GNSS re-processing results at GOP and the latest updates of ITRS/ETRS

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outline

- Introduction into reference systems/frames
- GOP repro1
  - daily/weekly raw time-series generated
  - multi-year combination
- Application of GOP repro1 results
  - testing last EPN ITRF2005-based cumulative solutions
  - testing ITRF2008 discontinuities for subset of stations
- GOP repro1+ - extended solution to all EPN stations
  - first results full EPN repro1 at GOP (IGS05 and IGS08-based solution)
  - evaluation of new ITRF2008 and its densification in Europe
- New ITRF2008 and its European densification
- Summary

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ITRS – International Terrestrial Reference System

- is a *geocentric* system co-rotating with the Earth's diurnal motion in space
- the *center of mass* is defined for the whole Earth, including oceans and atmosphere
- the *unit of length* is *an SI meter*
- the *scale* (the scale of the spatial coordinates) is consistent with the TCG (Geocentric Coordinate Time)
- its *orientation* was initially given by the BIH orientation at 1984.0
- the *time evolution of the orientation* is ensured by using a *no-net-rotation condition* with regards to horizontal tectonic motions over the whole Earth

- precise definition - see the *IERS Conventions (2010)*, especially *Chapter 4*
- the ITRS *is realized by* estimating the *coordinates and velocities* of a set of stations observed by VLBI, LLR, GPS, SLR, and DORIS
- such ITRS realization is called International Terrestrial Reference Frame (ITRF)

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ITRF – International Terrestrial Reference Frame

- a set of physical points with defined 3D cartesian coordinates
- this both above *realize the ideal reference system (ITRS)*
- the tracking network equipped with the instruments of all techniques (especially GNSS) is evolving and the period of data available increases with time, the ITRF is constantly being updated
- 12 realizations of the ITRS were set up from 1988. The latest is the ITRF2008 (adopted in 2010, but IGS switch at GPS week 1632)
- more at *http://itrf.ensg.ign.fr*

ITRF contains:

- cartesian station coordinates and velocities (variance/covariance matrix)
- site catalogue, local ties,
- DOMES identification numbers & discontinuity list
- *Existing realizations:* ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008

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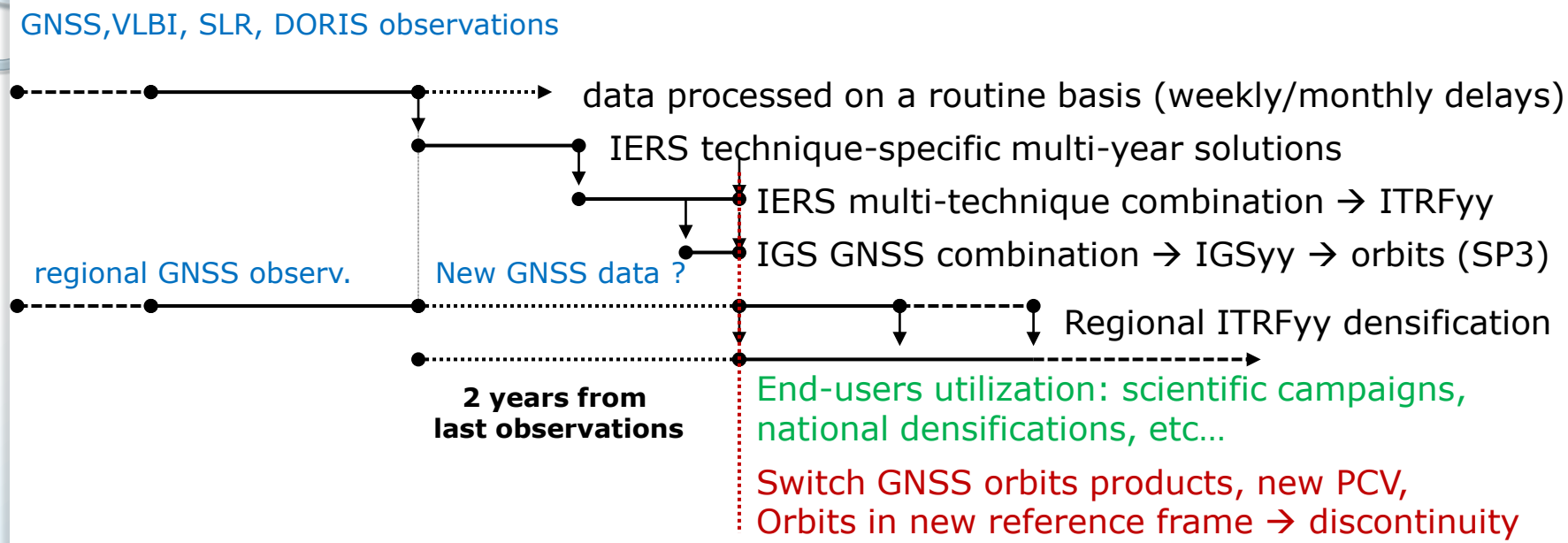
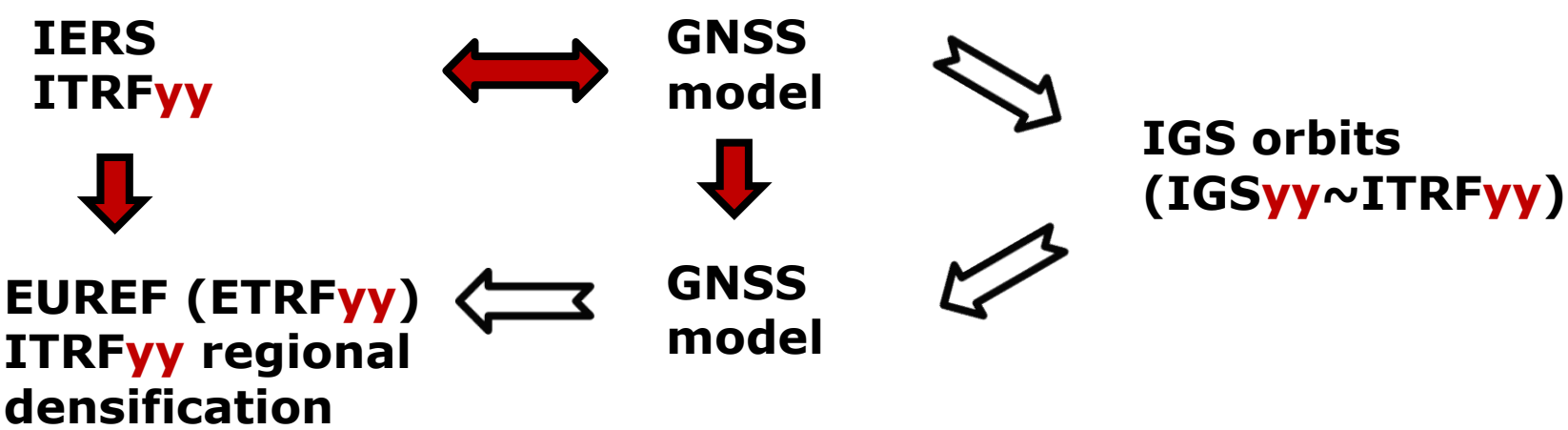
Original reference system realization cycle





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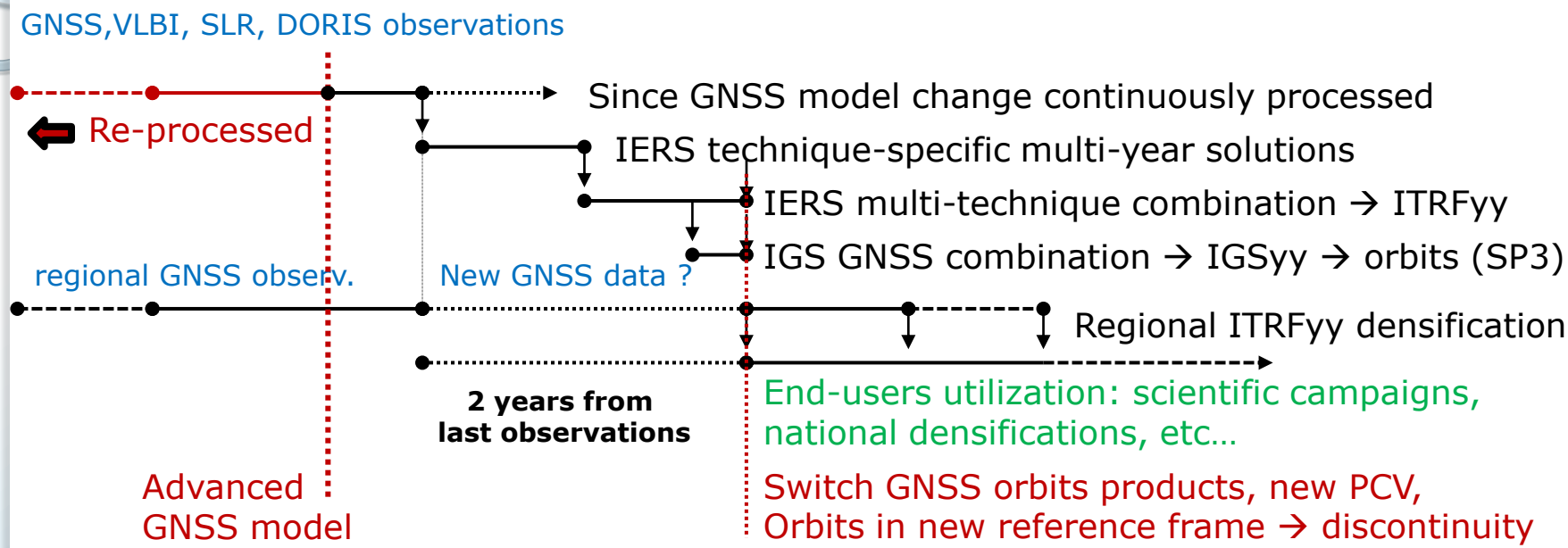
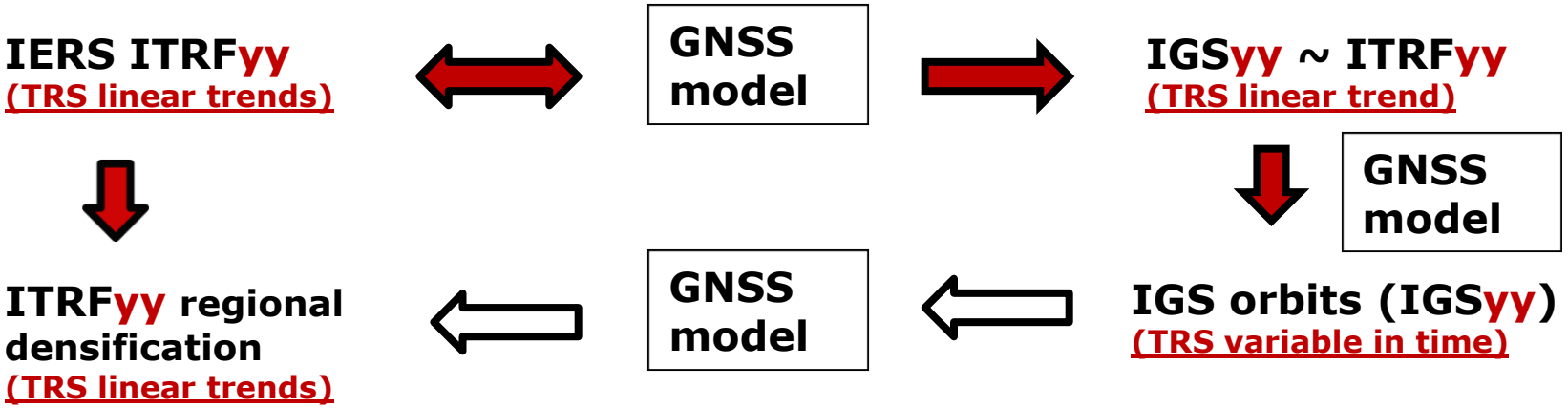
New RF cycle – with re-processing





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IGS-Repro1 and IGS08 realization of ITRF2008

- IGS Repro1 – the first homogeneous GNSS data processing product

(Modelling: IGS05 APCV, ITRF2005, IERS2003 conventions, additional sites, atmosphere,...)

1. Re-processed IGS ACs' solutions (1994-2007) -> daily, weekly solutions
2. Routine IGS AC's solutions (2008-...) -> daily, weekly, based on Repro1 strategies
3. IGS daily/weekly combination
4. IGS multi-year solution as the contribution to ITRF2008
5. IGS Repro1 orbit & clock combinations (use of IGS05 ~ ITRF2005 RF)
6. IGS Repro1 tropospheric product estimation (use of IGS05 ~ ITRF2005 RF)

- 11 AC's analysis centres contributed (including TIGA stations)
- More details: http://acc.igs.org/reprocess.html
- ITRF2008 is based on GNSS repro-1 solution (and VLBI,SLR,DORIS) with total IGS solution period containing years 1997 - 2009.5
- IGS08 – derived back from ITRF2008 as RF densification to provide more stations and thus more robust RF for the IGS core products and, additionally, derived applying site-specific corrections for a new APCV model (I08!)
- Since GPS week 1632, new ITRF2008/IGS08 and IGS08 PCV files were applied in standard IGS/EUREF daily and weekly processing

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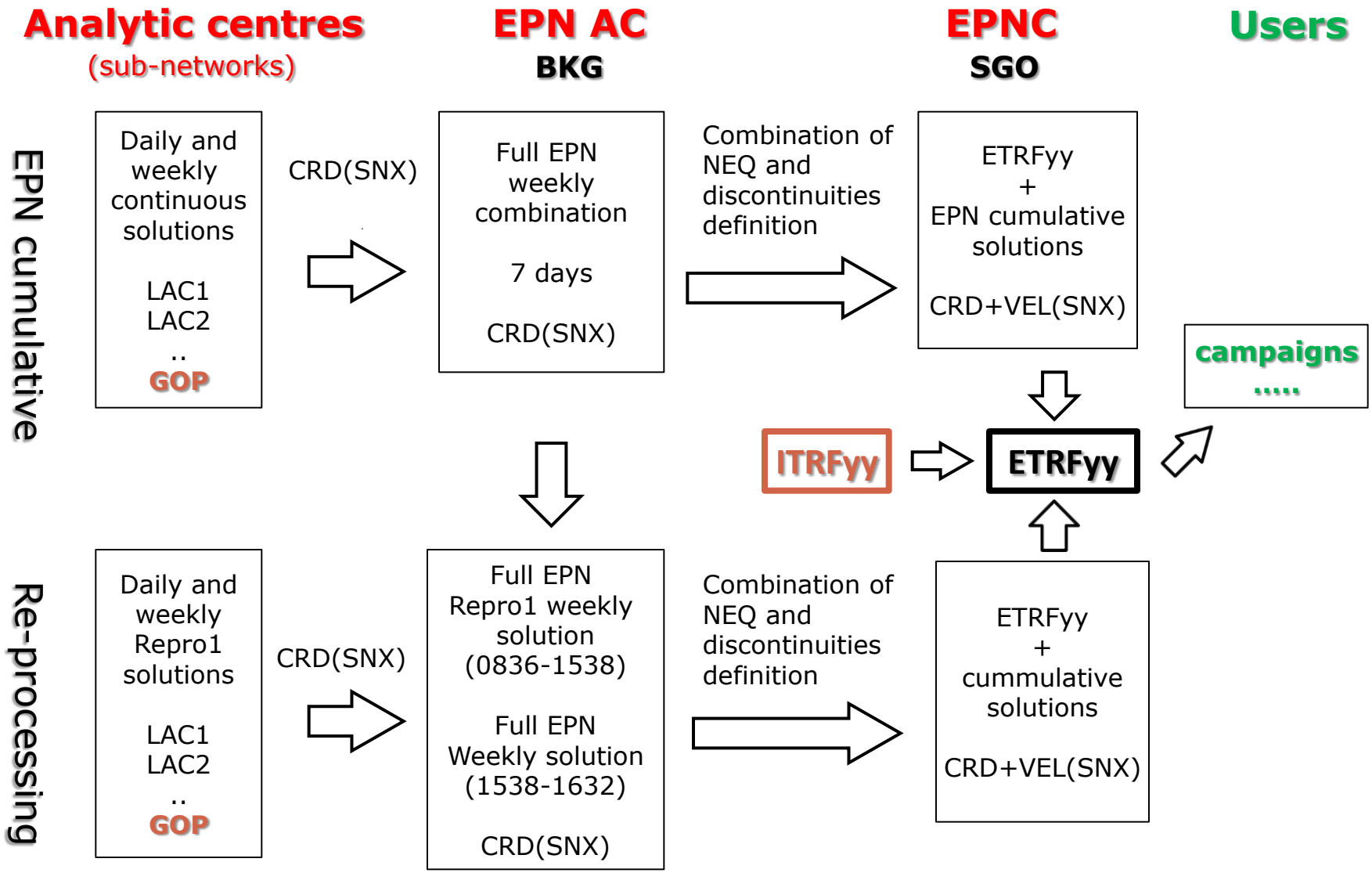
GOP Repro1:

