EUREF Regional Densification of ITRF2005

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- Draft -

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0 Introduction

A cumulative solution will be calculated from all available weekly EPN solutions to realise a European densification of ITRF2005. A strategy for such multiyear combination will be developed, which includes all necessary operation steps and the parameter setup. Special attention must be paid to the datum definition. The results will be submitted to an ITRS Combination Centre of the IERS to integrate the new solution in the global ITRF realisation. Comparisons with other EPN cumulative solutions are welcome.

1 ITRF2005 Densification

The global ITRF2005 solution has been released in 2006 and serves now as reference for a regional densification in Europe by using the weekly EPN solutions. The EPN applies GNSS technology, which is one technique contributing to ITRF. The Internation GNSS Service (IGS) generated a global GNSS solution and submitted it to the ITRF Combination Centres as ITRF2005 contribution. The cumulative EPN solution needs to be consistent with the mentioned IGS contribution with respect to the definition of station inconsistencies. Station inconsistencies may be caused by equipment changes or by events affecting the station marker. Significant station inconsistencies are typically handled by defining a new sub-station. All sub-stations are identified by the so-called “solution numbers” and separate coordinates and velocities are solved for them. The solution numbers of the IGS stations, which belong to the EPN, has similarly to be set in the cumulative EPN solution. Also the time span of observations considered in the multiyear solution has to be identical in the IGS and EPN solution and goes until end of 2005. According these requirements the EPN weekly solutions from the GPS weeks 860 to 1355 will be combined. All processing steps of this work will be carried out with the Bernese GPS Software Version 5.0, release December 15, 2006. The IERS is asked to compare the results with quantities from the EPN Time Series special project that runs the CATREF software.

2 Multiyear EPN Solution Strategy

The weekly EPN combined SINEX files of the weeks 860 to 1355 have been converted to normal equations (NEQs) in the first step. A total number of 496 NEQs have been combined with the ADDNEQ2 programme, where station coordintates and velocities of all stations and corresponding solution numbers have been estimated. No other parameter types have been solved for. The definition of solution numbers to account for station inconsistencies, the outlier rejection criteria and the datum definition of the combination will be explained in the following sections.

2.1 Processing Steps

The processing was performed in three analysis Steps that are shown in Figure 1.

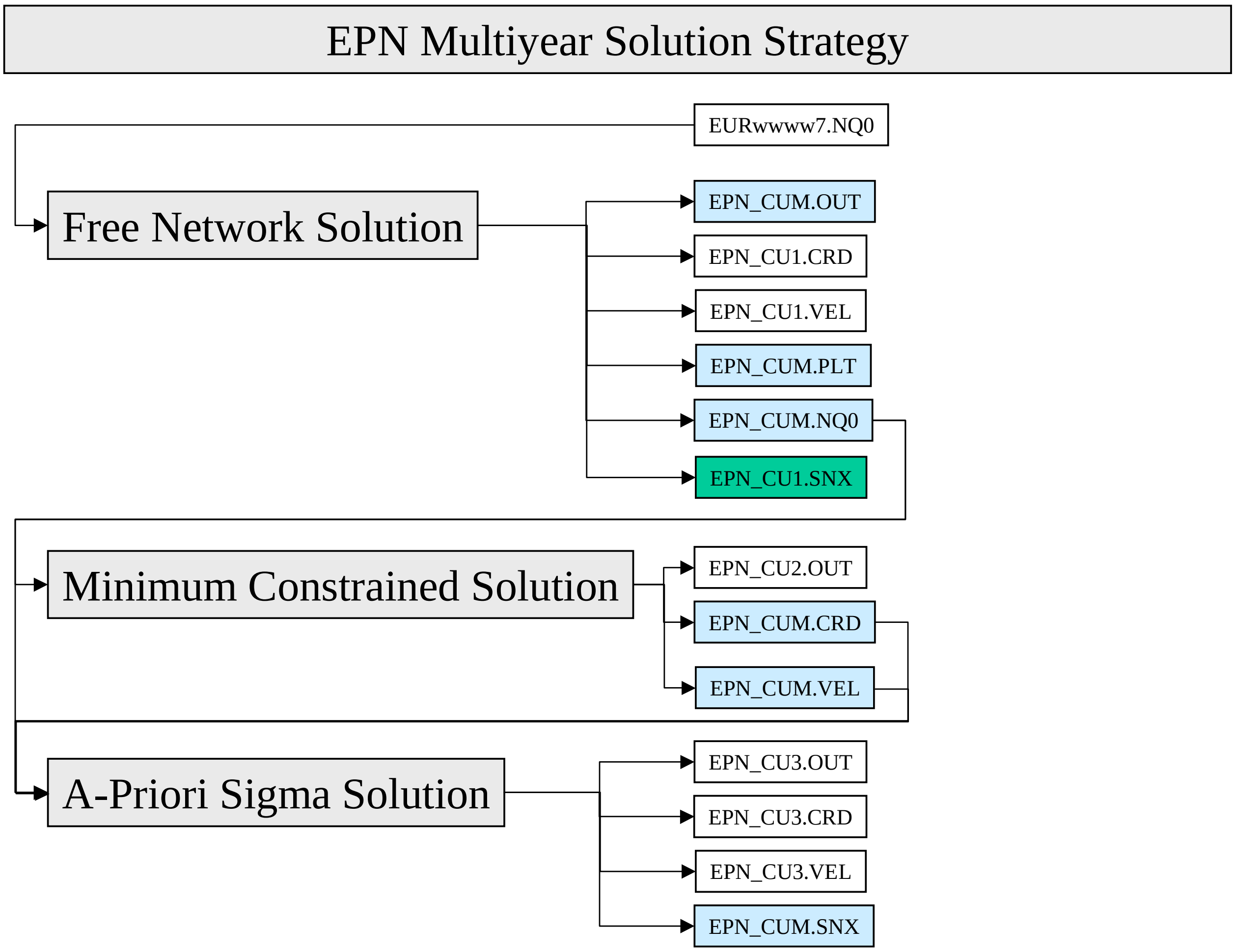


Figure 1: Processing Steps of Multiyear Combination

First test runs discovered a long processing time (up to 4 hours) if we apply minimum constraint conditions during the stacking procedure of the 496 NEQs. To get rid of such inconvenience we compute a free network solution in the first step and store the resulting NEQ file (EPN_CUM.NEQ). Even if we don't define any constraint, the NEQ system becomes regular, because of some minor regularisations evoked by, e.g., fixed satellite orbits. This step provides weekly residuals for all stations in the EPN_CUM.PLT file and we save the EPN_CU1.SNX SINEX file for test purposes.

Minimum constraint conditions (MCCs) are applied to the coordinates and velocities of a selected number of reference stations in the second step. This is our intended datum definition strategy and the resulting coordinates and velocities are saved to become our final results (EPN_CUM.CRD/VEL). It might be difficult to remove such defined constraints from a SINEX file for subsequent analysis steps. Therefore we run a separate step to create the combined SINEX file.

The third step introduces the station coordinates and velocities of the second step as a-priori numbers and applies a constraint of 0.1 mm for all parameters. The processing result is saved as SINEX file. The SINEX file includes exactly the same coordinate and velocity values as found in step 2. But now we could reliably convert the SINEX file back to NEQs if requested.

