Influence of network geometry on densification on the Faroe Islands 2011

Shfaqat Abbas Khan[1], Mette Weber [2], Karsten Enggaard Engsager[1,2], and Per Knudsen[1]

[1]Department of Geodesy, National Space Institute (DTU-Space), Technical University of Denmark, Copenhagen, Denmark.
[2]National Survey and Cadastre (KMS), Denmark.

Abstract. The National Survey and Cadastre in Denmark (Kort & Matrikelstyrelsen; KMS) is responsible for the definition of the national referencesystem on the Faroe Islands. In 2008 KMS and the Environmental Agency on the Faroe Island (Umhvørvisstovan; US) decided to define a new national reference system on the Faroe Islands. This new reference system consists of a GPS based reference frame and a height reference frame based on levelling. Furthermore, a geoid model and a map projection are determined. The geoid model is determined by the National Space Institute at the Technical University of Denmark (DTU Space).

The reference system on the Faroe Islands is based on ETRS89, which is realized through GPS observations at four points. Since the Faroe Islands (FO) are located at the northwestern corner of the EUREF network (figure 1 & 2), we study the influence of network geometry on densification on the Faroe Islands.

Keywords. GPS, network solutions,

1. Introduction

The realization of ETRS89 on the Faroe Islands (FO) is based on GPS data collected during the NKG campaign in September/October 2008. The points used for the EUREF densification project is the 4 manually observed fix points in Torshavn (TORH), Klaksvik (KLAK), Sørvagur (SORV) and Tvøroyri (TVOR). The stations are observed by KMS for 7 full days from September 29 to October 4, 2008 (DOY 272 to 278). The station location is shown in Figure 1.

Besides data from the four FO stations, data is also collected from EPN stations shown in Figure 2 and 3. These stations are used as fiducial stations. Data is available for all fiducial stations from DOY 272 to 278, and the stations fulfil the criteria in section 3.2 in the “Guidelines for EUREF Densifications” [Bruyninx et al., 2010].

To study impact of network geometry on coordinate estimation at FO, we perform two tests using different fiducial stations and different geometry. The first test (test #1) involves 10 fiducial stations all located south or east to FO (see fig 2, top). For the second test (test #2) we use 5 fiducial stations located all around FO (see fig 2, bottom).

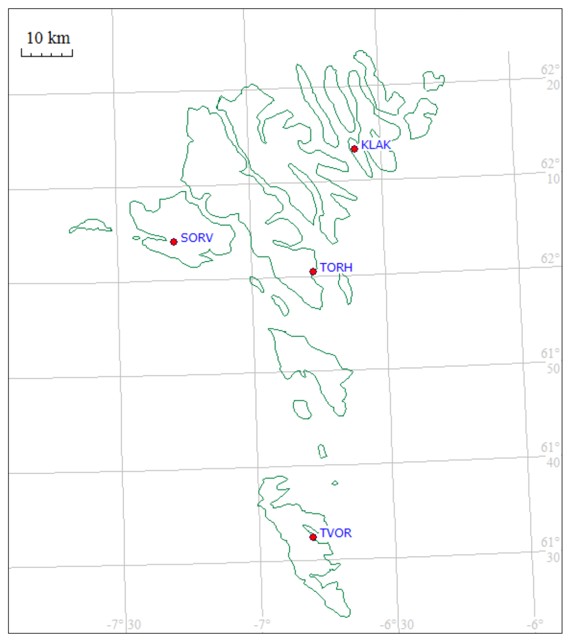

Figure 1. Densification stations at the Faroe Islands (FO)

2. Data processing

Processing software was the Bernese GPS Software Version 5.0 (BSW). The baseline processing strategy was broadly similar to the one recommended for double difference processing in the BSW manual [Dach et al., 2007]. Only GPS data were used in the processing.