GPS re-processing on daily and weekly basis long-term combination

ITRF2005/2008 densifications in Europe



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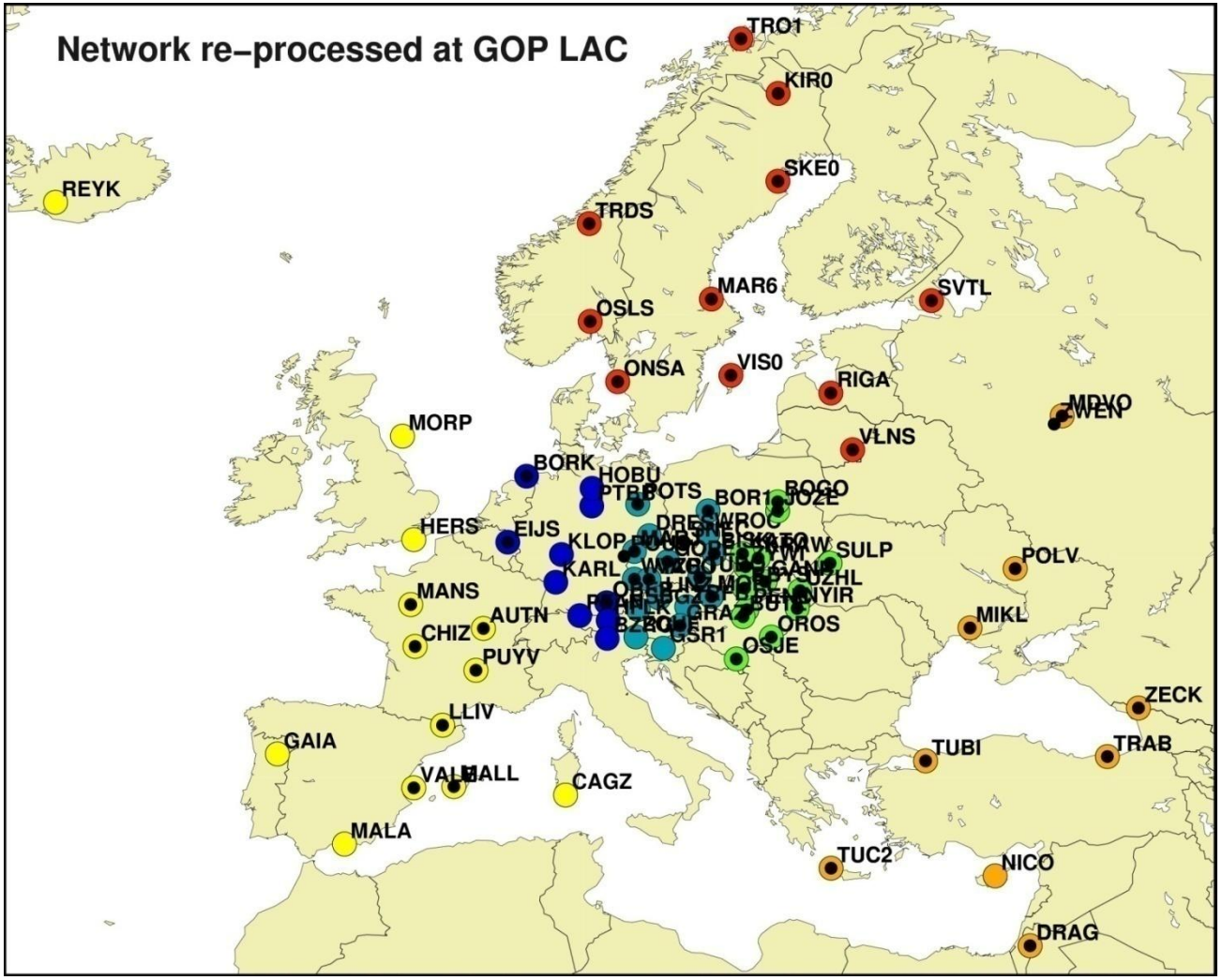
GOP re-processing (1996-2010)

- Consistent up-to-date models applied
- A long-term homogeneous solution
- Coordinate time-series for geodynamics and reference frame
- Troposphere parameters time-series for climate studies



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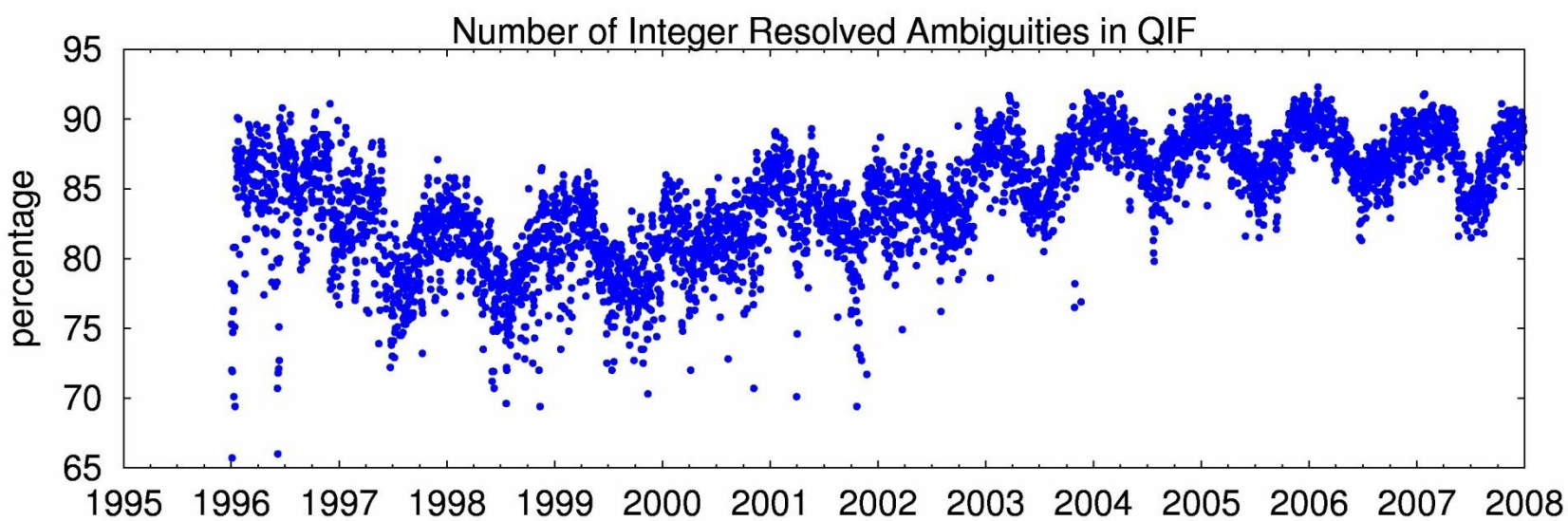
Some characteristics

- 1st, 2nd and 3rd iterative solution – enhancing processing strategy
- Specific problems causing crash in GOP-repro1 has been solved:
  - 1999:266 … >50% observations removed -> irrelevant drift in IG1 clocks
  - 2004:101 … RXOB3 setup wavelength factor 2/1 for G10, but crashed in MAUPRP for station GRAZ (RINEX file corrected)
- Processed required benchmark data set processed (year 2006)
- Preliminary tested a capability of processing full EPN network
- Ambiguity solution using QIF strategy:



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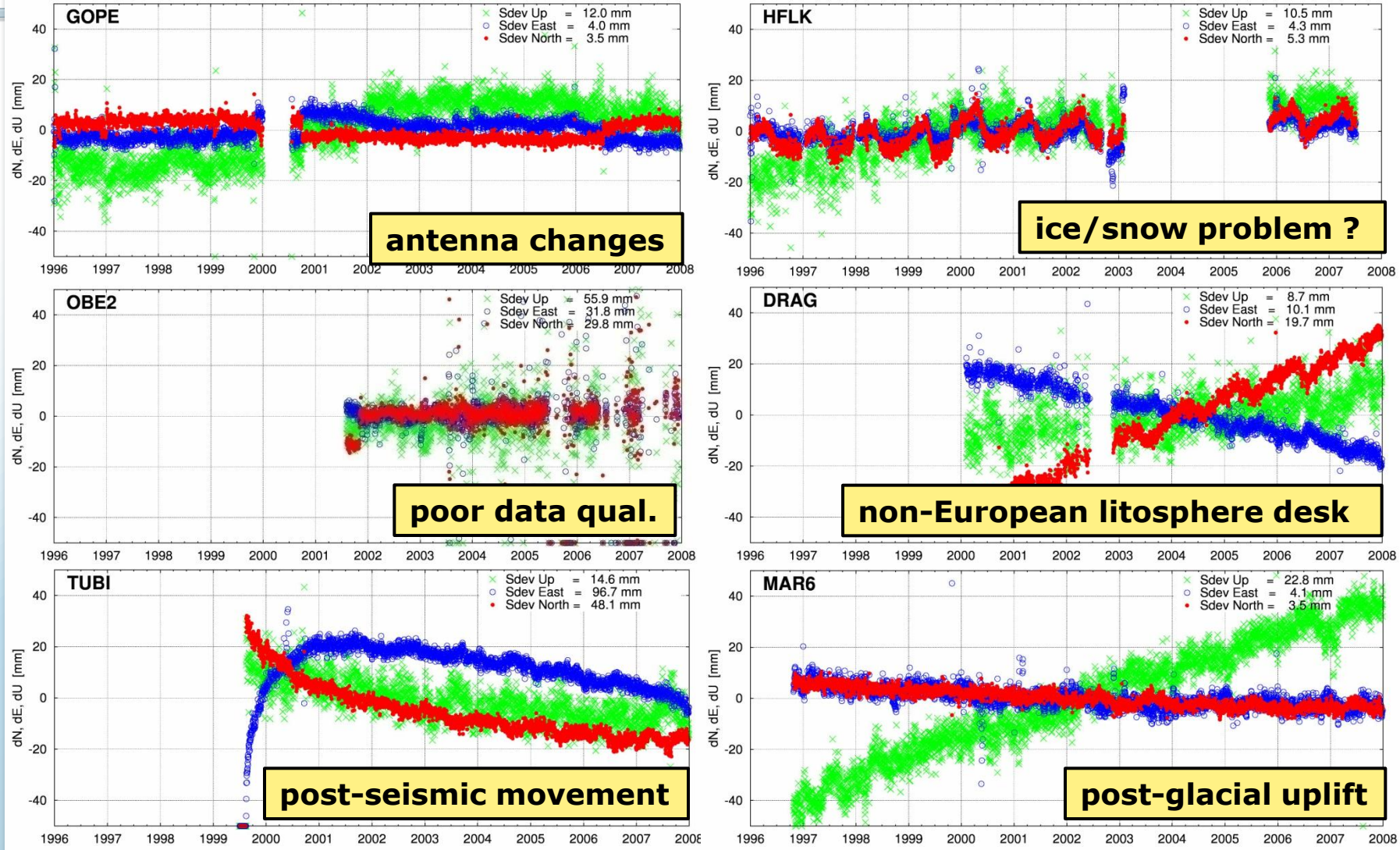
GOP raw coordinate time-series

plot of daily-based independent solutions applying single RF



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GOP Repro1 - combination

- 15-year solution based on weekly solutions
- implicitly coordinates parameters in NEQs (other parameters pre-eliminated)
- Setup the estimation of coordinates and velocities
- NNT minimum constraint solution for CRD+VEL of all common stations [w.r.t. ITRF2005]
- 1st combination → roughly check residuals, bad data periods
- 2nd combination →define discontinuities in CRD+VEL
- 3rd combination → select best set of fiducial stations
- finally 17 fiducial stations for NNT CRD+VEL datum definition
- **Results:** coordinate and velocity estimates (with given time periods) + discontinuity table + data exclusion tables + residual coordinate time series + residuals on fiducial stations

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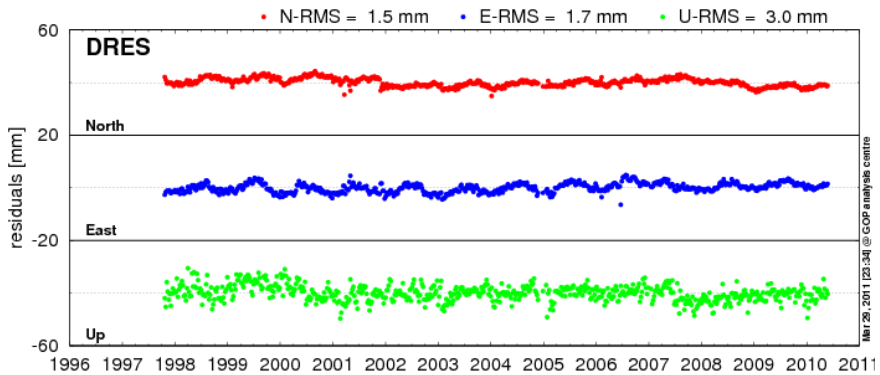
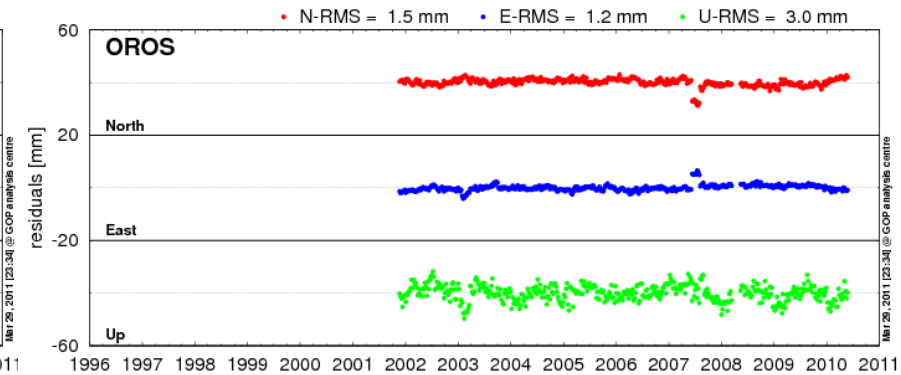
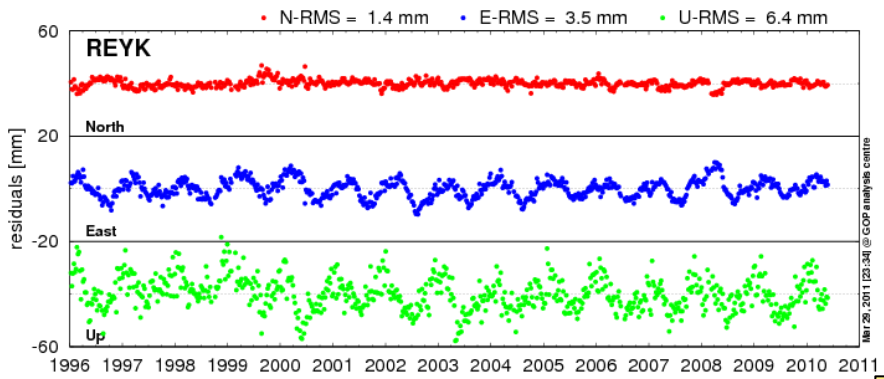
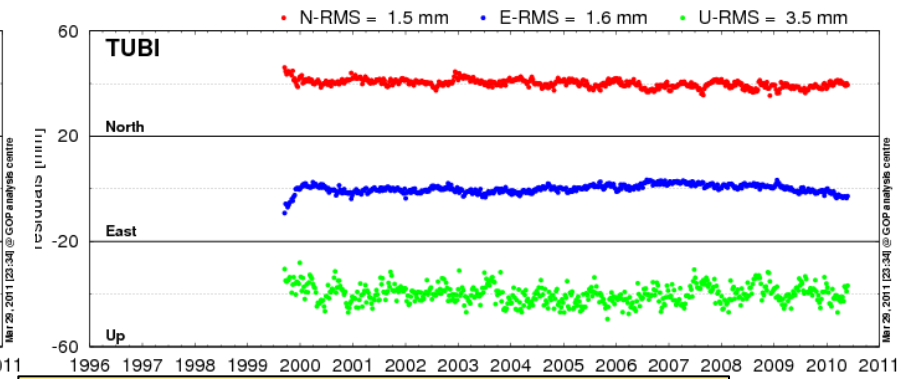
Combination process - results

