Precise GNSS Data Analysis

Junping Chen
陈俊平

Shanghai Astronomical Observatory

junping@shao.ac.cn

http://www.shao.ac.cn/shao_gnss_ac

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Content(9) GNSS若干问题(1)

- 数据处理软件平台的搭建

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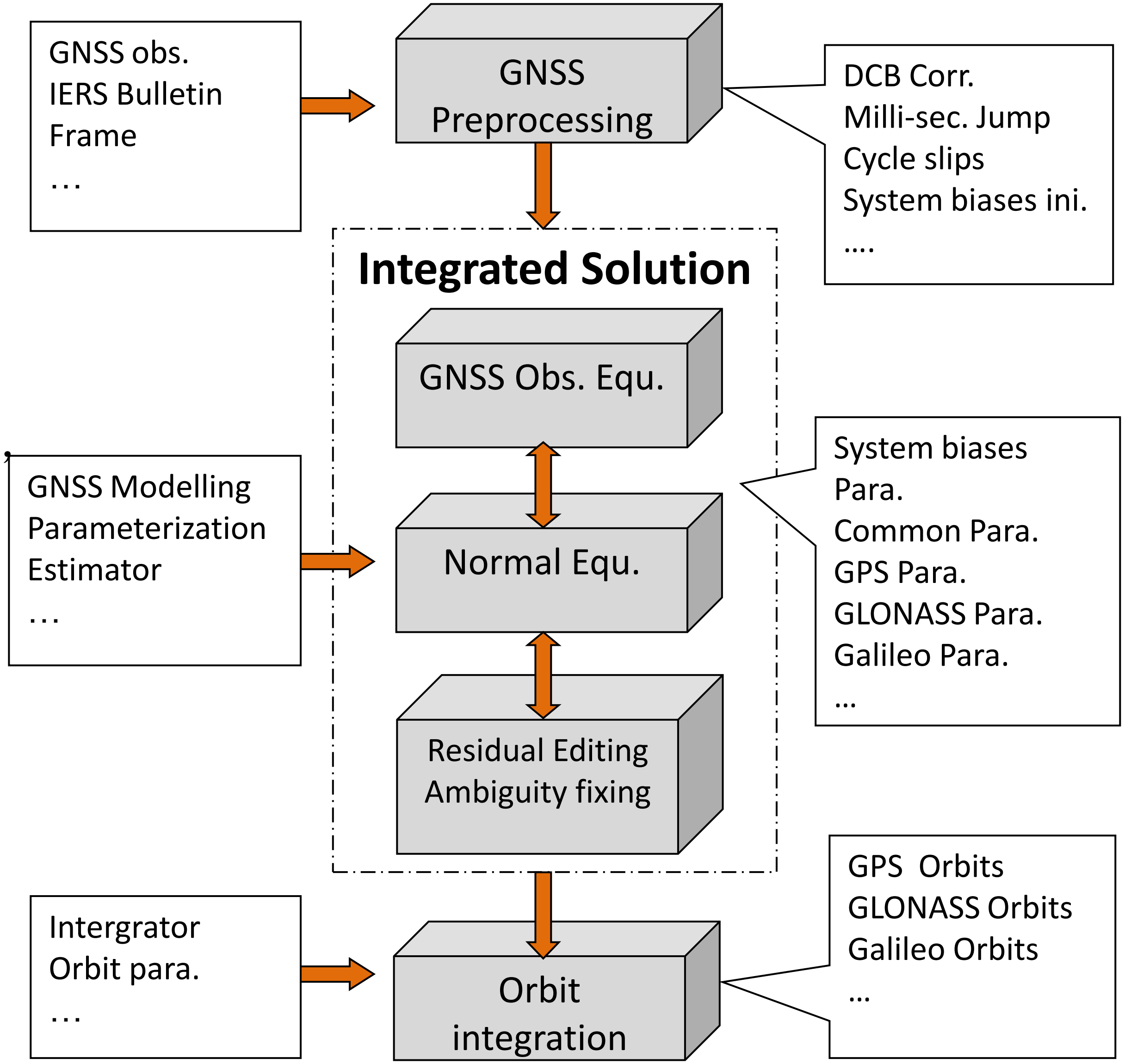
Platform