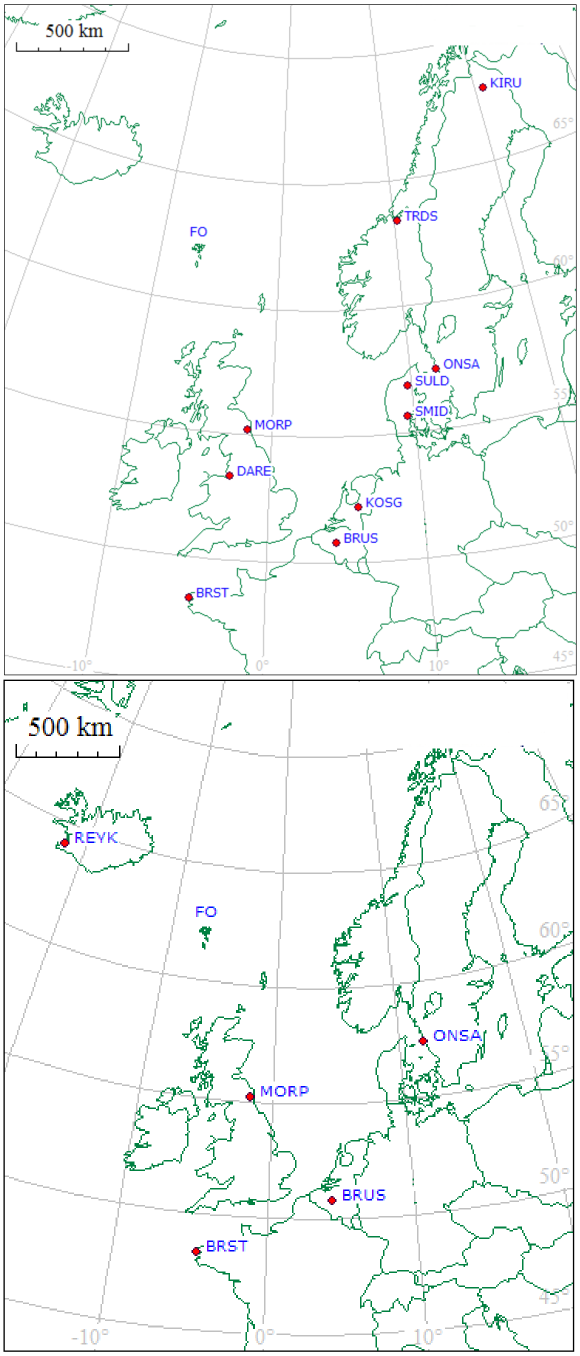

Figure 2. IGS/EPN fiducial stations used in test #1 (top) and test #2(bottom)

Most of the text in this section is also given in the EUREF IE/UK 2009 Final report [Greaves, 2010].

2.1. External data

All external data files used in the processing are listed in Table 1 below.

Products	Source
ITRF2005 coordinates	ftp://ftp.epncb.oma.be/pub/station/coord/EPN/
Ocean tide loading parameters	http://www.oso.chalmers.se/~loading/, model FES2004, no correction for the motion of the centre of mass of the solid Earth.
Antenna phase centre offsets	ftp://ftp.epncb.oma.be/pub/station/general/epn_05.atx
Differential clock biases	ftp://ftp.unibe.ch/aiub/CODE/yyyy/, P1C1yymm.DCB & P1P2yymm.DCB files.
Ionosphere maps	ftp://ftp.unibe.ch/aiub/CODE/yyyy/, CODwwwwd.ION files
Final, precise GPS orbits	ftp://cddis.gsfc.nasa.gov/gps/product/wwww/, igswwwwd.sp3 files
Satellite clocks	ftp://cddis.gsfc.nasa.gov/gps/product/wwww/, igswwwwd.clk_30s files
Earth rotation parameters	ftp://cddis.gsfc.nasa.gov/gps/product/wwww/, igswwwwd.erp files

Table 1: External data products used in the processing

2.2. Reference frame coordinates

The ITRF2005 epoch 2005.0 coordinates of the fiducial stations and their corresponding velocities were extracted from the file EPN_A_ITRF2005_C1600.SSC. The coordinates and velocities are shown in Table 2.