2.2 Station Inconsistencies

The station inconsistencies (also named "offsets") are defined in accordance to the IGS contribution to ITRF2005 in the first preference. In the second preference we used the offsets according to the EPN Time Series Special Project (SP). Additional offsets has been introduced during the EPN multiyear analysis procedure as far as required in the data screening and as far to fulfil some requirements of the Bernese Software ADDNEQ2 programme, e.g., "dummy" solution for first epoch, if station starts in the middle of the covered time period. For outlier definition we checked first the EPN multiyear solution residuals and as second preference the EPN Time Series SP settings. EPN stations belonging to ITRF2005 where flagged "I" and the remaining stations "E". The corresponding schema is shown in Figure 2.

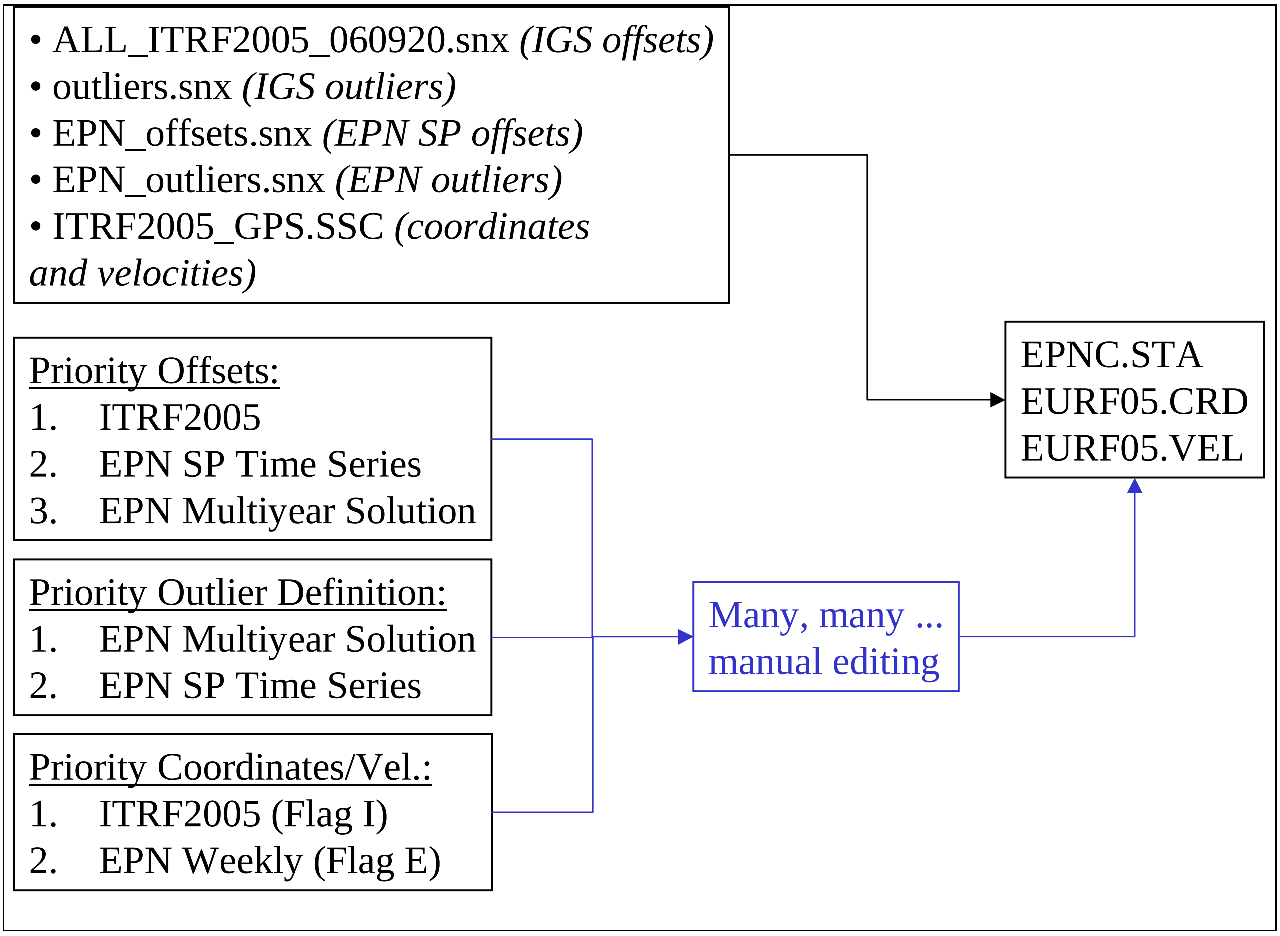


Figure 2: Definition of Offsets and Outliers

2.3 ADDNEQ2 Features

Some features of the ADDNEQ2 programme became significant for the combination procedure. If the (pseudo) observation of the first epoch of the station time series in not available, e.g., it is marked, then you have to setup to new solution number for the period from the first epoch until the epoch of the first available observation. There will be no coordinate estimation for this solution number. You have to proceed for a missing observation of the last epoch accordingly.

We had to specify the option "Truncate all NEQ station names after position 14" in the input Menu 3.2 of the ADDNEQ2 programme to disable the historic definition of sub-stations.

The change of the DOMES number for a 4-char abbreviation of a station leads to a change of the “point number (PT) to B, C, …” in the resulting SINEX file

If we write a one digit number between the 4-char abbreviation and the DOMES number of a station in the Bernese coordinate file, this number will be used to define the “solution number” in the resulting SINEX file. This is the way as we introduced the solution numbers into the analysis.

3 Data Analysis

Some important steps in the analysis by usage of Bernese Software Version 5.0 are specified in the following.

3.1 Project Setup

The Process Control File (PCF) “EPN_CUM.PCF” controls the Bernese Processing Enging (BPE) to perform all analysis steps. The Process Control Scripts (PCSs), which are started by the PCF, are given in Table 1.

PCS	Analysis Steps
EPNC_COP	Copy NQ0-files from sub-directory EPN/SAVC to EPN/SOL (first and last week of files to be copied are defined as parameter in the PCF-file)
ADDNEQ2C	Combination of NEQs according EPN_**CUF** option directory
ADDNEQ2C	Combination of NEQs according EPN_**CUM** option directory
ADDNEQ2C	Combination of NEQs according EPN_**CUW** option directory
EPNC_SAV	Copy result files to sub-directory EPN/CUM (a file name extension for the solution series is defined as parameter in the PCF-File)
EPNC_DEL	Clean sub-directories /STA, /SOL and /OUT

Table 1: Control File for Bernese Processing Engine

3.2 General Files

A couple of general files have to be defined for running Bernese GPS Software. Such information files are summarized in Table 2.

Dateiname	Typ	Status
$E/EPN/STA:		
EPNC.STA	station information file	applied to ADDNEQ2C PCS
/discontinuities: ALL_ITRF2005_060920.SNX outliers.snx EPN_offsets.txt EPN_outliers.txt	textfile	basic information for EPNC.STA
ITRF2005_GPS.SSC		ITRF2005 coordinates and velocities
EURF05.CRD	coordinates file	a-priori
EURF05.VEL	velocity file	a-priori
REF_STAC.FIX	station selection file	list of reference stations

Table 2: General Input Information Files for Processing

3.3 Datum Definition

It is the goal to define the datum through so-called „Minimum Constraint Conditions (MCC)“, which will be applied to a carefully selected set of ITRF2005 stations as a subset of the EPN. We observed arithmetic instability from the ADDNEQ2 program, if we apply the MCC and store both, NEQs and SINEX files, from that program run. It may also become difficult for analysis software others than Bernese GPS Software to remove the MCC form such generated SINEX files in subsequent processing. To get rid of that problem we chose a two-step approach.