➢多星座整体数据处理平台iGPOS

❖系统一致的轨道、钟差、框架、ERP等

❖整体处理GPS，GLONASS，GALILEO，BD

❖整体处理GNSS，SLR & VLBI的数据（GGOS）



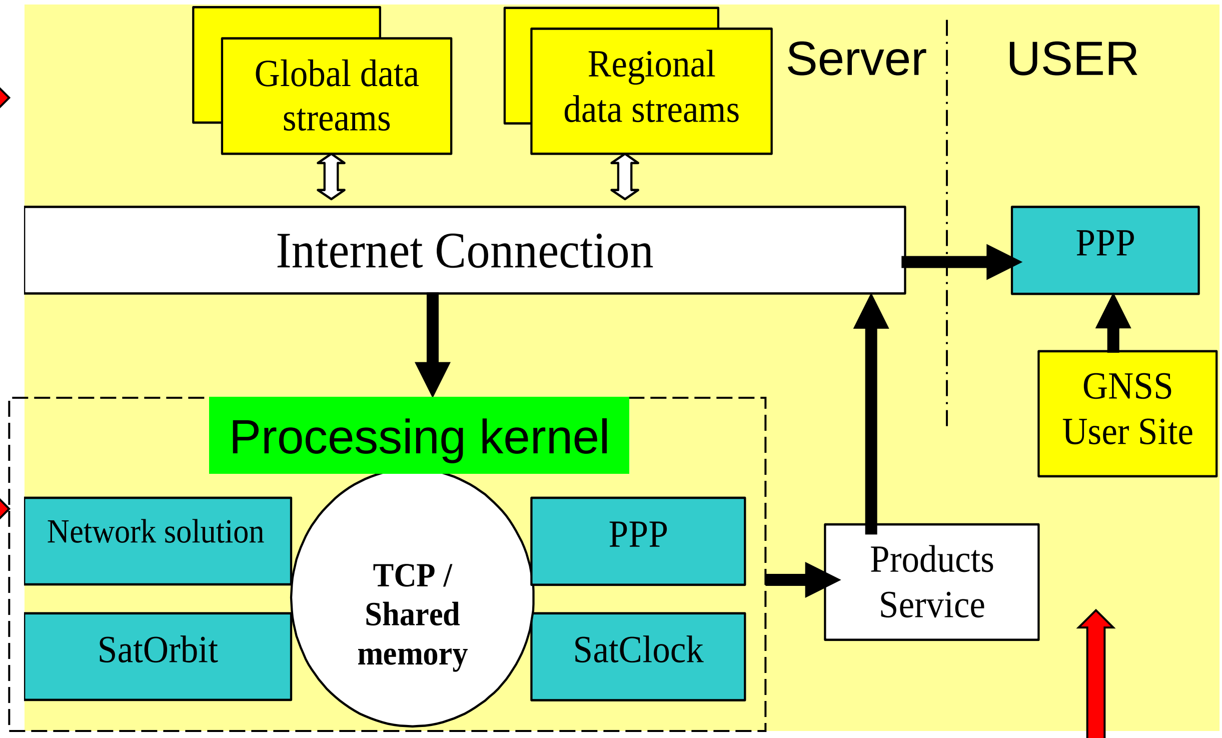
Real-time Data Analysis

实时通信数据流

- Ntrip通信
- 实时数据服务器(Server)
- 实时数据客户端(Client)

实时处理GNSS软件

- 实时处理/后处理
- 多站网络解算/单站定位
- 提供实时产品



- 实时产品接收
- 单站定位
- 测站监测

产品服务用户定位

GNSS若干问题(2)

