

Coordinate transformation between International Terrestrial Reference System and coordinates used for the islands Bonaire, St. Eustatius and Saba (BES)

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Version: 5 April 2023

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by Netherlands Partnership Geodetic Infrastructure ([NSGI](https://www.nsgi.nl/))

1 Introduction

1.1 Coordinate systems in the Caribbean Netherlands

The International Terrestrial Reference System (ITRS) is the official worldwide coordinate system. ITRS is prescribed by the United Nations and national and international standards. Precise orbits of Global Navigation Satellite Systems (GNSS) by the International GNSS Service (IGS) for use in Precise Point Positioning (PPP) are given in ITRS.

National and local coordinate systems are linked to ITRS via a regional system like the European Terrestrial Reference System 1989 (ETRS89) or are linked to ITRS directly. The islands Bonaire, St. Eustatius and Saba of the Caribbean Netherlands (Dutch: *BES-eilanden*) each have their own local coordinate system per island, called DPnet. St. Eustatius and Saba originally had two variants of the coordinate system, one for the topographic map and the other used for the cadastral map. The difference is a constant shift in the x-coordinate and a constant shift in the y-coordinate. For St. Eustatius, the coordinates of the topographic map are now used, also for the cadastral map. For Saba, the coordinates of the cadastral map are used, also for other purposes.

For storage and exchange of geo-information at sea, the International Hydrographic Organisation (IHO) has agreed upon World Geodetic System 1984 (WGS 84). WGS84 is the coordinate system used by GPS, the GNSS of the United States' military. WGS84 and coordinate systems of other GNSS are periodically aligned to ITRS. Since ellipsoidal heights in ITRS and WGS84 are only geometrical and have no physical meaning, other height references are used too. Dienst der Hydrografie uses WGS84 coordinates with the maritime reference surface Lowest Astronomical Tide (LAT) as chart datum for the Dutch part of the Caribbean Sea.

1.2 Coordinate transformation

Since 1 January 2021, the cadastral organisations of Bonaire, St. Eustatius and Saba are part of the Netherlands' Cadastre, Land Registry and Mapping Agency (Kadaster). Kadaster is working together with the Hydrographic Service of the Royal Netherlands Navy and Rijkswaterstaat in the Netherlands Partnership Geodetic Infrastructure (NSGI) to maintain the geodetic infrastructure.

This document is restricted to the transformation between ITRS and DPnet coordinates of the Caribbean Netherlands. It uses the ITRS realisation ITRF2014. The realisation of WGS84 currently used by GPS is WGS84-G2139, which is aligned within a few centimetres to ITRS realisation ITRF2014 (and ITRF2020). The use of map projections like Universal Transverse Mercator (UTM) projection or Web Mercator projection are not described.

This document describes the parameters needed to implement the transformation for St. Eustatius and Saba. ITRS coordinates of fixed points are changing with about 1.8 cm per year due to tectonics of the Caribbean plate. Therefore,

the transformation parameters are time-dependent. For GIS and other applications where dynamic coordinates are inconvenient, we recommend to use ITRF2014 coordinates for the beginning of the year 2020, epoch 2020.00. This reference epoch is a convenient choice as the same epoch will be used by the expected new Caribbean Terrestrial Reference Frame 2022 (CATRF2022) too.

The precision of the transformation parameters is limited due to: (1) the short span of 1-2 years for the used times series of the NSGI/KNMI-operated GNSS reference stations SEUS, SEUT, SABA and SABY, (2) the low number of 6 first-order reference points (Dutch: *DP-punten*) that were measured per island, and (3) the discrepancies up to 0.05 m between GNSS measurements and original coordinates of the reference points. The expected 3D precision of the parameters is better than 0.1 metre up to the year 2030. Improved parameters will be computed when more measurement data become available. The projection and transformation parameters can be used with GNSS reference stations of IGS, NSGI or another reference for ITRF2014 coordinates. Use with a GNSS reference station in a different reference frame or with unknown epoch, will give inconsistent coordinates.