Step 1: The datum is defined according the MCC and the resulting station coordinates and velocities are saved.

Step 2: The coordinates and velocities as saved from step 1 are now constrained by 0.1 mm a-priori sigma in a second ADDNEQ2 run. Results are stored in SINEX format.

The coordinates and velocities as stored in the SINEX file are equivalent to results from a MCC approach and the constraints of 0.1 mm to all stations could easily be removed during a conversion of the SINEX file back to NEQ for further analysis.

3.4 Contributing NEQ Files

Weekly NQ0-files have been saved during the routine processing since the beginning of the EPN permanent tracking and processing. There exists more than 1 solution for each station coordinate in such NQ0-files, because of the redundancy from the combination of 16 sub-network solutions. It is important for the multiyear solution to convert the weekly SINEX files in the first step into NQ0-files, which will include exact one coordinate solution for every station.

3.5 Referenz Station Selection and Validation

The selection of ITRF2005 stations as reference requires a careful check. Not all ITRF2005 station coordinates are as good determined to allow for contribution to the datum definition. Not all ITRF2005 station coordinates of the EPN may result with high precision from the EPN multiyear combination. The ITRF2005 is a combination of all geodetic space techniques and considers local ties of collocated sites, but EPN refers purely on GPS observations. The situation becomes even more complicated, if we define a set of solution numbers for one particular stations, as it has been performed for ITRF2005 and for the EPN multiyear solution.

Table 3 shows a list of all ITRF2005 stations, which belong to the EPN for the period covered here. The number of solutions as defined for ITRF2005 and EPN are given. The residuals of the free network solution (without selection of any reference site) have been inspected to select the reference stations for the initial analysis step. The final selection have been identified after two iterations and in-between residual checking.

ITRF2005 Stations of EPN	# Solution Numbers		Selected for Reference	
	ITRF2005[1]	EPN	initial[2]	final
AMMN 22201M001	1	1	–[3]	–
ANKR 20805M002	4	4	4	1(4)

[1] Reference File ITRF2005_GPS.SSC, number of provided coordinate/velocity solutions (total number of substations in brackets)
[2] Number of selected solutions (particular solution numbers in brackets)
[3] No solution for that stations in EPN multiyear solution combination available

ITRF2005 Stations of EPN	**# Solution Numbers**		**Selected for Reference**	
	ITRF2005[1]	**EPN**	**initial[2]**	**final**
BOGO 11502M002	1	***2***	–[4]	–
BOR1 12205M002	2	2	–[4]	–
BRST 10004M004	1	1	–[4]	–
BRUS 13101M004	2	2	2	2
BUCU 11401M001	2	2	2	2
CAGL 12725M003	3	3	3	3
CAGZ 12725M004	1	1	1	–
CASC 13909S001	2	2	2	1(1)
DRAG 20710S001	1	1	–[4]	–
GENO 12712M002	1	1	1	1
GLSV 12356M001	1	1	1	1
GOPE 11502M002	2(of 6)	***5***	2(1,5)	2(1,5)
GRAS 10002M006	3	3	–	–
GRAZ 11001M002	4	4	4	2 (1,2)
HERS 13212M007	3(of 4)	4	1(4)	1(4)
HERT 13212M010	1	1	–[4]	–
HFLK 11006S003	1	1	–[4]	–
HOFN 10204M002	2	2	2	2
IENG 12724S001	1	1	1	–
JOZ2 12204M002	1	1	1	1
JOZE 12204M001	2	***3***	–[4]	–
KELY 43005M001	1	***2***[5]	–[4]	–
KIRU 10403M002	1	1	–[3]	–
KOSG 13504M003	2	2	2	2
LAMA 12209M001	2(of 3)	***4***	–[4]	–
LAMP 12706M002	1	1	1	1
LPAL 81701M001	1	1	–[4]	–
LROC 10023M001	1	1	1	1
MADR 13407S012	8 (of 9)	***9***	–[4]	–
MATE 12734M008	4	4	1 (4)	1 (4)
MDVO 12309M002	4	***5***	–[4]	–
MEDI 12711M003	2	2	2	2
METS 10503S011	1	1	1	1
MORP113299S001	1	1	–[4]	–
NICO 14302M001	2	2	–[4]	–
NOT1 12717M004	1	1	–[4]	–
NOTO 12711M003	2	2	–[4]	–
NPLD 13234M003	2	2	2	1(1)
NSSP 12312M001	1	1	–[4]	–
NYAL 10317M003	3	3	–[3]	–
NYA1 10317M003	2	2	2	1 (2)
OBE2 14208M003	2	2	2	2
OBER 14208M001	1	1	1	1
ONSA 10402M004	3	3	3	1(3)
PADO 12750S001	1	1	1	1
PDEL 31906M004	1	1	–[4]	–

[4] Quality of ITRF2005 or EPN solution not suitable to be used as reference station
[5] 43005M002 of ITRF2005 represented in EPN by solution number 2 of 43005M001

ITRF2005 Stations of EPN	# Solution Numbers		Selected for Reference	
	ITRF2005[1]	EPN	initial[2]	final
PENC 11206M006	2	2	2	2
POLV 12336M001	1	1	1	1
POTS 14106M003	1	1	1	1
PTBB 14234M001	3	3	3	1(1)
QAQ1 43007M001	3	3	–[4]	–
RABT 35001M002	1	1	–[4]	–
RAMO 20703S001	3	3	–[4]	–
REDU 13102M001	1	1	–[4]	–
REYK 10202M001	3	3	–[4]	–
SFER 13402M004	4(of 5)	***5***	4(2,3,4,5)	1(3)
SJDV 10090M001	2	2	1(2)	1(2)
SPT0 10425M001	1	1	1	1
THU1 43001M001	2	2	1(1)	1(1)
THU3 43001M002	1	1	1	1
TLSE 10003M009	1	1	1	1
TOUL 10003M004	1	1	1	1
TRAB 20808M001	1	1	1	1
TROM 10302M003	1	1	–[3]	–
TRO1 10302M006	4	4	4	2(2,3)
UPAD 12750M002	2	2	1(2)	1(2)
UZHL 12301M001	1	1	1	1
VENE 12741M001	2(of 6)	***6***	–[4]	–
VILL 13406M001	4(of 5)	5	3(2,3,4)	2(3,4)
WSRT 13506M005	1	1	1	1
WTZR 14201M010	3	3	1(3)	1(3)
YEBE 13420M001	1	1	1	1
ZECK 12351M001	2	2	–[4]	–
ZIMM 14001M004	2	2	2	1(2)
ZWEN 12330M001	4	***5***	–[4]	–

Table 3: Reference Station Selection for EPN Multiyear Combination

Validation of Reference Stations

The initial selection of reference stations is validated through a comparison of the resulting coordinates from the free network solution and the minimum constraint solution against the ITRF2005 values. It has to be validated that there occur no significant large residuals from the Helmert transformation for the selected reference stations. This check confirms that the network will not be degraded if we constrain the reference stations in the final analysis step, and that the EPN multiyear solution is best possible aligned to ITRF2005. We assume that this comparison includes implicitly a control of the station velocities, because the velocities are the basis to determine the coordinates at the reference epoch January 1, 2000.