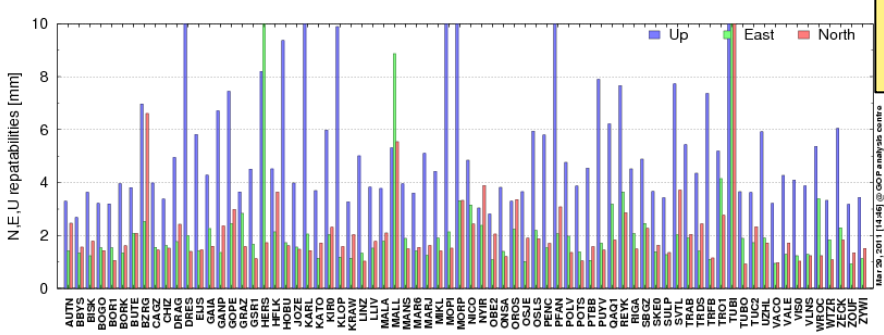


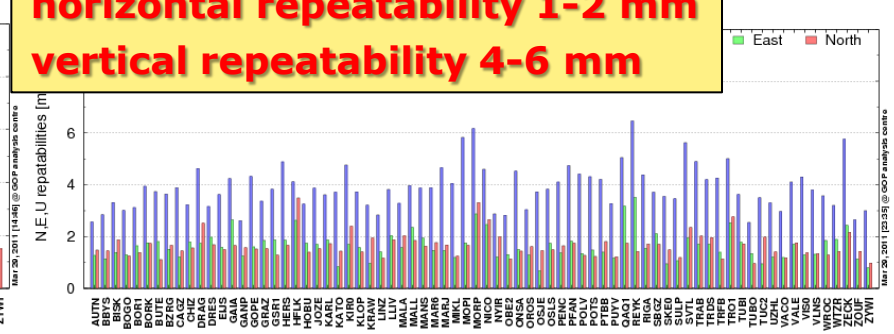






horizontal repeatability 1-2 mm
vertical repeatability 4-6 mm





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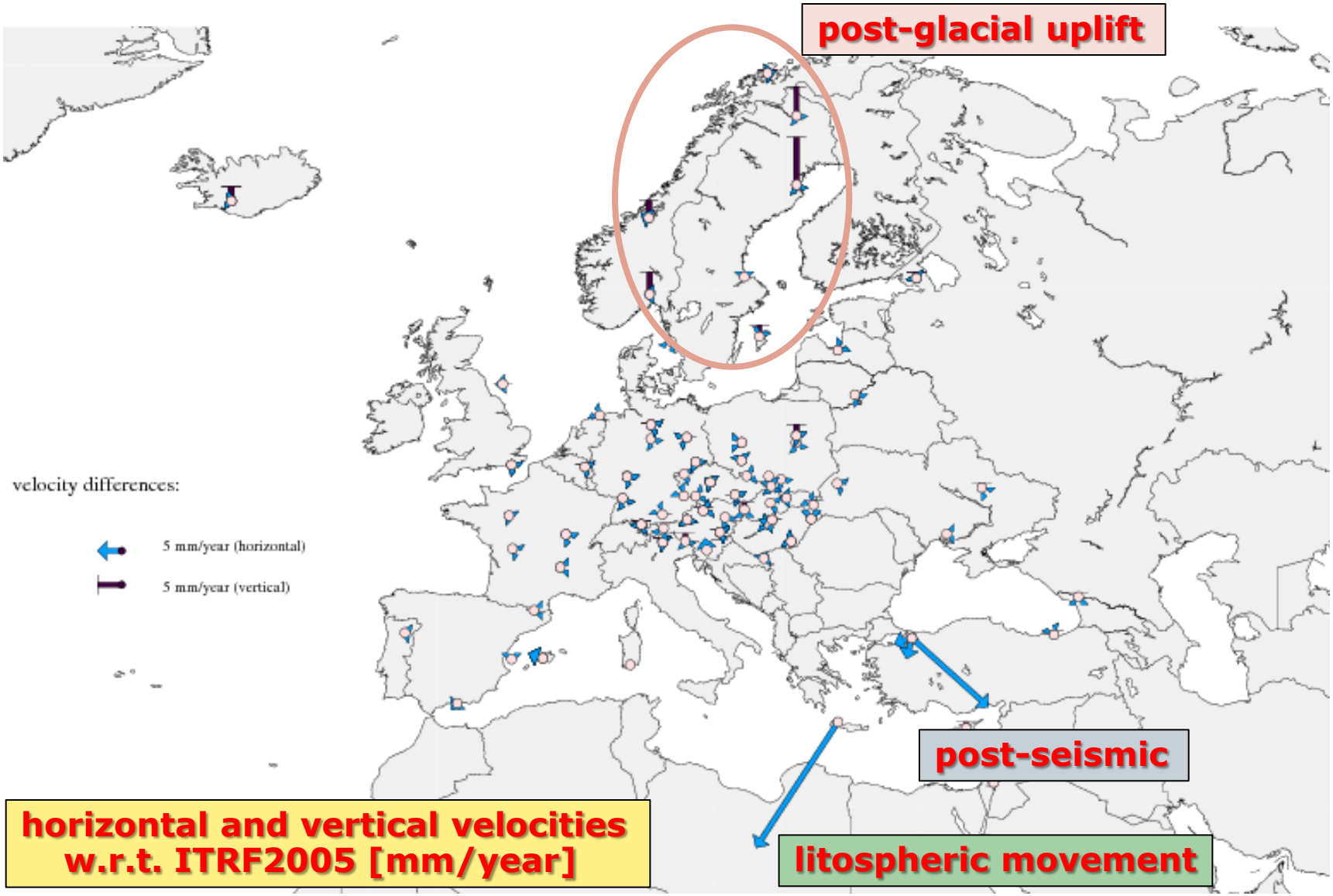
Residual velocity field (w.r.t. ITRF2005)



horizontal and vertical velocities w.r.t. ITRF2005 [mm/year]

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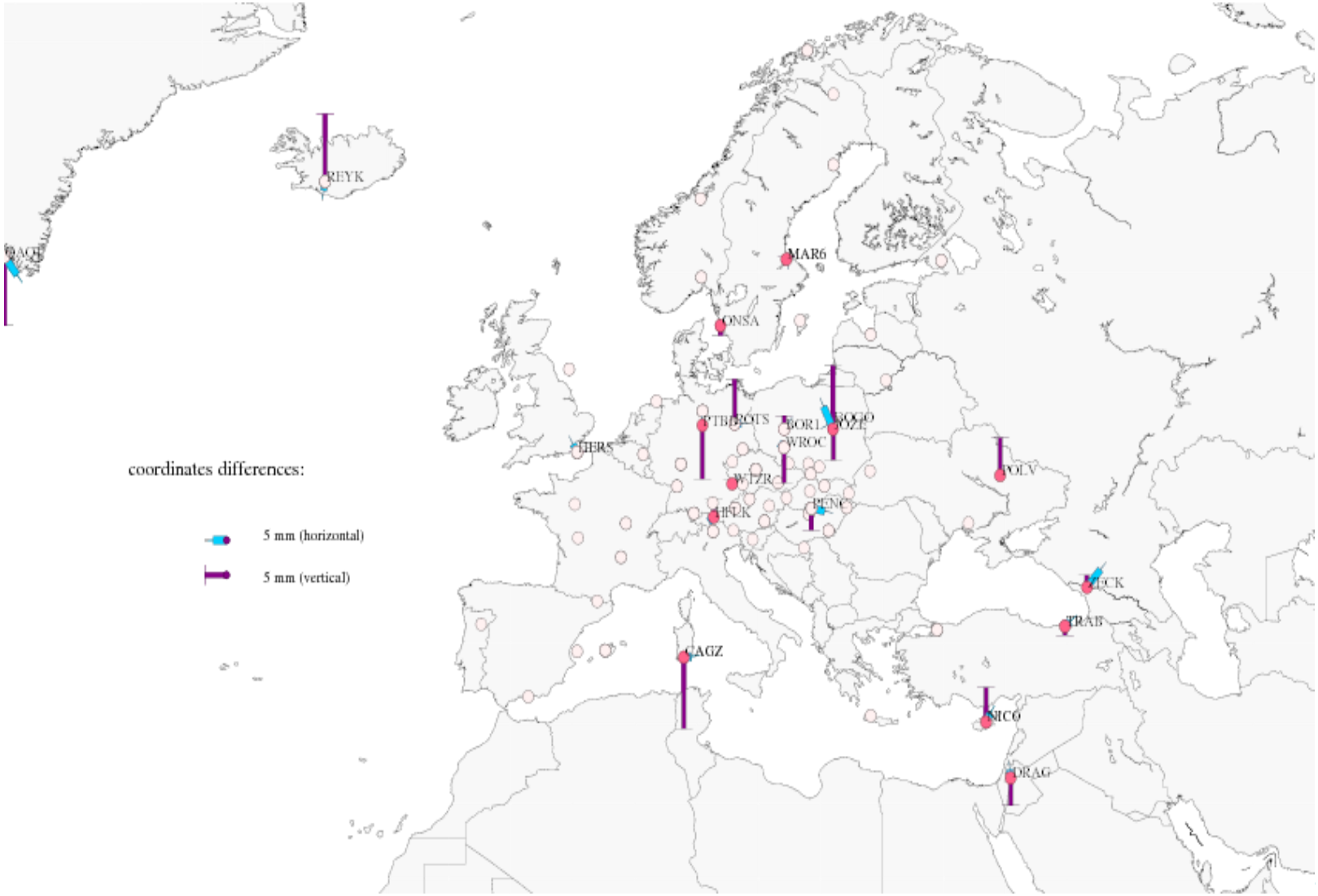
NEU residuals on fiducial stations

Helmert tranformation - 3 translations [mm] (17 stations)



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GOP Repro1
application of the results:

testing datum of EPN cumulative solution
checking discontinuity tables

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Motivation

- EUREF Serbia 2010 campaign (EUREF TWG Lisbon)
  - small N-S tilt observed
  - medium network at the SE Europe only
  - → check the datum of EPN cummulative solution (EPNC)
- EUREF IE/UK 2009 campaign
  - significant N-S tilt observed
  - large network extent
- EUREF Czech 2009 campaign
  - insignificant N-S tilt
  - large network, but data from 2004-2008 processed

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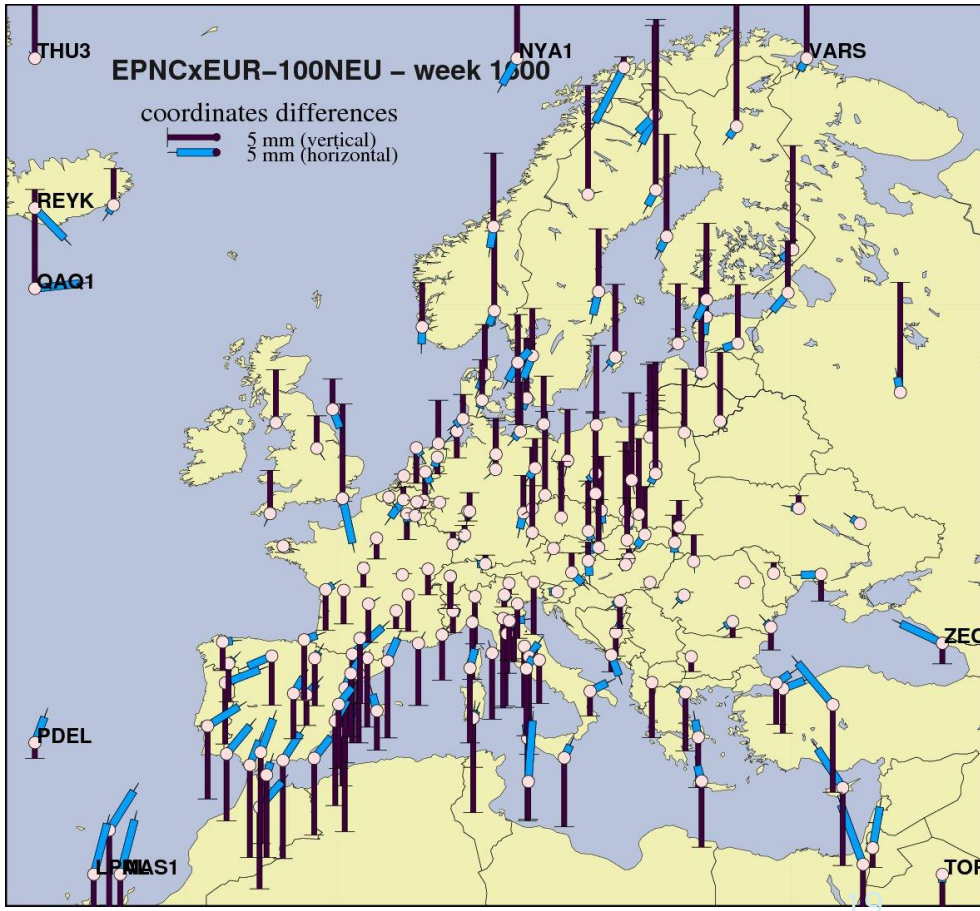
Testing RF datum definition in Europe

- **Observed N-S tilt between recent EUREF AC weekly combinations (or EUREF campaigns) and the EPN cumulative solution combination**
- **GOP repro-1 provides a 'homogeneous' weekly results to look into history**

Comparing weekly coordinates and coordinates and velocities from the EPN cumulative solution (EPNC1600) and EPN week 1600 sol.



- **Helmert transformations:**
  - NEU / XYZ (on a weekly basis)
  - 3-TRA
  - 3-TRA + 3-ROT + 1-SCL
- **Datum definition assessed by:**
  - All common stations set as fiducial
  - Iteratively select the 'consistent' set
  - Solution numbers per sites applied

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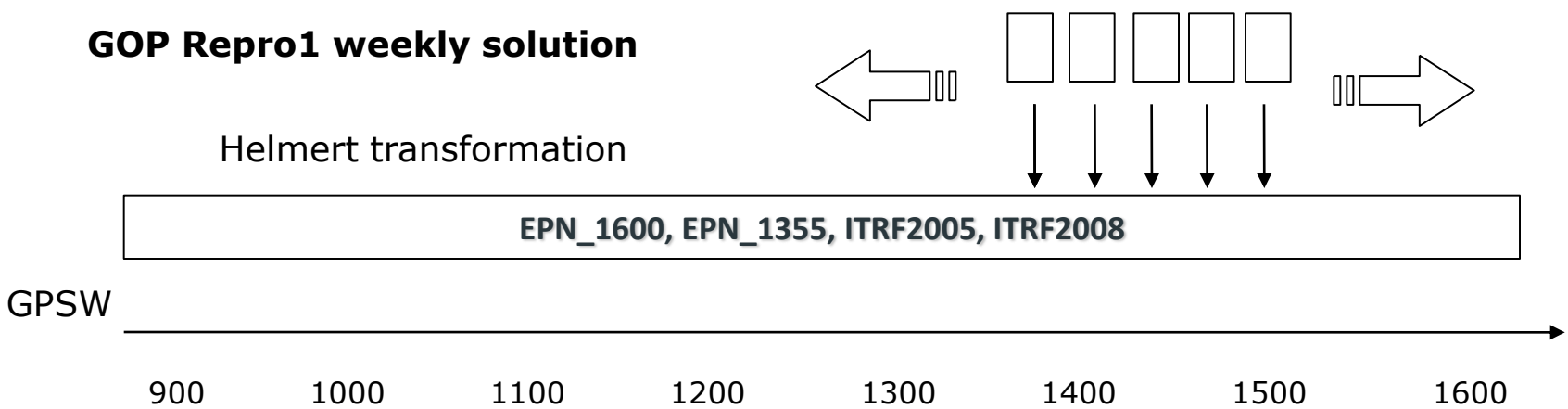
Testing datum of EPN cumulative solution

- **Compared CRD on weekly basis:**
  - **2a-set EUREF AC (weekly CRD)**
  - **2b-set GOP repro1 (weekly CRD)**

  } independent weekly solutions

- **Reference solution (CRD+VEL in ref. epoch)**
  - **1a-set EPNC_1355 (CRD+VEL)**
  - **1b-set EPNC_1600 (CRD+VEL)**
  - **1b-set ITRF2005 (CRD+VEL)**
  - **1c-set ITRF2008 (CRD+VEL)**