Due to the size of St. Eustatius and Saba, the geoid is modelled implicitly as a tilted plane by the datum transformation parameters. No additional geoid model is used for these coordinate transformations.

Parameters for Bonaire will be added to a next version of this document. Parameters by the local Kadaster office provide the 2D transformation for the reference frame and epoch in which the coordinates of the GNSS reference station of Kadaster Bonaire have been determined. The yearly change of the coordinates of this GNSS reference station and the corresponding yearly change of the transformation parameters is not known. The precision of the transformation parameters is better than 0.1 metre when used for 2D RTK measurements in combination with the GNSS reference station of Kadaster Bonaire. However, the precision of the height is only below 1 metre. The use of these parameters for the transformation to and from ITRS or WGS84, for instance in GIS software or for GNSS surveying without the GNSS reference station of Kadaster (e.g. PPP-RTK), would result in coordinates with an offset below 1 metre.

2 Parameters

2.1 ITRS

2.1.1 Ellipsoid

Parameters of GRS80 ellipsoid

$a = 6378137$ m half major (equator) axis of GRS80 ellipsoid
 $f = 1/298.257222101$ flattening of GRS80 ellipsoid (dimensionless)

2.1.2 Map projections

Optional

2.2 Transformation from ITRS to DPnet

2.2.1 St. Eustatius

Parameters of 3D similarity transformation and their yearly rates from ITRF2014 to St. Eustatius DPnet

$t_X = -1276.8187$ m translation in direction of X axis
 $t_Y = +2017.6083$ m translation in direction of Y axis
 $t_Z = -667.3989$ m translation in direction of Z axis
 $\alpha = +490.03015 \cdot 10^{-6}$ rad = +101.075975" rotation angle around X axis
 $\beta = -1032.07065 \cdot 10^{-6}$ rad = -212.879853" rotation angle around Y axis
 $\gamma = +332.27704 \cdot 10^{-6}$ rad = +68.537059" rotation angle around Z axis
 $\delta = +431.78240 \cdot 10^{-6}$ scale difference (dimensionless)

$\dot{t}_X = -0.00745$ m yearly rate of translation in direction of X axis
 $\dot{t}_Y = -0.00876$ m yearly rate of translation in direction of Y axis
 $\dot{t}_Z = -0.01401$ m yearly rate of translation in direction of Z axis
 $\dot{\alpha} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000" yearly rate of rotation angle around X axis
 $\dot{\beta} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000" yearly rate of rotation angle around Y axis
 $\dot{\gamma} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000" yearly rate of rotation angle around Z axis
 $\dot{\delta} = +0.000000 \cdot 10^{-6}$ yearly rate of scale difference (dimensionless)

$t_0 = 2020.00$ reference epoch (years)

NB: The three rotation parameters and their yearly rates ($\alpha, \beta, \gamma, \dot{\alpha}, \dot{\beta}, \dot{\gamma}$) are for use with the formulas according to the "coordinate frame" convention that assumes the positive rotation direction to be anticlockwise. The signs of these parameters must be inverted for the alternative "position vector" convention.

The transformation should be performed with full rotation matrix. A frequently used alternative formula with an approximated rotation matrix will cause errors of several decimetres.

2.2.2 Saba

Parameters of 3D similarity transformation and their yearly rates from ITRF2014 to Saba DPnet

$t_X = -1137.8063$ m translation in direction of X axis
 $t_Y = +2066.1024$ m translation in direction of Y axis

$t_Z = -110.2520$ m	translation in direction of Z axis
$\alpha = +1042.34209 \cdot 10^{-6}$ rad = +214.998490"	rotation angle around X axis
$\beta = -2323.17020 \cdot 10^{-6}$ rad = -479.188251"	rotation angle around Y axis
$\gamma = +800.92710 \cdot 10^{-6}$ rad = +165.203074"	rotation angle around Z axis
$\delta = +402.48266 \cdot 10^{-6}$	scale difference (dimensionless)
$\dot{t}_X = -0.00730$ m	yearly rate of translation in direction of X axis
$\dot{t}_Y = -0.00849$ m	yearly rate of translation in direction of Y axis
$\dot{t}_Z = -0.01351$ m	yearly rate of translation in direction of Z axis
$\dot{\alpha} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000"	yearly rate of rotation angle around X axis
$\dot{\beta} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000"	yearly rate of rotation angle around Y axis
$\dot{\gamma} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000"	yearly rate of rotation angle around Z axis
$\dot{\delta} = +0.000000 \cdot 10^{-6}$	yearly rate of scale difference (dimensionless)
$t_0 = 2020.00$	reference epoch (years)

