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Development of the GNSS – Based Geodetic Infrastructure in the Czech Republic in Context of International Projects

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UN/Latvia Workshop on GNSS Applications
Riga,Latvia, 14 – 18 May 2012

Outline

1. Introduction
2. GNSS – Based International projects and Services with Czech Participation
3. Permanent GNSS stations and networks in the Czech Republic
4. Data Analysis and Research - Overview
5. Summary

1. Introduction

- Galileo Application Congress Prague 2012 – Jan 26 – 27, 2012 Prague Mariott Hotel
- GSA Headquarters in Prague
- Development in GNSS applications in agriculture and transport in the Czech Republic appreciated
- GNSS applications in geodesy, surveying, mapping and cadastre address smaller user segment, but still are very important (reference frames, satellite orbits, precise georeferencing)

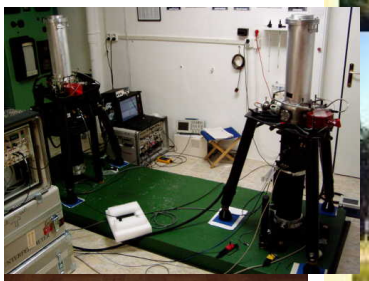
GNSS-Based International Projects and Services with Czech Participation

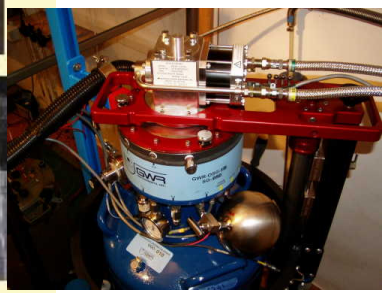
- International GNSS Service (IGS)
- EUREF Permanent Network (EPN)
- EUPOS (CZEPOS as a national contribution)
- EUMETNET Projects (COST 716, TOUGH, E-GVAP, E-GVAP II)
- Consortium CEGRN (Central European Geodynamic Reference Network, projects CERGOP, CERGOP2)
- International DORIS Service (IDS)

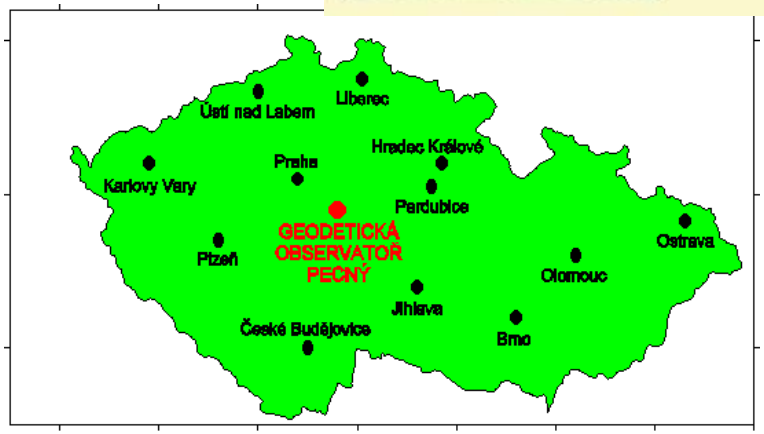
Permanent GNSS Stations and Networks in the Czech Republic

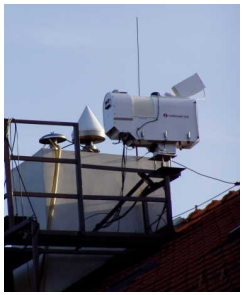
- Fundamental Geodetic Observatory Pecný – GOPE, http://www.pecny.cz (IGS, EPN, CZEPOS, VESOG, E-GVAP II)
- CZEPOS: http://czepos.cuzk.cz, Czech Positioning System, **28 PS**, operated by the Land Survey Office + **27 PS** of neighbour countries
- GEONAS: http://geonas.irsm.asc.cz, **19 PS**, experimental monitoring network operated by the Institute of Rock Structure and Mechanics, Acad. Sci. CR
- VESOG: http://pecny.asu.cas.cz/vesog/, research and experimental GNSS network operated by the RIGTC GOP and academic institutions, **8 PS**
- TopNet: http://www.geodis.cz, **23 PS**, includes also 11 GEONAS and 3 VESOG PS, operated by the private company GEODIS Brno
- Trimble VRS NOW Czech: http://www.geotronics.vrsnow, **24 sites** + 8 sites of Trimble VRS NOW Deutschland, operated by Geotronics Praha, s.r.o. private company
- several smaller networks, operated by private companies, e.g. *byS@T* and others
- **Total: 98 permanent stations, 12 of them EPN**

Fundamental Geodetic Observatory Pecný (GOPE) – RIGTC at Ondřejov









GOPE – Fundamental GNSS Station

- Established in 1993, since 1995 has been contributing to IGS (International GNSS Service)
- Topcon Net-G3 receiver, Topcon CR-G3 antenna with a spherical radom TPSH, individual PC calibration
- Tracking the following GNSS: GPS NAVSTAR (L1C, L1P, L2P, L2C), GLONASS (L1C, L2P)
- Post-processing data + real-time data
- Post-processing data downloaded in RINEX 2.10 format in daily files with 30 sec sampling rate, hourly files/ 1 and 30 sec, 15-min files/ 1 sec
- Data are forwarded to the following data centers:

- GOP - RIGTC, Czech Republic (hourly and daily 30 sec data)
- BKG, Frankfurt am Main, Germany (hourly and daily 30 sec data)
- OLG, Graz, Austria (hourly and daily 30 sec data)
- CZEPOS, Land Survey Office, Czech Republic (hourly 1 sec data)
- CDDIS, NASA, U.S.A. (15-minute 1 sec data)

- Real-time RTCM 2.3 and RTCM 3 data streams forwarded in NTRIP envelope to VESOG caster and further to BKG and CZEPOS casters

Permanent GNSS station GOPE

Topcon CR-G3 antenna with TPSH radom

Topcon Net-G3 receiver

GOPE Participation in the M-GEX IGS project

- station GOP6 – excentric site of the main GOPE station in the Multi-GNSS Experiment
- Leica GRX1200+GNSS receiver + Leica AR25.R4 antenna with a spherical radom LEIT and individual PC calibrations
- Satellite tracking: GPS NAVSTAR (L1C, L1P, L2P, L2C, L5), GLONASS (L1C, L2P), Galileo (E1, E5a, E5b, AltBoc), SBAS (L1)
- Post-processing data in RINEX 2.10 (directly generated by the receiver) and RINEX 3.01 (conversion from 2.11 using own software in the operation centre):
  - hourly and daily files/ 30 sec data
  - 15 min files of 1 sec data
- Post-processing data forwarded to:
  - CDDIS, NASA, USA (only RINEX 3.01)
  - BKG, Frankfurt am Main, Germany (only RINEX 3.01)
  - IGN, Paris, France(RINEX 2.10 and 3.01)
  - GOP, RIGTC, Czech Republic (only RINEX 2.10)
- Real-time data streams
  - binary data Leica LB2
  - RTCM 2.3 a RTCM 3
  - NTRIP envelope forwarded to NTRIPcaster VESOG/GOP, RIGTC, Czech Republic, binary data LB2 forwarded to the M-GEX caster of the BKG, Frankfurt/Main, Germany

GOP6 M-GEX Site - antenna

GOPE Participation in the JAXA MGM Project

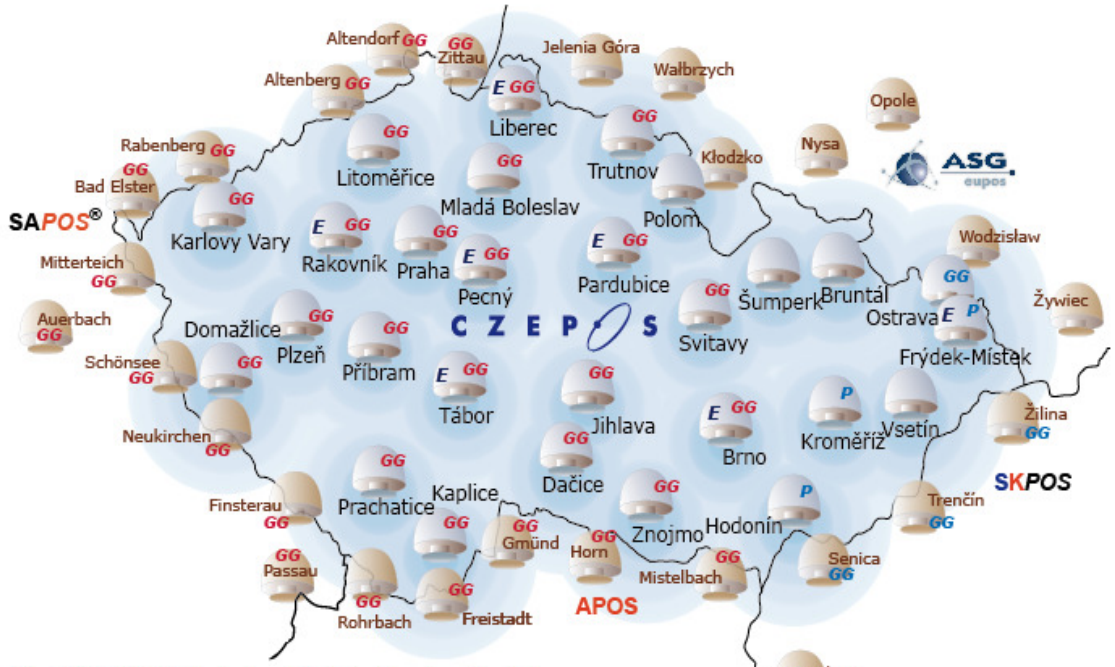
- MGM (Multi-GNSS Monitoring network) Project organized by the Japan Aerospace Agency JAXA – GOPE participates as a hosting station operating a receiver provided on loan by JAXA
- Javad DELTA-G3T receiver is connected through a signal splitter to the Leica AR25.R4 antenna with a spherical radom LEIT installed at the GOP6 site
- Satellite tracking:
- GPS NAVSTAR (L1C, L1P, L2P, L2C, L5)
- GLONASS (L1C, L1P, L2P, L2C)
- Galileo (E1, E5)
- SBAS (L1, L5) including the first QZSS satellite
- Real-time data forwarded to the NTRIP caster of the MGM project in Japan as Javad binary data
- Providing post-processing data generated by the Javad receiver for the M-GEX project under negotiations

GOPE - receivers

Leica GRX1200+GNSS receiver at GOP6

Javad DELTA-G3T receiver at GOP7/GOP6M

CZEPOS – operated by Land Survey Office

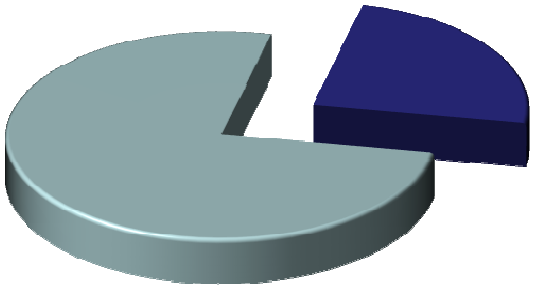


GG - GPS+GLONASS, station is included in network solution

GG - GPS+GLONASS, station isn't included in network solution

P - upgraded receiver (GPS+GLONASS), antenna only GPS

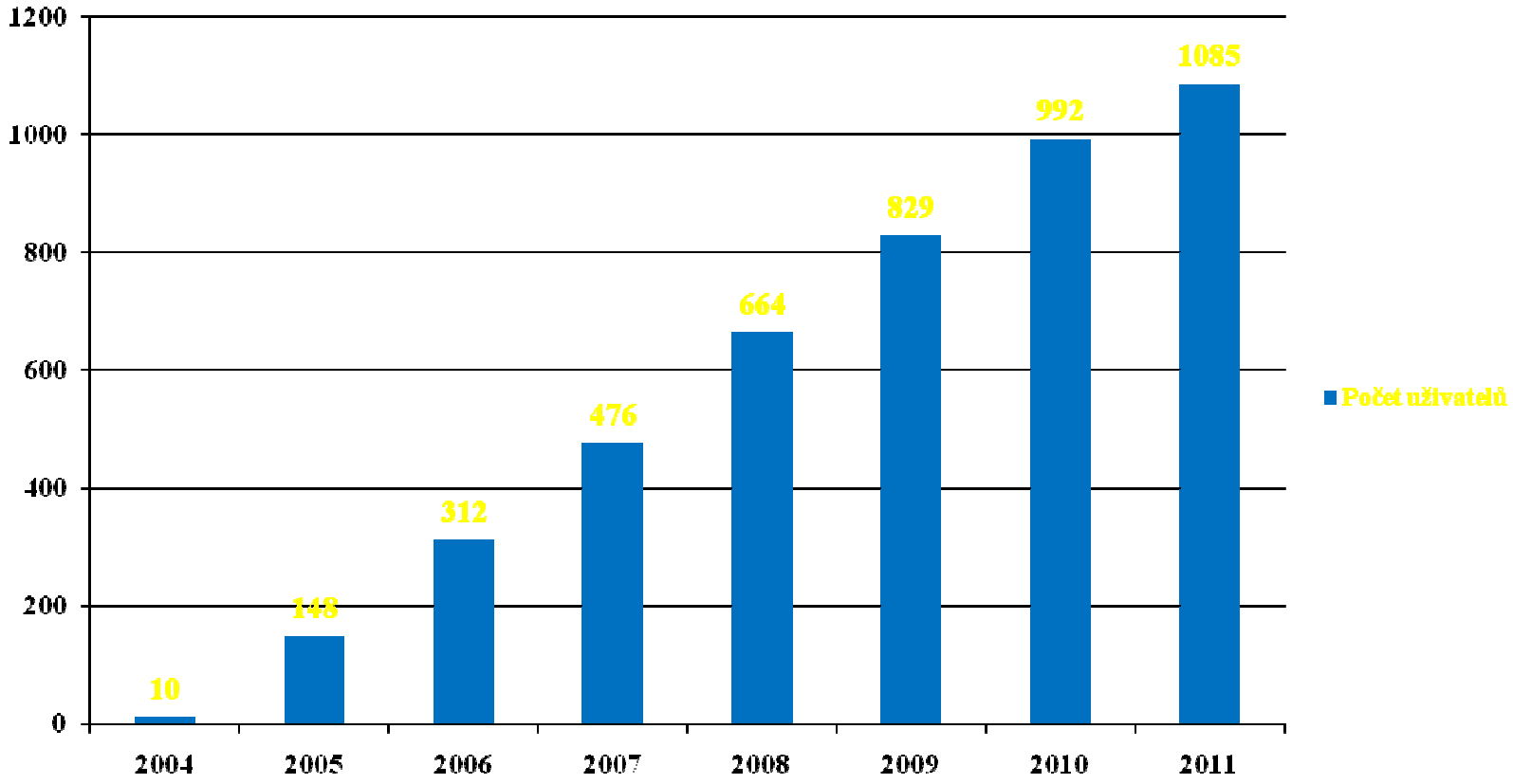
E - EUREF (EPN)