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- 精密单点定位

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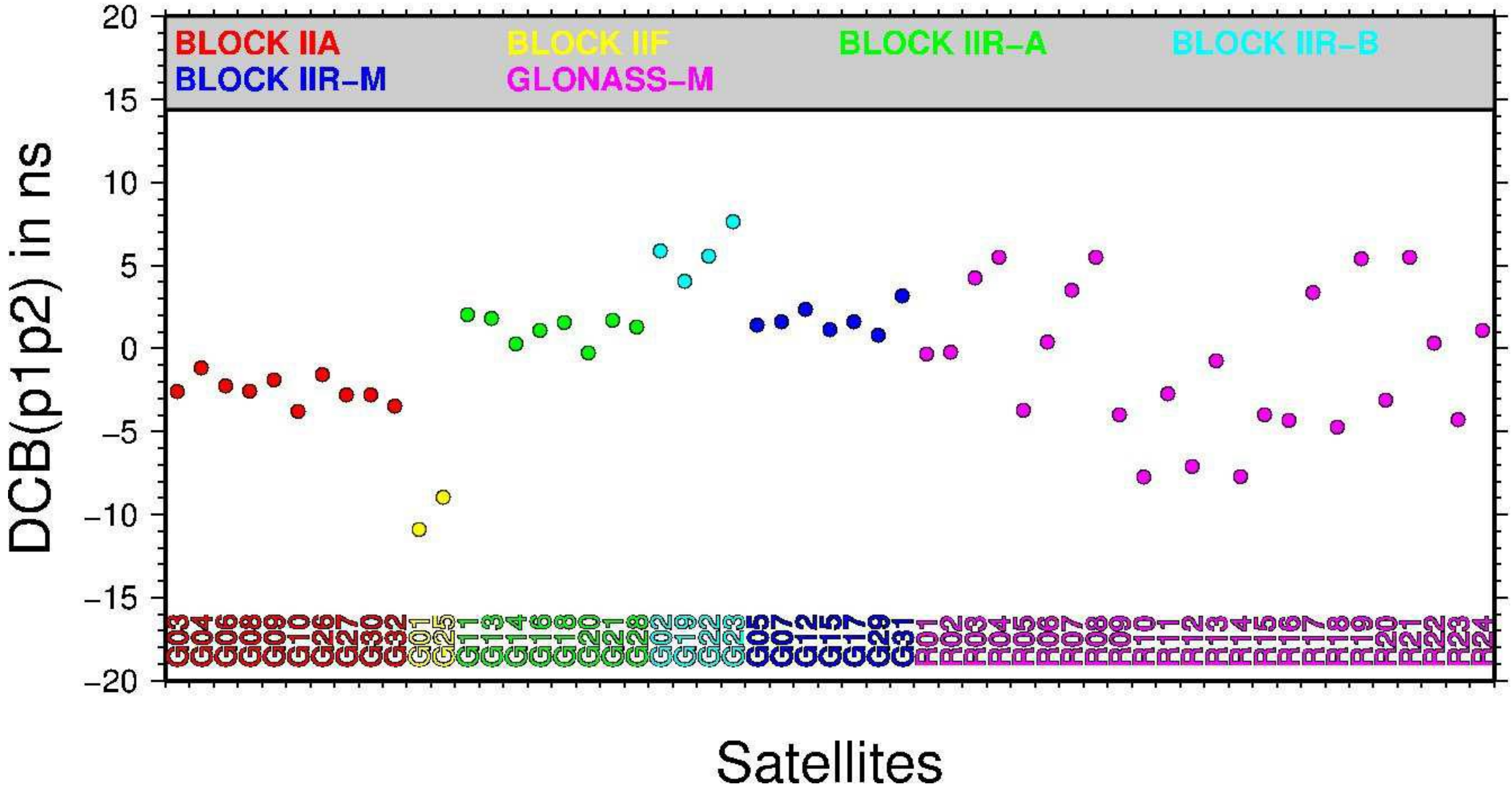
PPP定位模型

$$P_i^j = \rho_i^j + c\cdot(dt_i - dt^j) + DCB_i^j - I_i^j + T_i^j + \varsigma_i^j$$

$$L_i^j = \rho_i^j + c\cdot(dt_i - dt^j) + DPB_i^j + \lambda\cdot N_i^j - I_i^j + T_i^j + \varepsilon_i^j$$