NB: The three rotation parameters and their yearly rates ($\alpha, \beta, \gamma, \dot{\alpha}, \dot{\beta}, \dot{\gamma}$) are for use with the formulas according to the "coordinate frame" convention that assumes the positive rotation direction to be anticlockwise. The signs of these parameters must be inverted for the alternative "position vector" convention.

The transformation should be performed with full rotation matrix. A frequently used alternative formula with an approximated rotation matrix will cause errors of several metres.

2.3 Transformation from DPnet to ITRS

2.3.1 St. Eustatius

Parameters of 3D similarity transformation and their yearly rates from St. Eustatius DPnet to ITRF2014

$t_X = +1276.2485$ m	translation in direction of X axis
$t_Y = -2016.6406$ m	translation in direction of Y axis
$t_Z = +667.4403$ m	translation in direction of Z axis
$\alpha = -489.68745 \cdot 10^{-6}$ rad = -101.005288"	rotation angle around X axis
$\beta = +1032.23330 \cdot 10^{-6}$ rad = +212.913401"	rotation angle around Y axis
$\gamma = -331.77143 \cdot 10^{-6}$ rad = -68.432770"	rotation angle around Z axis
$\delta = -431.59604 \cdot 10^{-6}$	scale difference (dimensionless)
$\dot{t}_X = +0.00743$ m	yearly rate of translation in direction of X axis
$\dot{t}_Y = +0.00875$ m	yearly rate of translation in direction of Y axis
$\dot{t}_Z = +0.01402$ m	yearly rate of translation in direction of Z axis
$\dot{\alpha} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000"	yearly rate of rotation angle around X axis
$\dot{\beta} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000"	yearly rate of rotation angle around Y axis
$\dot{\gamma} = +0.000000 \cdot 10^{-6}$ rad = +0.0000000"	yearly rate of rotation angle around Z axis
$\dot{\delta} = +0.000000 \cdot 10^{-6}$	yearly rate of scale difference (dimensionless)
$t_0 = 2020.00$	reference epoch (years)

NB: The three rotation parameters and their yearly rates ($\alpha, \beta, \gamma, \dot{\alpha}, \dot{\beta}, \dot{\gamma}$) are for use with the formulas according to the “coordinate frame” convention that assumes the positive rotation direction to be anticlockwise. The signs of these parameters must be inverted for the alternative “position vector” convention.

The transformation should be performed with full rotation matrix. A frequently used alternative formula with an approximated rotation matrix will cause errors of several decimetres.

2.3.2 Saba

Parameters of 3D similarity transformation and their yearly rates from Saba DPnet to ITRF2014

$t_X = +1138.7432$ m	translation in direction of X axis
$t_Y = -2064.4761$ m	translation in direction of Y axis
$t_Z = +110.7016$ m	translation in direction of Z axis
$\alpha = -1040.48388 \cdot 10^{-6}$ rad = $-214.615206''$	rotation angle around X axis
$\beta = +2324.00304 \cdot 10^{-6}$ rad = $+479.360036''$	rotation angle around Y axis
$\gamma = -798.50729 \cdot 10^{-6}$ rad = $-164.703951''$	rotation angle around Z axis
$\delta = -402.32073 \cdot 10^{-6}$	scale difference (dimensionless)
$\dot{t}_X = +0.00726$ m	yearly rate of translation in direction of X axis
$\dot{t}_Y = +0.00848$ m	yearly rate of translation in direction of Y axis
$\dot{t}_Z = +0.01353$ m	yearly rate of translation in direction of Z axis
$\dot{\alpha} = +0.000000 \cdot 10^{-6}$ rad = $+0.0000000''$	yearly rate of rotation angle around X axis
$\dot{\beta} = +0.000000 \cdot 10^{-6}$ rad = $+0.0000000''$	yearly rate of rotation angle around Y axis
$\dot{\gamma} = +0.000000 \cdot 10^{-6}$ rad = $+0.0000000''$	yearly rate of rotation angle around Z axis
$\dot{\delta} = +0.000000 \cdot 10^{-6}$	yearly rate of scale difference (dimensionless)
$t_0 = 2020.00$	reference epoch (years)