  } long-term datum realization



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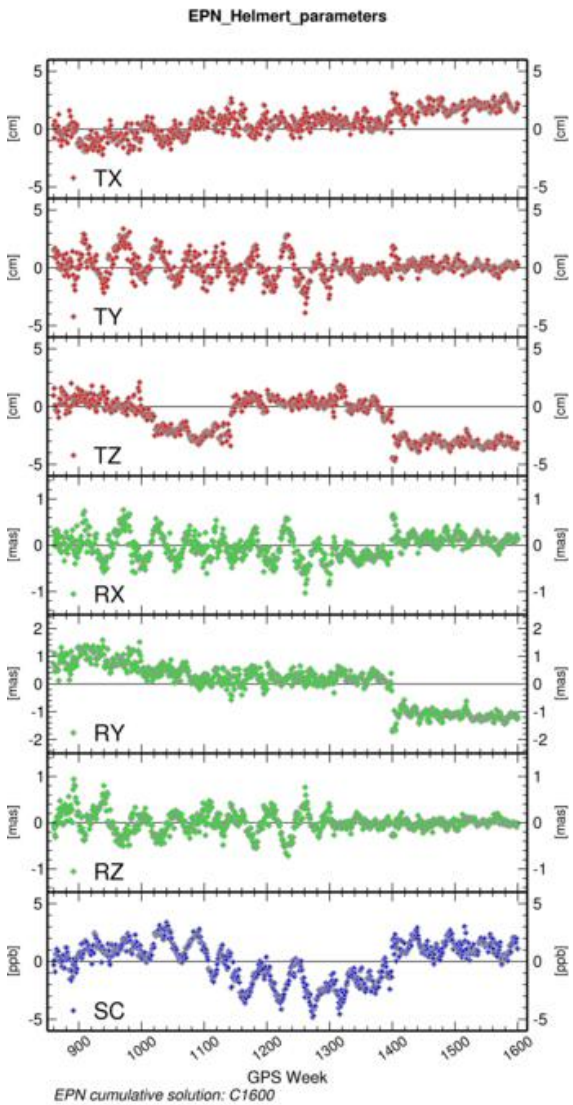
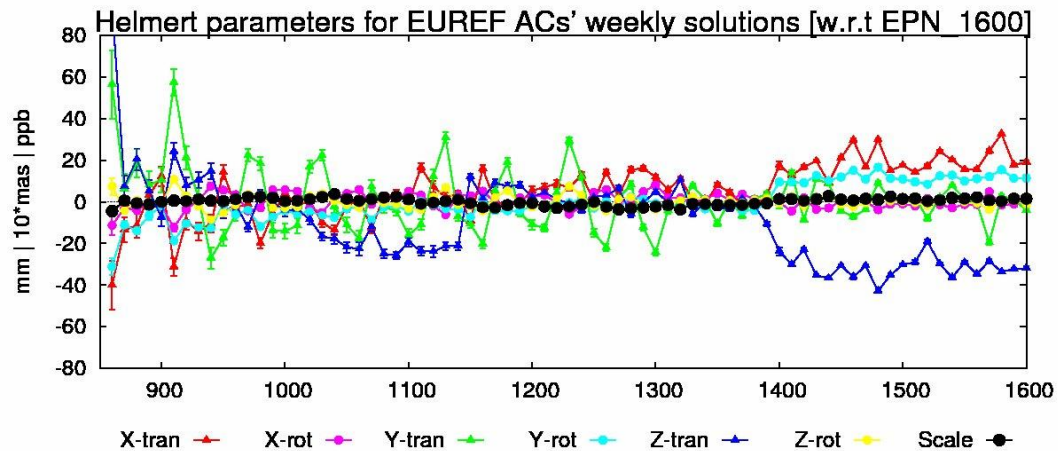
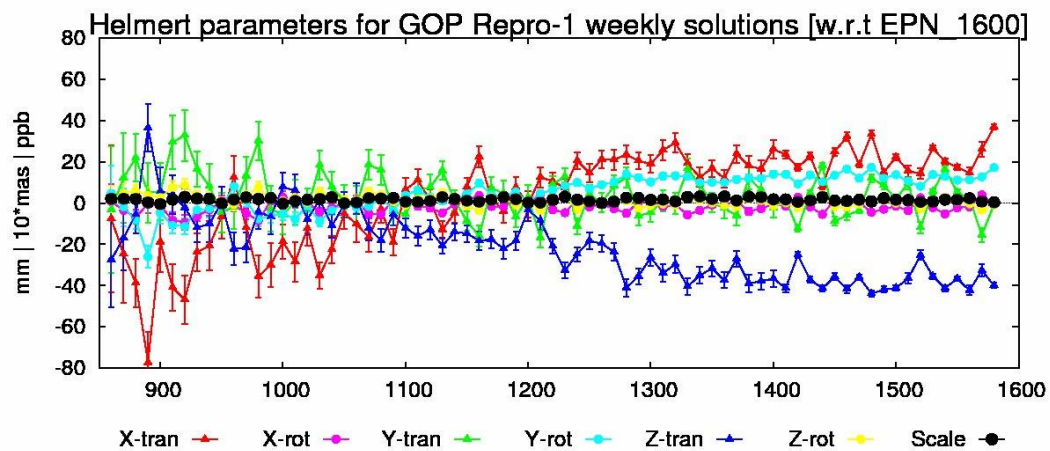
Helmert parameters (XYZ)







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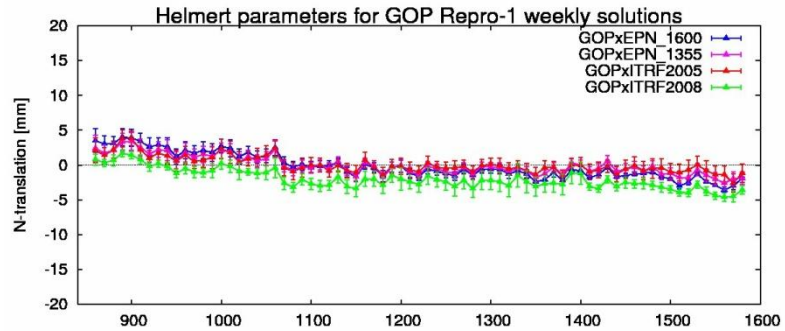
Helmert parameters (NEU)

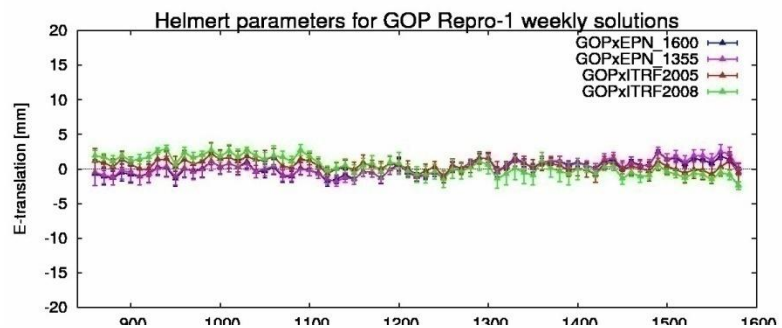
GOP-repro1

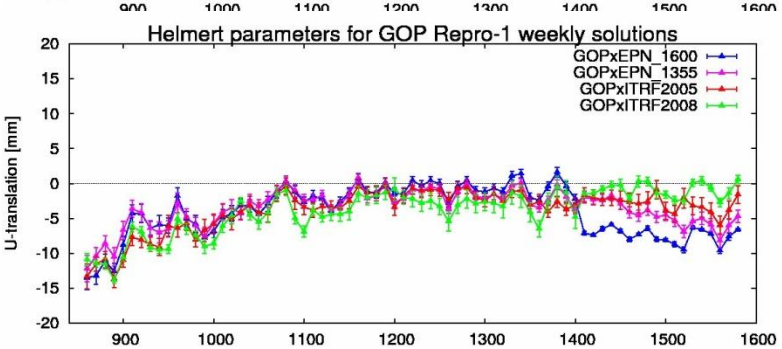
x

EPN_1600, EPN_1355, ITRF2005, ITRF2008

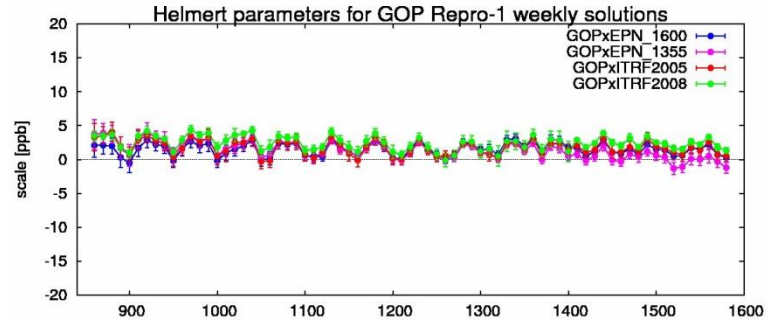
N, E, U - translations

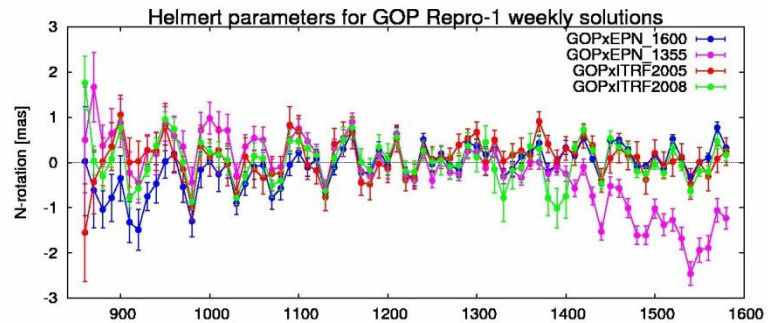


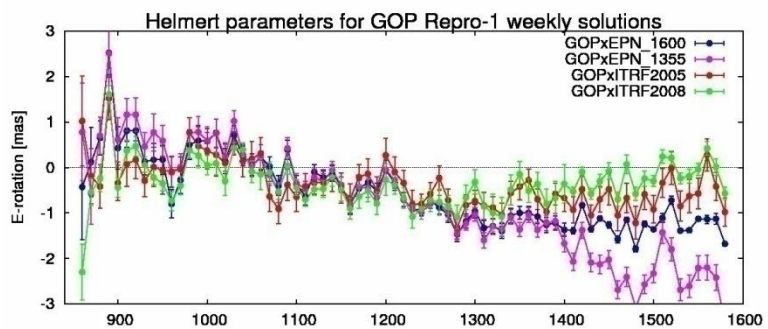


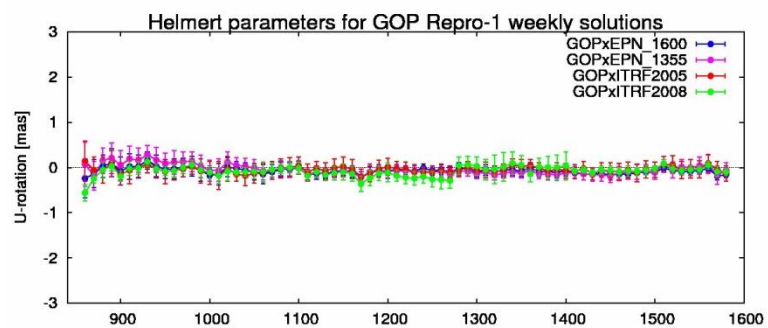


N, E, U, rotations + scale









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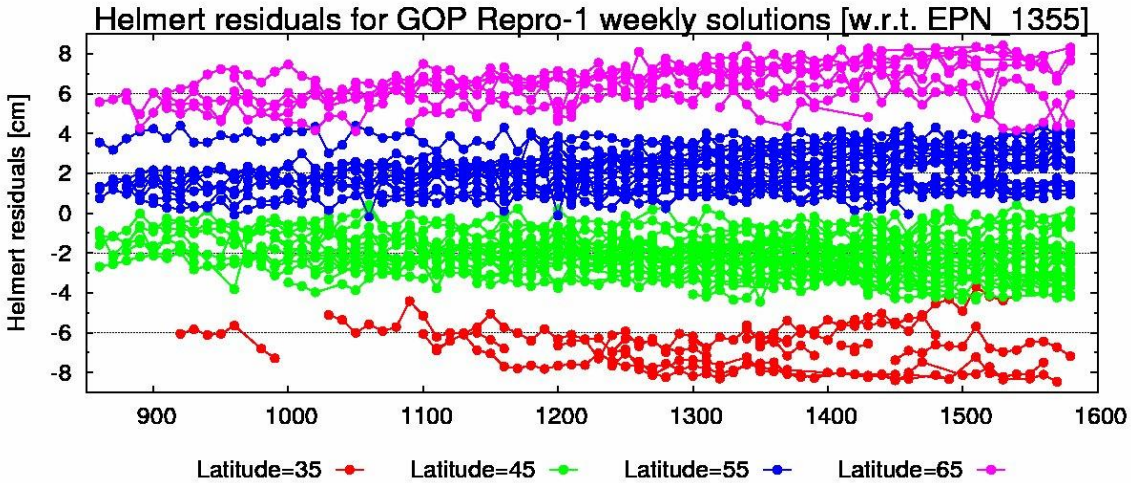
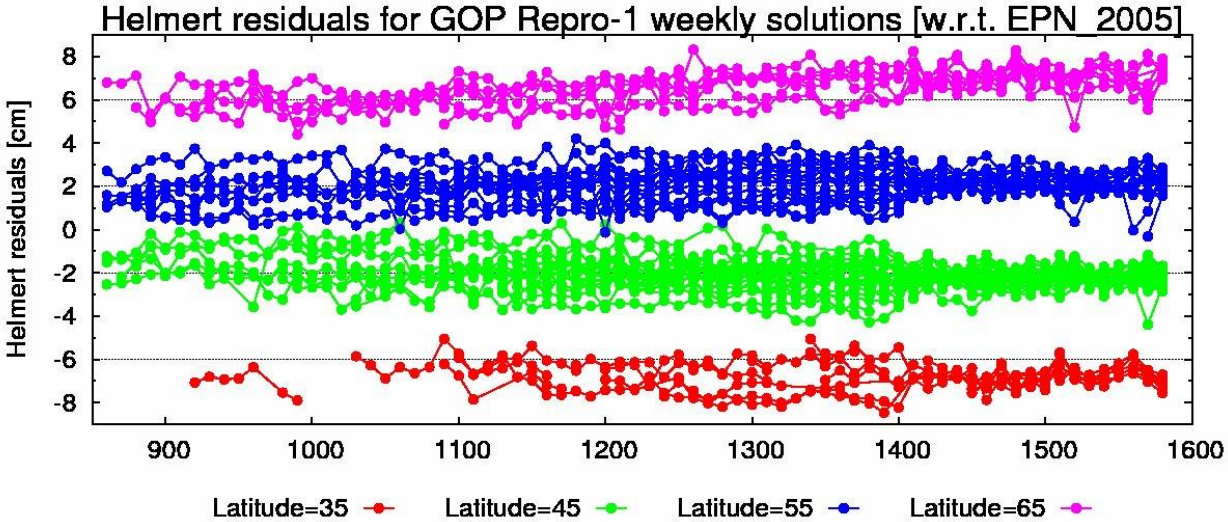
Coordinates UP residuals @ fiducials



GOP repro-1
x
EPN_C1355

GOP repro-1
x
EPN_C1600



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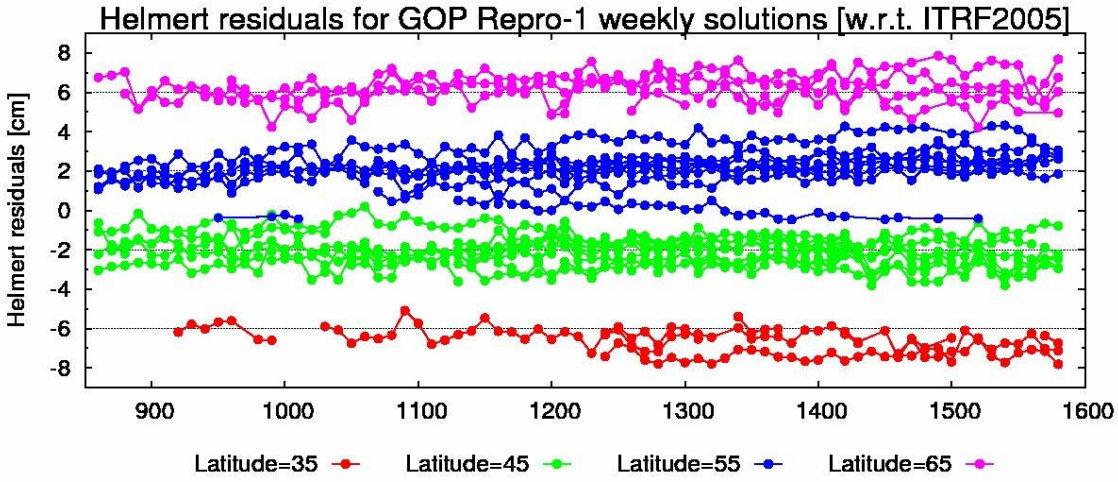
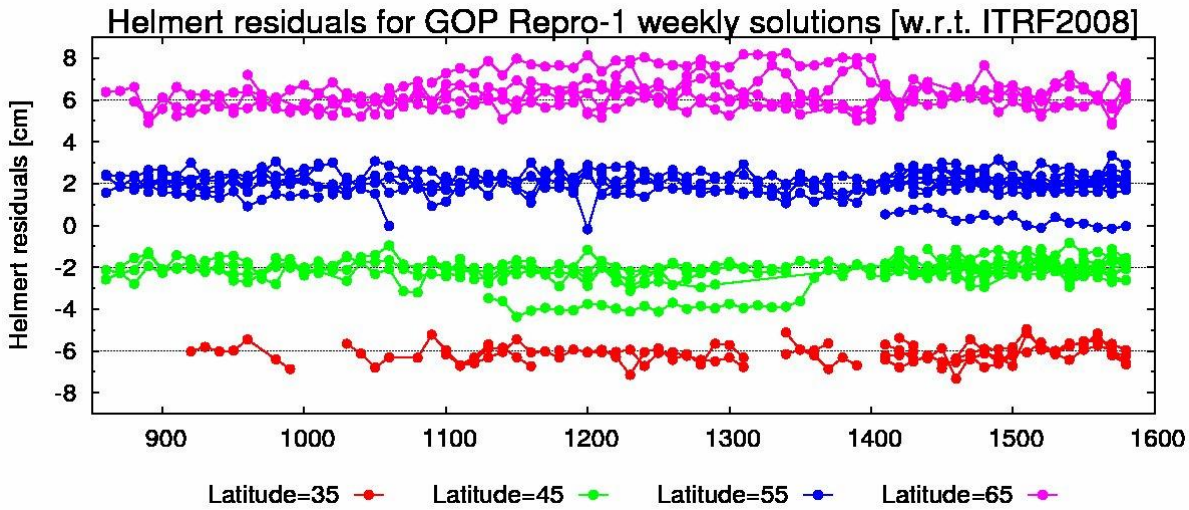
Coordinates UP residuals @ fiducials



GOP repro-1
x
ITRF2005

GOP repro-1
x
ITRF2008



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Possible improvements in RF

(updates vs. densifications)

Additional observation in space-domain

- DENSIFICATION – the improvement of RF realisation in space CRD(!)+VEL

Additional observation in time-domain

- UPDATE – the improvement of RF realisation in time CRD+VEL(!)