Station ID	X (m)	Vx (m/yr)	Y (m)	Vy (m/yr)	Z (m)	Vz (m/yr)
TRDS	2820170.8250	(-0.0139)	513486.0510	(0.0113)	5678935.9490	(0.0120)
MORP	3645667.8410	(-0.0112)	-107277.2370	(0.0159)	5215053.5300	(0.0111)
DARE	3811965.3550	(-0.0111)	-175799.8330	(0.0164)	5093615.7090	(0.0112)
SULD	3446394.2080	(-0.0134)	591713.1480	(0.0143)	5316383.4610	(0.0104)
SMID	3557911.2310	(-0.0141)	599176.6820	(0.0149)	5242066.4500	(0.0103)
KOSG	3899225.1350	(-0.0138)	396731.9400	(0.0162)	5015078.4290	(0.0106)
ONSA	3370658.5450	(-0.0129)	711877.1390	(0.0144)	5349786.9540	(0.0120)
BRUS	4027893.7510	(-0.0128)	307045.8250	(0.0163)	4919475.1220	(0.0112)
BRST	4231162.5840	(-0.0116)	-332746.6800	(0.0171)	4745130.9270	(0.0111)
KIRU	2251420.7990	(-0.0157)	862817.2210	(0.0104)	5885476.7160	(0.0129)
REYK	2587384.4150	(-0.0216)	-1043033.5090	(-0.0028)	5716564.0030	(0.0059)

Table 2: ITRF2005 epoch 2005.0 coordinates and velocities of fiducial stations

2.3. Antenna calibrations and ocean tide loading

Absolute antenna calibrations were used throughout the processing. The epn_05.atx file was used as a template to create a custom antenna calibration file for the campaign.

Ocean tide loading parameters used throughout the processing were obtained from http://www.oso.chalmers.se/~loading/, using model FES2004 with no correction for the motion of the centre of mass of the solid Earth. Station coordinates used for the ocean tide loading parameter computation came from an initial precise point positioning (PPP) run through one whole day of data for all stations.

2.4. Daily processing strategy

The scripts used for the daily processing are listed in Table 3. Further details on key aspects of the processing are given in the following sections. An elevation cut off angle of 3 degrees and cos*z* elevation dependent weighting was used throughout the processing.

1	GET_IGS	This script copies the needed files into the respective campaign directory. Control that a certain set of files are present.
2	POLUPD	Create BSW ERP format file from precise IGS ERP file
3	PRETAB	Create tabular orbit file using files from steps 1 and 2 as input. Also save satellite clocks.
4	ORBGEN	The program integrates the equation of motion using the positions given in the tabular orbit file to produce Bernese standard orbit file used in all processing programs needing orbit information.
5	CCRNXC	This program converts clock RINEX files into a Bernese satellite clock file (extension CLK). The file resides in the campaign´s ORB directory.
6	RNXSMTAP	This script and the following form a unit. The purpose is to clean data on the RINEX level. This script prepares the parallelization, the actual processing is done in the next PID. The next PID is RNXSMT_P who clean and smooth RINEX files.
7	SMTBV3	Calls RXOBV3 who import smoothed RINEX files into BSW format. Export coordinates for use as a priori values.
8	CODSPP	Station by station single point positioning from code observations using precise SV clocks from step 5. Coordinate results used to update a priori coordinate values. Receiver clock estimates saved in observation files.
9	GPSEST	Station by station zero difference processing using precise IGS orbits (step 1), ERPs (step 2), clocks (step 5) and a priori coordinates from step 8. Save coordinates, residuals and normal equations.
10	RESRMS & SATMRK	Screen and mark high residuals from previous GPSEST run
11	GPSEST	Same as step 9 but use screened observation files from step 10 and a priori coordinates from step 9.