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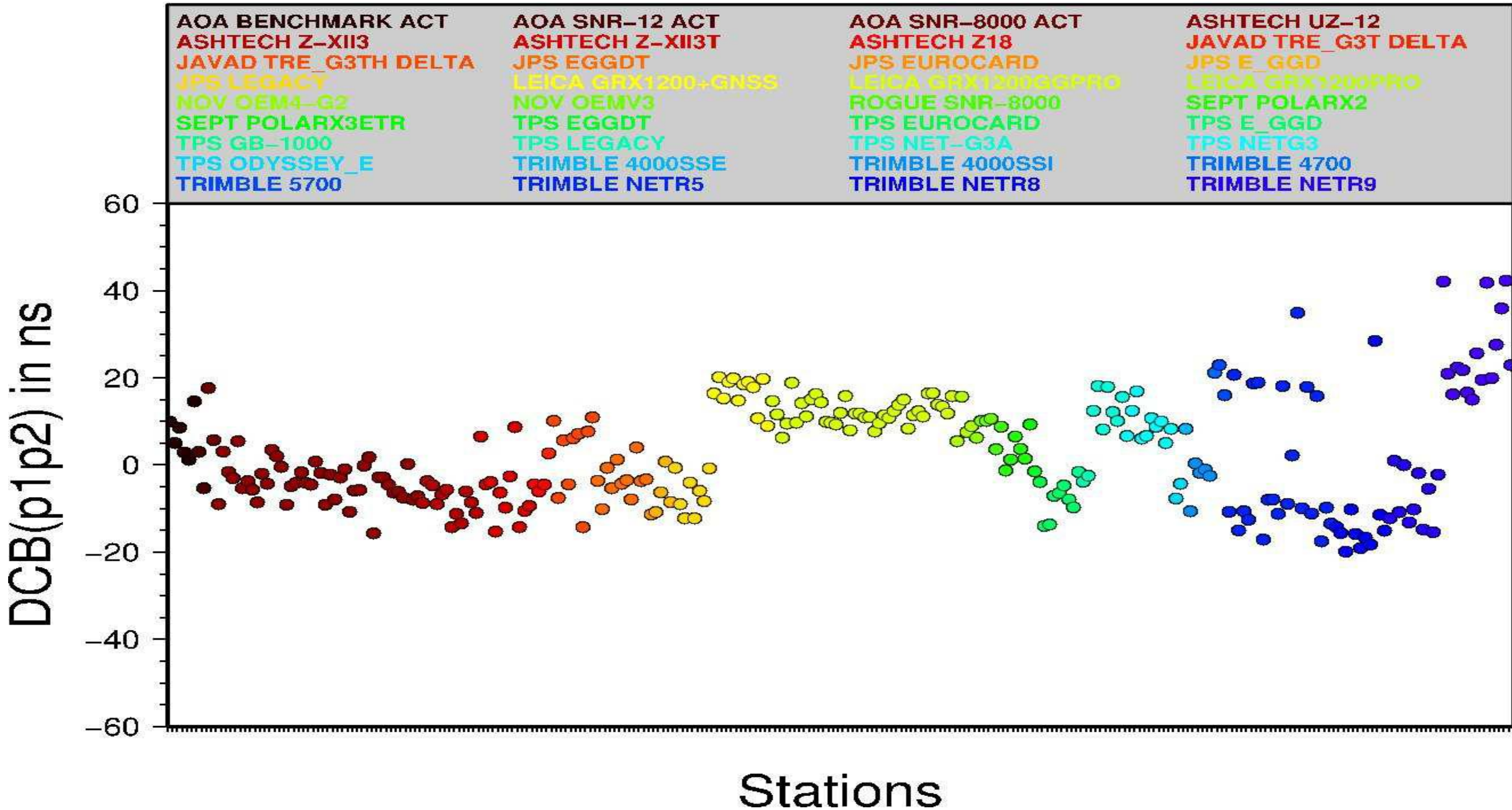


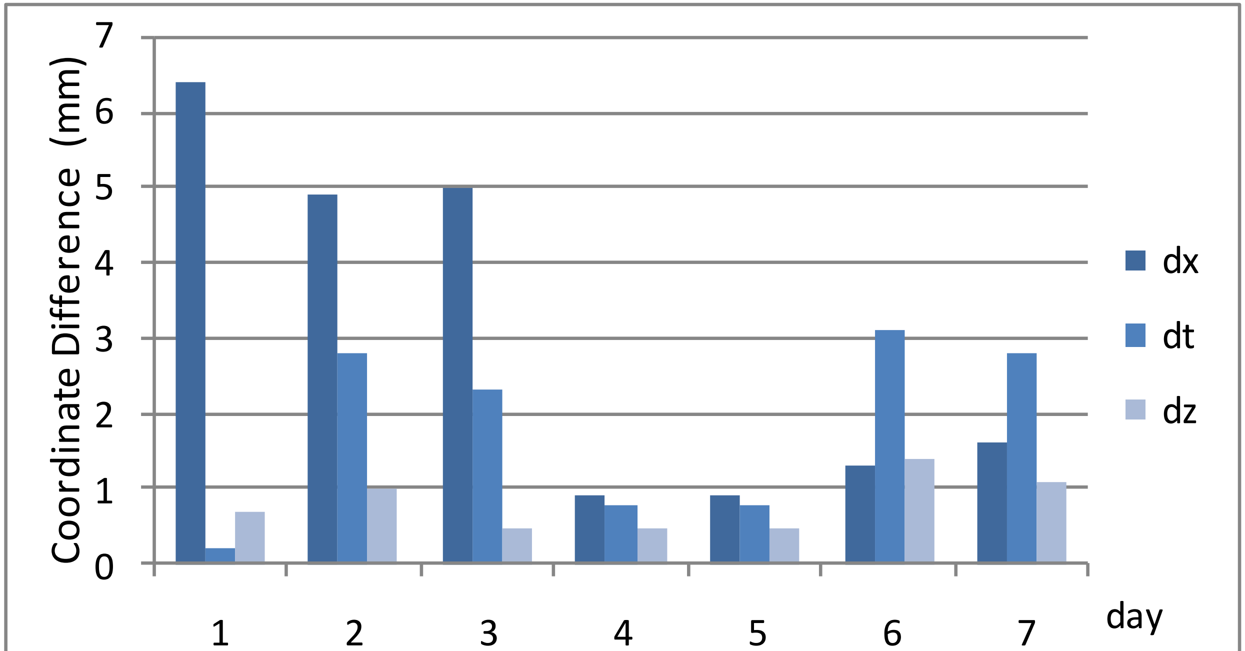
PPP定位模型

$$P_i^j = \rho_i^j + c\cdot(\bar{d}t_i - \bar{d}t^j) - I_i^j + T_i^j + \varsigma_i^j$$

