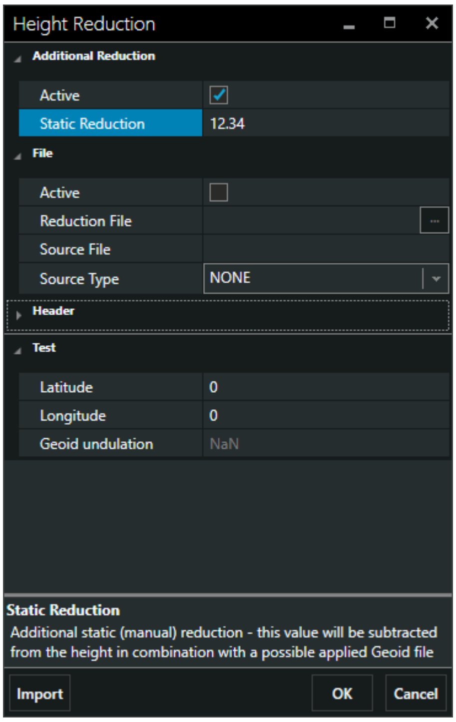
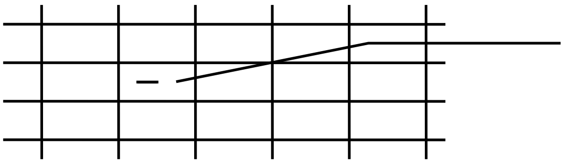


Figure 14 Specifying constant separation for entire area

5.2 Geoidal file

For some areas, this approach will be too inaccurate, and a more detailed solution must be applied.

NaviPac supports a uniform square grid (eg Danish Normal Zero), where the separation in a certain point is calculated on the basis of the four neighbour points.



Correction is calculated as a linear interpolation between the four corners in the surrounding box.

It must be noted that NaviPac expects this grid to be in the local datum, since it uses the vessel reference position (latitude/longitude in selected ellipsoid) as the look-up point.

NaviPac uses a binary format to store this information, as the following structure (C and C++ notation) is used (all positions are in degrees, ie latitude/longitude):

```
#define geoideFile "$EIVAHOME\setup\Geoide.bin"

typedef struct GeoHead

{

      double startE, endE, deltaE; // Start of grid and delta Longitude
      double startN, endN, deltaN; // Start of grid and delta Latitude

      int noE, noN;                          // #points in Longitude and Latitude

} GeoHead;  // Header stored in top of file

static CArray<float,float> theMatrix;    // The grid stored in matrix
```

The grid data is then stored, starting from most north-western part, moving eastward and then southward.

If you want to specify your own file, the above must be considered.

First of all you must import a file from the original source. This is done via the **Import** button