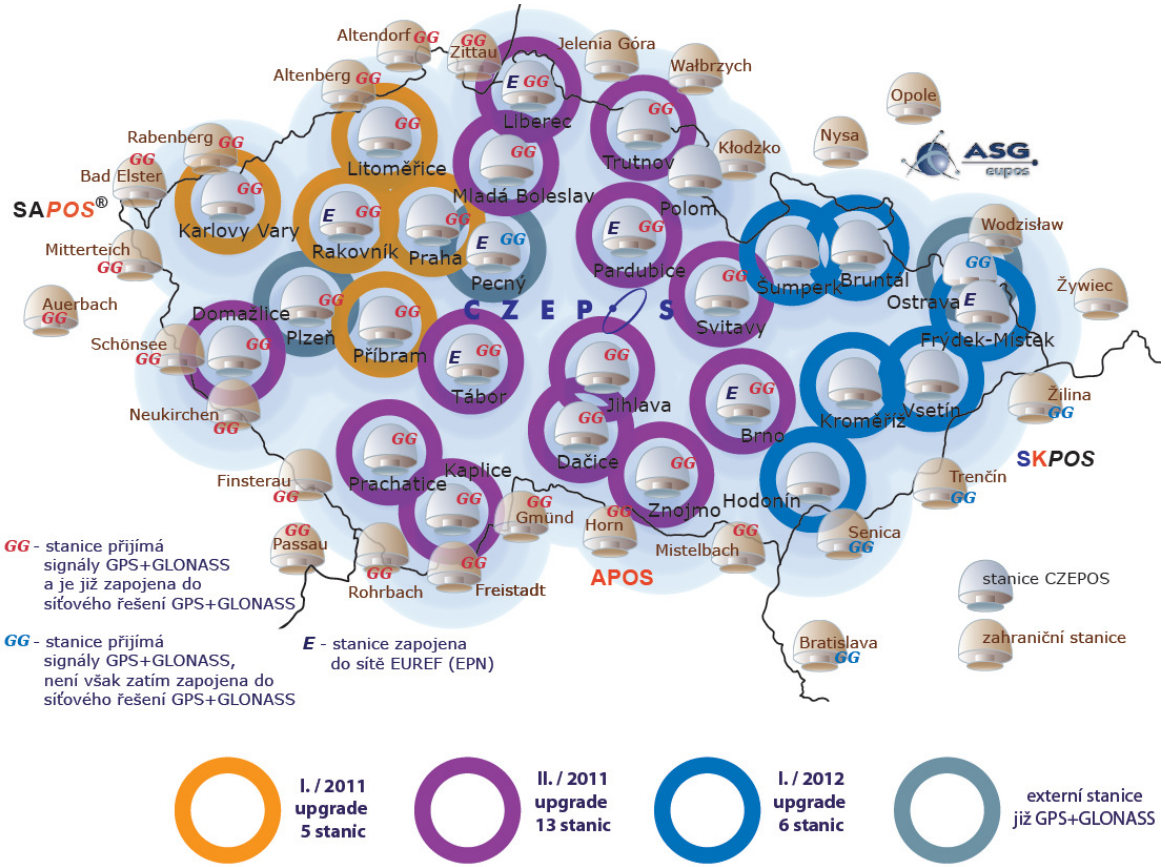
private sector

public sector

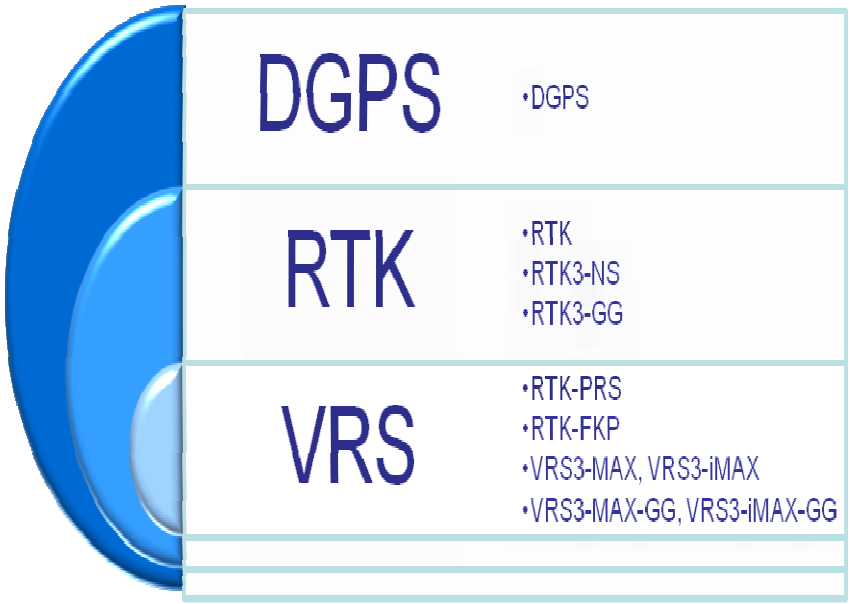
CZEPOS – number of users



CZEPOS – upgrade schedule

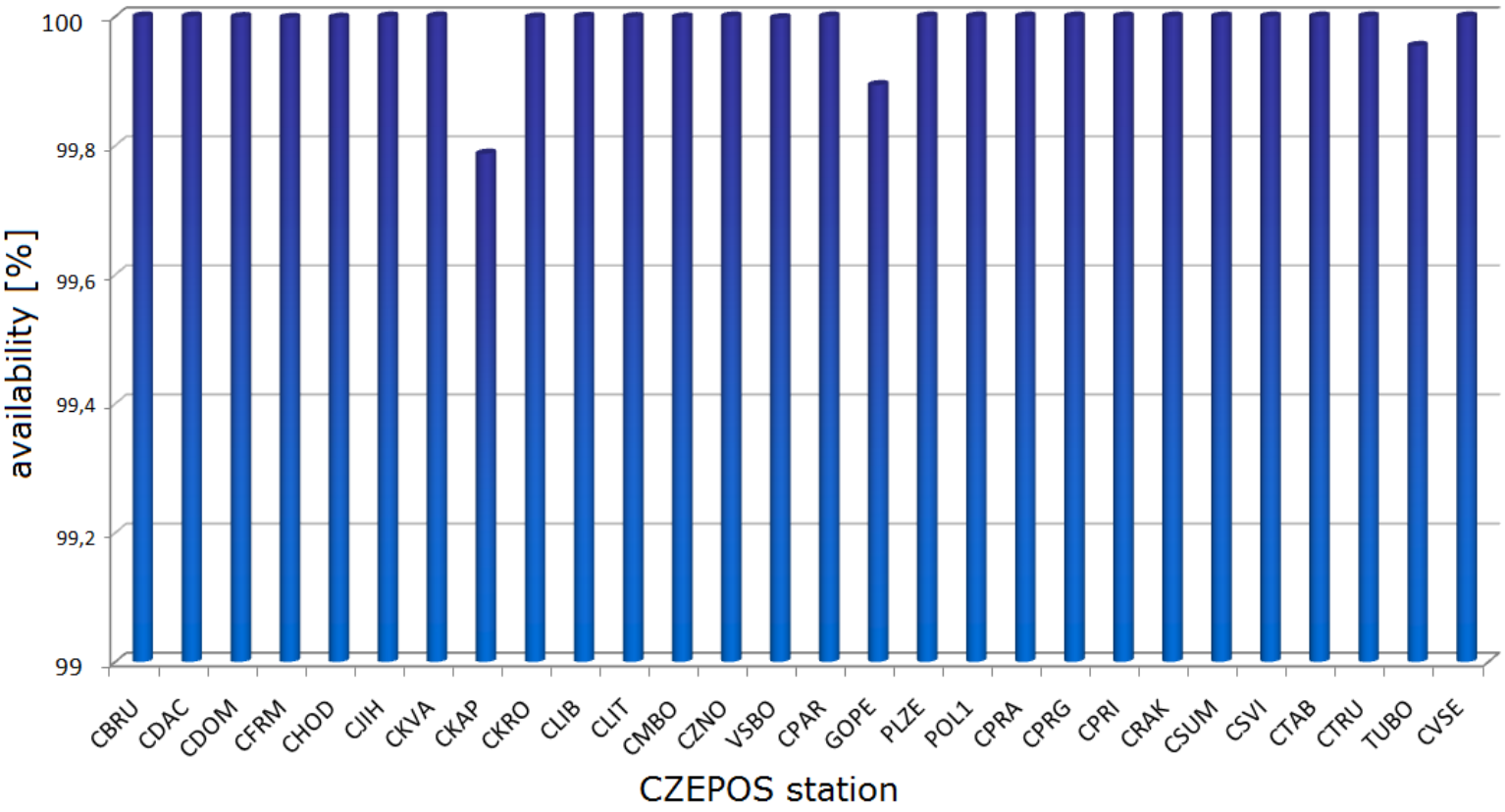


CZEPOS Services

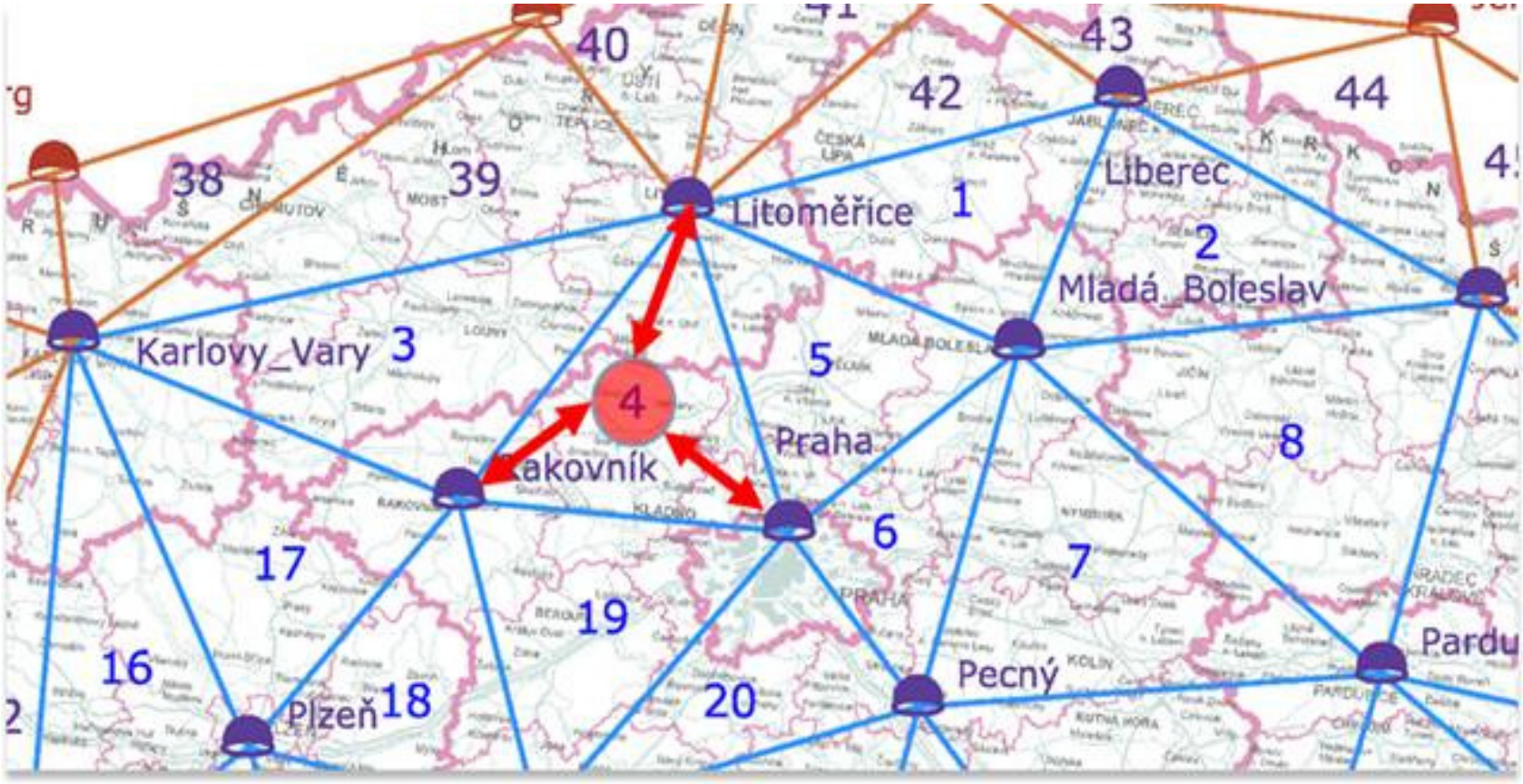


- **Real-time services:** RTK, RTK-FKP, RTK-PRS, RTK3, VRS3 = 80 Kč (3,26 €) / 1 hour, DGPS = 20 Kč (0,82 €) / 1 hour
- **Post-processing:** data interval 1 – 4 sec = 80 Kč (3.26 €), 5 – 9 sec = 16 Kč (0.65 €), 10 – 19 sec = 8 Kč (0.33 €), ≥ 20 sec = 4 Kč (0.16 €)