Figure 3, Figure 4, and Figure 5 show the residuals of a 7 parameter Helmert transformation between the free network, minimum constraint and ITRF2005 coordinates of the reference stations as selected in the initial processing. Obviously some of the reference station coordinates are poorly determined and are not suitable for datum definition. We applied a rejection criteria of 1 cm for position and 2 cm for height to the residuals of Figure 3 and identified the following stations to be disregarded as reference:

GRAZ(4), SFER(2), TRO1(1), TRO1(4), ONSA(1) and VILL(2)

, where the solution numbers are given in brackets.
A new solutions has been calculated with the reduced reference station list. All selected reference stations fulfil now the rejection criteria, if we compare the free network solution against the ITRF2005 coordinates. If we compare the minimum constraint solution against ITRF2005, we detect a couple of stations, where the Helmert residuals exceed the rejection criteria. These stations have been disregarded as reference as well:

> **ANKR(1), ANKR(2), ANKR(3), CAGZ(1), CASC (1), GRAZ(3), IENG(1), NPLD(2), ONSA(2),PTBB(2), PTBB(3), SFER(4), SFER(5),and ZIMM(1).**

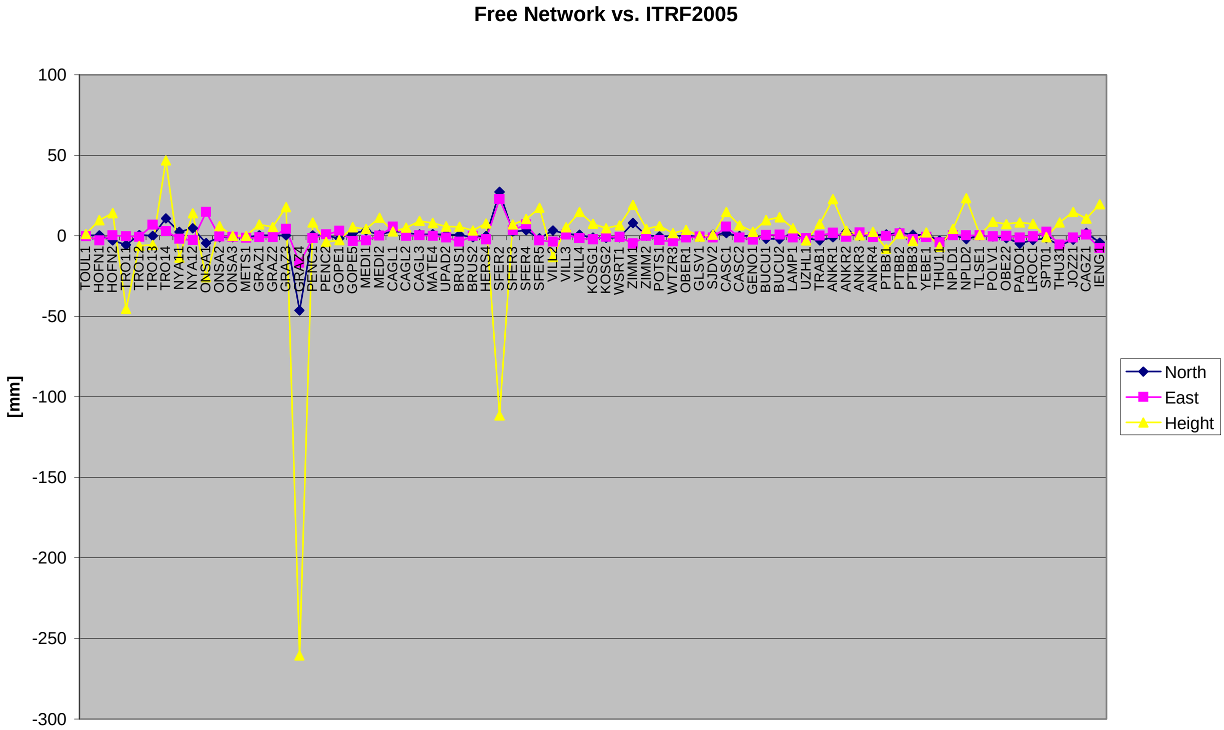


Figure 3: Initial Reference Station Residuals - 7 Parameter Helmert Transformation - Free/ITRF2005

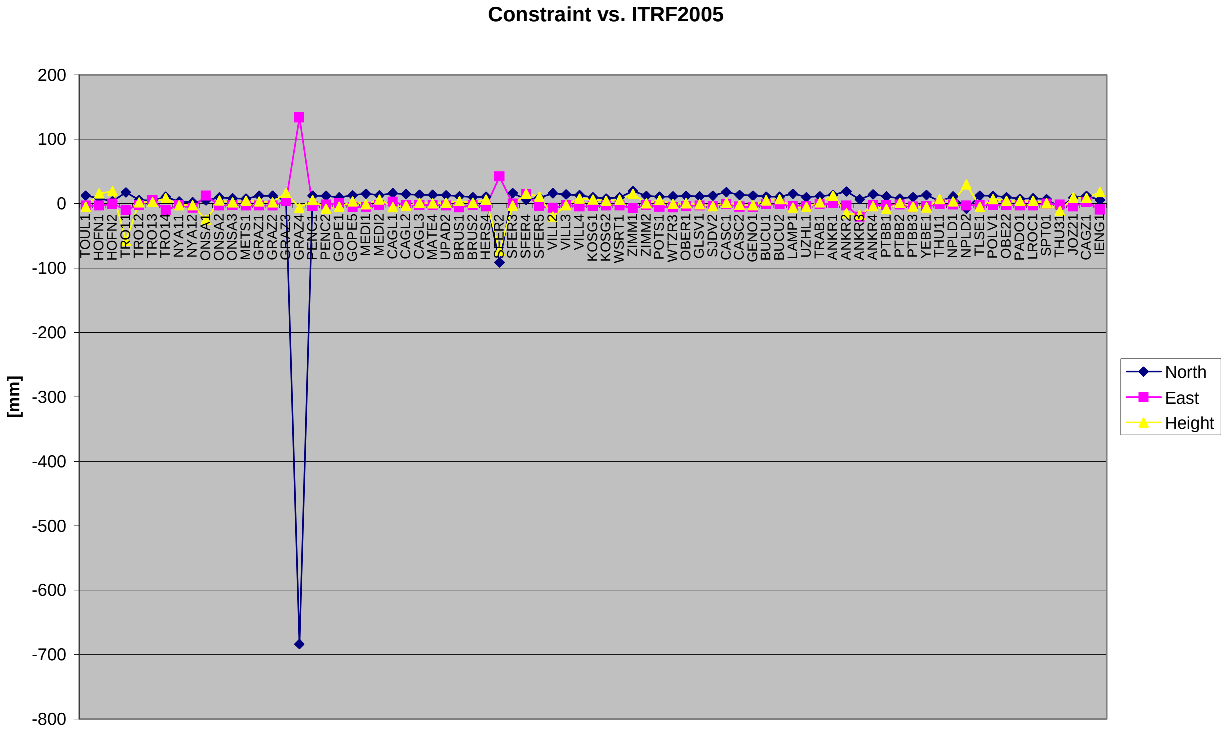


Figure 4: Initial Reference Station Residuals - 7 Parameter Helmert Transformation - Const./ITRF2005