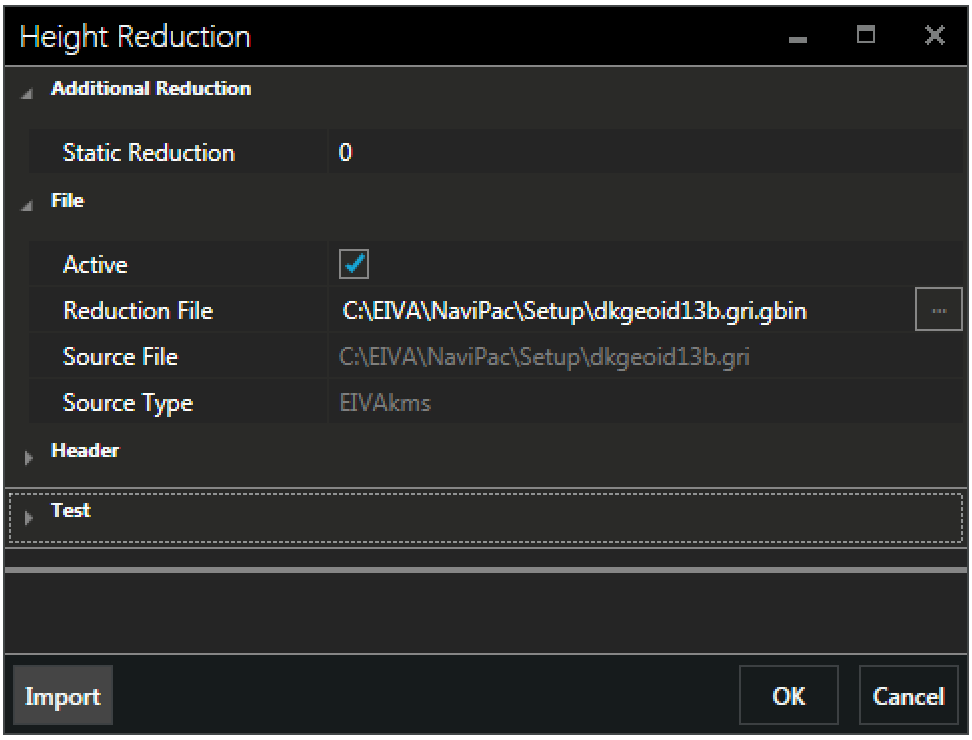


Figure 15 Importing source file

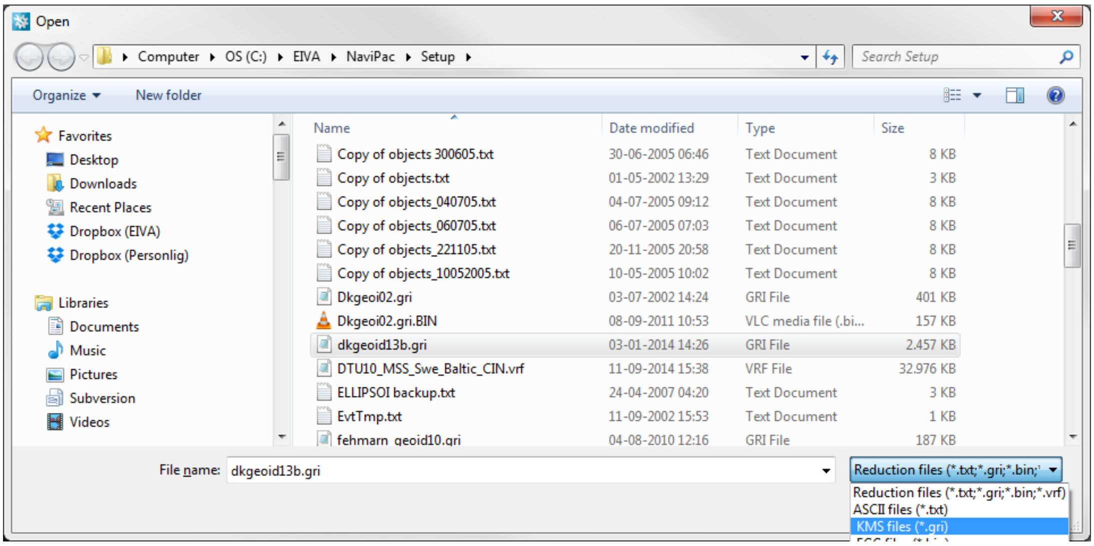


Figure 16 Select source file and format

The system will then read the selected file and convert to the internal EIVA.bin format. See more on formats below.

Alternatively, you may select a reduction file directly via the Reduction File entry