12	ADDNEQ2	Combine individual station normal equations and a priori coordinates from step 11. Output final PPP coordinates and daily PPP normal equations
13	CRDMERGE	Create new a priori coordinate file for double difference processing using final PPP coordinates from step 12.
14	SNGDIF	Create phase single difference observation files using the OBSMAX strategy.
15	MAUPRP_P	Observation pre processing. Filter out observations: • Lower than 3º elevation; • Unpaired (L1 but no L2 or vice versa); • In "small pieces" (<301 seconds, gap between continuous obs <61seconds). Identify data with no cycle slips and in remaining data find and if possible repair cycle slips.
16	GPSEST	Baseline by baseline ambiguity free solution. Troposphere parameters estimated. Residuals (normalised) and normal equations saved.
17	RESRMS & SATMRK	Screen and mark high residuals from previous GPSEST run.
18	GPSEST	Same as step 16 but use screened observation files from step 17.
19	ADDNEQ2	Combine individual baseline normal equations from step 18. Output coordinates and troposphere parameters.
20	GPSQIFAP	Prepare the parallel execution of the ambiguity resolution step. Program BASLST is used to select baselines up to a maximum length of 2000 km.
21	GPSQIF_P	One GPEST is started for each baseline to be processed. Baseline by baseline ambiguity resolution using the QIF algorithm.
22	GPSEST	Final free network processing of all baselines in a single run. Coordinates and normal equations saved.
23	ADDNEQ2	Based on the normal equations from the previous GPEST run, a final solution is computed.
24	HELMR1	Helmert transformation of coordinates from step 22 to coordinates of EPN A fiducial stations to check for problems at fiducial stations.

Table 3. List of scripts for the daily processing strategy

2.5. Troposphere and ionosphere strategy

A simple troposphere strategy was applied in programs CODSPP and MAUPRP. CODSPP used the Saastamoinen model and MAUPRP

used Niell (combined wet and dry) zenith path delay model and mapping function.

In the ambiguity free and ambiguity resolution GPSEST runs the Dry Niell a priori model was used plus the estimation of zenith path delay Wet Niell parameters every hour with a 5 m a priori weight for the absolute and relative parameters.

For the final GPSEST runs for PPP and double difference processing a Dry Niell a priori model was used plus the estimation of zenith path delay Wet Niell parameters every hour. Horizontal gradient parameters with a tilting model were also computed every 24 hours. A 5 m a priori weight for the absolute and relative parameters was used.

The ionosphere free L3 combination was used throughout the processing to remove the effects of the ionosphere. The exception to this was at the QIF ambiguity resolution stage when the L1+L2 observable was used and an a priori ionosphere model introduced.

2.6. Ambiguity resolution

The a priori coordinates for the ambiguity resolution processing were introduced from the previous ambiguity free stage and the CODwwwwd.ION model was introduced so ionosphere parameters were not estimated.

2.7. Daily free network solution processing

The final daily free network solutions were produced by processing all baselines in a single GPSEST run (step 22). A priori coordinates from the ambiguity free processing were introduced. The "CORRECT" correlation strategy was used to ensure the statistically correct modeling of correlations between all baselines. The sampling interval was 180 seconds. The troposphere and ionosphere strategy was as described in the section above. The previously resolved ambiguities were introduced as known integer values. Normal equations were saved for later use in the final combined solution.

The EPN A fiducial station coordinates from this solution were transformed to their “correct” coordinates from the ‘EPN_A_ITRF2005_C1600.SSC’ file.

2.8. Final combined network solution

An a priori coordinate file was produced that contained the “correct” coordinates of the fiducial EPN A stations from the ‘EPN_A_ITRF2005_C1600.SSC’ file. Translation as minimal constraint on the fiducial stations was used for datum definition in the combined solution.

The daily solutions were combined using program ADDNEQ2 and the daily coordinate repeatabilities, compared to the combined solution, were analysed for outliers. Outliers for individual, daily repeatabilities were set at the BSW defaults of 10 mm for N and E and 20 mm for U.