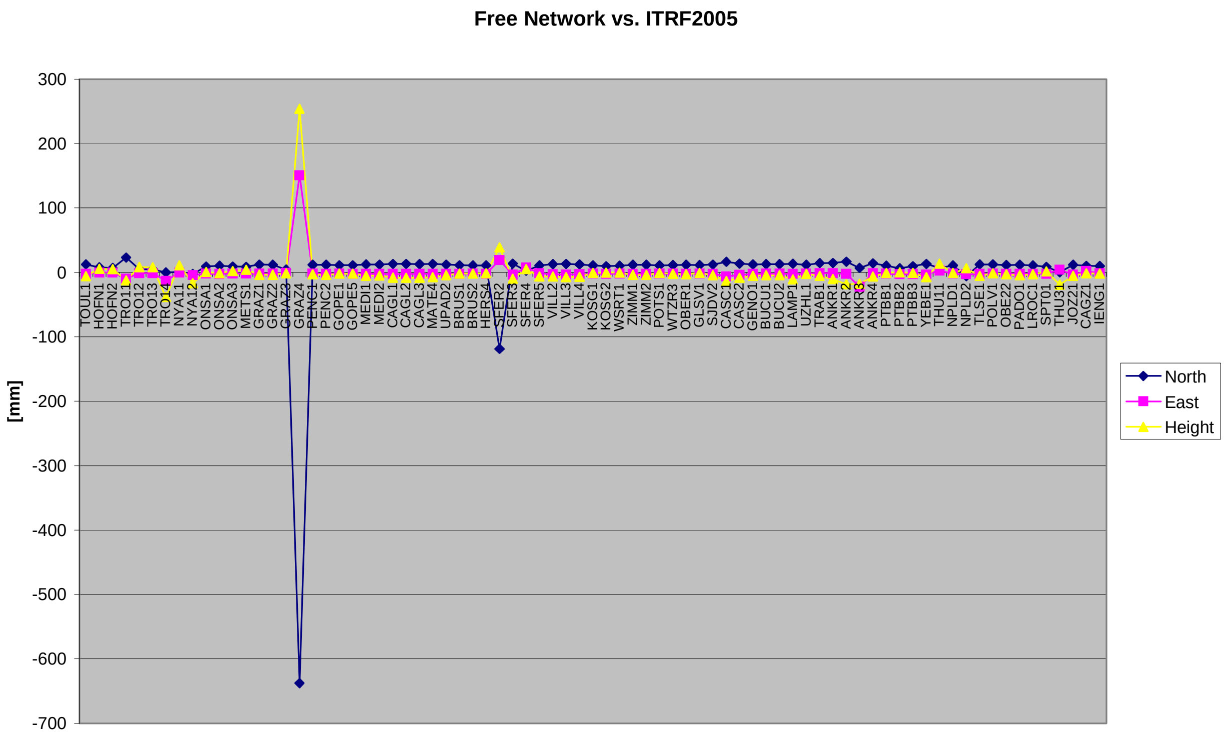


Figure 5: Initial Reference Station Residuals - 7 Parameter Helmert Transformation - Free/Const.

The comparison of the free network, minimum constrained and ITRF2005 solutions are now repeated for the final selection of reference sites. The residuals are shown in Figure 6,Figure 7 and Figure 8. The residuals are now much smaller compared to the initial reference station selection. All reference stations fulfil the rejection criteria of <1 cm for position and <2 cm for height.

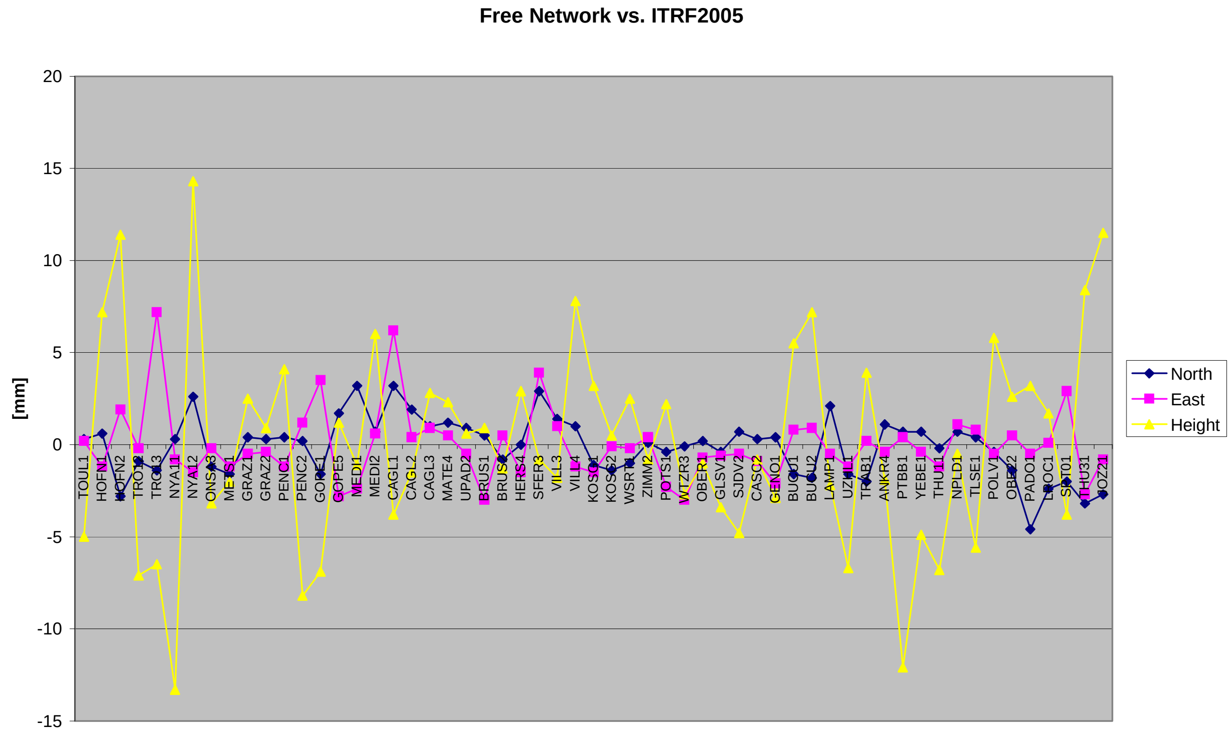


Figure 6: Final Reference Station Residuals - 7 Parameter Helmert Transformation - Free/ITRF2005