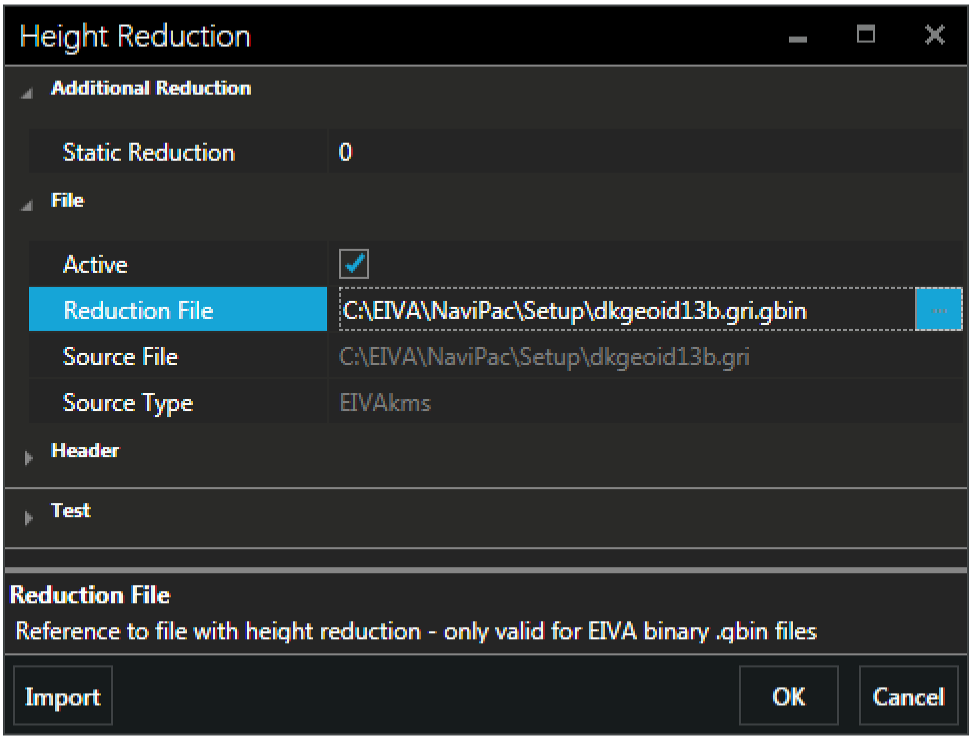


Figure 17 Selecting reduction file

After import or load the **Header** section shows information about the loaded are

5.2.1 EIVA file format

Another solution is to specify the separation in an ASCII file and use the interpreter from NaviPac, which is simpler. The format is based on DNN (Danish Normal Zero) from KMS (also known as the *.gri format).

The first line identifies the grid layout, by giving the start latitude, end latitude, start longitude, end longitude, delta latitude and delta longitude. All values are given in degrees.

```
54.800000  57.800000  8.000000  10.800000  0.0100000  0.0200000

  40.229  40.177  40.125  40.071  40.015  39.960  39.903
  39.846  39.792  39.739  39.686  39.641  39.595  39.551
  39.512  39.472  39.440  39.408  39.378  39.352  39.326
```

Correction at 8.00 , 57.8

Correction at 8.02 , 57.8

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.193	39.172
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.047	39.028
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38.904	38.883
38.862	38.840	38.819	38.798	38.778	38.756	38.736
38.715	38.694	38.676	38.659	38.641	38.624	38.605
38.589	38.572	38.556	38.541	38.526	38.509	38.493
38.478	38.463	38.448	38.435	38.422	38.406	38.393
38.382	38.376	38.370	38.364	38.359	38.353	38.347
38.342	38.338	38.334	38.330	38.326	38.323	38.319
38.317	38.313	38.307	38.302	38.295	38.287	38.280
38.268	38.255	38.241	38.223	38.205	38.185	38.165
38.143	38.121	38.098	38.073	38.045	38.020	37.996
37.972	37.948	37.927	37.903	37.881	37.857	37.834
37.812	37.786	37.758	37.731	37.701	37.672	37.642
37.611	37.578	37.547	37.515	37.484	37.453	37.422
37.390	37.358	37.326	[illegible]	[illegible]	[illegible]	37.198
37.165	37.130	37.096	[illegible]	[illegible]	[illegible]	36.955
36.919						

Correction at 10.8 , 57.8

40.200	40.150	40.100	[illegible]	[illegible]	[illegible]	39.889
39.836	39.783	39.733	[illegible]	[illegible]	[illegible]	39.553

. . . .

Correction at 8.0 , 57.79

Then one section follows per ‘horizontal line’ in the grid, as it starts in the upper left corner and moves right and downward (starting from the most north-western part, moving eastward and then southward).