To produce the final campaign solution the daily network solutions were combined using program ADDNEQ2.

3. Results

3.1. Results of Test 1

The computed ITRF2005 epoch 2008.7514 (2008, day 275) coordinates for the stations on the Faroe Islands are listed in table 4. These results are obtained by using 10 fiducial sites.

Station	X [m]	Y[m]	Z[m]
KLAK	2960777.7973	-342299.5774	5620225.5716
SORV	2971444.8959	-379959.1922	5612156.0081
TORH	2980573.3540	-353744.2849	5608957.1107
TVOR	3026017.0842	-360951.8324	5584332.3819

Table 4. ITRF2005 epoch 2008.7514 coordinates for the stations on the Faroe Islands

3.2. Results of Test 2

We process the data using the exact same procedure for both test 1 and test 2. The only difference is number of fiducial sites and their location. The computed ITRF2005 epoch 2008.7514 coordinates for the stations on the Faroe Islands obtained by using 5 fiducial sites are listed in table 5.

Site	X[m]	Y[m]	Z[m]
KLAK	2960777.7938	-342299.5759	5620225.5647
SORV	2971444.8914	-379959.1895	5612156.0046
TORH	2980573.3504	-353744.2818	5608957.1081
TVOR	3026017.0824	-360951.8291	5584332.3833

Table 5. ITRF2005 epoch 2008.7514 coordinates for the stations on the Faroe Islands

3.3. Difference between using 5 or 10 fiducial stations

The difference in final ETRF2000 coordinates between using 5 fiducial stations and 10 fiducial stations (as shown in figure 2) is listed in table 6. (Thus, table 6 displays the difference between table 4 and table 5).

Station	X[m]	Y[m]	Z[m]
KLAK	-0.0035	0.0015	-0.0069
SORV	-0.0045	0.0027	-0.0035
TORH	-0.0036	0.0031	-0.0026
TVOR	-0.0018	0.0033	0.0014

Table 6. Difference in XYZ between using 5 and 10 stations.

Station	N[m]	E[m]	U[m]
KLAK	0.0000	0.0011	-0.0078
SORV	0.0026	0.0022	-0.0053
TORH	0.0023	0.0026	-0.0042
TVOR	0.0026	0.0031	0.0002

Table 7. Difference in NEU between using 5 and 10 stations.

4. Conclusions

Bernese Software 5.0 was used for the data processing of the ETRS89 densification campaign on the Faroe Islands. Respectively, 10 and 5 IGS sites were used as fiducial stations for the calculation of ITRF2005 epoch 2008.7514 coordinates for four local sites.

We note that the difference between using 5 and 10 fiducial station is up to 3.1 mm for the horizontal coordinates and 7.8 mm for the vertical coordinates.

The relative small difference between the two solutions may be caused by e.g. atmosphere loading, co-seismic displacement at REYK, which has not been taken into account in the data processing.

5. References

Boucher, C., Altamimi, Z. (2008), Memo: Specifications for reference frame fixing in the analysis of a EUREF GPS campaign, Version 7 : 24-10-2008, http://etrs89.ensg.ign.fr/memo-V7.pdf.

Bruyninx, C., Altamimi, Z., Caporali, A., Kenyeres, A., Lidberg, M., Stangl, G., Torres, G. A. (2009), Guidelines for EUREF Densifications, Version 2: 04-05-2010, ftp://epncb.oma.be/pub/general/Guidelines_for_EUREF_Densifications.pdf.

Dach, R., Hugentobler, U., Fridez, P., Meindl, M. (eds) (2007), Bernese GPS Software Version 5.0, Astronomical Institute of the University of Bern, Switzerland.

Greaves, M. (2010), EUREF IE/UK 2009, Final report on the processing and analysis of the EUREF IE/UK 2009 campaign.

Khan, Shfaqat Abbas, Mette Weber and Karsten Enggaard Engsager (2011), EUREF densification 2008 Faroe Island, EUREF Permanent Network, Moldova 2011.