$$L_i^j = \rho_i^j + c\cdot(\bar{d}t_i - \bar{d}t^j) + \lambda\cdot\bar{N}_i^j - I_i^j + T_i^j + \varepsilon_i^j$$

$$c\cdot(\bar{d}t_i - \bar{d}t^j) = c\cdot(dt_i - dt^j) + DCB_i^j$$

$$\lambda\cdot\bar{N}_i^j = \lambda\cdot N_i^j + DPB_i^j - DCB_i^j$$



组合系统PPP定位模型

$$L_i^{jG} = \rho_i^{jG} + c\cdot(\bar{d}t_i - \bar{d}t^j)^G - I_i^{jG} + T_i^{jG} + \lambda^G \cdot \bar{N}_i^{jG} + \varsigma_i^j$$

$$L_i^{jR} = \rho_i^{jR} + c\cdot(\bar{d}t_i - \bar{d}t^j)^G + ISB_i^{jR} + \lambda^R \cdot \bar{N}_i^{jR} - I_i^{jR} + T_i^{jR} + \varepsilon_i^j$$

$$\begin{aligned} ISB_i^{jR} &= c\cdot(\bar{d}t_i - \bar{d}t^j)^R - c\cdot(\bar{d}t_i - \bar{d}t^j)^G + IFB_i^{jR} \\ &= TO + \Delta DCB_i^j + IFB_i^{jR} \end{aligned}$$

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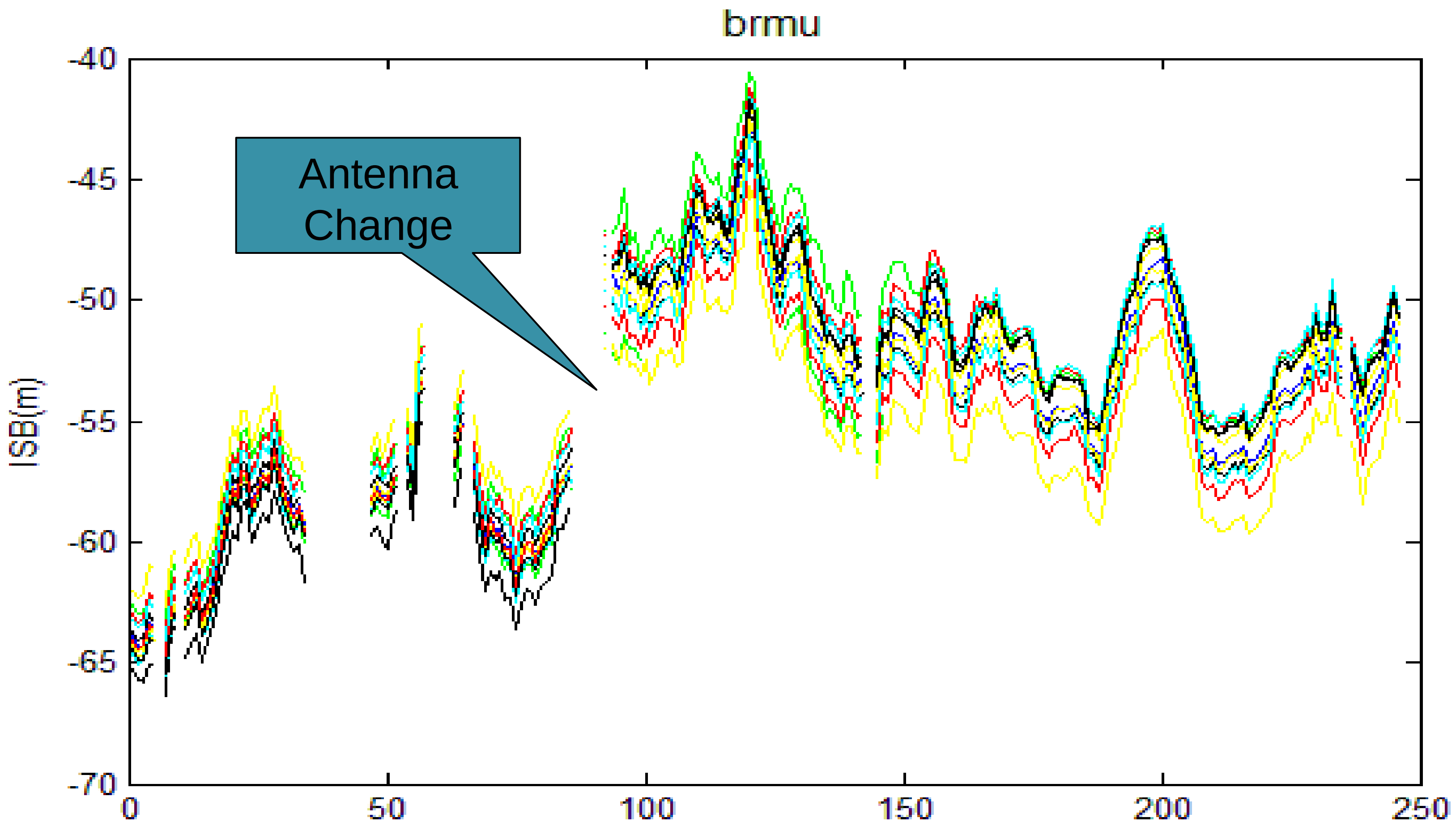
GPS/GLONASS inter-system bias