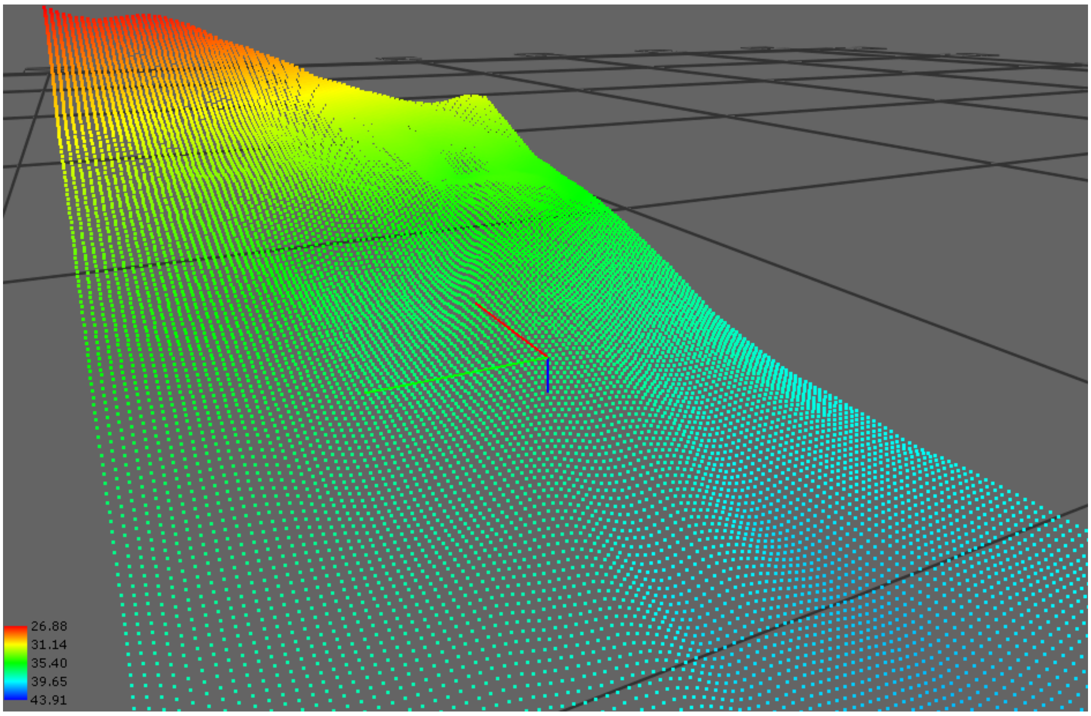


Figure 18 Testing a resulting model

5.2.2 EGG 97

NaviPac supports the European Gravimetric (Quasi) Geoid 1997 (EGG97) by importing the binary geoide (*.bin) files. Some details can, for example, be found at https://www.ife.uni-hannover.de/en/research/main-research-focus/regional-gravity-field-and-geoid-modelling/european-geoid-calculations/

5.2.3 GCG05

NaviPac also supports the special German combined quasigeoid model GCG05 – learn more at http://www.geodatenzentrum.de/docpdf/quasigeoid.pdf.

The data is supported via import of the regular grid data loaded from the ASCII format file:

```
51.7916667 10.0125 44.8080
51.7916667 10.0375 44.8185
51.7916667 10.0625 44.8410
```

```
51.7916667 10.0875 44.8630
51.7916667 10.1125 44.8880
51.7916667 10.1375 44.9195
51.7916667 10.1625 44.9535
```

The data gives one line per point as defined by latitude, longitude, separation:

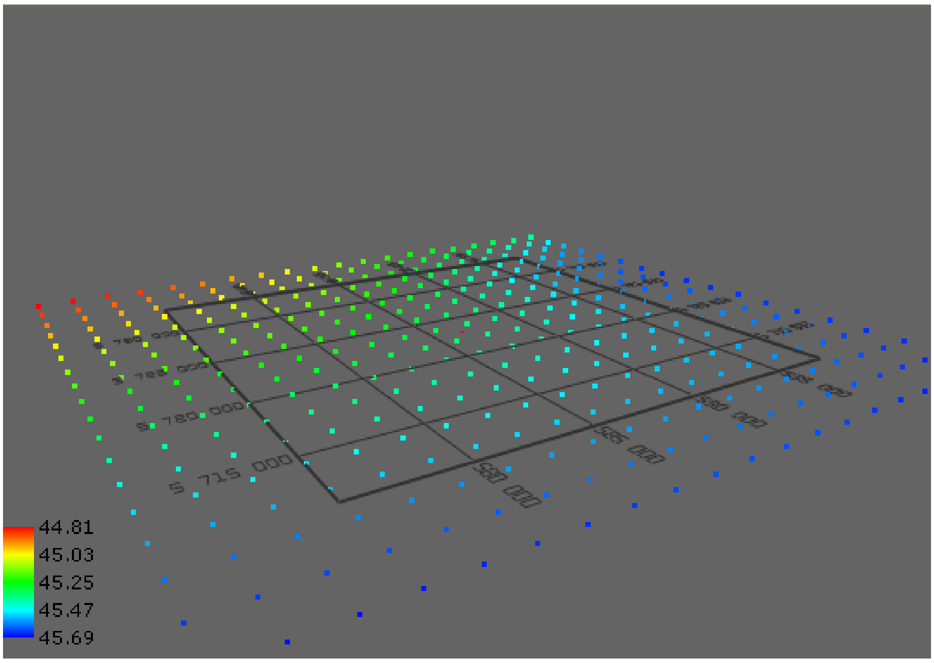


Figure 19 Resulting GCG model

5.2.4 VORF

NaviPac 3.8.5 and later versions support the Vertical Offshore Reference Frame (VORF) as defined for UK waters.