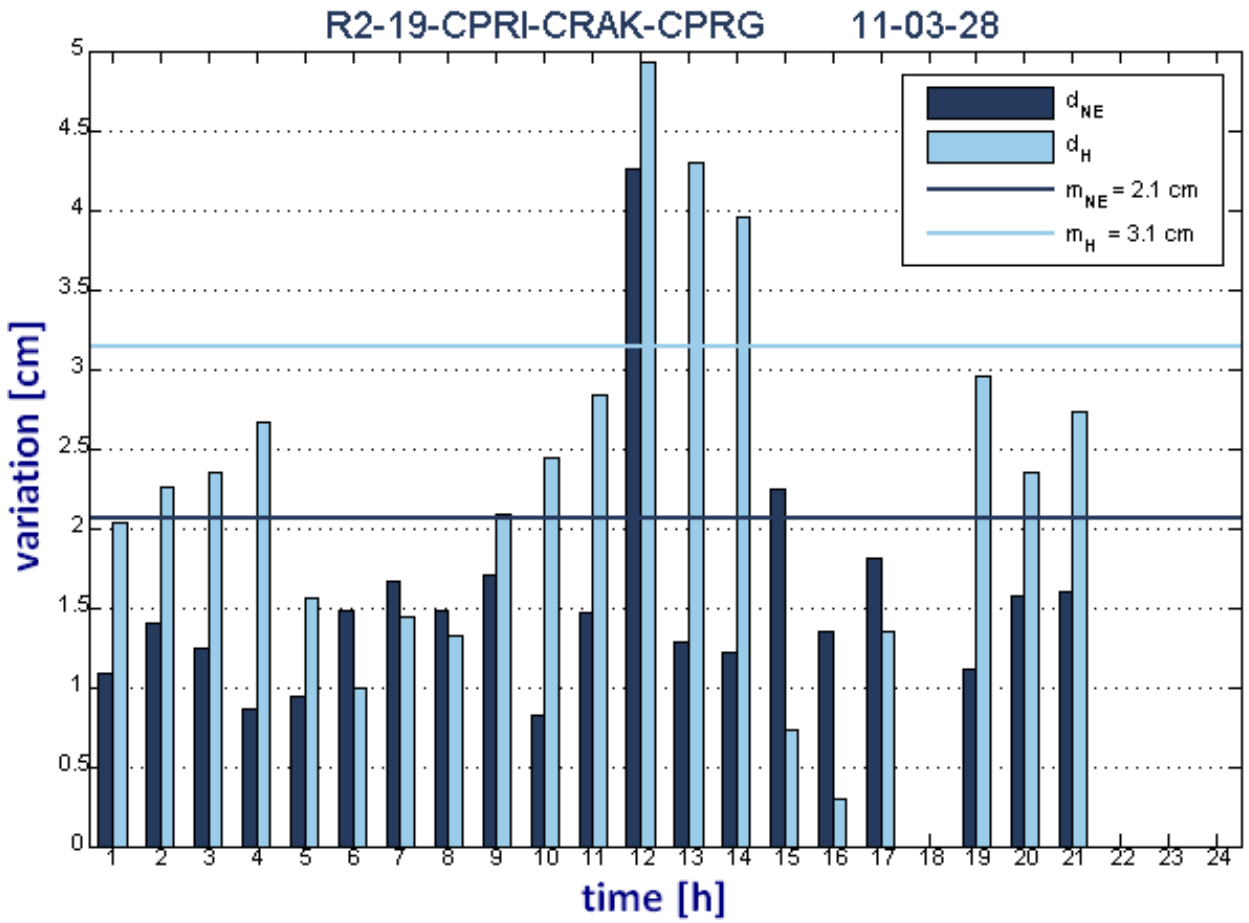
CZEPOS – availability of services



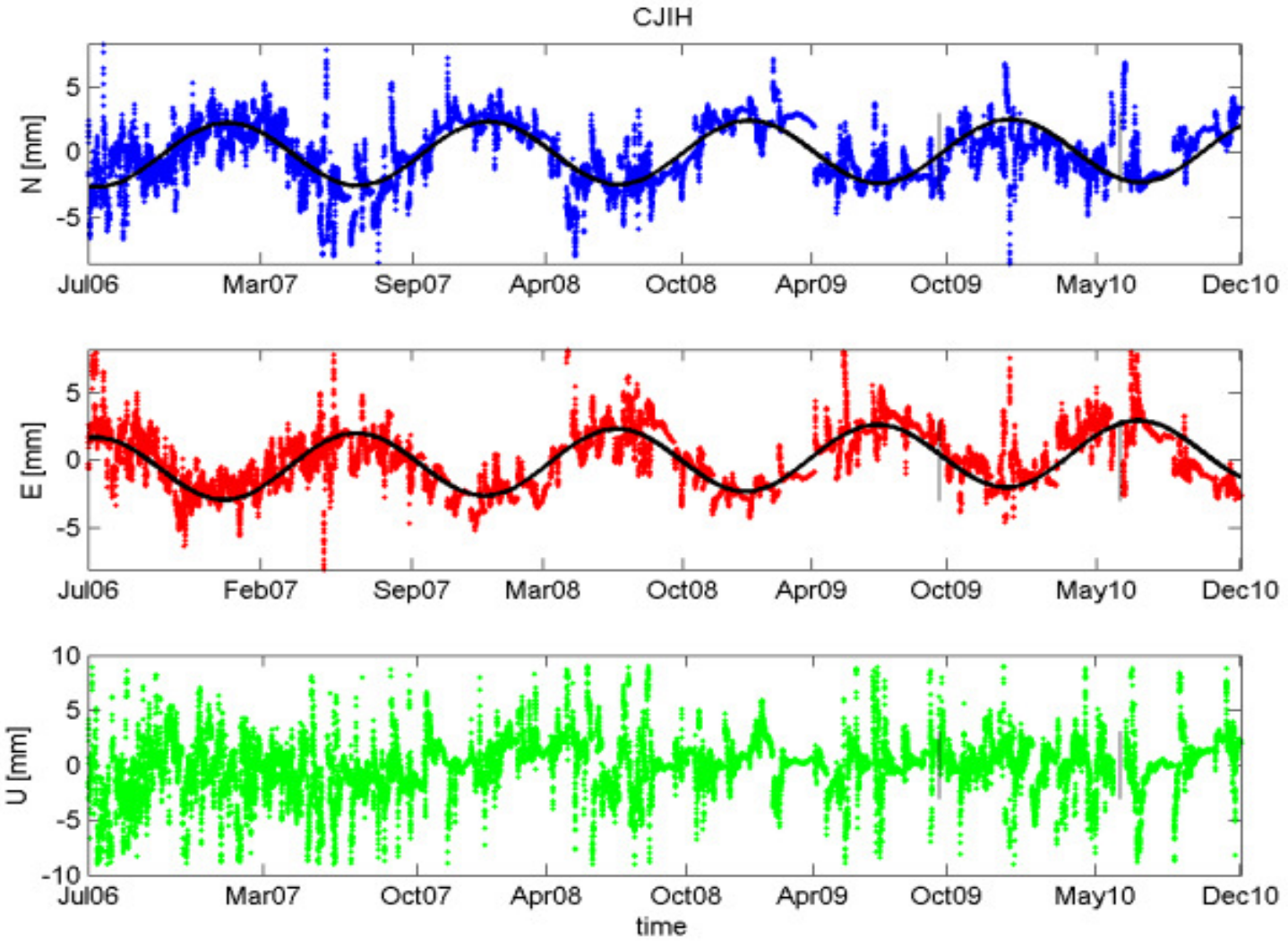
CZEPOS – permanent check of the network solution – approach (Land Survey Office)



CZEPOS – permanent check of the network solution - results



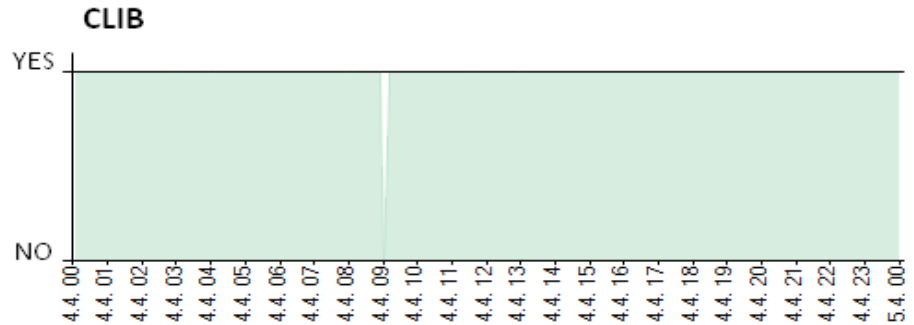
CZEPOS – monitoring of stability



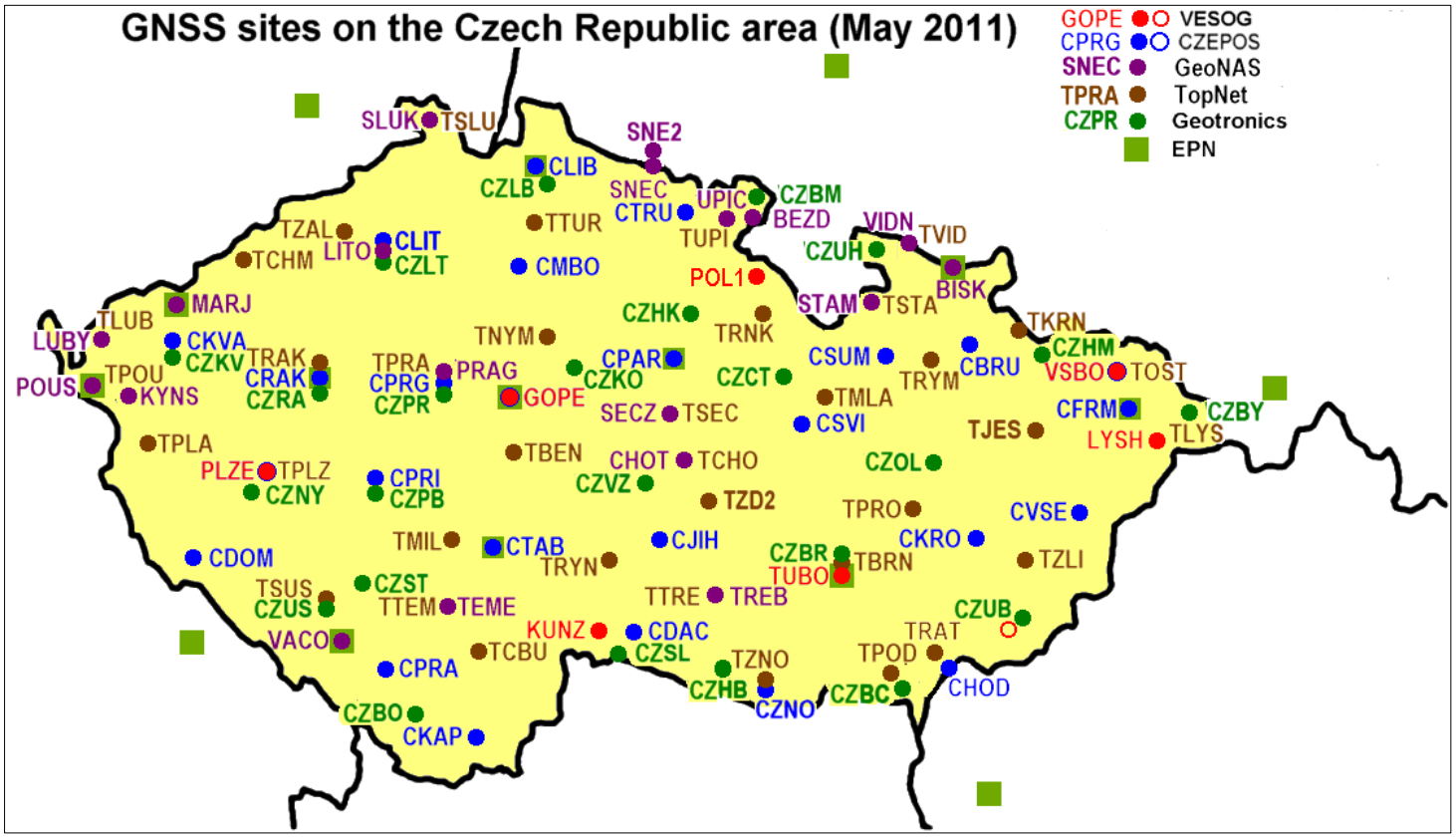
CZEPOS: Functionality of services

service	status	testing time
FKP	YES	4/5/2011 10:16:59 AM
PRS	YES	4/5/2011 10:15:59 AM
RTK3-NS	YE	
VRS3-iMAX	YE	
VRS3-MAX	YE	

n	station	code	RTK status	DGPS status	testing time
1	Pardubice	CPAR	YES	YES	4/5/2011 10:06:00 AM
2	Svitavy	CSVI	YES	YES	4/5/2011 10:07:00 AM
3	Jihlava	CJIH	YES	YES	4/5/2011 10:08:00 AM
4	Dačice	CDAC	YES	YES	4/5/2011 10:09:00 AM
5	Tábor	CTAB	YES	NO	4/5/2011 10:10:00 AM
6	Příbram	CPRI	YES	YES	4/5/2011 10:10:59 AM
7	Karlovy Vary	CKVA	YES	YES	4.
8	Domažlice	CDOM	YES	YES	4.
9	Prachatice	CPRA	YES	YES	4.
:	:	:	:	:	



Permanent GNSS networks in the CR (2)



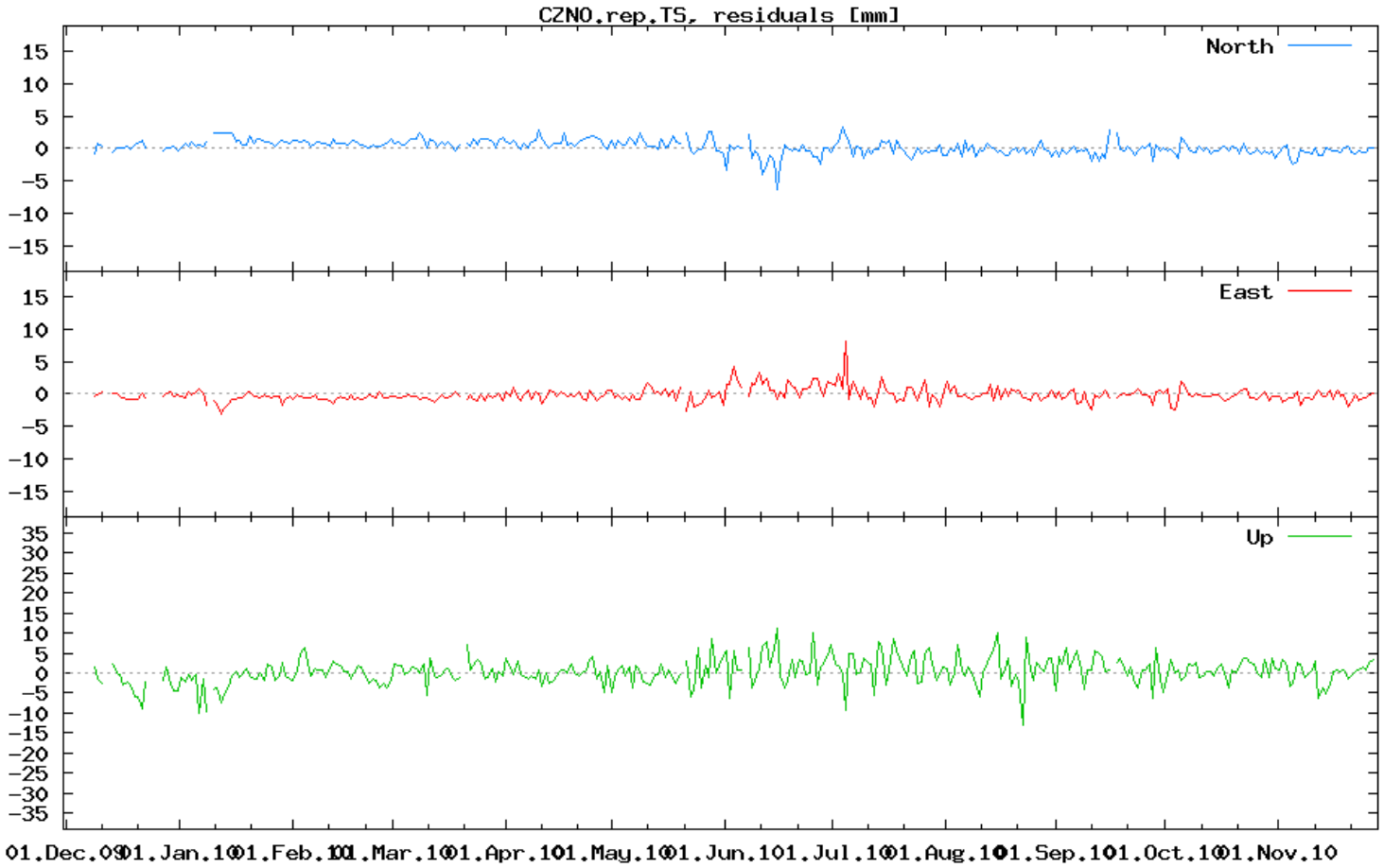
Analysis and Research

- Monitoring of permanent sites in the CR
- EPN Data Center GOP
- EPN Analysis Center GOP
- IGS rapid orbits
- GNSS Ground-based meteorology
- Geodynamics – EPN velocities, CEGRN
- IDS Analysis Center GOP