NB: The three rotation parameters and their yearly rates ($\alpha, \beta, \gamma, \dot{\alpha}, \dot{\beta}, \dot{\gamma}$) are for use with the formulas according to the “coordinate frame” convention that assumes the positive rotation direction to be anticlockwise. The signs of these parameters must be inverted for the alternative “position vector” convention.

The transformation should be performed with full rotation matrix. A frequently used alternative formula with an approximated rotation matrix will cause errors of several metres.

2.4 DPnet

2.4.1 Ellipsoid

Parameters of International 1924 (Hayford) ellipsoid

$a = 6378388$ m	half major (equator) axis of International 1924 ellipsoid
$f = 1/297$	flattening of International 1924 ellipsoid (dimensionless)

NB: This ellipsoid is used for the conversion between geocentric Cartesian coordinates and geographic coordinates as well as for the map projection.

2.4.2 Map projection St. Eustatius

Parameters of Transverse Mercator projection for St. Eustatius DPnet

$\varphi_0 = 0^\circ$	latitude of central point
$\lambda_0 = -63^\circ$	longitude of central meridian
$k = 0.9996$	scale factor (dimensionless)
$x_0 = 500000 \text{ m}$	false Easting
$y_0 = 0 \text{ m}$	false Northing

NB: The International 1924 (Hayford) ellipsoid is used.

The coordinates of the former cadastral map of St. Eustatius have a constant offset of -499421.45 m for the x-coordinate and -1930396.26 m for the y-coordinate.

2.4.3 Map projection Saba

Parameters of Transverse Mercator projection for Saba DPnet

$\varphi_0 = 0^\circ$	latitude of central point
$\lambda_0 = -63^\circ$	longitude of central meridian
$k = 0.9996$	scale factor (dimensionless)
$x_0 = 29973.97 \text{ m}$	false Easting
$y_0 = -1947925.94 \text{ m}$	false Northing

NB: The International 1924 (Hayford) ellipsoid is used.

The coordinates of the former topographic map of Saba have a constant offset of -470026.03 m for the x-coordinate and -1947925.94 m for the y-coordinate.