VORF is a simple ASCII file with gridded points:

```
# ETRF to HAT transformation. [Latitude] [Longitude] [New Depth]
[Uncertainty]. The file has 6509 valid points.
51.60000000 1.49600000 46.6389 0.1277
51.60000000 1.50400000 46.6275 0.1278
```

```
51.60000000 1.51200000 46.6106 0.1281
51.60000000 1.52000000 46.6001 0.1283
```

Unlike other format types, the VORF format is able to handle missing coordinates (land, etc).
The support will only apply to files defined from lover left corner and with a uniform gridding (same cell size)

5.2.5 US Geoid model

NaviPac supports the special binary geoide model for the US called GEOID09. Details and files can be obtained from the official NOAA web page:
http://www.ngs.noaa.gov/GEOID/GEOID09/

5.2.6 Test of the geoidal file

You may test the loaded via in the Test section by entering latitude and longitude:

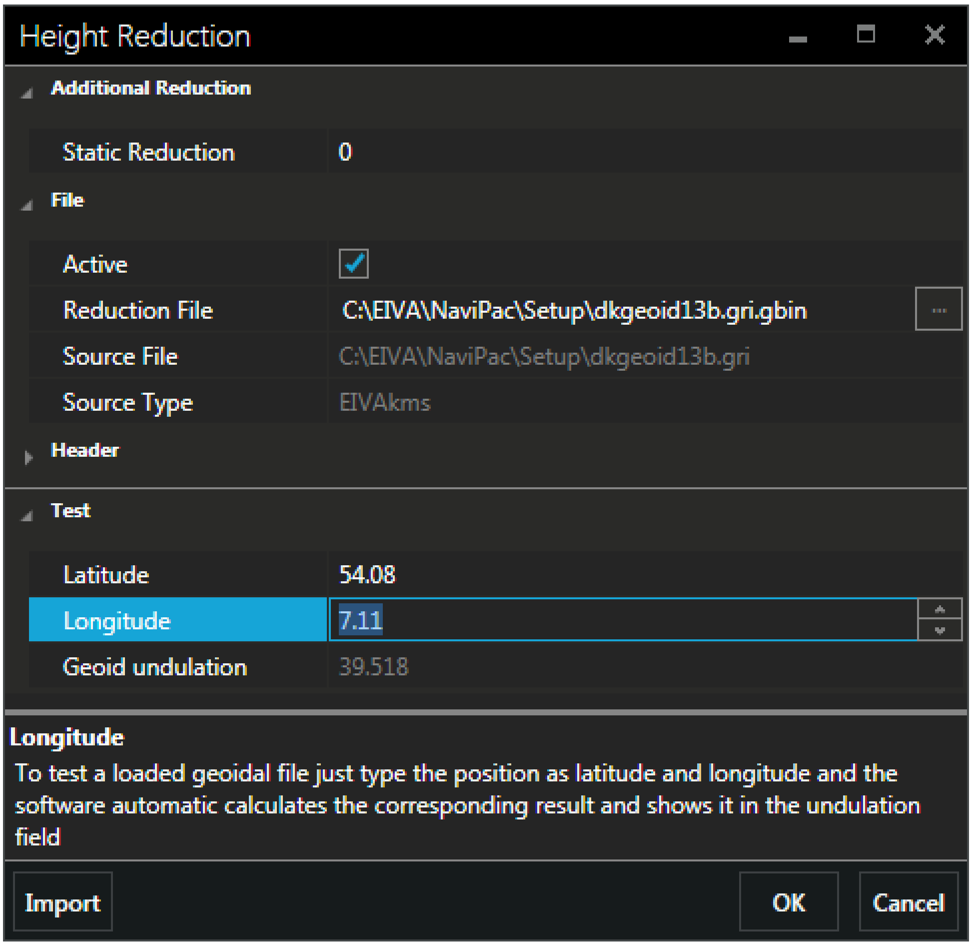


Figure 20 Automatic test of geoid separation

6 ITRF

NaviPac may include time-based datum shift parameters to account for situations where the datum shift is changing over time.