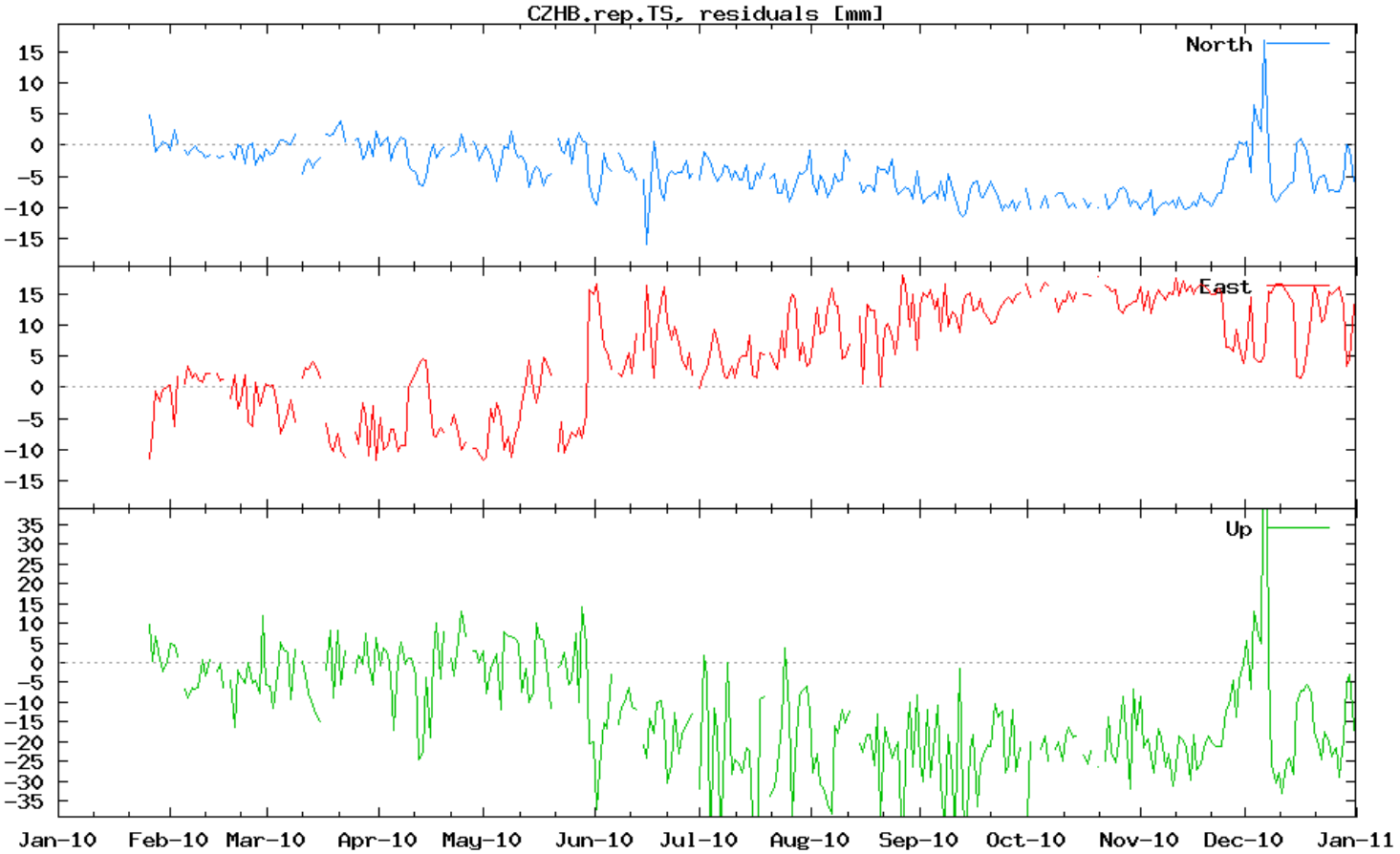
Monitoring of the Czech permanent GNSS sites – Analysis Center GOP

- Check of stability and quality
- Rapid solution used as a basis
- EPN processing standards and guidelines
- 8:00 UTC the daily solution compared with coordinates + statistical test
- Limits: 7mm, 7 mm and 15 mm for N,E,U components

Monitoring results for the site CZNO (good) based on ultra-rapid solution



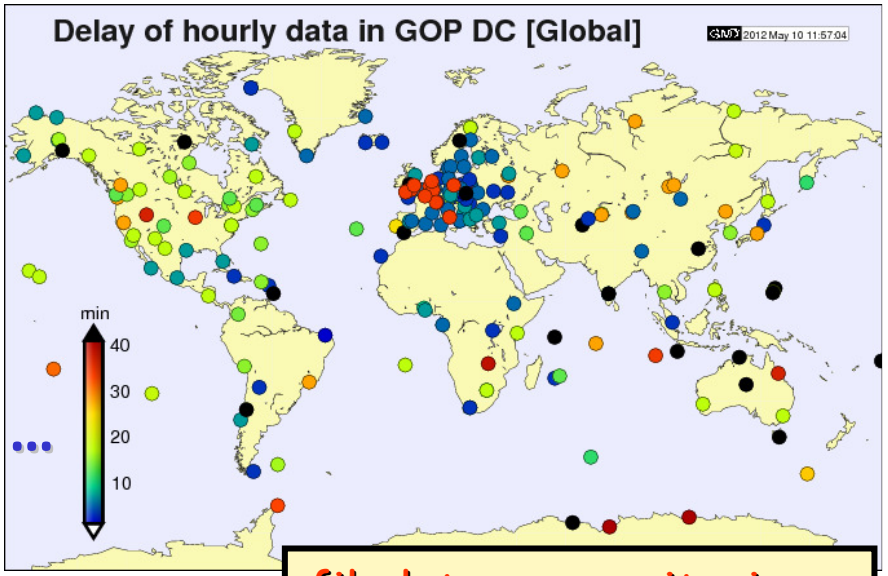
Monitoring results for the site CZHB (bad) based on ultra-rapid solution



GNSS data operation/dissemination

GOP operational centre

- GPS, GLONASS, Galileo, QZSS
- hourly, daily, real-time
- 30-sec, high-rate (1Hz)
- EUREF, IGS, VESOG, CZEPOS, …

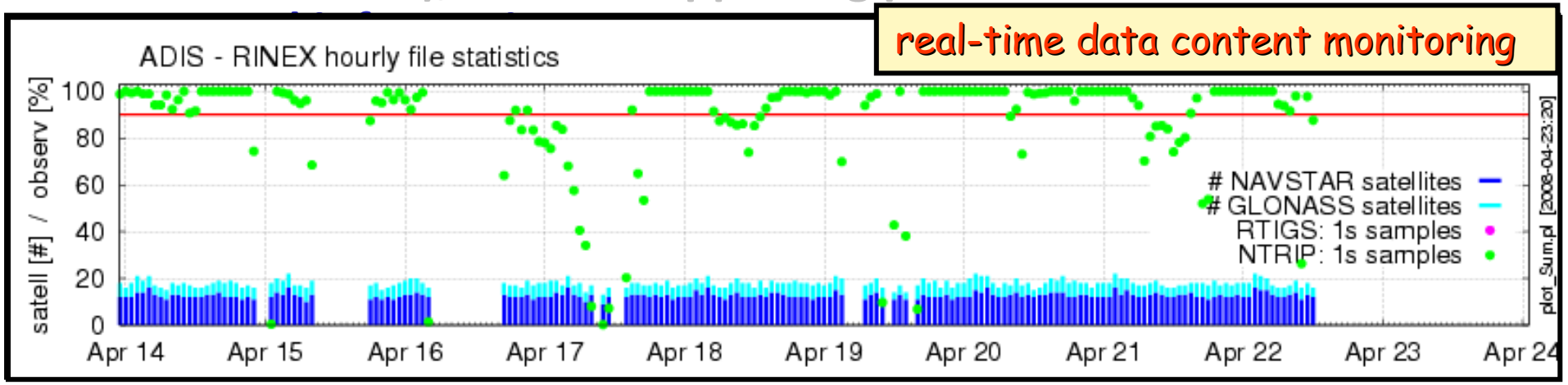


file latency monitoring

GOP Data Centre (EUREF, ..)

- **Files** – GNSS data (daily, hourly and historical), various supporting products

real-time data content monitoring



GPS+GLONASS precise orbit determination

GOP contribution to the International GNSS Service (IGS) – since 2004

software: Bernese GPS sw. V5.0 (GOP modified)

input: **hourly GPS data + navigation messages**

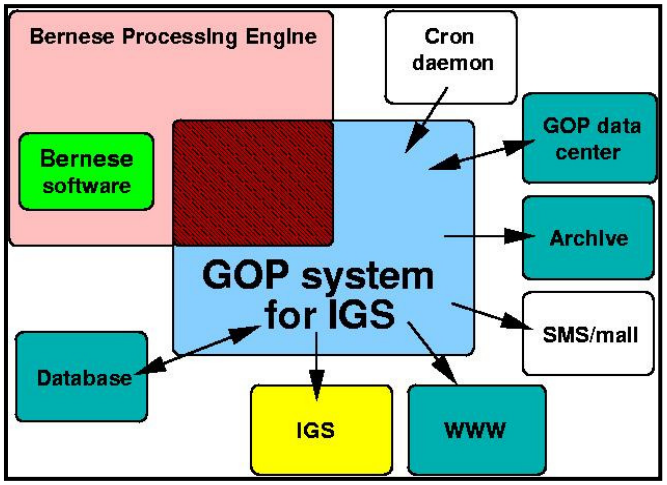
output: **ultra-rapid orbits (GPS+GLONASS)**

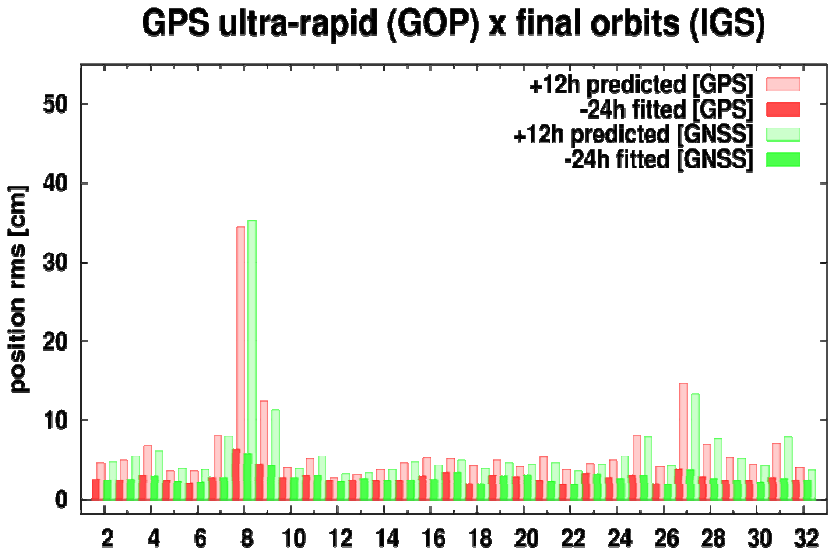
product: **2-day arcs fitting, 1-day arc prediction**

usage: **(near) real-time applications**

processing features:

- LSQ adjustment
- 6-hour update cycle
- double-differenced observations
- efficient strategy with no redundancy
- network split into continental clusters
- self-initializing processing system
- all satellites included, multi-GNSS
- automated manoeuvres detection
- originally developed at GOP

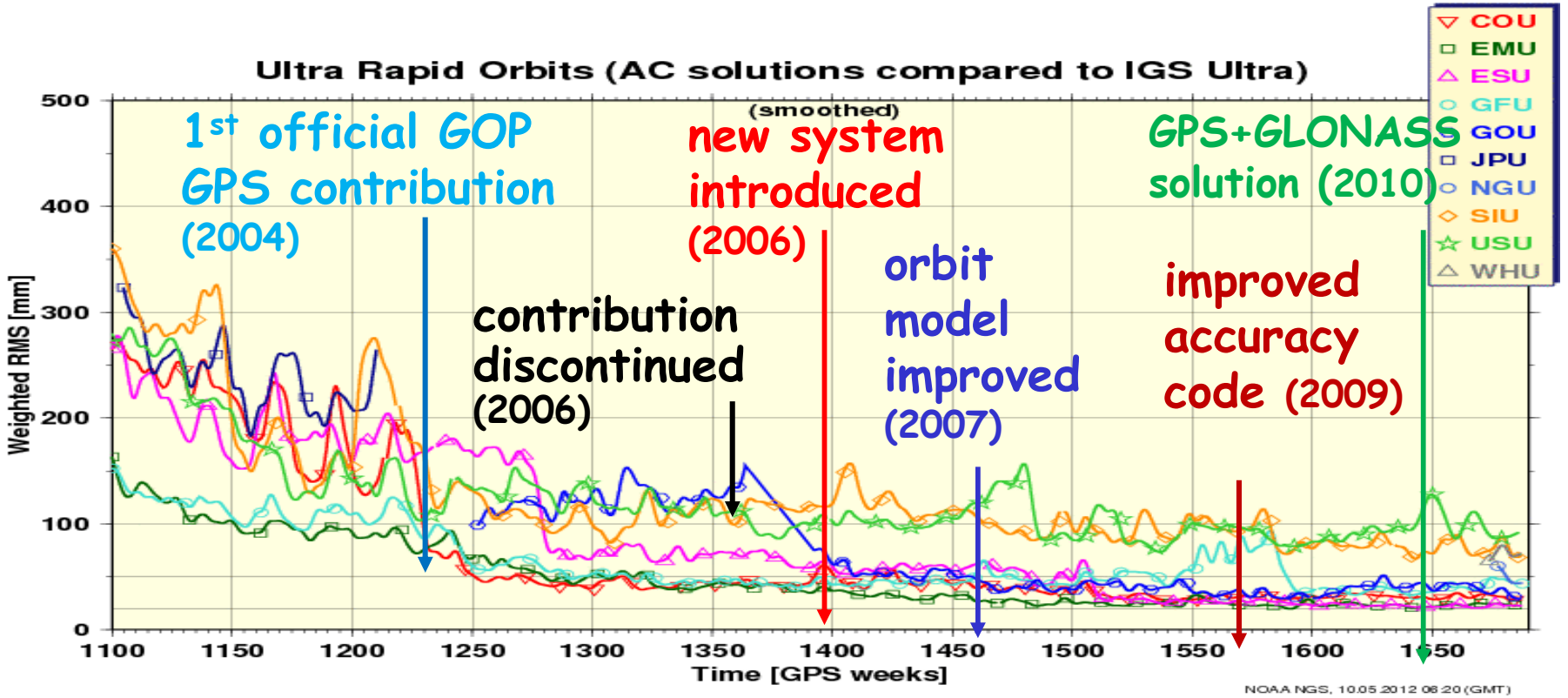




GOP orbits/ERP products (milestones)