Site: BRMU, GPS+GLONASS observations

Spanning from: 2011 181 to 2012 240

Constant bias parameter per Glo sat. at **Daily** interval

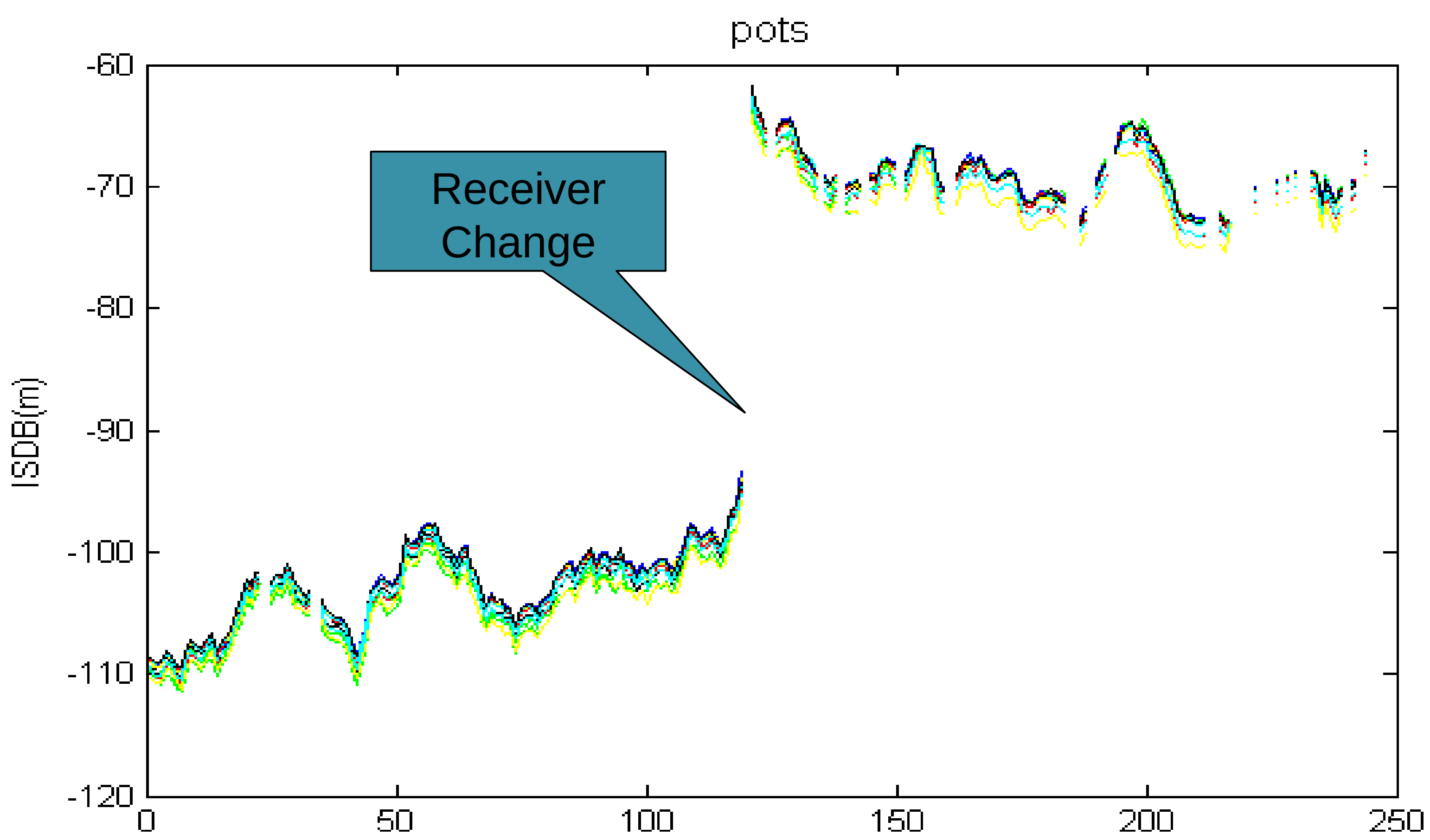


GPS/GLONASS inter-system bias