The basic NaviPac datum shift parameters will be adjusted daily using the **Speed of change** parameters, based on the reference date.

This type of datum shift can, for example, be relevant in North America, where the use of ITRF to NAD83 is widely used, and in Europe to shift from ITRF to EUREF89.

The definition is made in the NaviPac configuration application via the ITRF menu in the Geodesy properties:

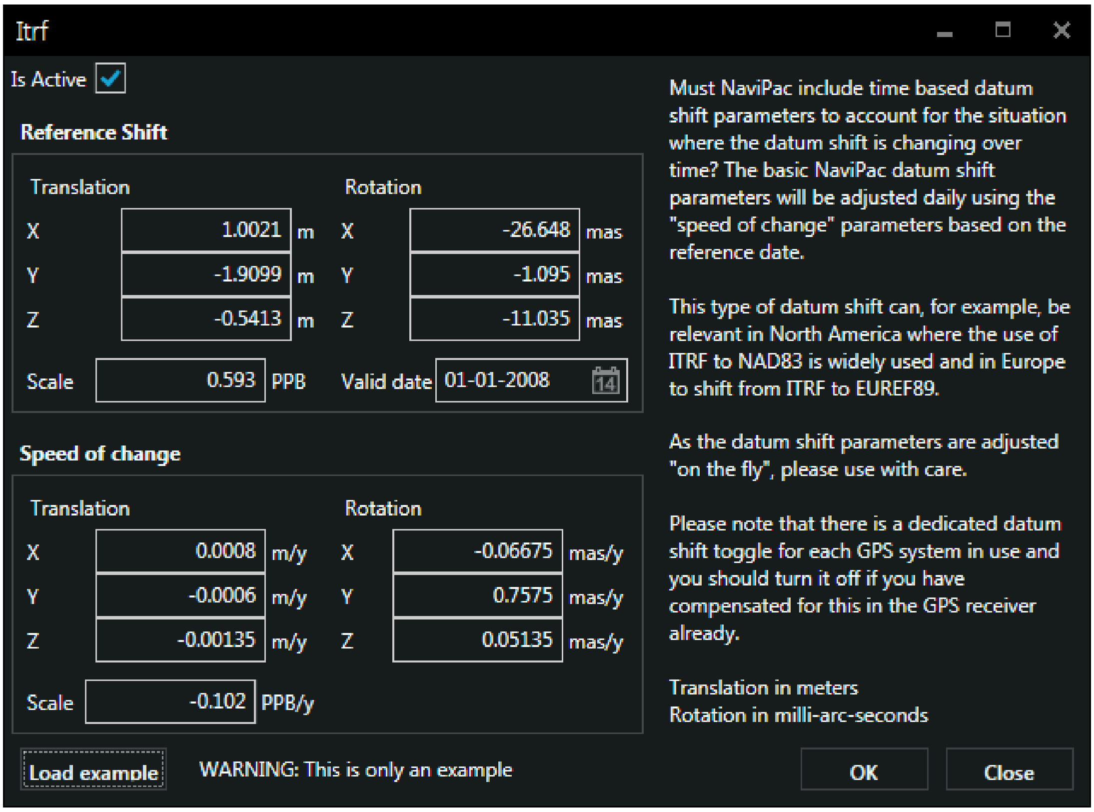


Figure 21 Defining ITRF in NaviPac

It consists of two parts, a basis 7-parameter transformation with date of validity and a speed of change. All this enables NaviPac to calculate the parameters at any time using simple extrapolation. Note: ITRF must also be enabled on each GPS receiver.

7 References

Kubik, Kurt. 1987. *Geographic Projection Systems.* International Institute of Aerial Survey and Earth Sciences (ITC) and The Ohio State University.

Seutter, Matthäus. Ca. 1740. *Daniæ Regnum cum Ducatu Holsatiæ et Slesvici: nec non Insulæ Danicæ, et lutia cum parte Scaniæ* [map]. Augsburg.

Snyder, John P. 1987. *Map Projections: A Working Manual.* Washington, D.C.: United States Government Printing Office.

Snyder, John P. 1982. *Map Projections Used by the U.S. Geological Survey/Bulletin No. 1532*. Washington, D.C.: United States Government Printing Office.

U.S. Geological Survey, National Mapping Division. 1981. *General Cartographic Transformation Driver No. J898.*

Wikipedia