GOP contribution to the International GNSS Service (IGS) – since 2004

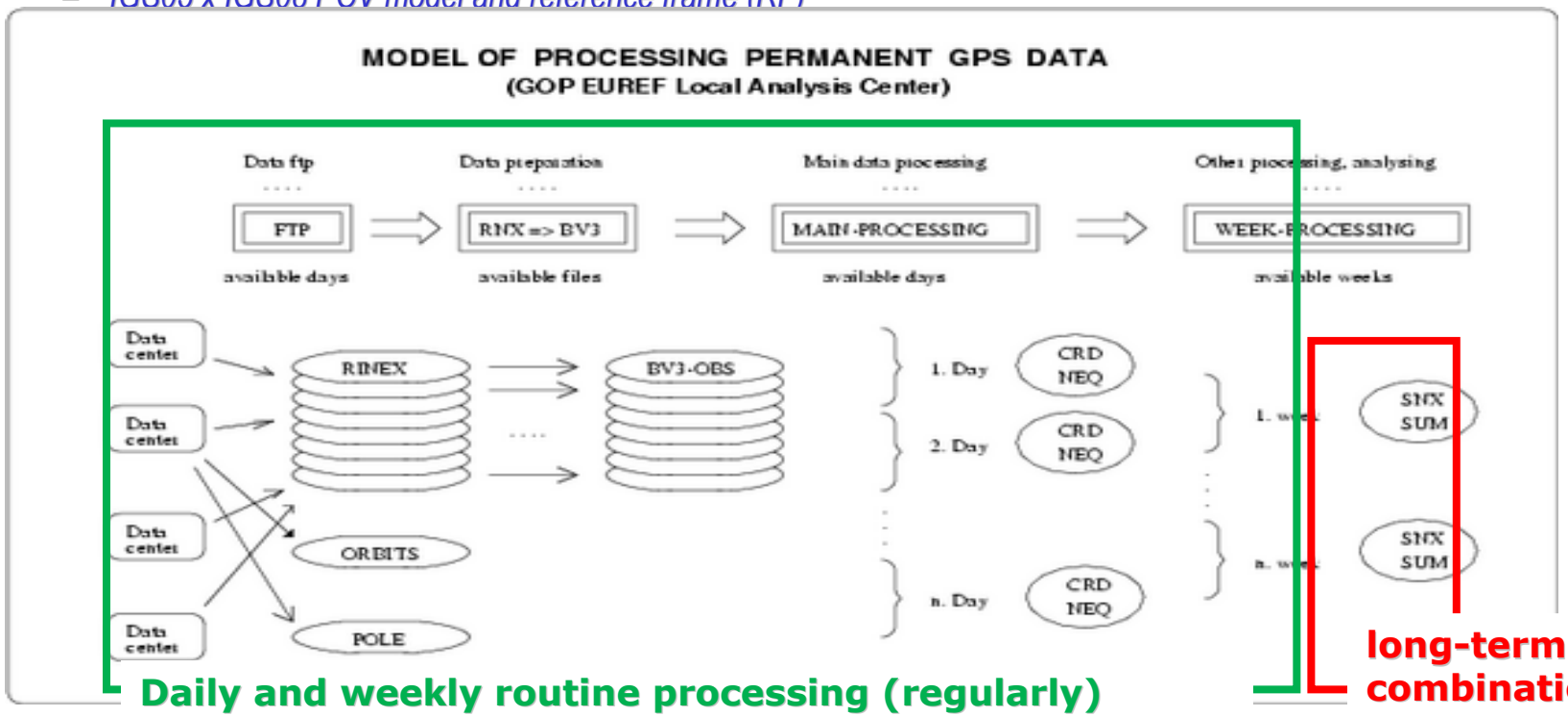
	orbits	clocks	Y,X pole	X,Y pole rates	length of the day
fitted prod.	<5 cm	-	0.1 mas	0.2 mas/day	0.03 ns
predicted prod.	10 cm		0.3 mas	0.3 mas/day	0.07 ns



Terrestrial reference frame realizations

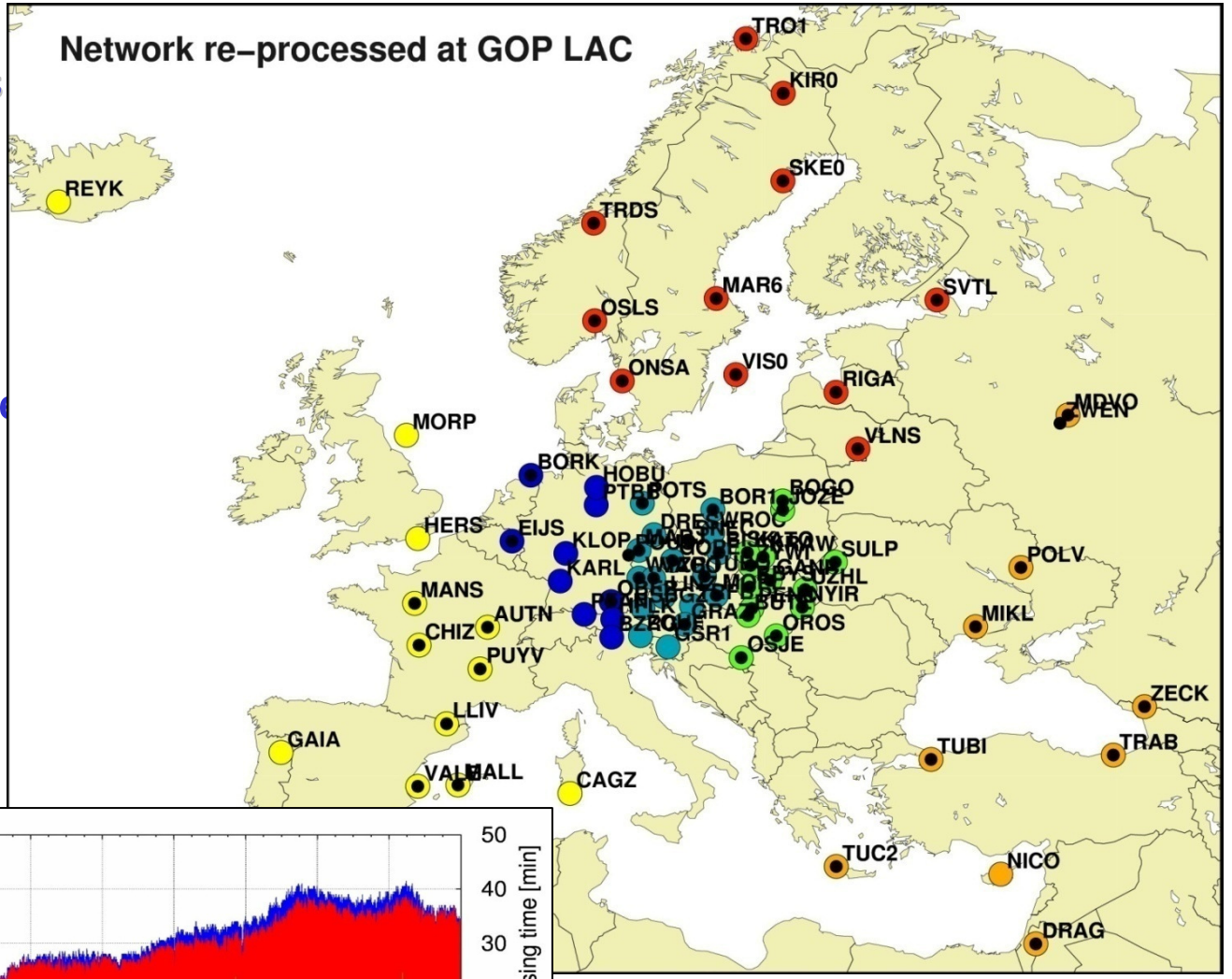
GOP contribution to the EUREF Permanent Network (EPN) – since 1997

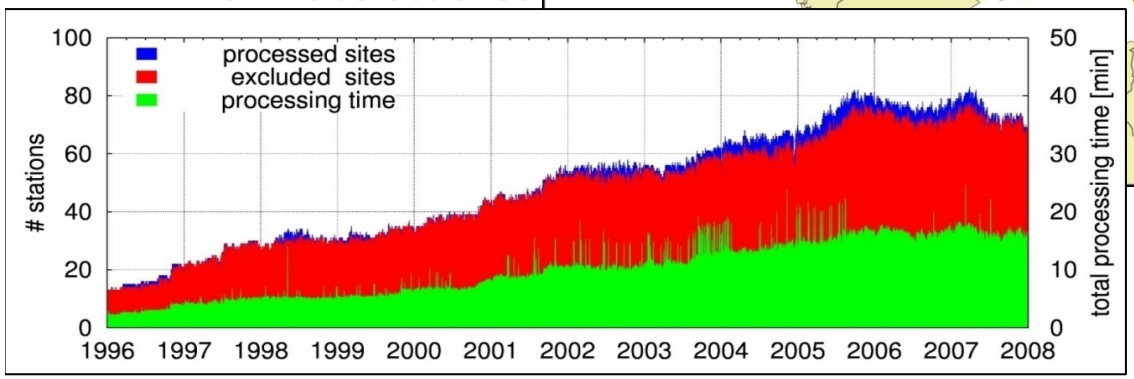
- GOP routinely contributes to EUREF RF maintenance and European ITRFxx realization
- GOP supported EPN reprocessing project (since 1996-2008) – repro1
- GOP daily & weekly full EUREF network reprocessing (~250 sites) using IGS05 and IGS08 - repro1+
- GOP combined full network for the assessment of
  - *EUREF ITRF2008 densification,*
  - *ITRF2008 of EUREF coordinates, velocities and their discontinuities*
  - *IGS05 x IGS08 PCV model and reference frame (RF)*



GOP sub-network re-processing (1996-2008)

- 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

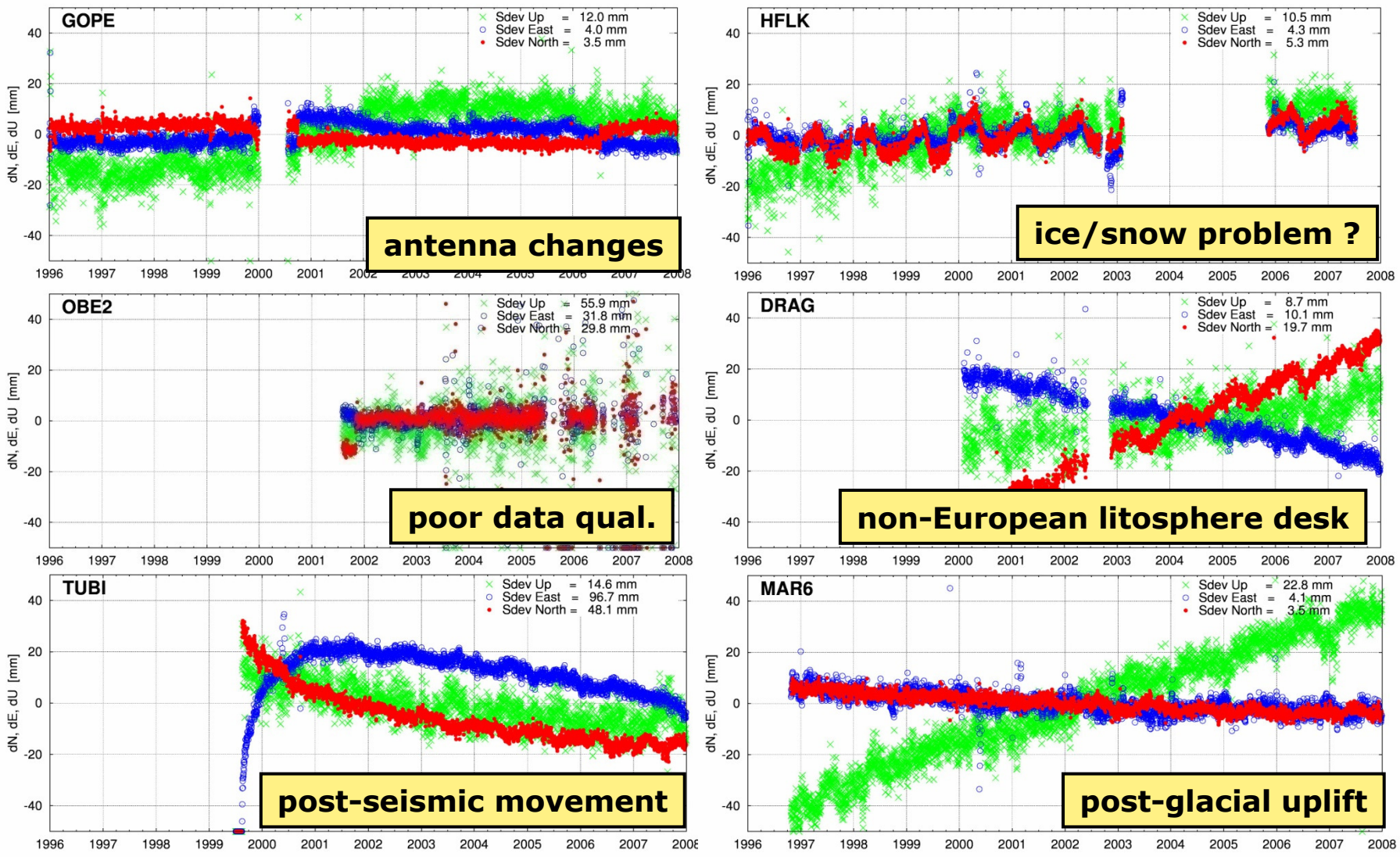




~5475 processed daily sessions
~60 processing days (8 CPUs)

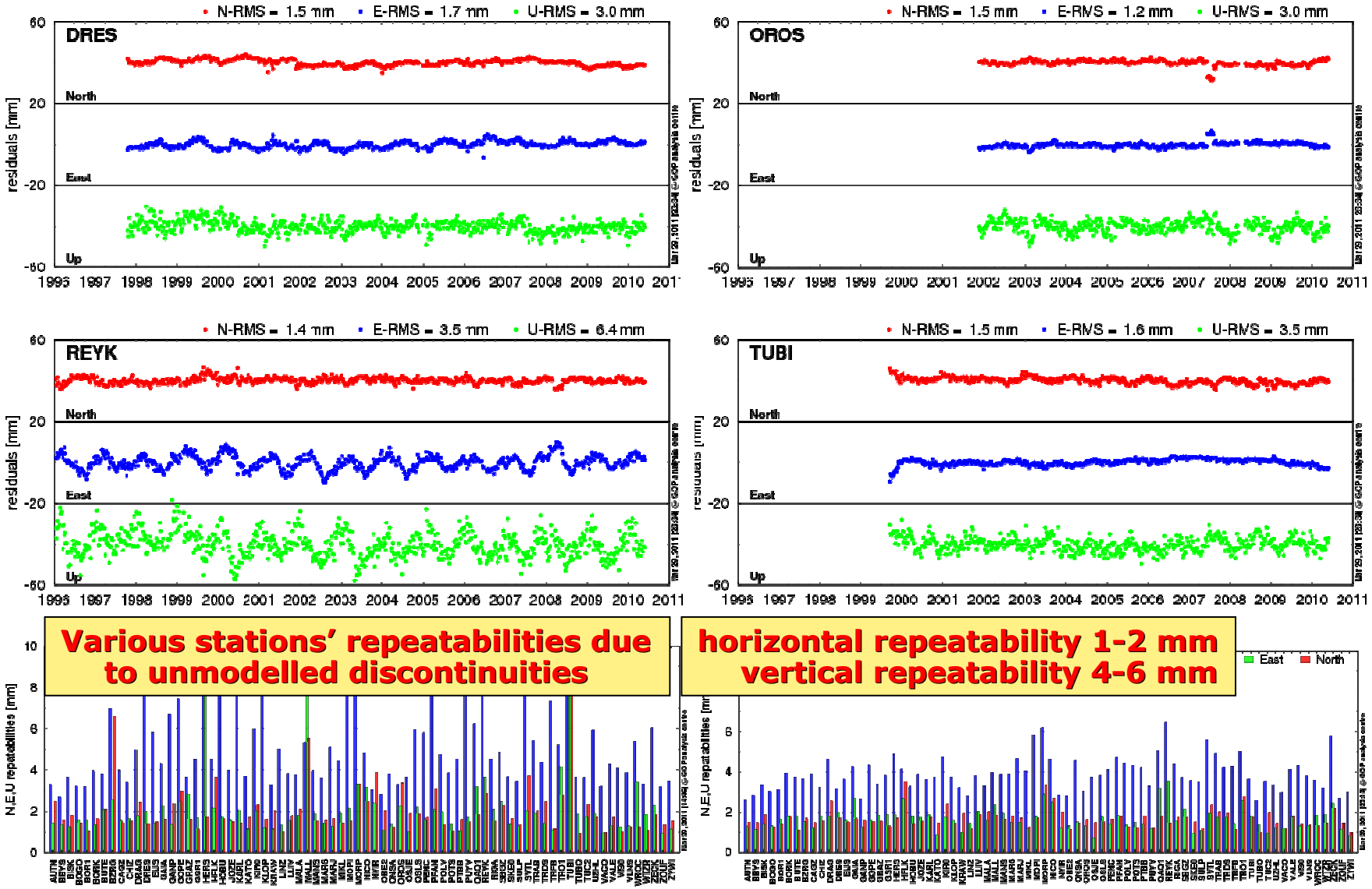
GOP reprocessing - raw coordinate time-series

plots of daily-based independent solutions expressed in a single reference frame!