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European ITRF2005 densification
(realization and utilization)

Users require up to 5 year of coordinate prediction (until now still ETRF2005 is used) => requires extrapolation based mainly on a velocity datum

Two ETRF2005 solutions were available from EUREF:

EPN_1355 (original ETRF2005) – regional GPS densification of ITRF2005

EPN cumulative sol (e.g. EPNC_1600) – regional GPS densification and update

→ **Both datum defined using NNT+NNR+NNS for CRD+VEL w.r.t. ITRF2005 !**

Some notes on ITRF2005 densification report:

- The detail report shows many interesting, but contradicting results and raise many questions.
- The table in report comparing ITRF2005 x EPNC_1355 shows non-zero rates in all translations, rotations and scale, however zero-values should be guarantee by MMC !
- dRY is clearly correlated with dTX+dTZ in Europe and represents N-S tilt (E-rotation)
- E-rot trend is observed about 0.2mas/year for EPNC_1600 cumulative solution
- 0.046mas/year (dRY) can only partly explain observed N-S tilting represented by E-rot trend
- Problem with QAQ1 fiducial station inclusion/exclusion - produces NW-SE tilt of the network
- NNT-only vs. NNT+NNR+NNS comparison – produces very similar trend as in inclusion of QAQ1
- Evident strong correlation of estimated coordinates and velocities in CRD+VEL(NNT+NNR+NNT)

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European ITRF2005 densification – (lessons learned)

NNT+NNR+NNS datum definition coordinates and velocities is highly sensitive for such cases like QAQ1. NNT-only solution was not sensitive to QAQ1 problem (clearly something wrong in EPN cumulative solution)

The NNT vs. NNT+NNR+NNS is generally a good quality indicator for a datum definition. It was usable even in non-consistent ITRF2005 densification!

Reprocessed solutions do not explicitly require NNT+NNR+NNS conditions, since a consistency in all orbit product is available!

However, the question of minimum constrain solution still need to be addressed (see later inconsistencies in ETRF2008 scale!)

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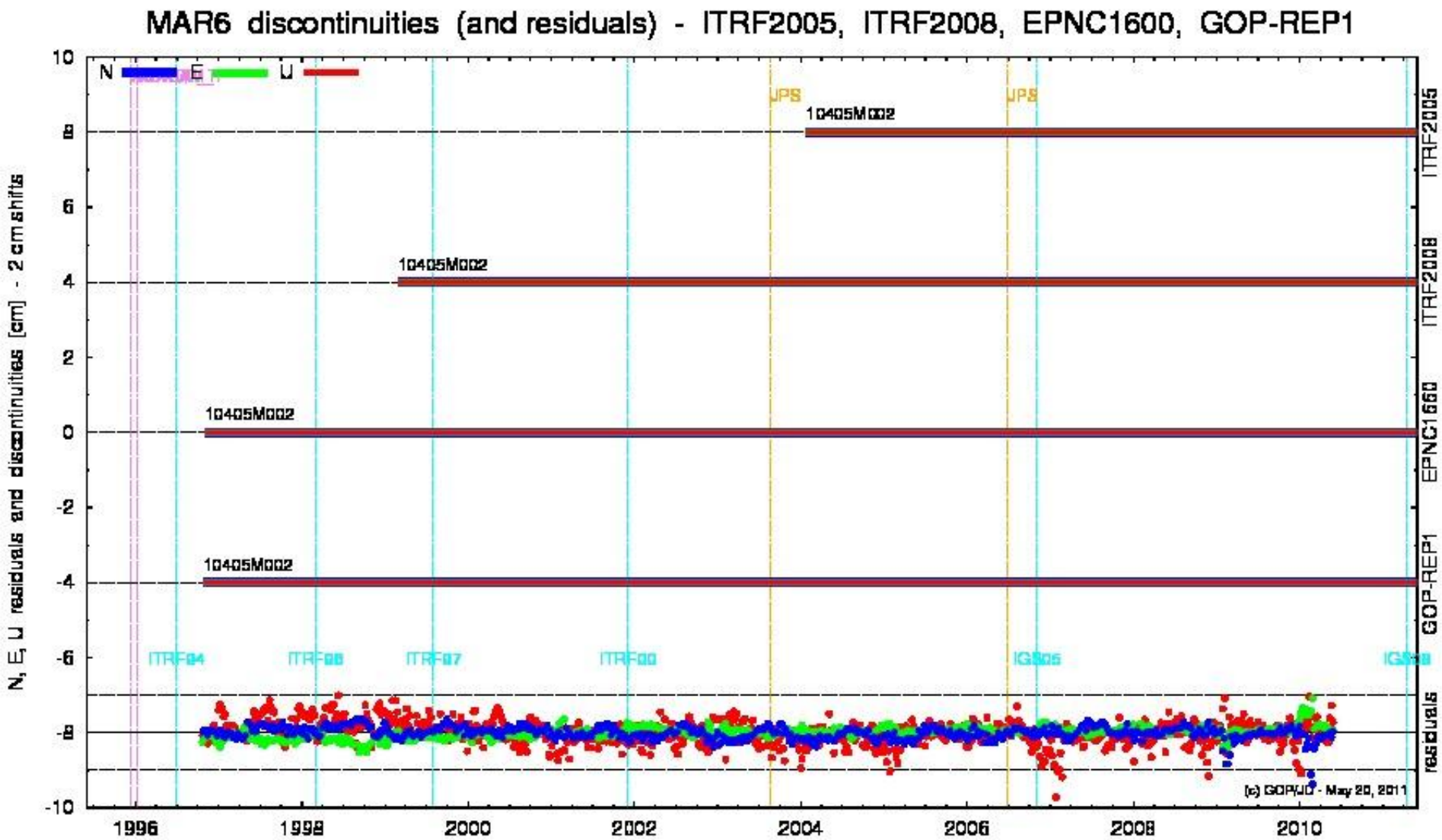
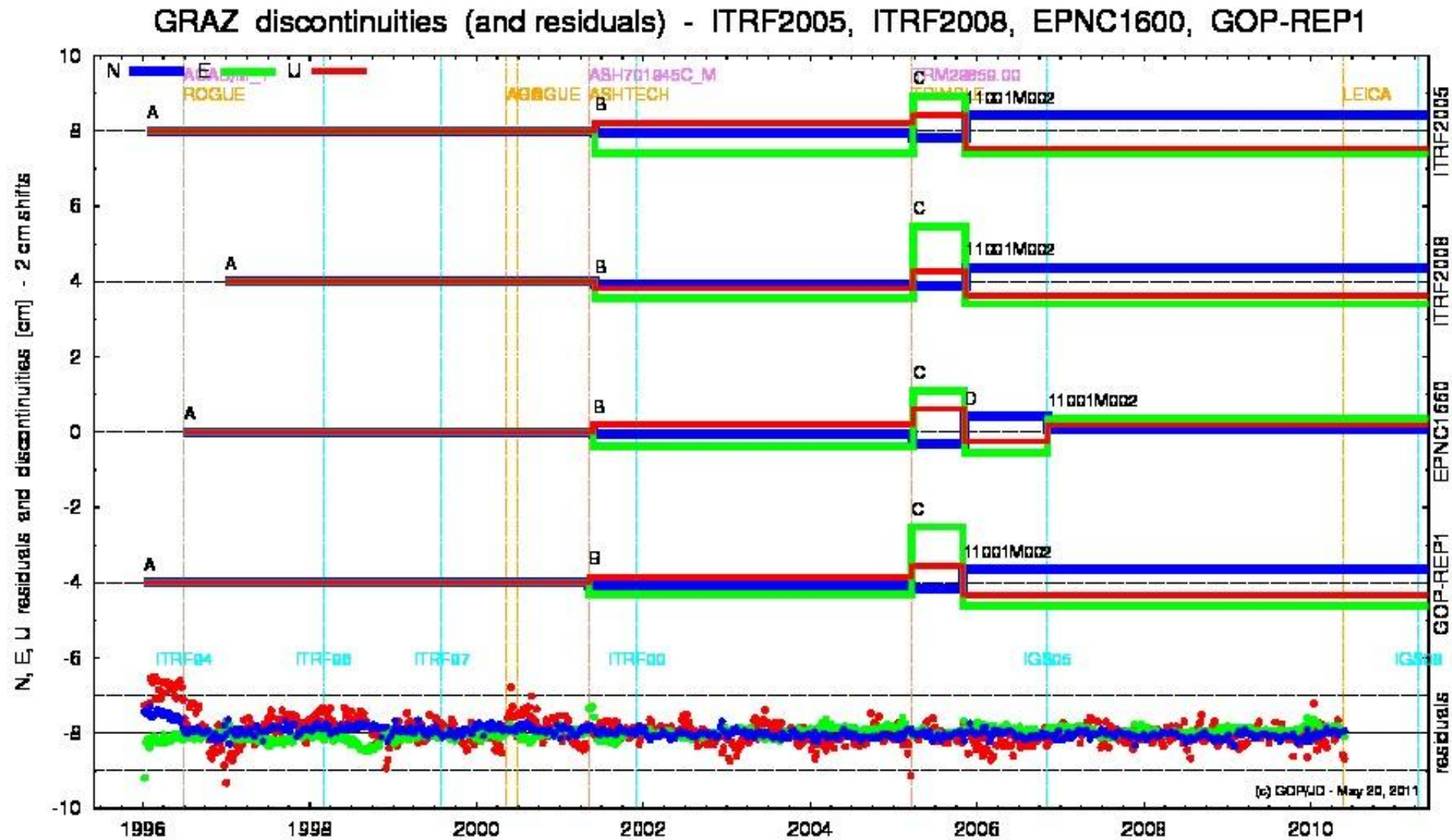
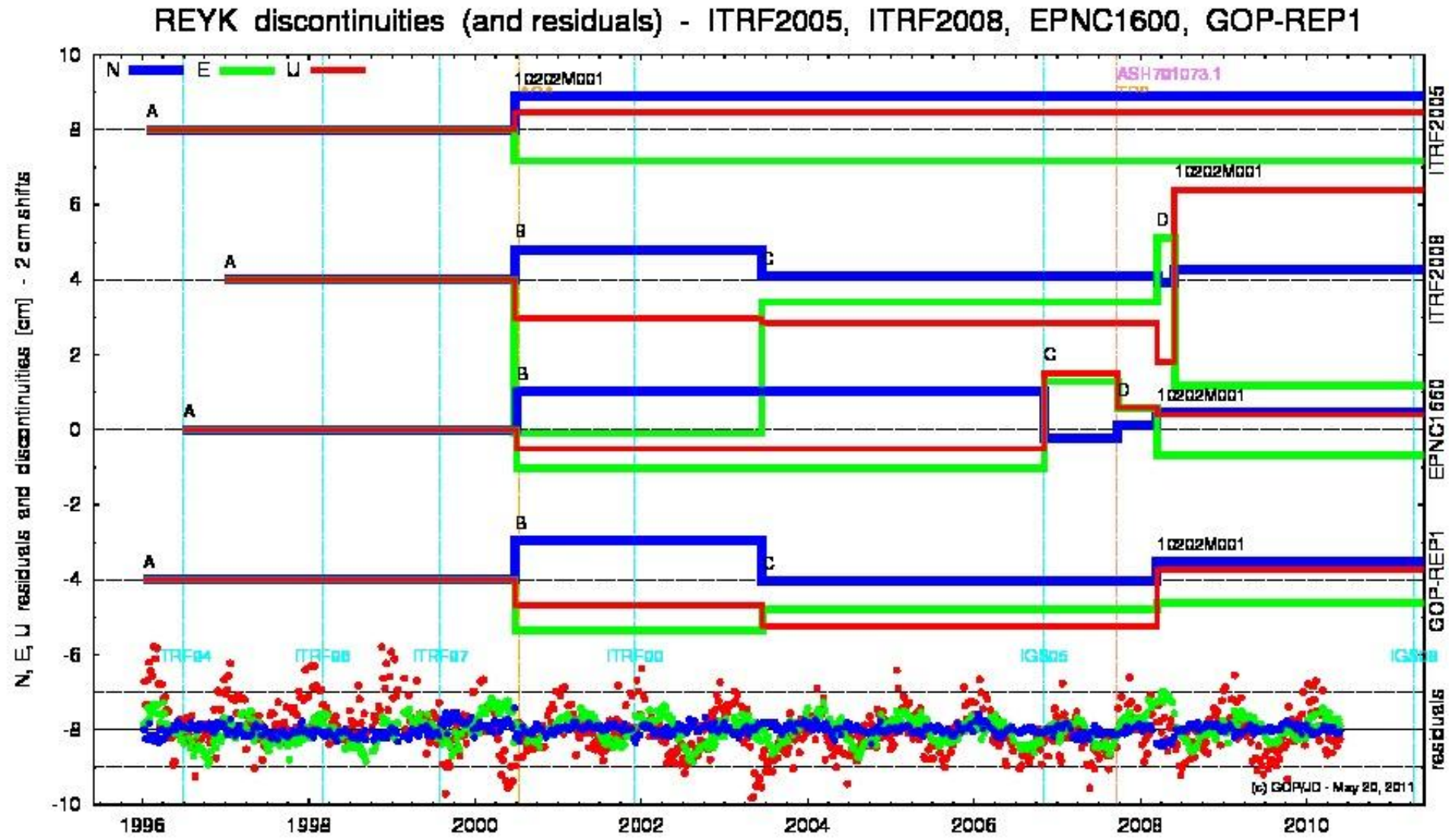
Discontinuities - OK



Discontinuities – GPSweek 1632



Discontinuities – ITRF2008 ?!