Site: POTS, GPS+GLONASS observations

Spanning from: 2011 181 to 2012 240

Constant bias parameter per Glo sat. at **Daily** interval

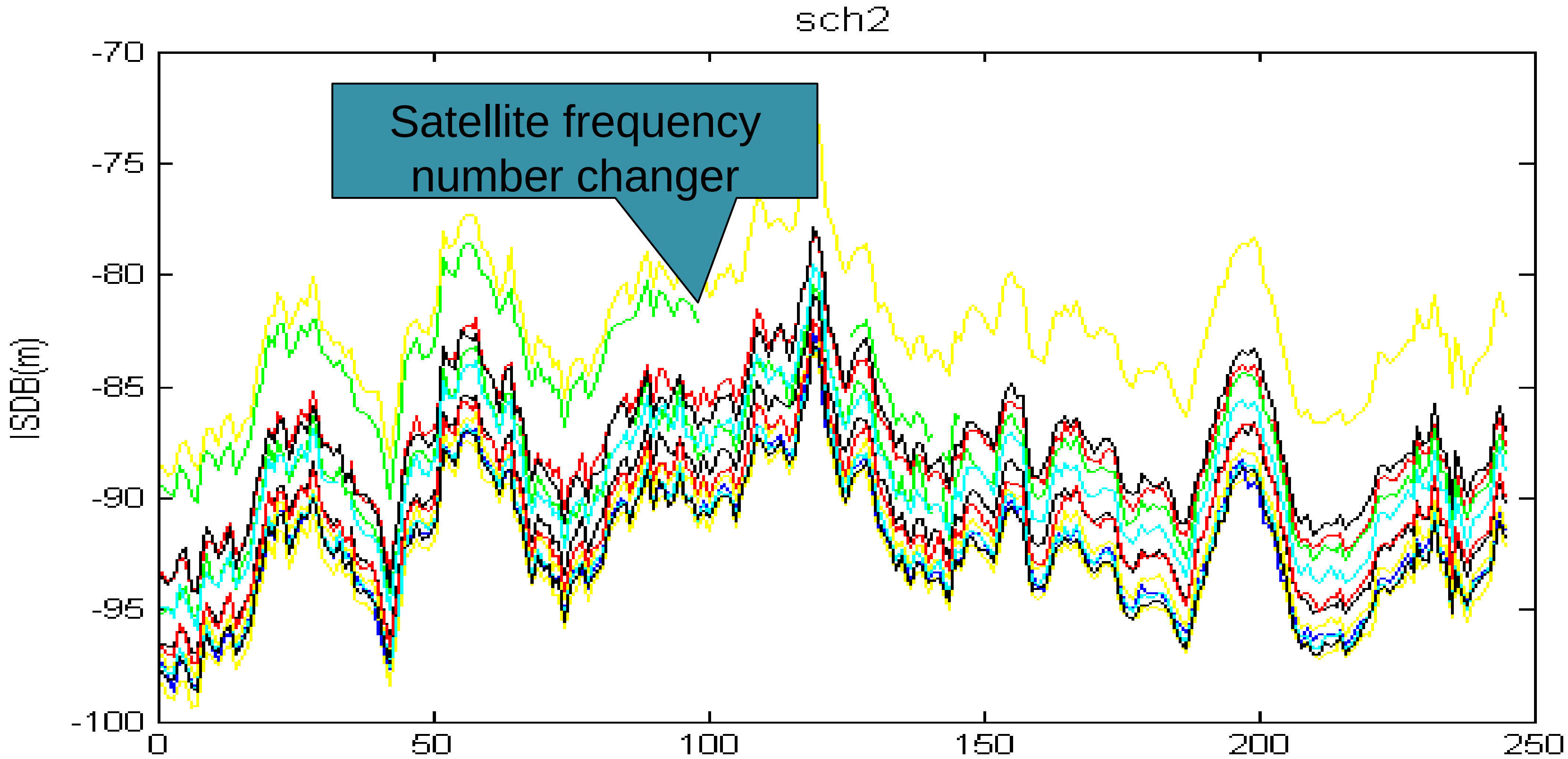


GPS/GLONASS inter-system bias