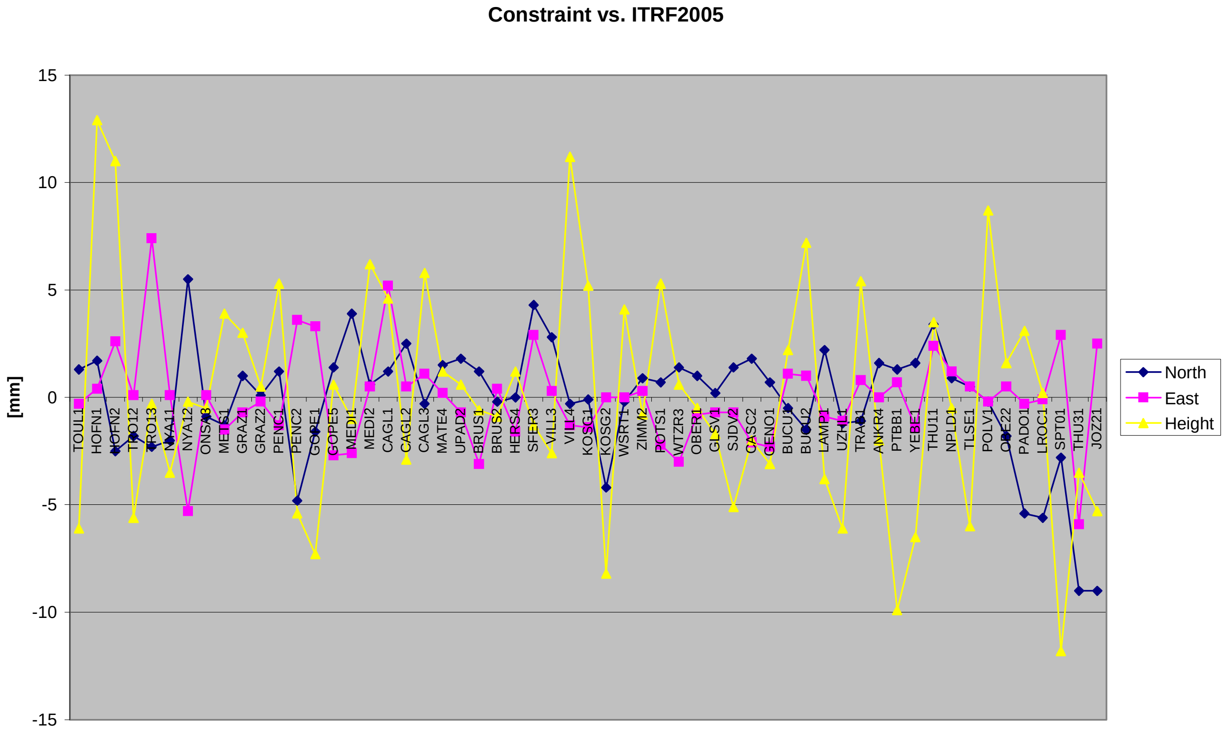


Figure 7: Final Reference Station Residuals - 7 Parameter Helmert Transformation - Const./ITRF2005

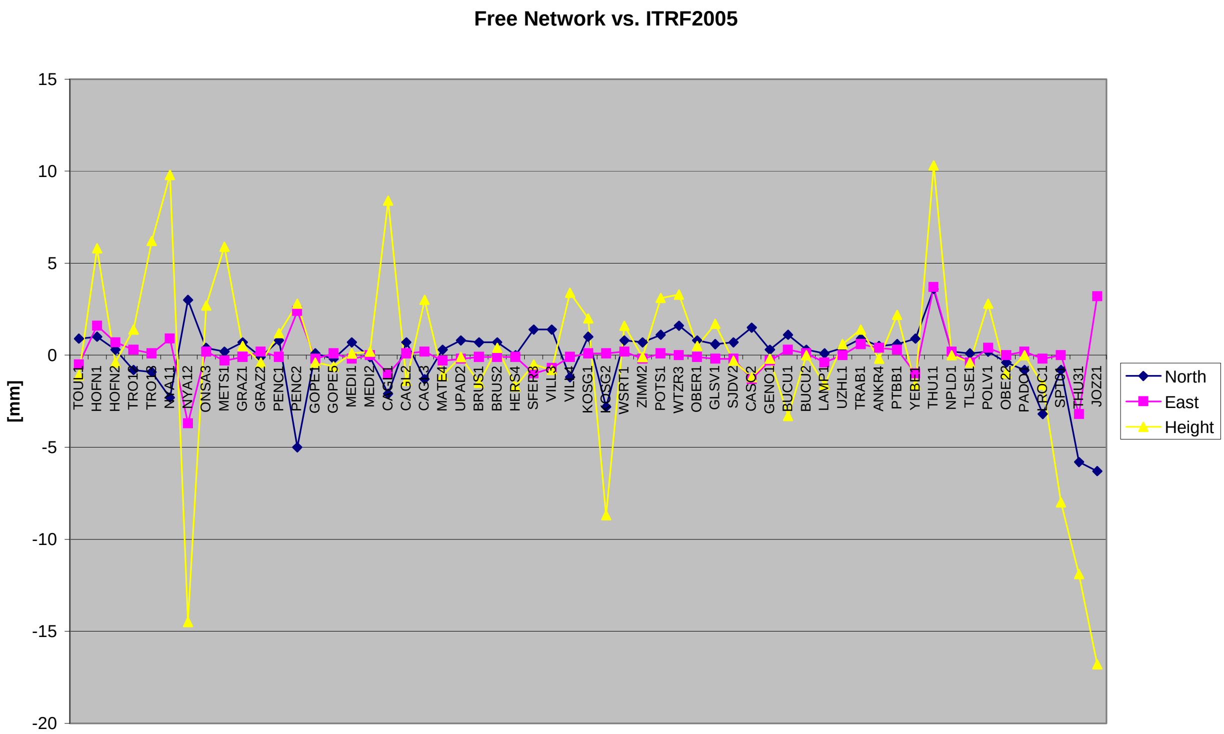


Figure 8: Final Reference Station Residuals - 7 Parameter Helmert Transformation - Free/Const.

The absolute numbers of the estimated Helmert parameters for the final reference station selection is given in Table 4:

- FreeNet/ITRF2005 : We found significant translation and rotation parameters, but even the free EPN network is aligned to the global network within a few cm. Perhaps not all constraints could be removed from the NEQs.
- MCC/ITRF2005: The estimated parameters result to nearly “zero” and confirm that the MCC solution is well aligned to ITRF2005. There occurs no increase of the formal error of the parameters, and it confirms that no network deformation hase bee caused through the MCC.

	FreeNet - ITRF2005	+/-	MCC - ITRF2005	+/-	FreeNet - MCC	+/-
TX [mm]	-12.3	2.4	-0.1	2.4	12.3	2.0
TX [mm]	-3.9	3.3	0.0	3.4	3.8	2.8
TZ [mm]	23.3	2.2	0.1	2.2	-23.2	1.8
RX [“]	0.00015	0.00010	0.00003	0.00010	0.00018	0.00009
RY [“]	-.00030	0.00008	-0.00030	0.00009	-0.00060	0.00007
RZ [“]	0.00008	0.00008	0.00003	0.00008	0.00005	0.00007
Scale	0.00040	0.00030	0.00080	0.00030	-0.00040	0.00030

Table 4: Final Reference Station Selection - Estimated Helmert Parameter

Coordinate Comparison

For further comparison both coordinate results, from the EPN cumulative solution and ITRF2005, are calculated for the reference epoch January 1, 2007 and are now directly compared without any transformation between them. This comparison could be calculated for in total 131 stations (some stations have more than one solution) and the coordinate difference is given in Figure 9. We observe differences of greater than 30 cm for some stations. Detailed investigation for the reasons of these difference has not been carried out, but it demonstrated once again the importance of a careful selection of the reference sites.