GOP Repro1+ solution of all EUREF stations

two solutions based on IGS05/IGS08 models and IGS05/IGS08 reference frames

(first results)

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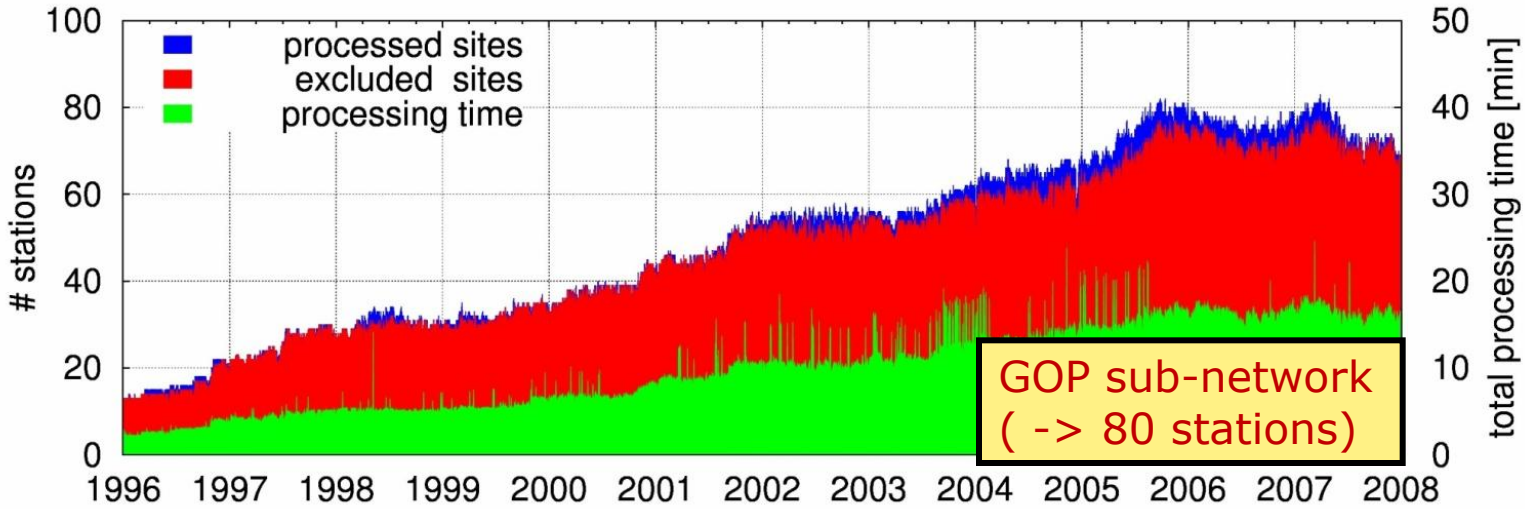
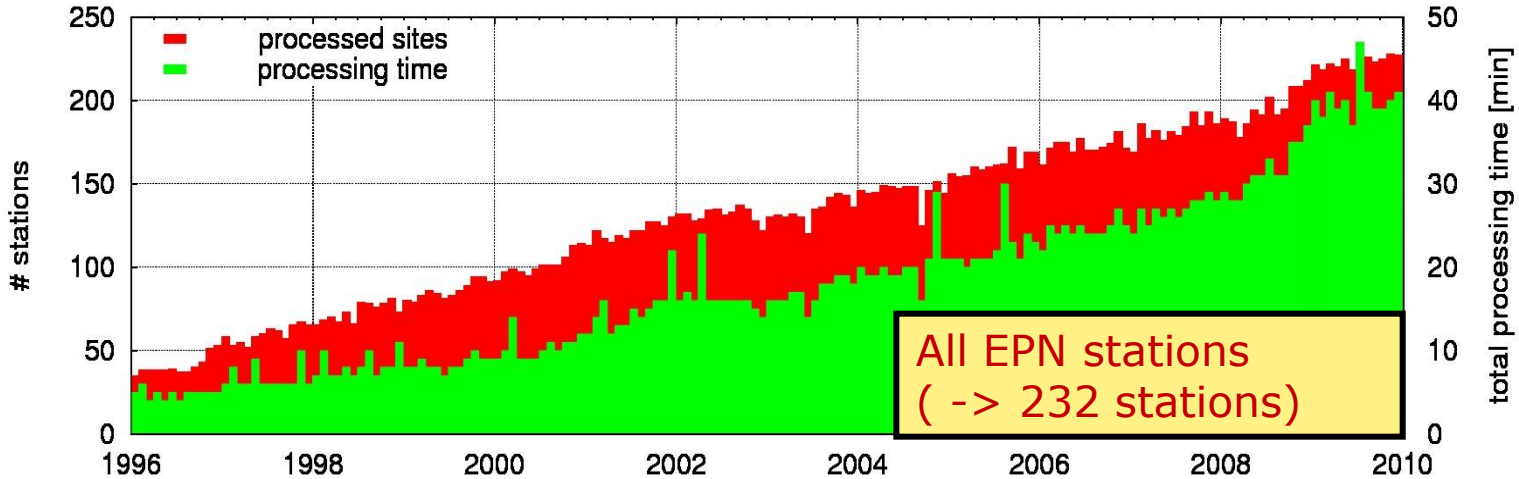
Optimization for EPN full solution





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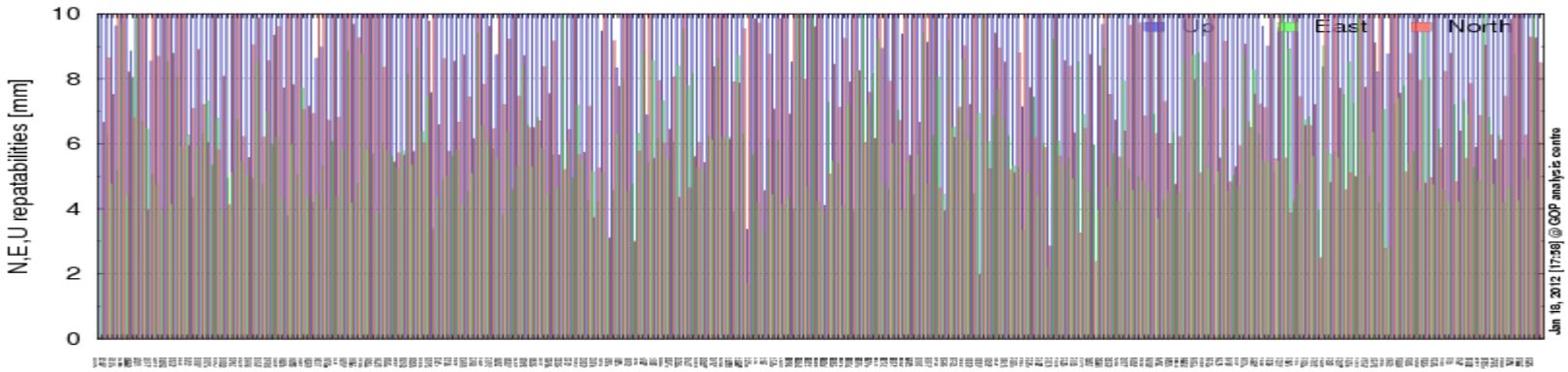
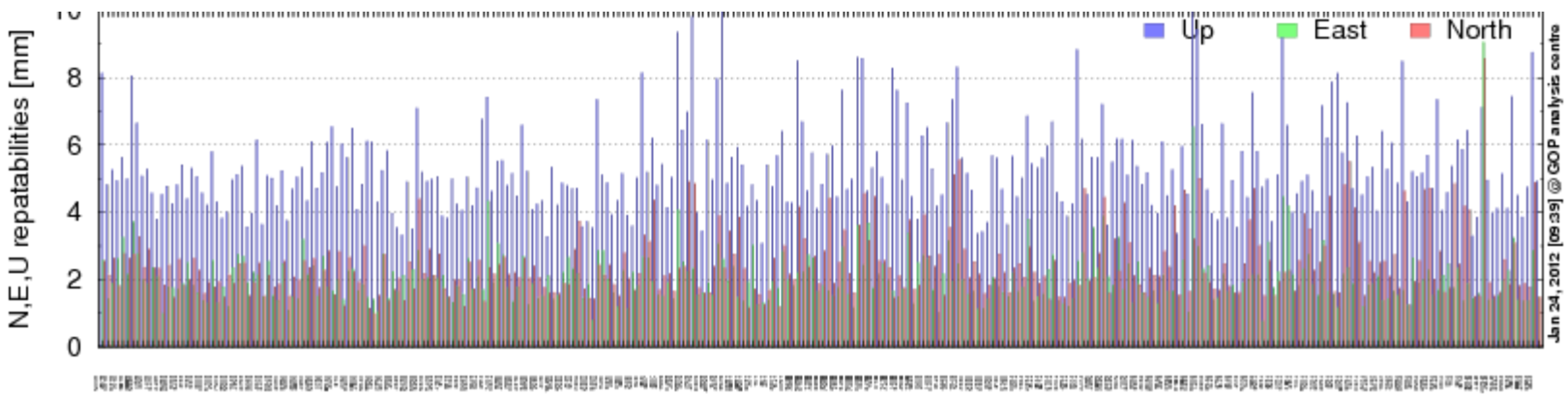
GOP Repro1+ CRD repeatabilities

Draft solution – without outlier rejection, discontinuity settings, …



Preliminary solution – no outliers, enhanced discontinuity settings, …



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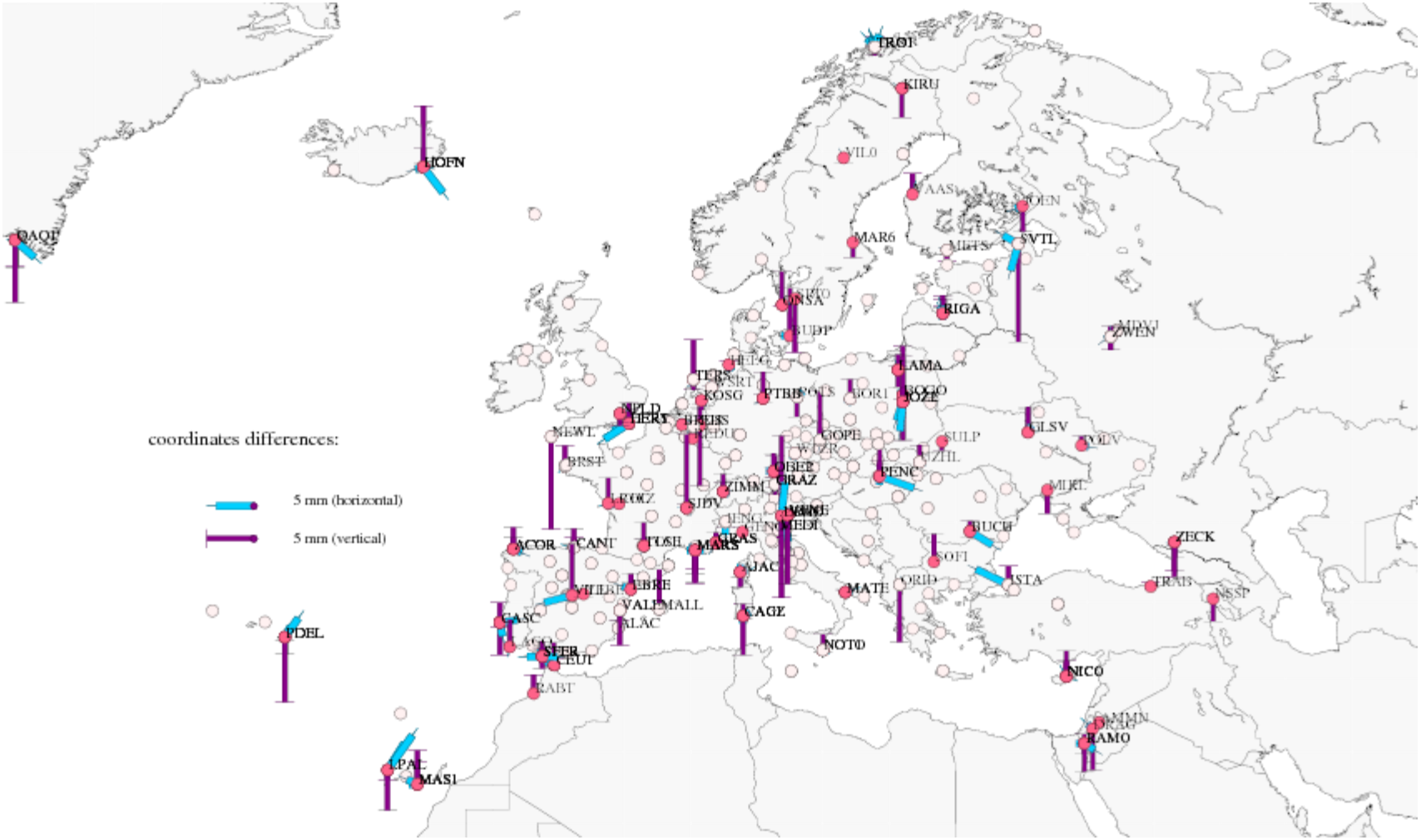
GOP Repro1+ (Helmert residuals)

In red: fiducial stations with residuals from Helmert transformation



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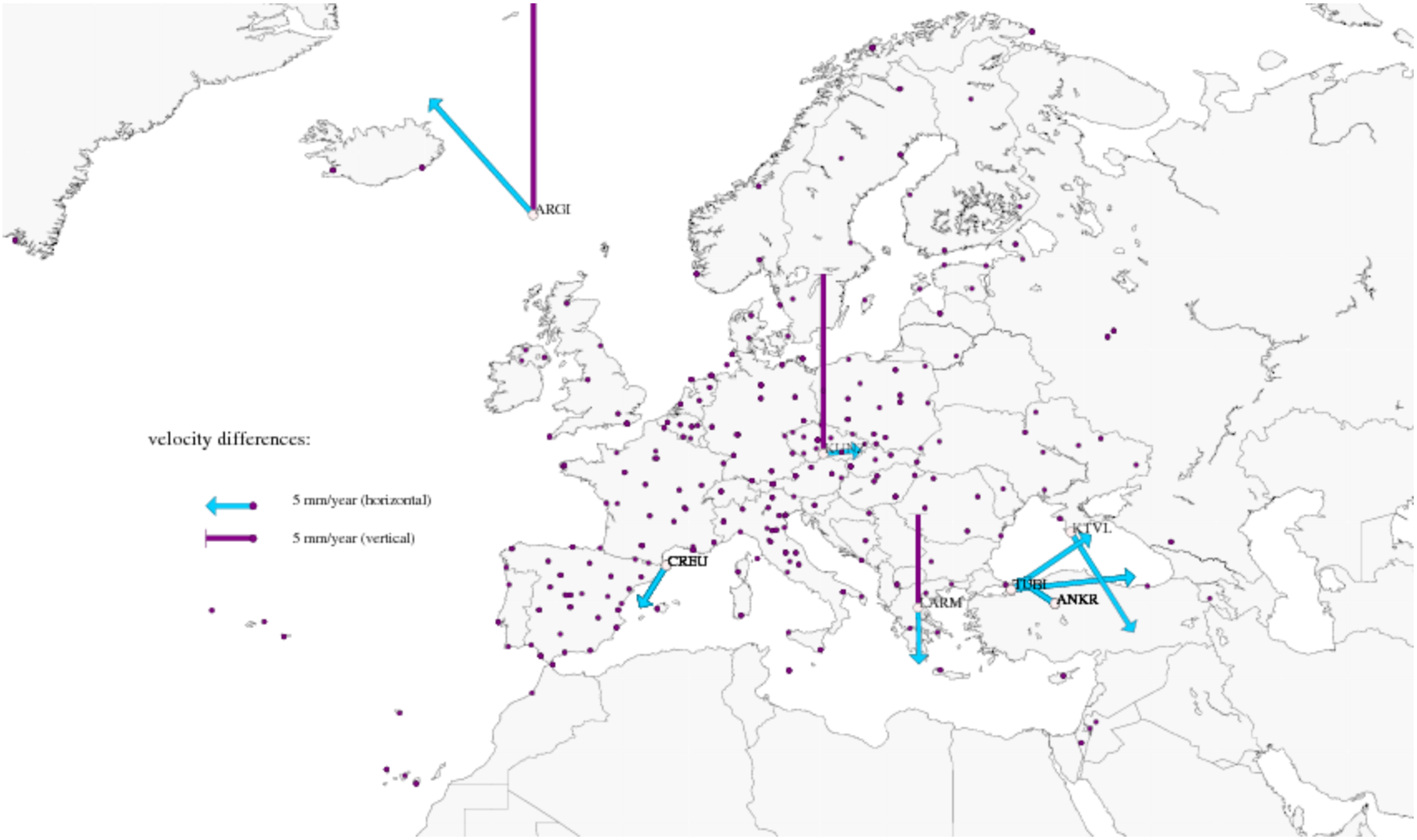
GOP Repro1+ (estimated velocities)

Velocities w.r.t. to ITRF2008 solution (European intraplate velocities)