Appendix 1: Diagrams

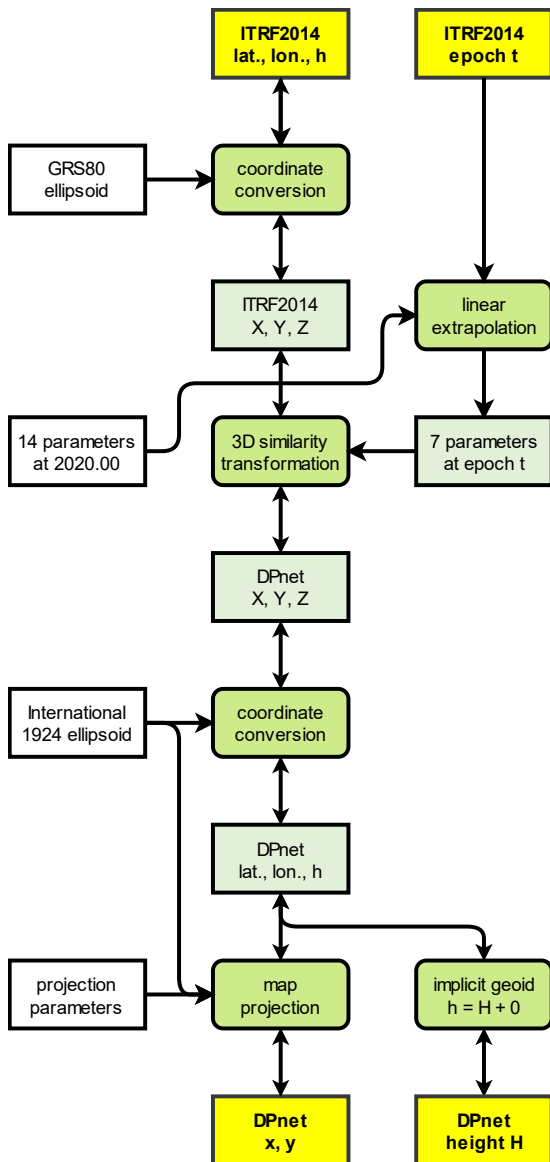


Figure A1.1 Time-dependent 3D transformation procedure.

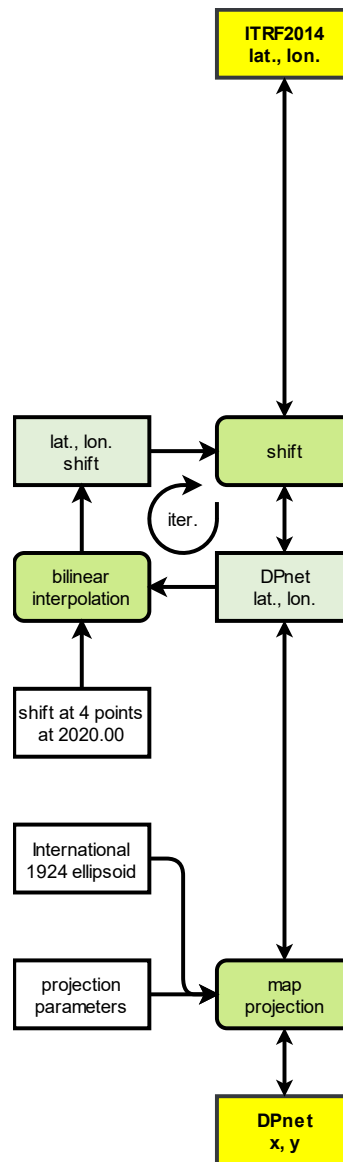


Figure A1.2 Workaround of 2D transformation procedure for fixed epoch 2020.00 (Section A3.2).

Appendix 2: Test points

To test for blunders in an implementation of the transformation the coordinates of the test points below can be used.

Test points for the transformation between ITRF2014 and DPnet

	latitude (°) or x (m)	longitude (°) or y (m)	height (m)	epoch
ITRF2014 at 2020-01-01	17.492677034	-62.980541749	58.1197	2020.00
ITRF2014 at 2022-07-02	17.492677366	-62.980541500	58.1197	2022.50
St. Eustatius DPnet	502000.0000	1934000.0000	100.0000	any
St. Eustatius former cadastral map coordinates	2578.5500	3603.7400	100.0000	any

	latitude (°) or x (m)	longitude (°) or y (m)	height (m)	epoch
ITRF2014 at 2020-01-01	17.627494963	-63.234771976	257.5641	2020.00
ITRF2014 at 2022-07-02	17.627495284	-63.234771733	257.5641	2022.50
Saba DPnet	5000.0000	1000.0000	300.0000	any
Saba former topographic map coordinates	475026.0300	1948925.9400	300.0000	any

Appendix 3: Implementation using open source library PROJ

The recommended open source library is PROJ version 7 or newer. Commands for the cct program of PROJ are given. A workaround for a PROJ.4-style string is provided too.

A3.1 3D transformation with PROJ pipeline

A3.1.1 St. Eustatius

ITRS coordinates can be transformed to DPnet with the commands below. Since the transformation is time-dependent, the recommended epoch is specified with the option `-t` (otherwise the epoch should be added to each input point as a fourth coordinate).