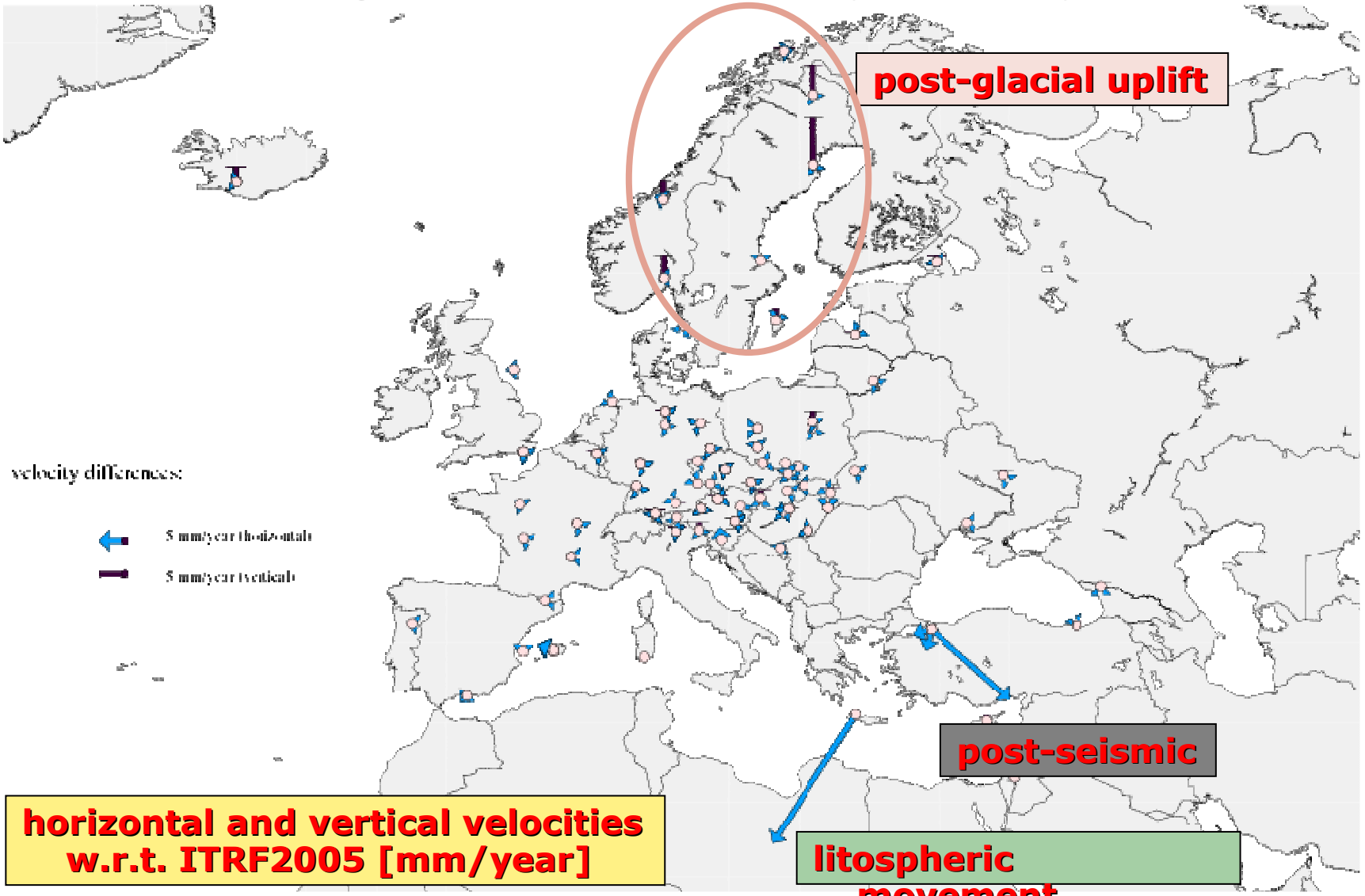
Multi-year combination results

estimation of stations' velocities and coordinates discontinuities



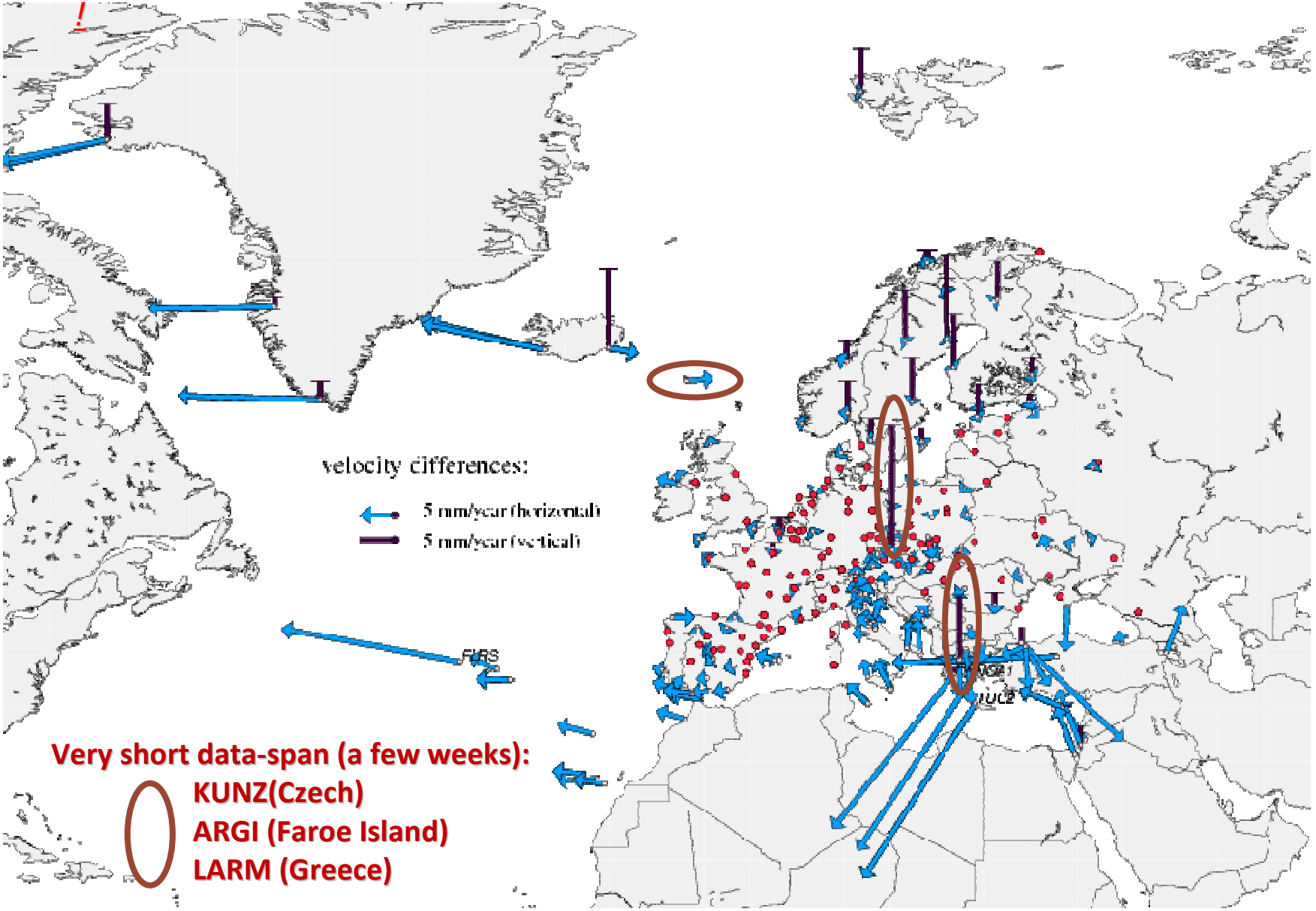
Velocity estimates based on combination

Original GOP EPN sub-network (~70 stations)

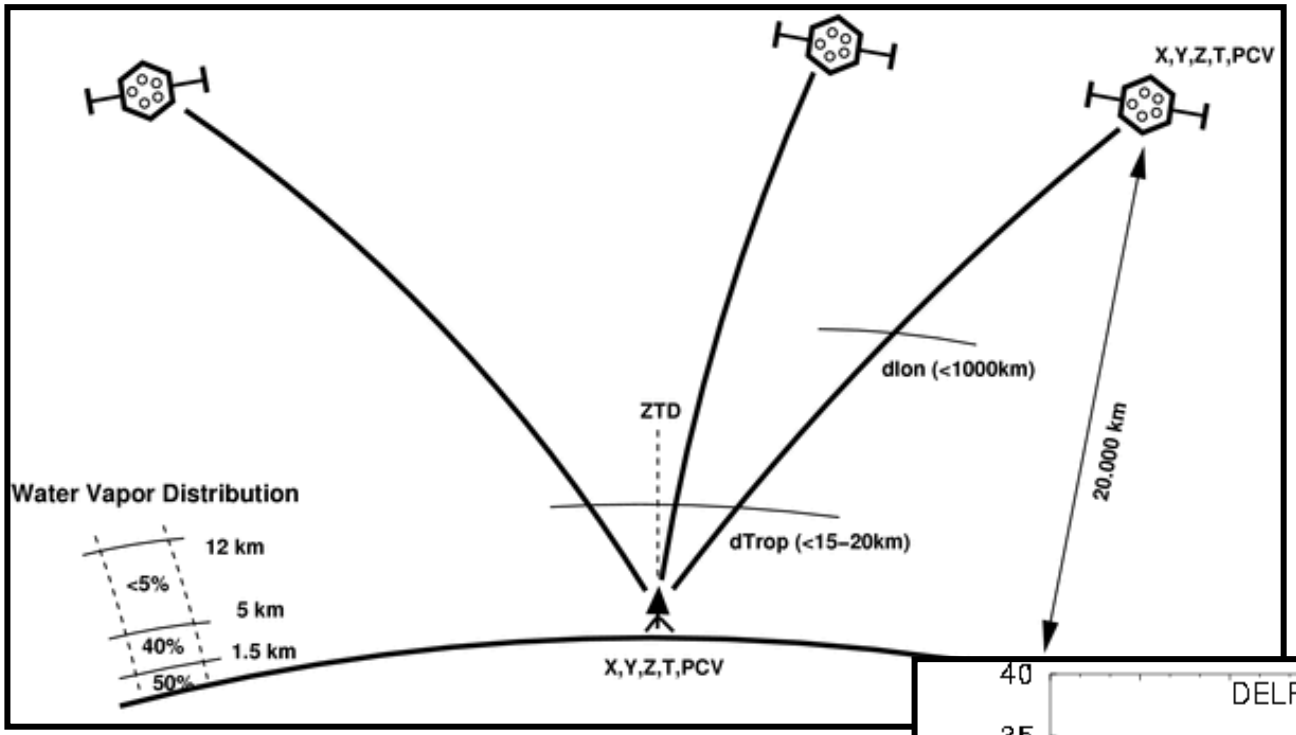


Velocities with respect to Eurasian plate

Based on complete EUREF Permanent network GOP repro1+ solution !

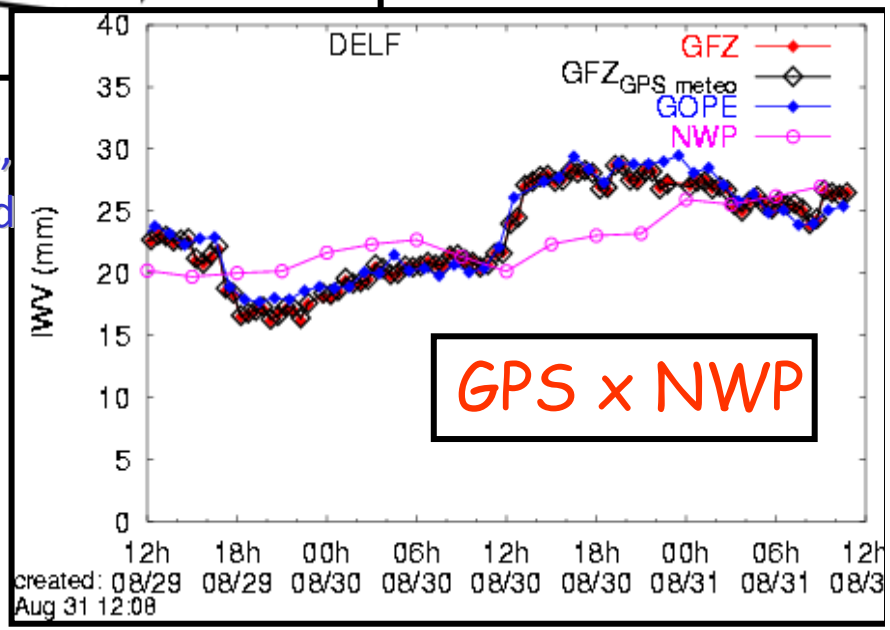


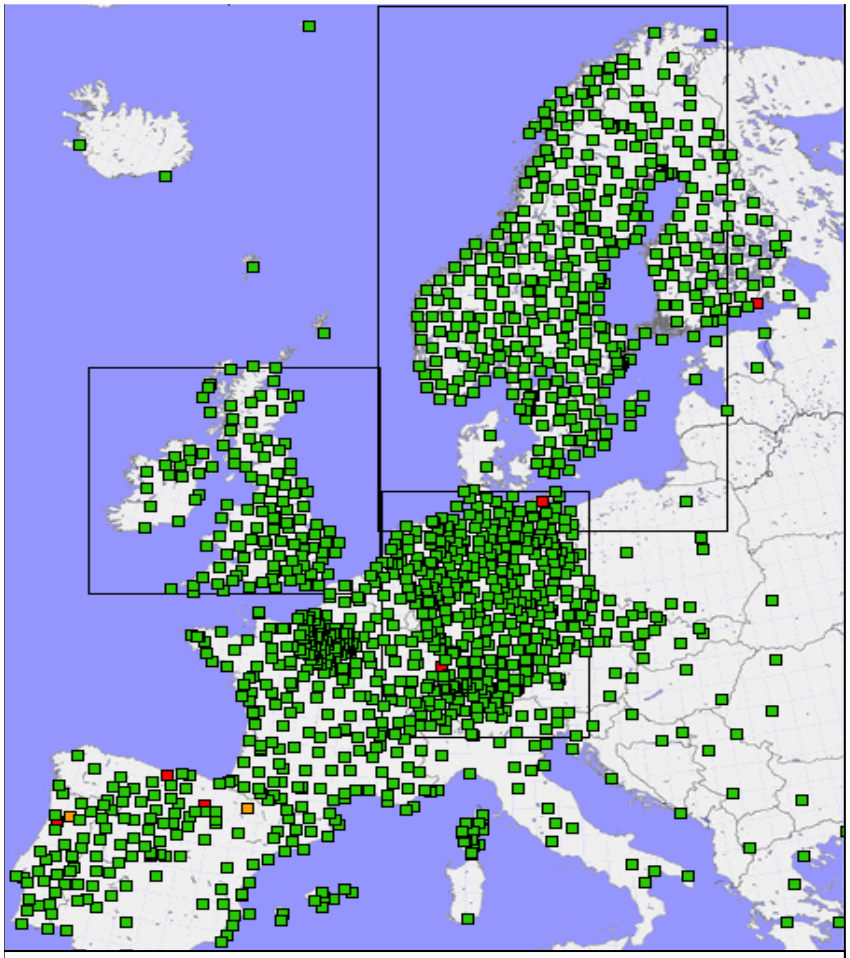
GPS-meteorology a Concept



we know precise receiver and orbit positions, we eliminate ionosphere effect (receiver and satellite clock error), we apply various models (ocean loading, antenna phase centers etc)

we estimate: troposphere path delays (receiver and satellite clocks)