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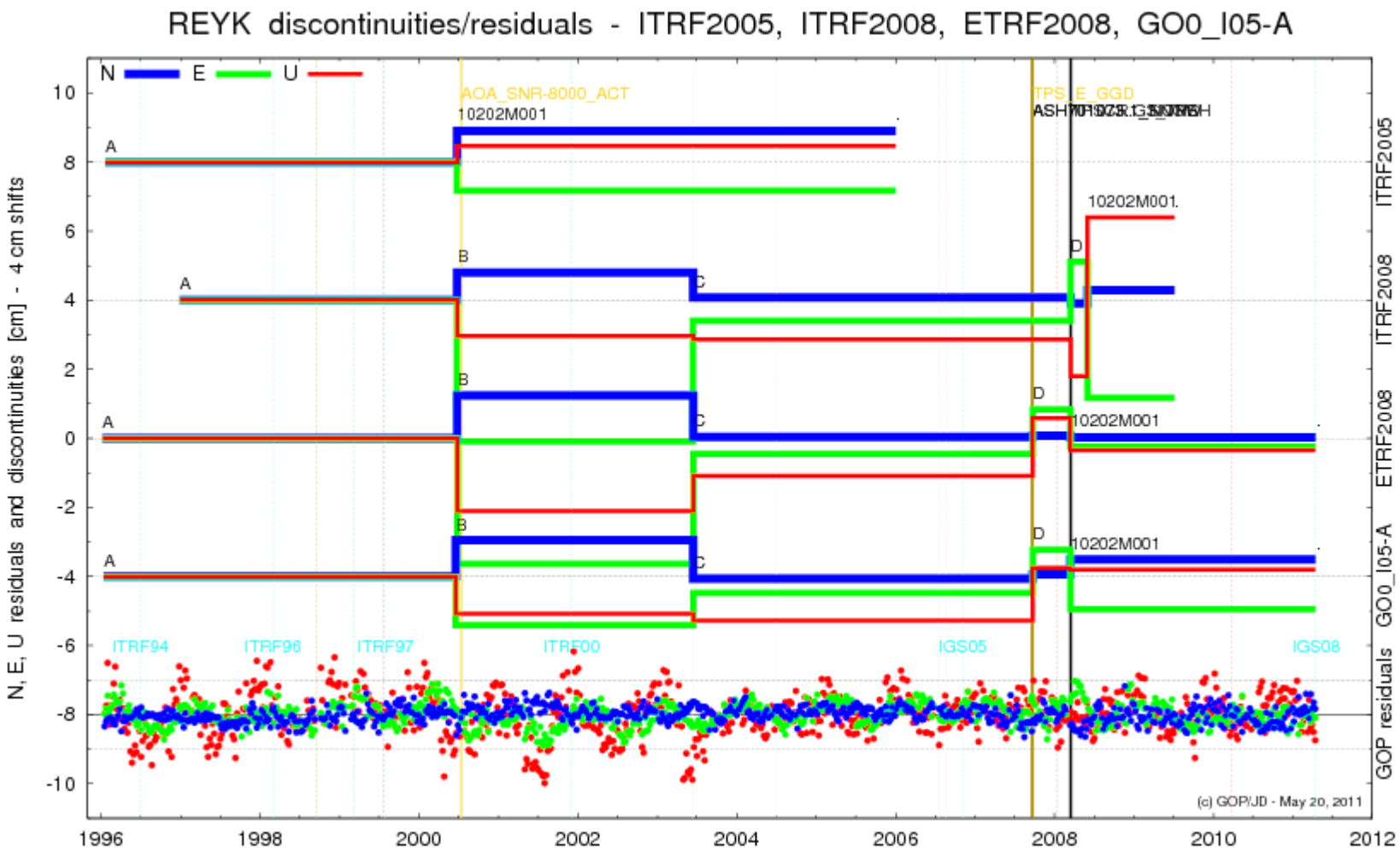
GOP Repro1+ (solutions example)



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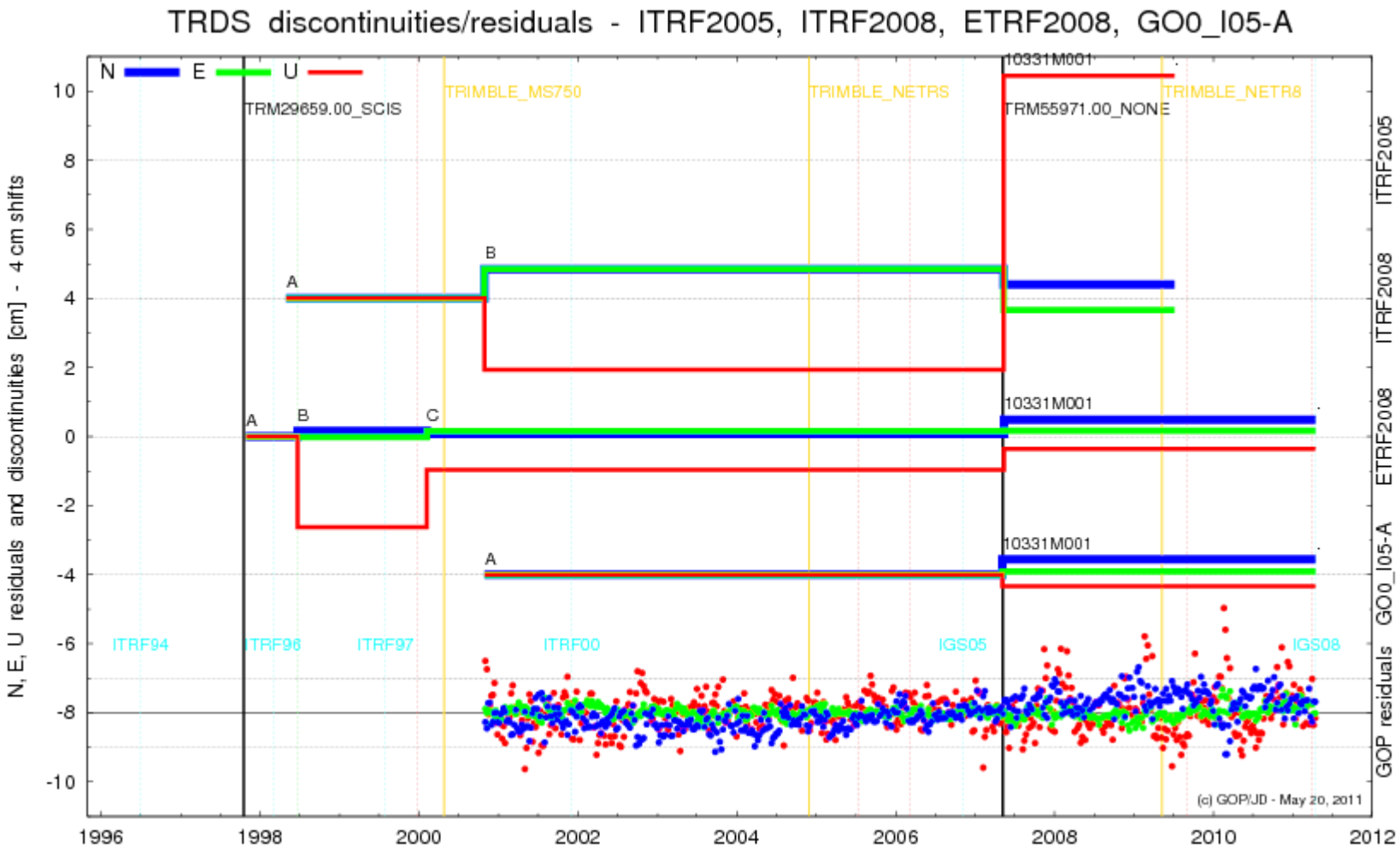
GOP Repro1+ (solutions example)



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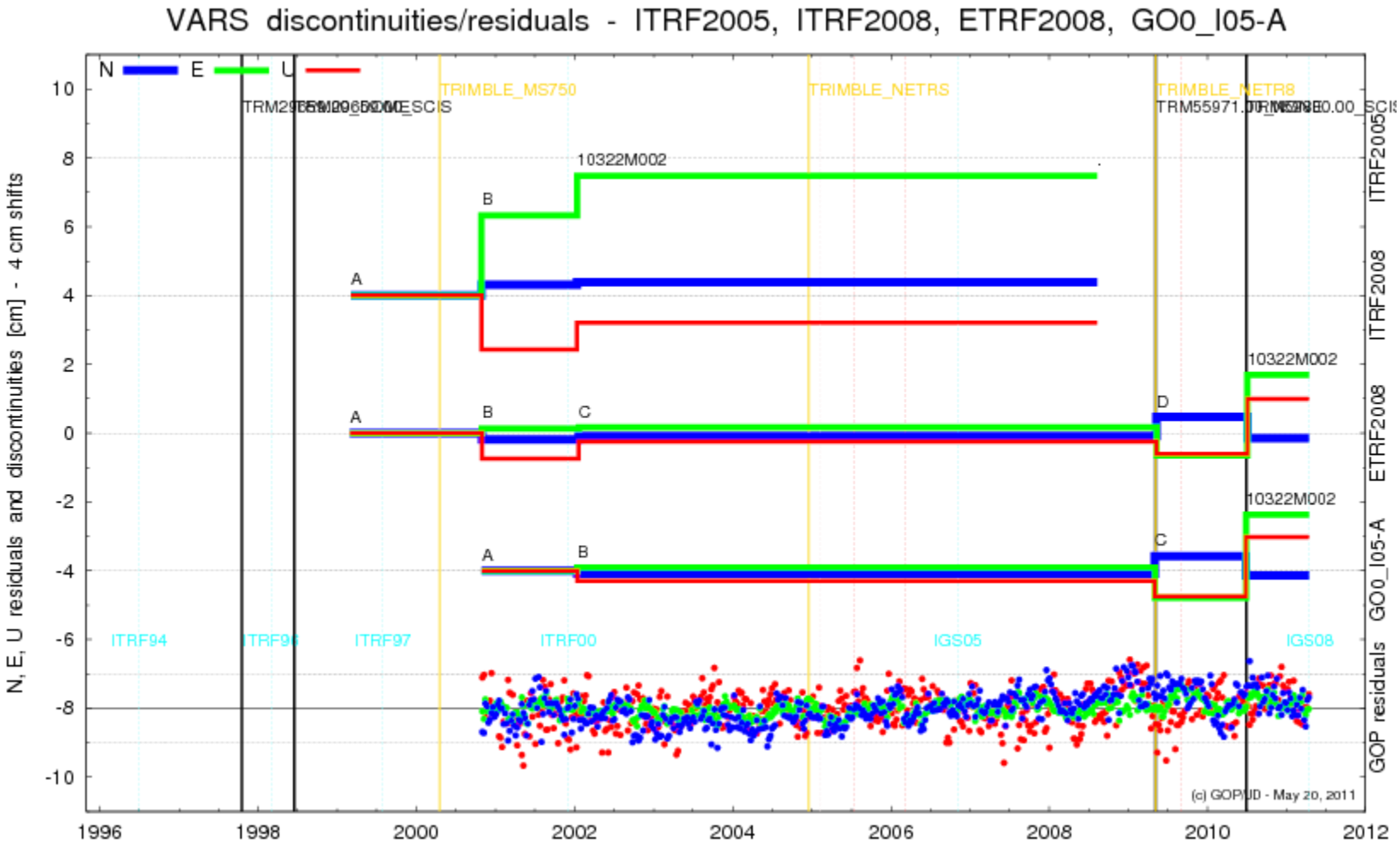
GOP Repro1+ (solutions example)



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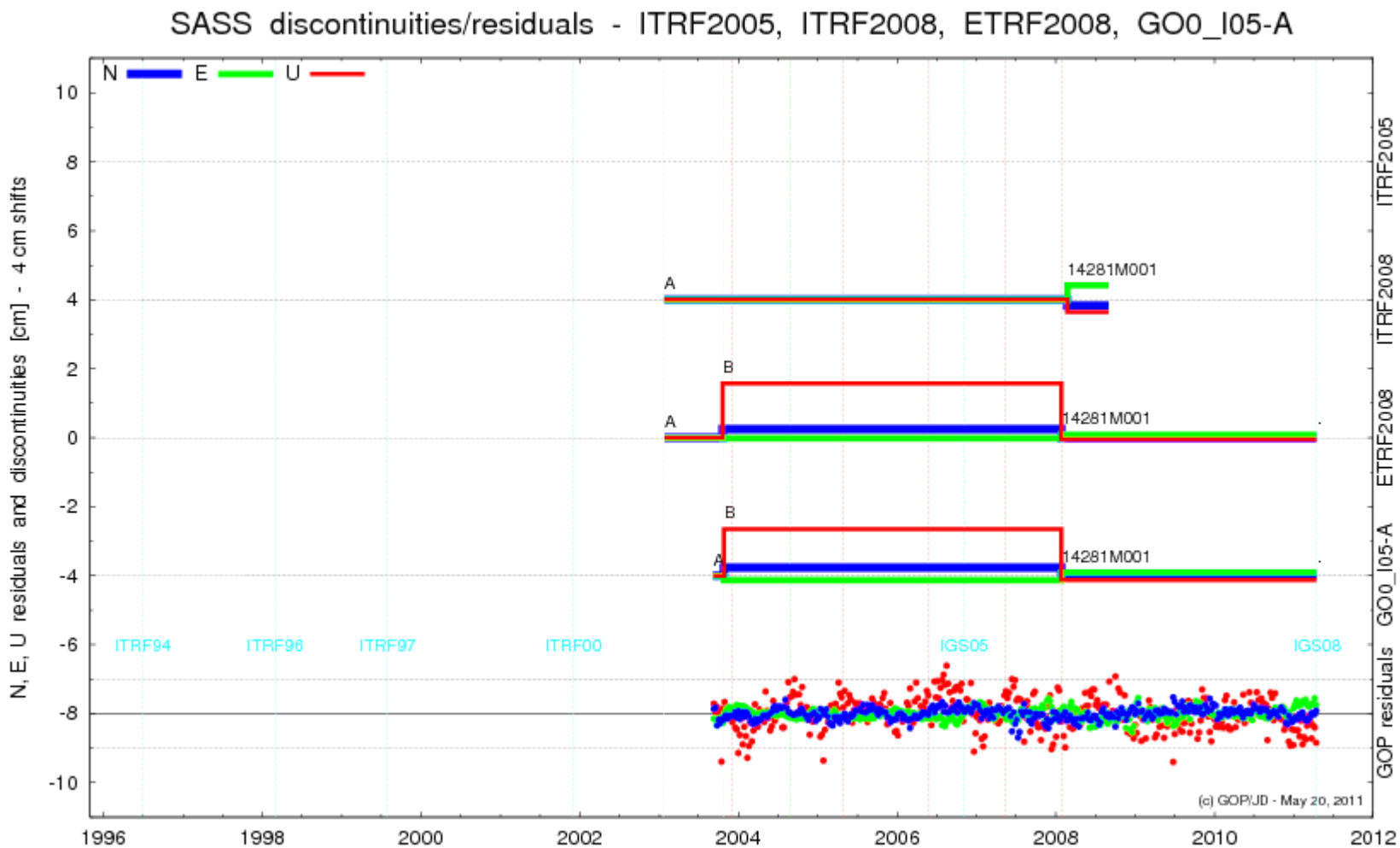
GOP Repro1+ (solutions example)



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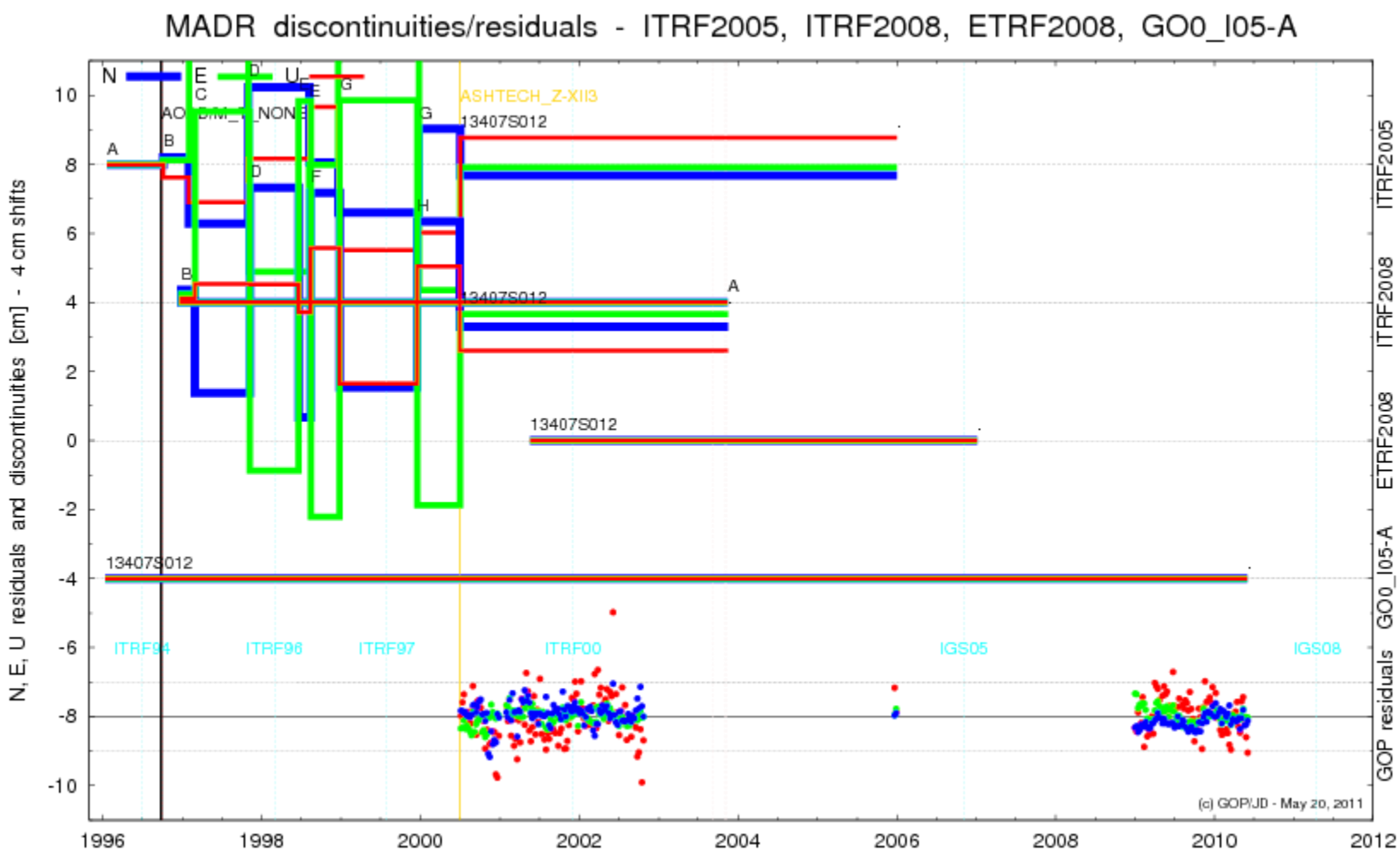
GOP Repro1+ (solution examples)