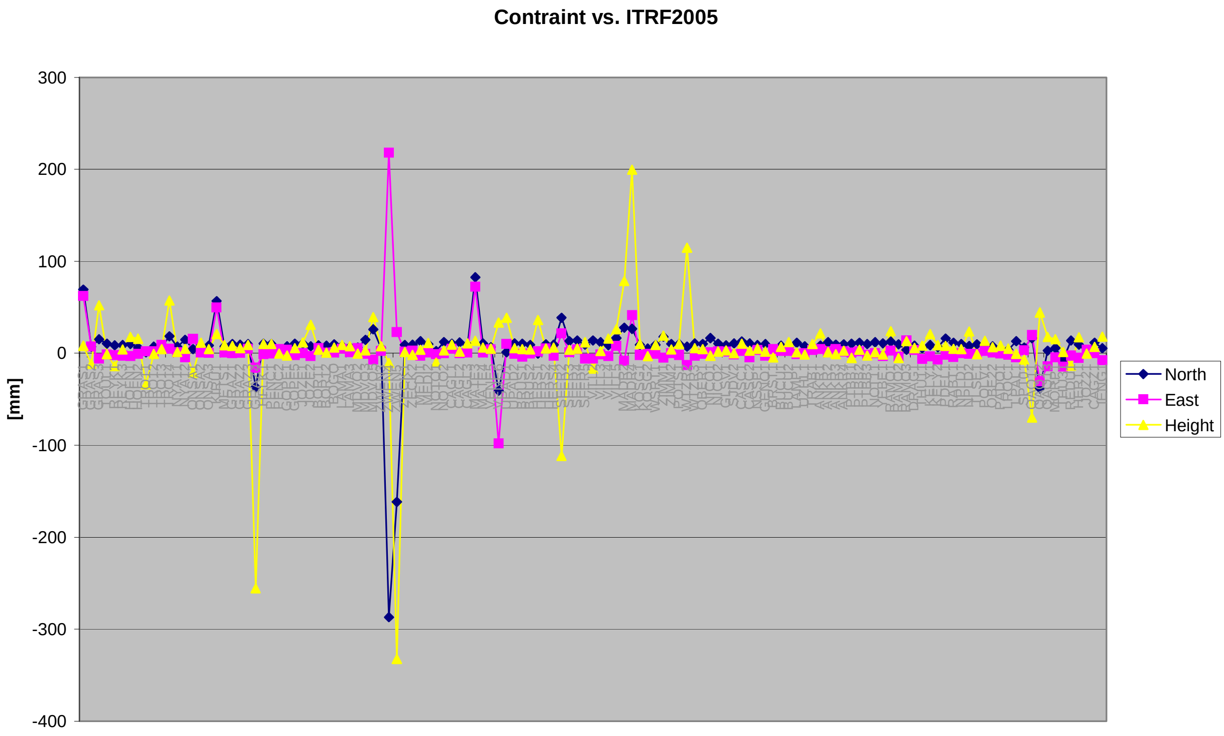


Figure 9: Coordinate Comparison - at Reference Epoch 2000.1

3.6 Table of Products

The result files of the EUREF regional densification of ITRF2005 are summarized in Table 5.

Filename	File Type
Report_ITRF2005_Densification.doc	MS-Word document (this file)
EPN_CUM.OUT	
EPN_CUM.PLT	
EPN_CUM.NQ0	binary normal equation file (internal only)
EPN_CU1.SNX	
EPN_CUM.CRD	
EPN_CUM.VEL	
EPN_CUM.SNX	

Table 5: EPN Multiyear Solution - Product Files

These files are publicly available at:

ftp://igs.bkg.bund.de/MISC/ITRF/ITRF2005/

Processing Runtime

All processing steps have been performed on a Linux PC with Intel Pentium 4 CPU 3.00 GHz processor. The runtime was:

Total Time:	20:00 mm:ss
Free network solution from weekly NEQs:	07:47 mm:ss
Minimum constrained solution from combined NEQ:	01:53 mm:ss
Full Constrained solution from combined NEQ:	09:36 mm:ss

4 Coordinates and Network Time Series

A few time series of station coordinates and network parameters will be given here to demonstrate the precision of the new cumulative solution.

4.1 Coordinate Time Series

Coordinate time series of the stations ONSA and WTZR are shown in Figure 10 as examples. The figures show residuals as they remain after applying a 7 parameter Helmert transformation between the weekly EPN solutions and the cumulative solution.

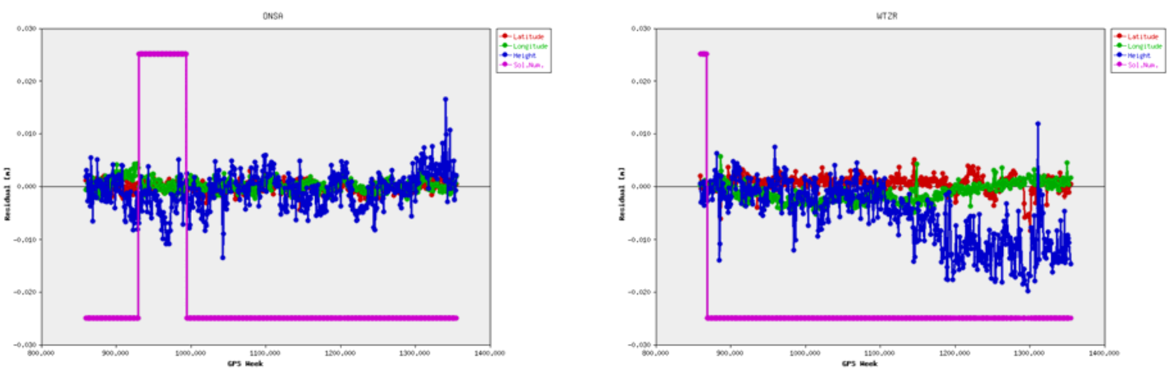
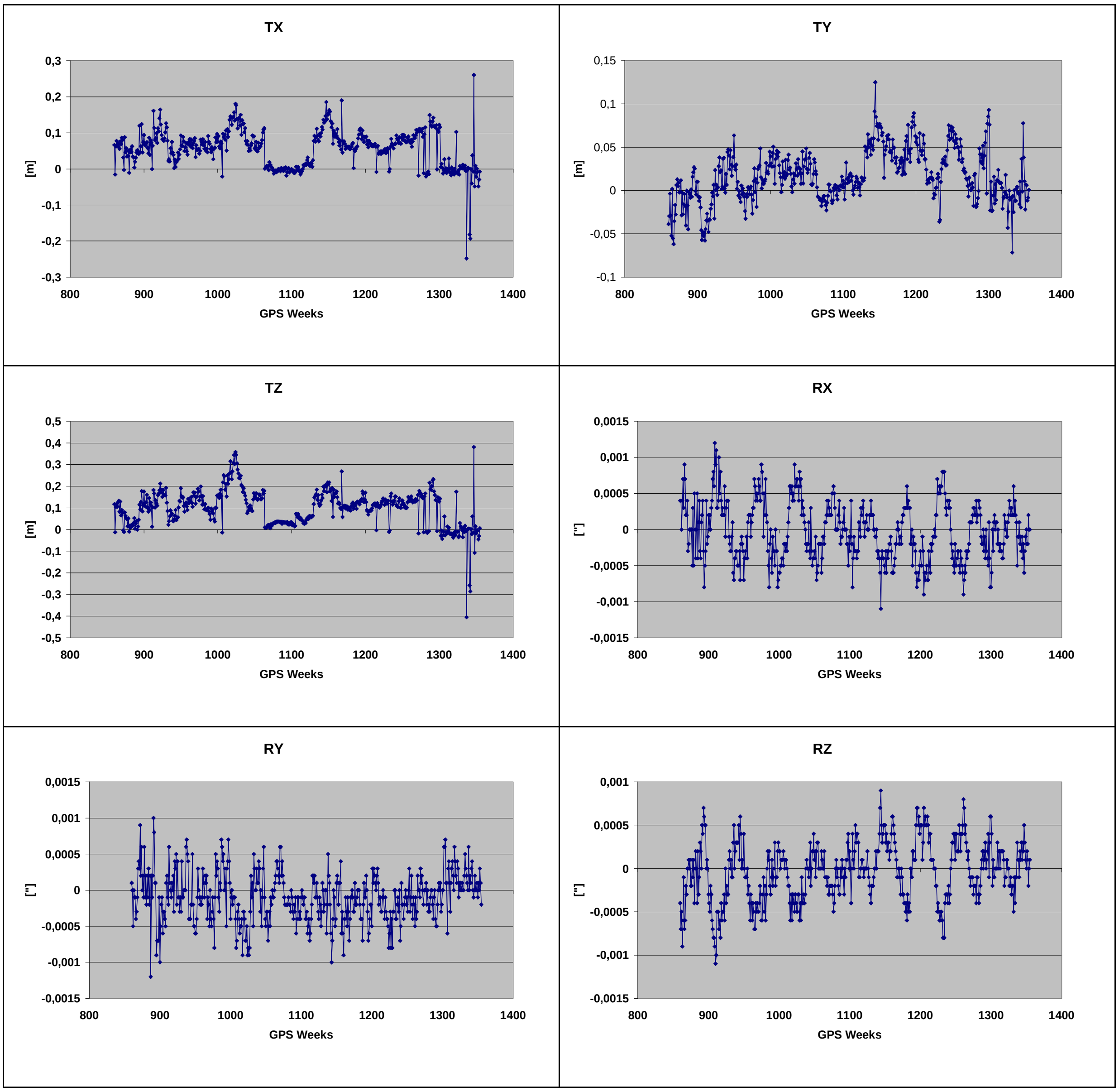