GOP activities within GPS-meteorology

……

COST-716 Action (1998-2003): *"Exploitation of Ground-Based GPS for Operational Numerical Weather Prediction and Climate Applications"*

- **15 Institutions, 7 ACs, > 200 GPS sites**

TOUGH (2003-2006): *„Targeting Optimal Use of GPS Humidity Measurements in Meteorology"*

- **15 Institutions, 12 ACs, > 400 GPS sites**

E-GVAP I (2006 - 2009), E-GVAP II (2010-2012)

„The EUMETNET GPS Water Vapor Programme"

- **13 Institutions, 12 ACs, > 1600 GPS sites**

COST Action (pre-proposal) – March 31, 2012

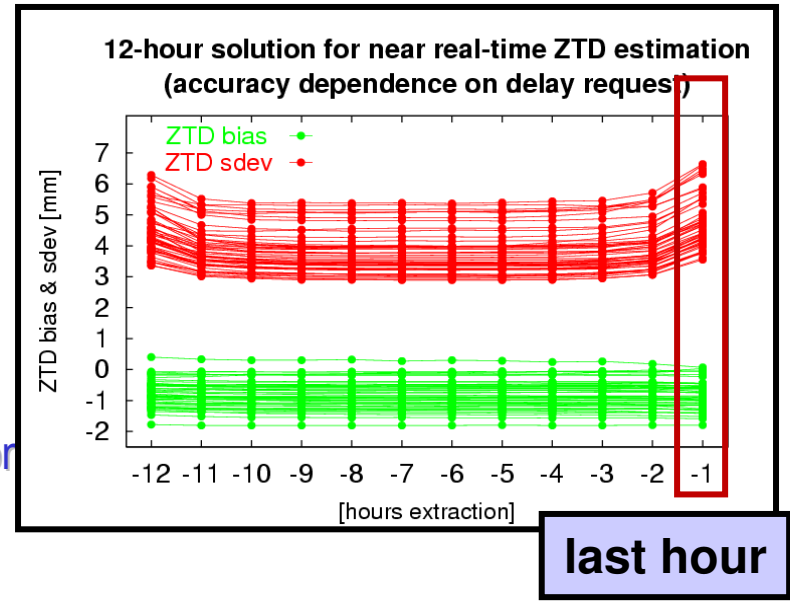
„Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)"

- **interested 37 institutions from 25 countries**

Near real-time ZTD solutions by GOP

Processing requirements

- hourly GNSS data and precise IGS ultra/rapid orbits

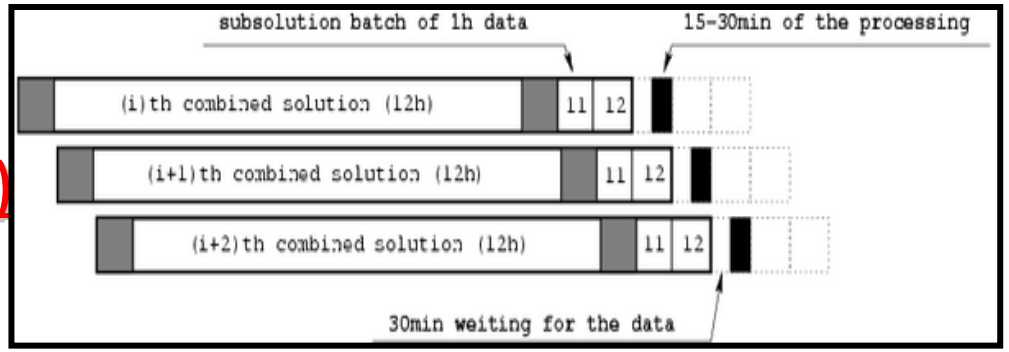


GOP processing features

- processed every hour in HH:20
- 4 hourly data batches and normal equations (NEQ)
- ZTD based on last 12 hours from NEQ combination
- Coordinates based on 28 days from NEQ combination
- processing efficiently distributed in the clusters

GOP ZTD characteristics

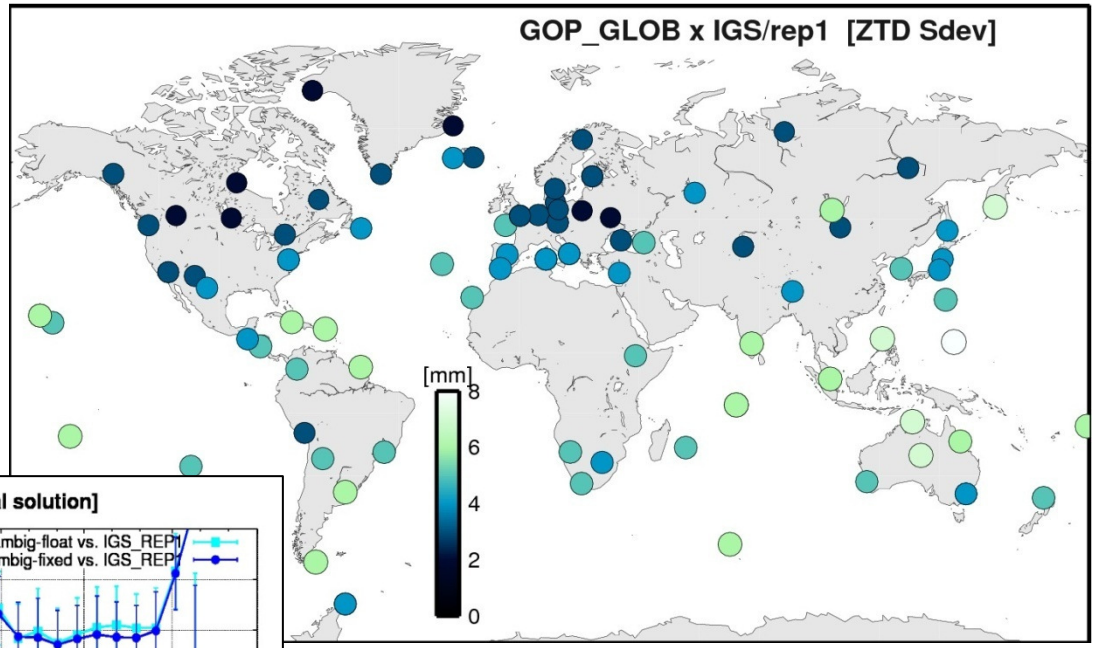
- ZTD product (HH:00 – HH:59) - linear trend model (piece-wise linear function)
- ZTD product filtering:
  - min 4 hours in NRT ZTD solution
  - min 2 days in NRT CRD solution

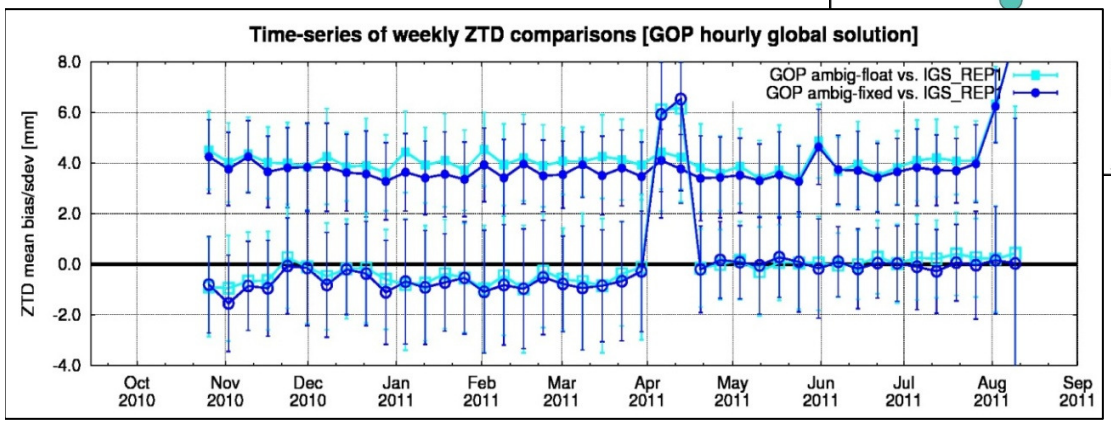


GOP ZTD solutions (E-GVAP)

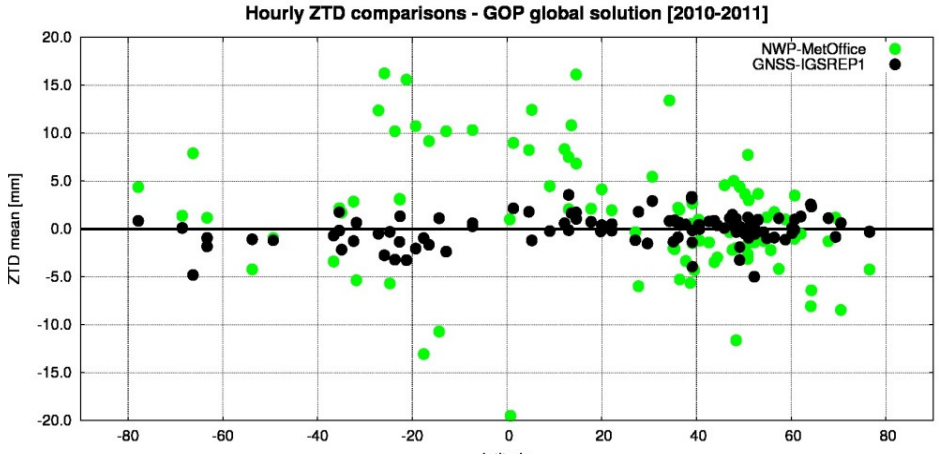
- Regional/national (GPS)
- Regional/national (GNSS)
- Global (GPS)

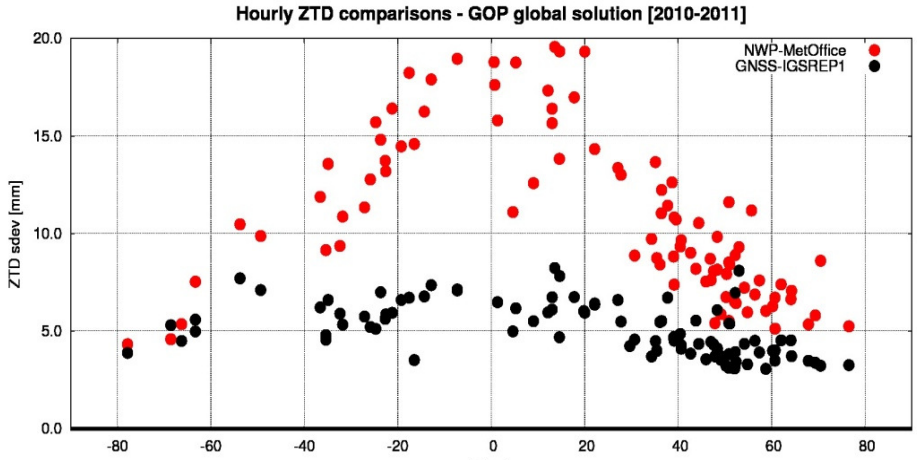
GOP global hourly ZTD 2010-2012





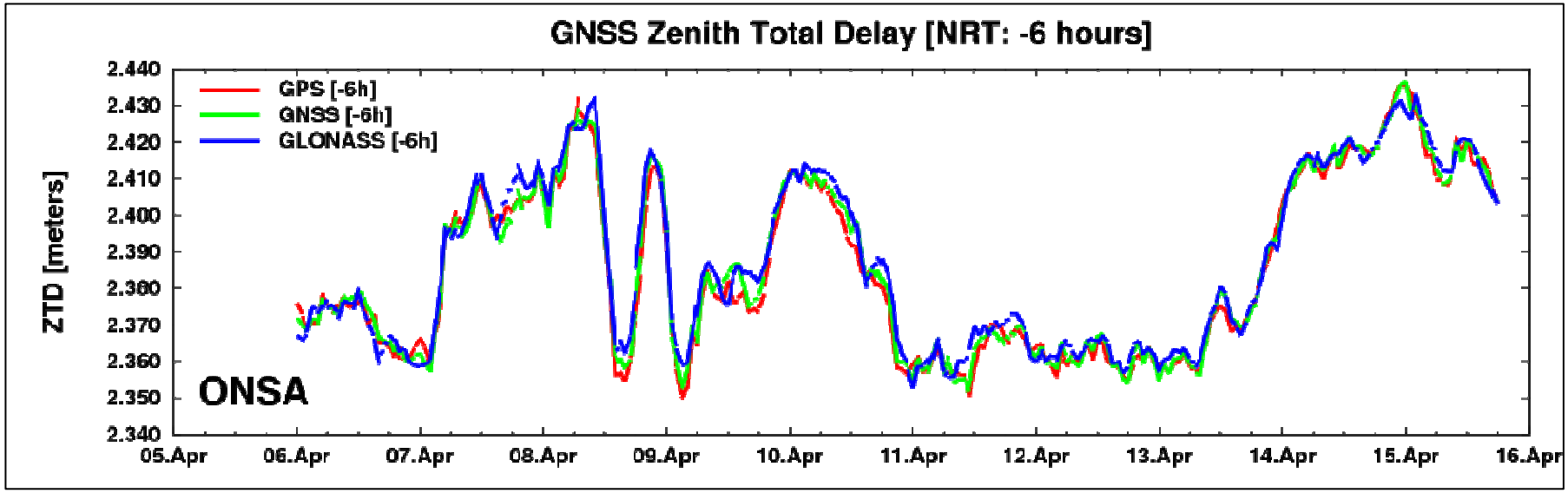
SDEV and BIAS more variable than regional ZTDs, however, still within 3-8 mm and 0-2 mm, respectively