From ITRF2014 at epoch 2020.00 to DPnet of St. Eustatius

```
cct -I -t 2020.00 -o output.txt +proj=pipeline +step +proj=utm +inv +zone=20 +ellps=intl +step
+proj=cart +ellps=intl +step +proj=helmert +x=1276.2485 +y=-2016.6406 +z=667.4403 +rx=-101.005288
+ry=212.913401 +rz=-68.432770 +s=-431.59604 +dx=0.00743 +dy=0.00875 +dz=0.01402 +t_epoch=2020.00
+convention=coordinate_frame +exact +step +proj=cart +inv +ellps=GRS80 +step +proj=axiswap
+order=2,1 input.txt
```

The For the inverse transformation from DPnet to ITRS, the option `-I` should be omitted.

From DPnet of St. Eustatius to coordinates of former cadastral map of St. Eustatius

```
cct -I -o output.txt +proj=affine +xoff=499421.4500 +yoff=1930396.2600 input.txt
```

The For the inverse transformation from coordinates of the former cadastral map to DPnet, the option `-I` should be omitted.

A3.1.2 Saba

ITRS coordinates can be transformed to DPnet with the commands below. Since the transformation is time-dependent, the recommended epoch is specified with the option `-t` (otherwise the epoch should be added to each input point as a fourth coordinate).

From ITRF2014 at epoch 2020.00 to DPnet of Saba

```
cct -I -t 2020.00 -o output.txt +proj=pipeline +step +proj=tmerc +inv +lat_0=0 +lon_0=-63
+k_0=0.9996 +x_0=29973.97 +y_0=-1947925.94 +ellps=intl +step +proj=cart +ellps=intl +step
+proj=helmert +x=1138.7432 +y=-2064.4761 +z=110.7016 +rx=-214.615206 +ry=479.360036 +rz=-
164.703951 +s=-402.32073 +dx=0.00726 +dy=0.00848 +dz=0.01353 +t_epoch=2020.00
+convention=coordinate_frame +exact +step +proj=cart +inv +ellps=GRS80 +step +proj=axiswap
+order=2,1 input.txt
```

The For the inverse transformation from DPnet to ITRS, the option `-I` should be omitted.

From DPnet to coordinates of former topographic map of Saba

```
cct -I -o output.txt +proj=affine +xoff=-470026.0300 +yoff=-1947925.9400 input.txt
```

The For the inverse transformation from coordinates of the former topographic map to DPnet, the option -I should be omitted.

A3.2 2D workaround with PROJ4-style string

A PROJ4-style string with a 3D similarity transformation (+towgs84 option) can not be used, because it uses approximate formulas of a 3D Helmert transformation that give an error of several metres due to the exceptionally large rotation angles. As a workaround, a grid shift file can be used. Grids in the NTV2 file format (.gsb) are provided with this document. These provide an 2D approximation of the transformation at fixed epoch 2020.00 with similar precision as the transformation with exact formulas. The difference is typically 0.02 m, except at the upper part of Mount Scenery at Saba.

A3.2.1 St. Eustatius

ITRS coordinates can be transformed to DPnet with the commands below. Since this workaround does not take into account that the transformation is time-dependent, it is only valid at the recommended epoch 2020.00. Note that the grid shift files (.gsb) must be available in the appropriate directory.

From ITRF2014 at fixed epoch 2020.00 to DPnet of St. Eustatius

```
+proj=utm +zone=20 +ellps=intl +nadgrids=seutrans2020.gsb +type=crs
```

The For the inverse transformation from DPnet to ITRS, the option -I should be omitted.

A3.2.2 Saba

ITRS coordinates can be transformed to DPnet with the commands below. Since this workaround does not take into account that the transformation is time-dependent, it is only valid at the recommended epoch 2020.00. Note that the grid shift files (.gsb) must be available in the appropriate directory.

From ITRF2014 at fixed epoch 2020.00 to DPnet of Saba

```
+proj=tmerc +lat_0=0 +lon_0=-63 +k=0.9996 +x_0=29973.97 +y_0=-1947925.94 +ellps=intl  
+nadgrids=sabtrans2020.gsb +type=crs
```