Figure 10: Station Coordinate Time Series

4.2 Network Time Series

Figure 11 shows the parameters and the corresponding RMS from 7 parameter Helmert transformations in a geocentric coordinate system between the weekly solutions and the cumulative solution. A test study has shown that the yearly signal in the Helmert parameters will mostly disappear, if we apply only 3 translation parameters in a topocentric coordinate system, where the RMS of the parameters remain the same as for the 7 parameter transformation.



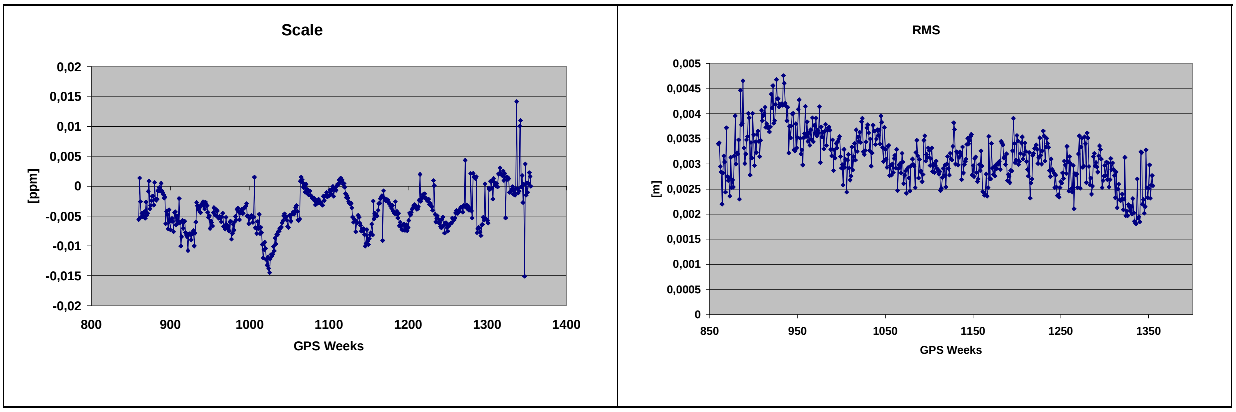


Figure 11: Helmert Parameters - Weekly Networks w.r.t. Multi-year Solution

4.3 Visualisation

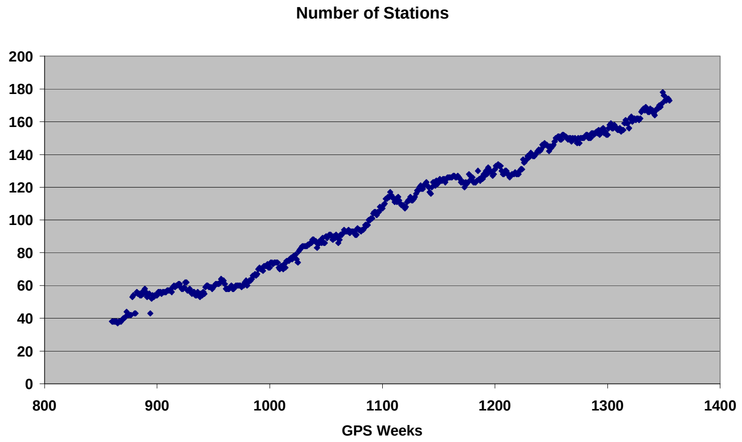


Figure 12: Number of Stations in Weekly EPN Solution

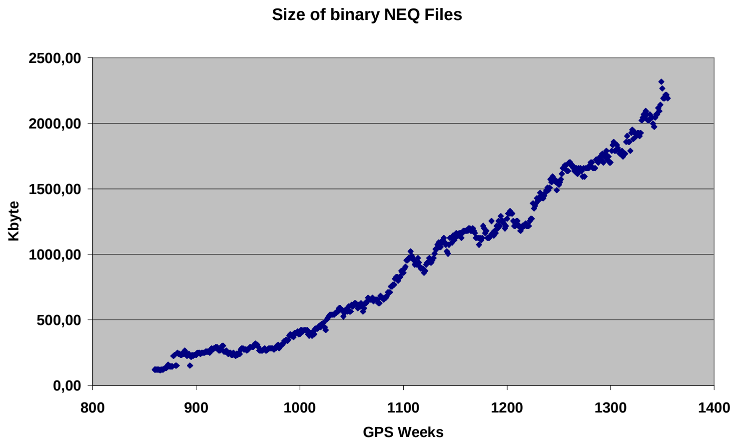


Figure 13: Size of Weekly Binary NEQ Files

Figure 14: Selected Reference Sites - 44 Stations (57 Solutions)

5 Summary

The new EPN cumulative solution of weekly SINEX files of the GPS weeks 860 to 1355 provides a regional densification of ITRF2005 for Europe. The definition of subsets of solution numbers for the stations are fully consistent. The proper selection of ITRF2005 references sites assures the alignment to the ITRF2005. The new cumulative solution provides dense and precise velocities for Europe.

6 References

[1] IGS discontinuity table for ITRF2005 at ftp://macs.geod.nrcan.gc.ca/pub/requests/sinex/IGS05/ALL_ITRF2005.snx

[2] IGS outlier table for ITRF2005: File "outlier.snx" from personal communication with Remi Ferland, NRCAN, Canada

[3] Discontinuities and outlier tables of EPN Coordinate Time Series Analysis Special Project at http://www.epncb.oma.be/_organisation/projects/series_sp/cumulative_solution.php

[4] ITRF2005 coordinate and velocity file ITRF2005_GPS.SSC at http://itrf.ensg.ign.fr

[5] EPN weekly coordinates in SINEX format at http://igs.bkg.bund.de

[6] Z. Altamimi, X. Collilieux, J. Legrand, B. Garayt, C. Boucher (2007): *ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters*, Journal of Geophysical Research, Vol. 112, doi:10.1029/2007JB004949, 2007