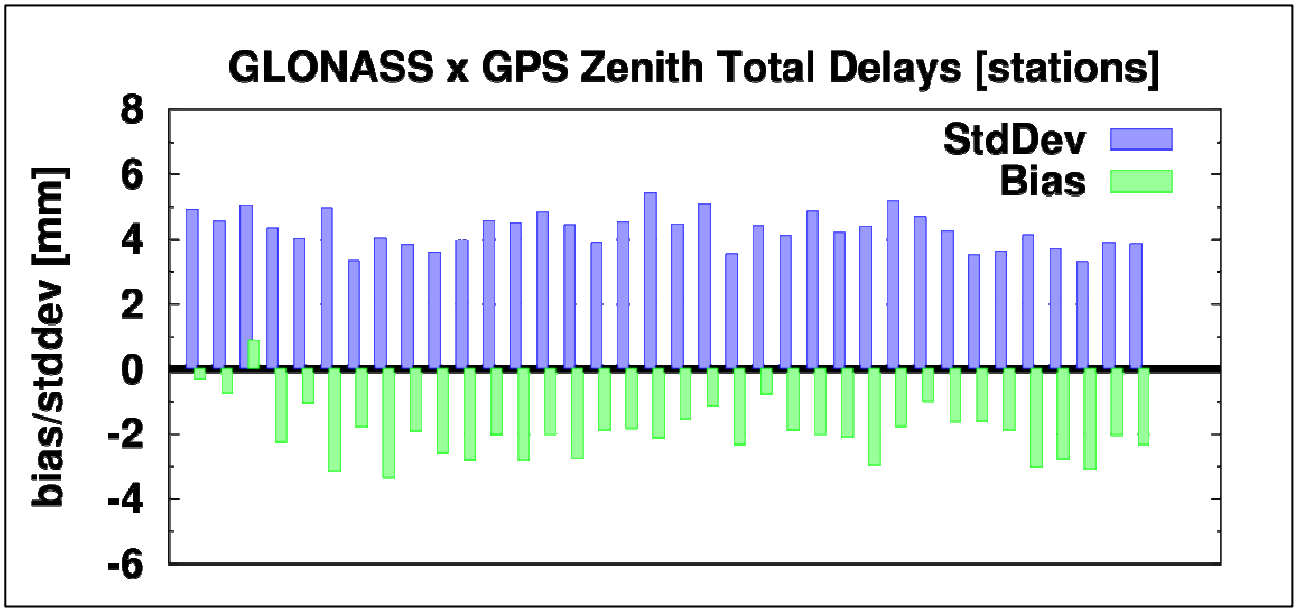
Figures show comparison to UK Met Office global NWM – strong latitude dependence

NRT ZTDs from GPS, GLONASS and multi-GNSS solutions



Using IGS05 APCV model a bias of 0-2 mm observed between stand-alone GPS and GLONASS ZTD solution.

By adopting IGS08 almost disappeared.



International DORIS Service - ACs

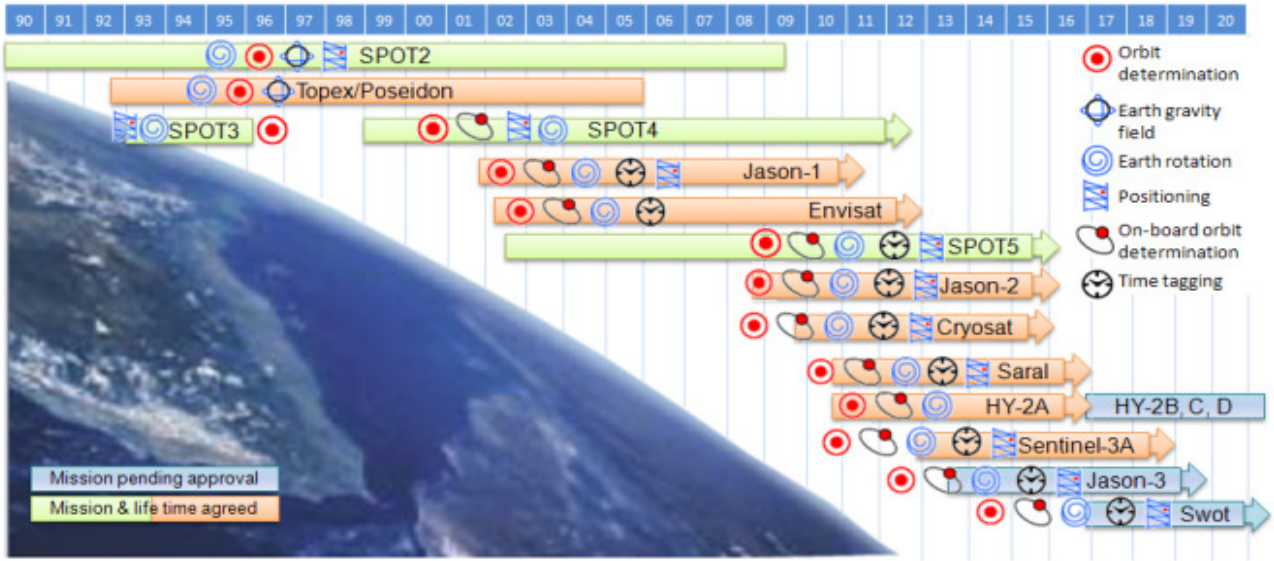
- ESA – ESA/ESOC, Germany
- GAU – Geoscience, Australia
- GSC – GSFC, USA
- IGN – IGN/IPGP, France
- INA – INASAN, Russia
- GOP – Geodetic Observatory Pecný, Czech Republic
- LCA – CNES/CLS, France
- NCL – University of Newcastle, UK

DORIS – Doppler Orbitography and Radiopositioning Integrated by Satellites

- From 1990
- Over 50 stations
- Good geographical distribution
- Currently 5 satellites
- New satellites in future

- IERS technique
- Doppler one-way observations
- Ground beacons, onboard receivers

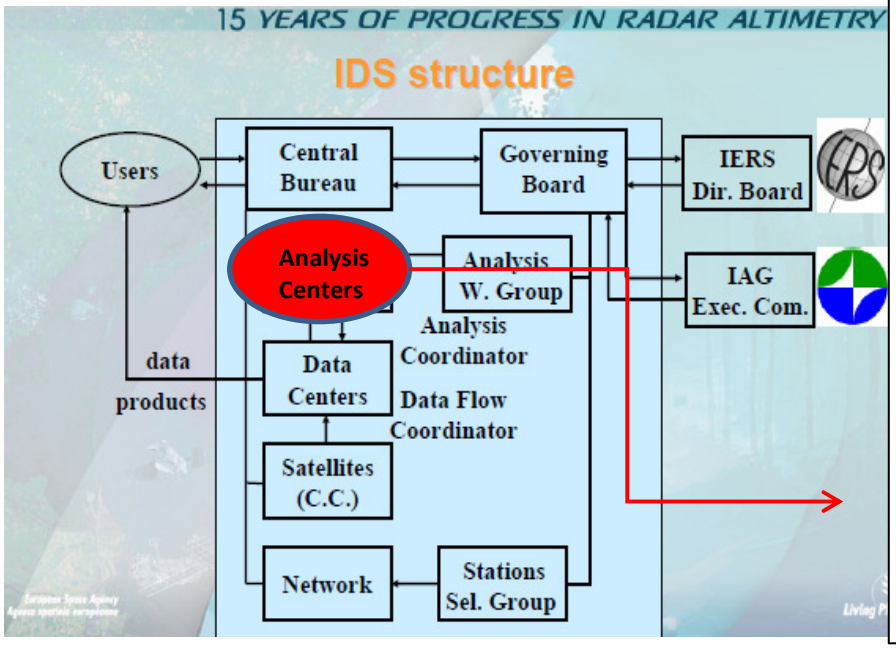
- Observation on 2 frequencies
- International service IDS

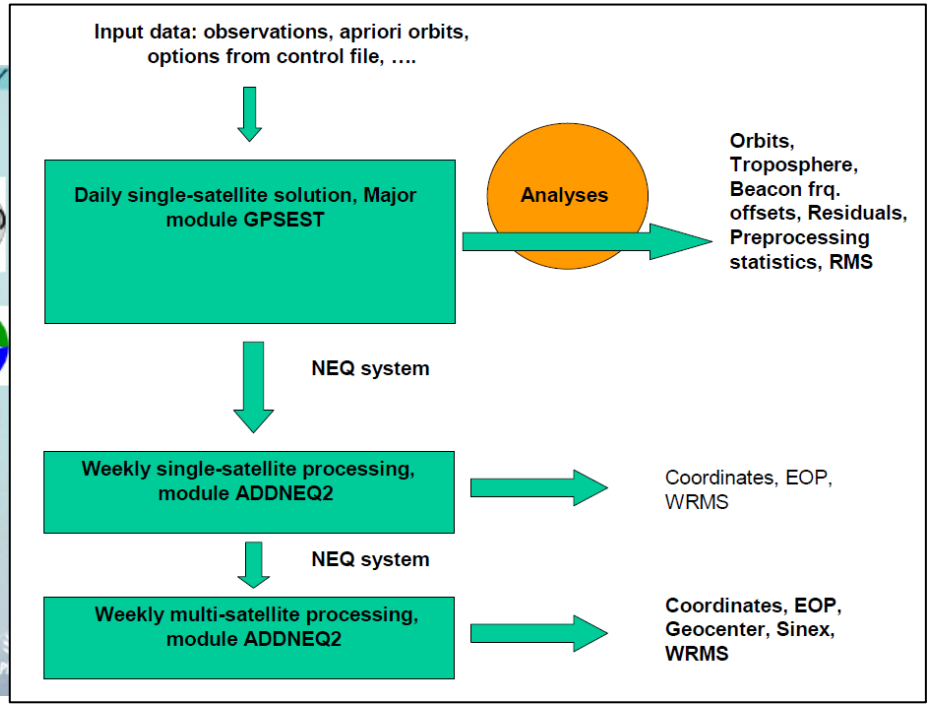


Source of figures: IDS presentations and web page

IDS DORIS Analysis Center at GOP

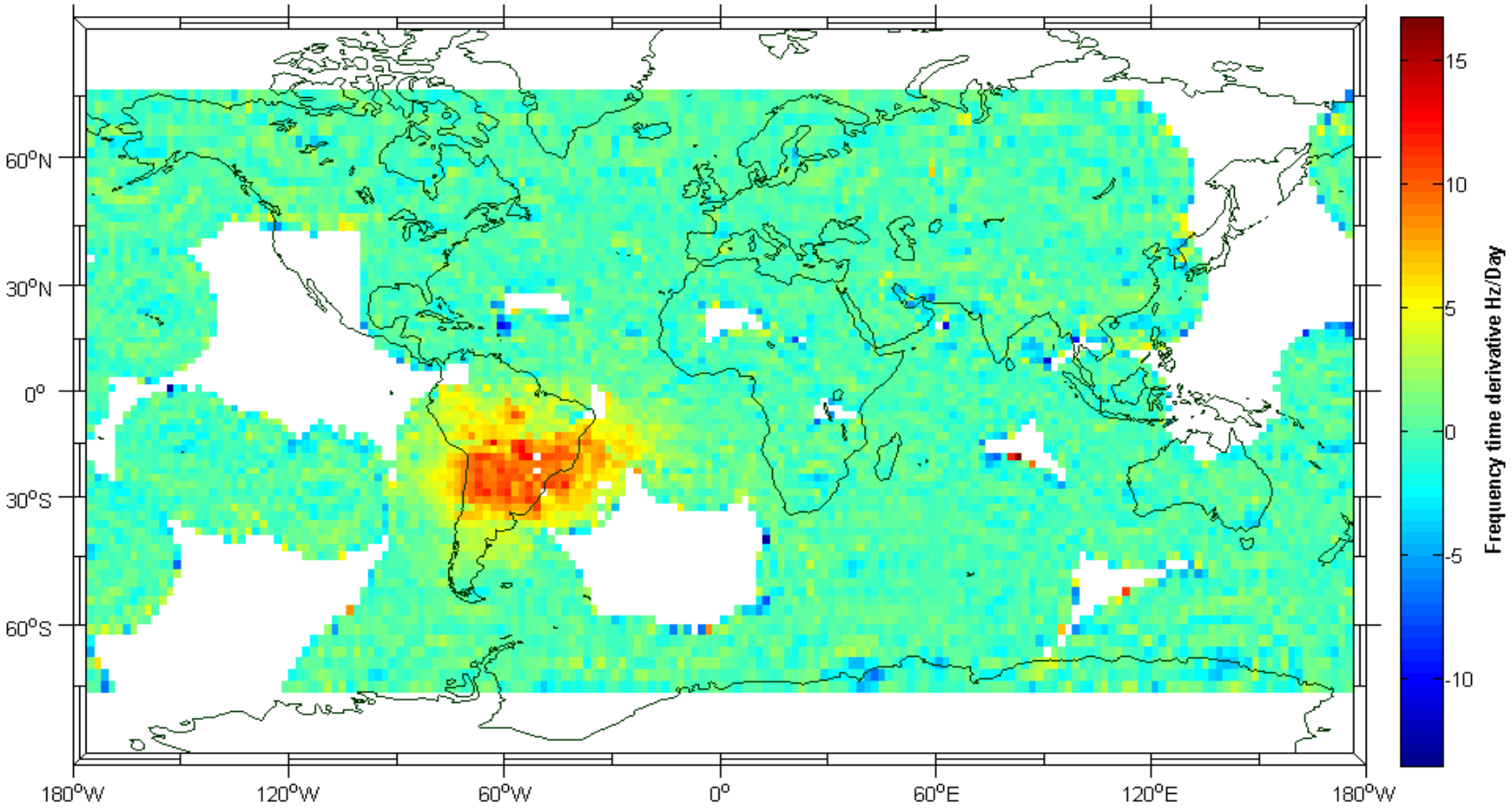
- Member of the International DORIS Service (IDS)
- Processing of observations
- Orbit determination
- Estimation of station coordinates, ERP, Troposphere, Frequency offset,…
- Daily and Weekly solutions
- Contribution to combined IDS products (solution for ITRF2008)
- Software platform: modified version of the Bernese 5.0
- Processing automation





IDS AC GOP: Development of the SPOT-5 empirical data correction model

South Atlantic Magnetic Anomaly – satellite is bombarded by high energy protons
Frequency drift of onboard oscillator, significant for satellites Jason-1 and SPOT-5
Offset in estimated parameters, over 10 cm in height for chosen stations (SPOT-5)
Grid map of the frequency drift, derived from the post-fit residuals
Corrections of measurements using the grid map.



Summary (1)

- GNSS-based geodetic infrastructure in the Czech Republic supporting surveying, mapping, cadastre and georeferencing has been successfully developing during the last decade and the number of its users has been rapidly increasing
- GOP develops and maintains observing and data managing systems for GNSS services and applications
- GOP contributes to the international scientific services and projects by precise scientific products such as orbits, ERP, EOP and reference frames within the International GNSS Service (IGS), the IAG Sub-commission for the European Reference Frame (EUREF), International DORIS Service

Summary (2)

- GOP is pursuing activities towards GNSS-based interdisciplinary applications by developing and providing operational products, such as monitoring the water vapor content in the atmosphere, station movements etc., in the areas of a special interest, like meteorology, climatology, geodynamics …

- Currently the GOP activities are focused on
  - developing a real-time capability for the positioning and atmosphere monitoring
  - supporting all multi-GNSS (GPS, GLONASS, Galileo,… observations and services
  - further enhancements of precise services, monitoring and evaluating databases