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GOP Repro1+ Preliminary result summary

- **Recognized problem with datasets (in various solutions)**
  - ITRF2008 – total 38 stations with shorten periods (9 significantly)
  - ETRF2008 – total 22 stations with shorten periods (3 significantly)
    - a few stations missing in solution (former EPN stations)
    - some data gaps not well handled and shifted discontinuity definitions
  - GOP Repro1(+) - total 35 stations with shorten periods (20 significantly)
    - missing in ROB historical archive, which was mirrored to GOP data centre
    - some stations additional to ETRF2008 solution (usually former stations)
    - some data gaps due to missing or excluded data (some different from ETRF2008)
- **Differences or problems in individual solutions**
  - ITRF2008 – REYK, SASS, TRDS, VARS, ALME, KELY, KIRU, MADR, NOTO, NYAL, ORID, POTS, WROC, SJDV, WSRT, WARN
  - ETRF2008 – GRAS, QAQ1, REYK
  - GOP Repro1(+) – DUBR, KELY, (BZRG, CREU, LAMA, OBET)
  - Differences in ETRF2008 x GOP : BELF, BELL, TERS, HERS, HOBU, MANS, METS, PUYV, SKE0, STAS, UNPG, TUC2, TUBI

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New ITRF2008 and its densification in Europe

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ITRF2008 - realization

- ***the origin*** - is defined in such a way that there are null translation parameters at epoch 2005.0 and null translation rates between the ITRF2008 and the ILRS SLR time series.
- ***the scale*** - is defined in such a way that there null scale and scale rate between ITRF2008 and the average of VLBI and SLR scales/rates.
- ***the orientation*** - is defined in such a way that there are null rotation parameters at epoch 2005.0 and null rotation rates between the ITRF2008 and ITRF2005. These two conditions are applied over a core network
- more at ***http://itrf.ensg.ign.fr/ITRF_solutions/2008***

ITRF2005 - ITRF2008	T1 [mm]	T2 [mm]	T3 [mm]	SC [10-9]	R1 [mas]	R2 [mas]	R3 [mas]
	-0.5	-0.9	-4.7	0.94	0.000	0.000	0.000
+/-	0.2	0.2	0.2	0.03	0.008	0.008	0.008
Rates	0.3	0.0	0.0	0.00	0.000	0.000	0.000
+/-	0.2	0.2	0.2	0.03	0.008	0.008	0.008

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New ITRF2008 European densification (ETRF2008)

- **Based on EPN Repro1 – GPS weeks: 0836 – 1538 (IGS05 models)**
- **Based on routine EPN solutions: 1538-1631 (before switch to IGS08 models)**
- **Excluded various stations/period showing outliers or other problems**
  - Provide stable time-series of North, East and Up formal RMSs
- **Conserved as many discontinuities from ITRF2008 – but not all !!!!**
  - Different ETRF2008 discontinuities supposed as improvement w.r.t. ITRF2008
  - ETRF2008 – guarantees consistency with valid site-log files
- **Minimum constraints solution: NNT+NNR+NNS for CRD+VEL w.r.t. ITRF2008**
  - However, NNT+NNS tested as well (no significant difference - OK!)
- **Datum based on selected set of 55 fiducial stations (92 common, 37 rejected)**
  - Various solution numbers applied (not all for a single station)
- **Provided consistent time-series of 7 Helmert parameters (TX,TY,TZ,RX,RY,RZ,SC)**
  - However, significant shift (+3ppb) and seasonal variation (1-4ppb) in scale
  - Others centred around zero, somewhere small trends, significant TZ variations!
- **Recognized and eliminated N-S tilted in ETRF2005 and EPNC1600 solutions !**

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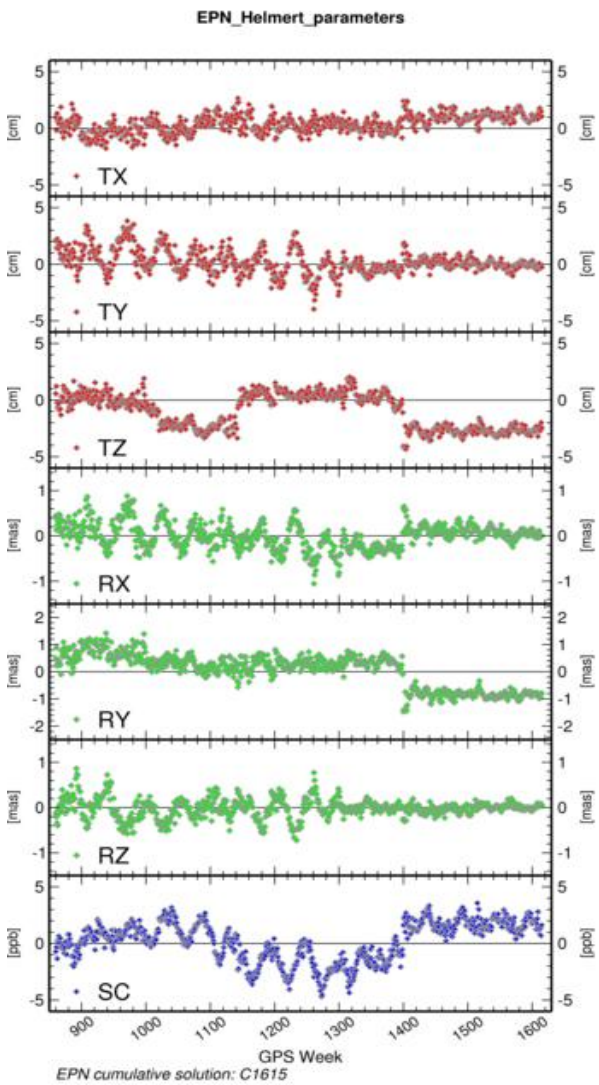
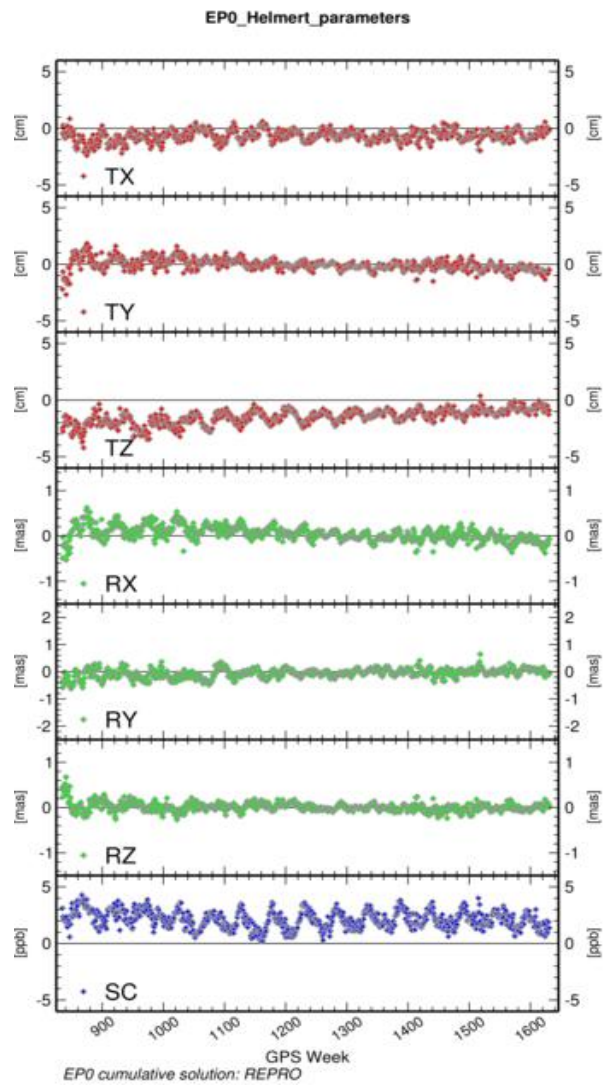
New ITRF2008 European densification (ETRF2008)

EPNC1600



ETRF2008



Courtesy of A.Kenyeres (2012)

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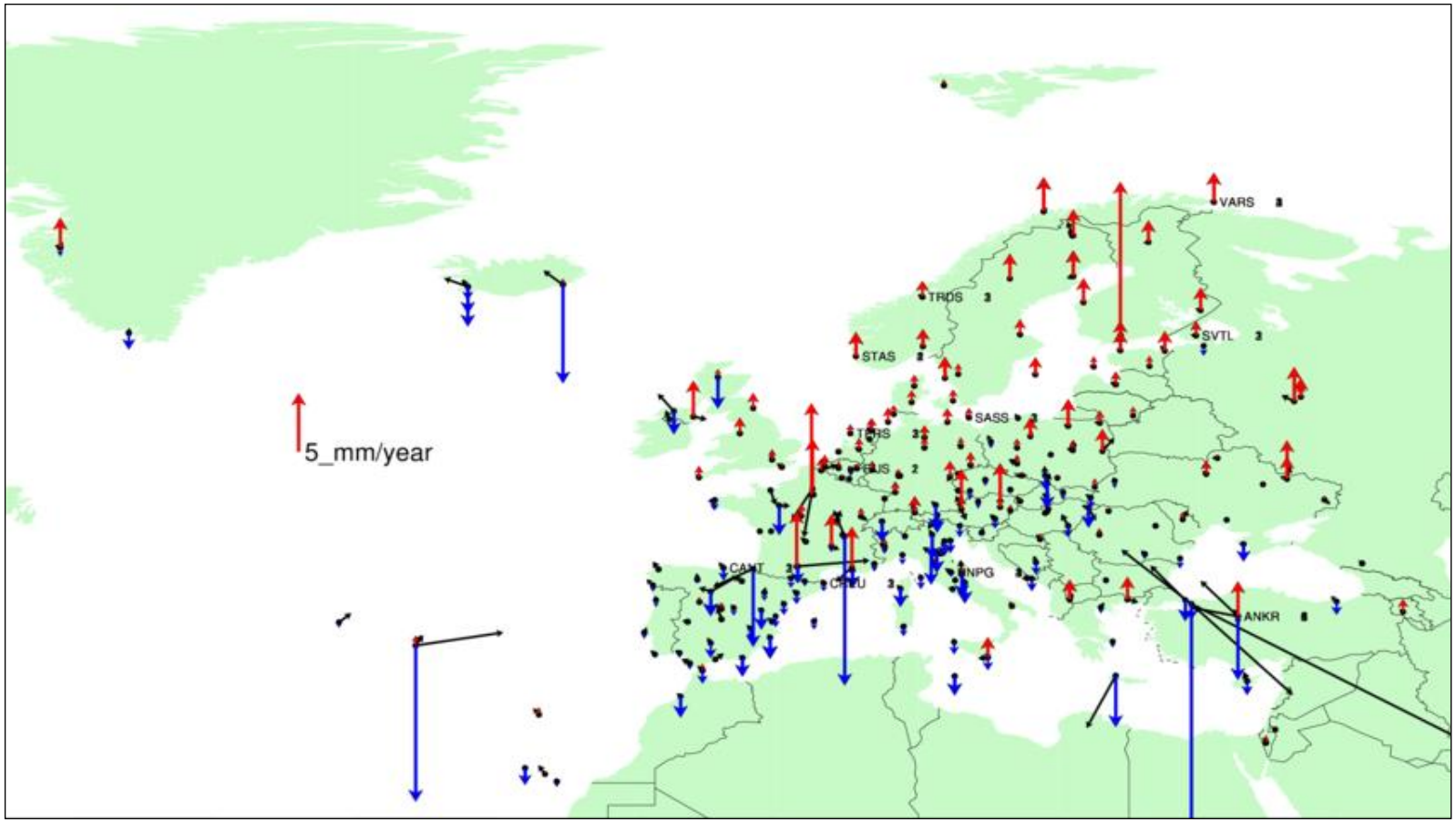
New ITRF2008 European densification (ETRF2008)

velocity comparison w.r.t. ETRF2005/EPNC_1600



Courtesy of A.Kenyeres (2012)

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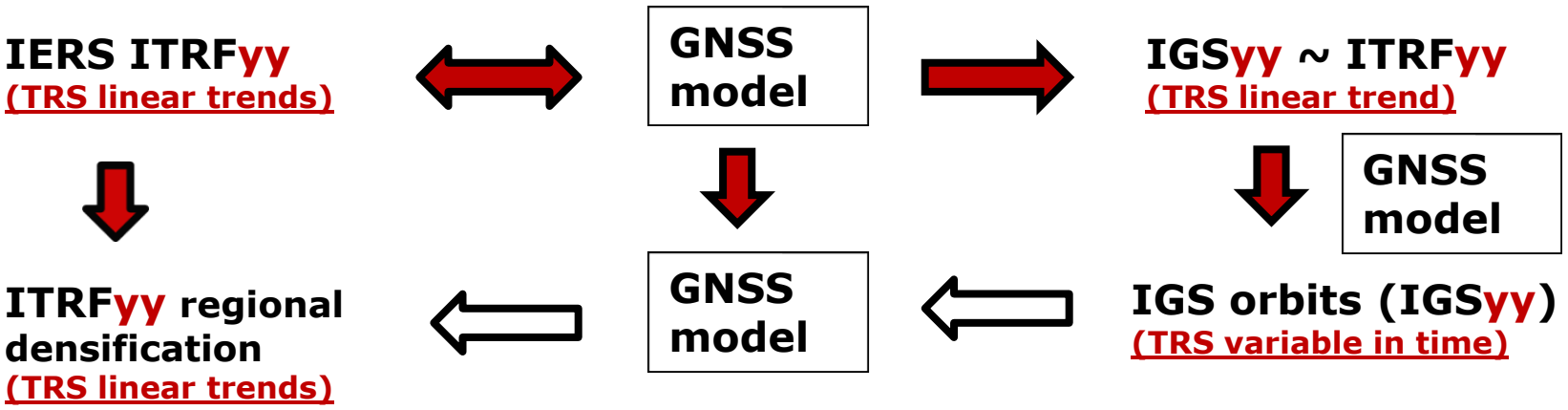
Minimum constrain solution - discussion



National campaign: NNT, NNT+NNS or NNT+NNR+NNS ?

- *smaller networks than European densification*
- *if using up-to-date models then NNT constraints should be fine (or NNT+NNS)*
- *orientation should be used from ITRF in orbits*
- *however scale has a problem between ITRF2008 and GNSS-based scale*

How to deal with the scale bias and variation between ITRF2008 and IGS08 and other bias/variations/trends in Helmert parameters time-series

- *Need to be addressed at EUREF TWG*
- *Some insight is expected from the first IGS08-based GOP repro (coming soon)*

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Summary

- GOP Repro1 results applications:
  - Assessment of the ETRF2005 and EPN cumulative solution problem
  - Checking selected stations in ITRF2008 solution (discontinuity/CRD/VEL)

- GOP Repro1+ results applications:
  - Independent check for ETRF2008/EPN cumulative solution
  - First full EPN Repro solution based on up-to-date IGS08 models
  - Testing the impact of new IGS08 models during GPS week 1632
  - Consistency of station discontinuities with ITRF2008 and ETRF2008
  - ETRF2008 datum definition testing and studying an optimal variant
  - Readiness and recommendations for Repro2 (database improving etc.)
  - Troposphere product: study the trends and variations in Europe
  - assess the potential in evaluation of time-variable gravity field models

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