Site: SCH2, GPS+GLONASS observations

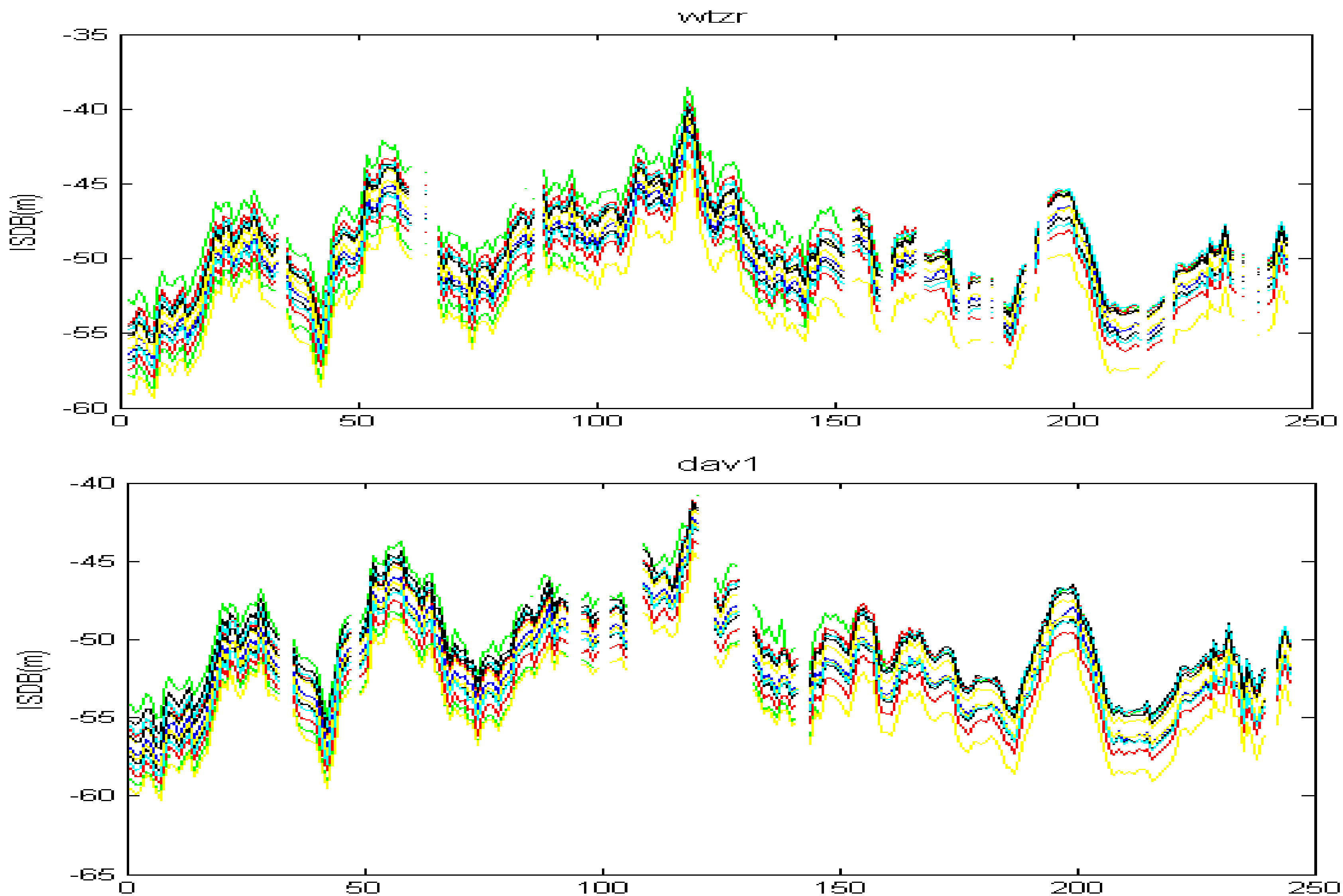
Spanning from: 2011 181 to 2012 240

Constant bias parameter per Glo sat. at **Daily** interval



GPS/GLONASS inter-system bias

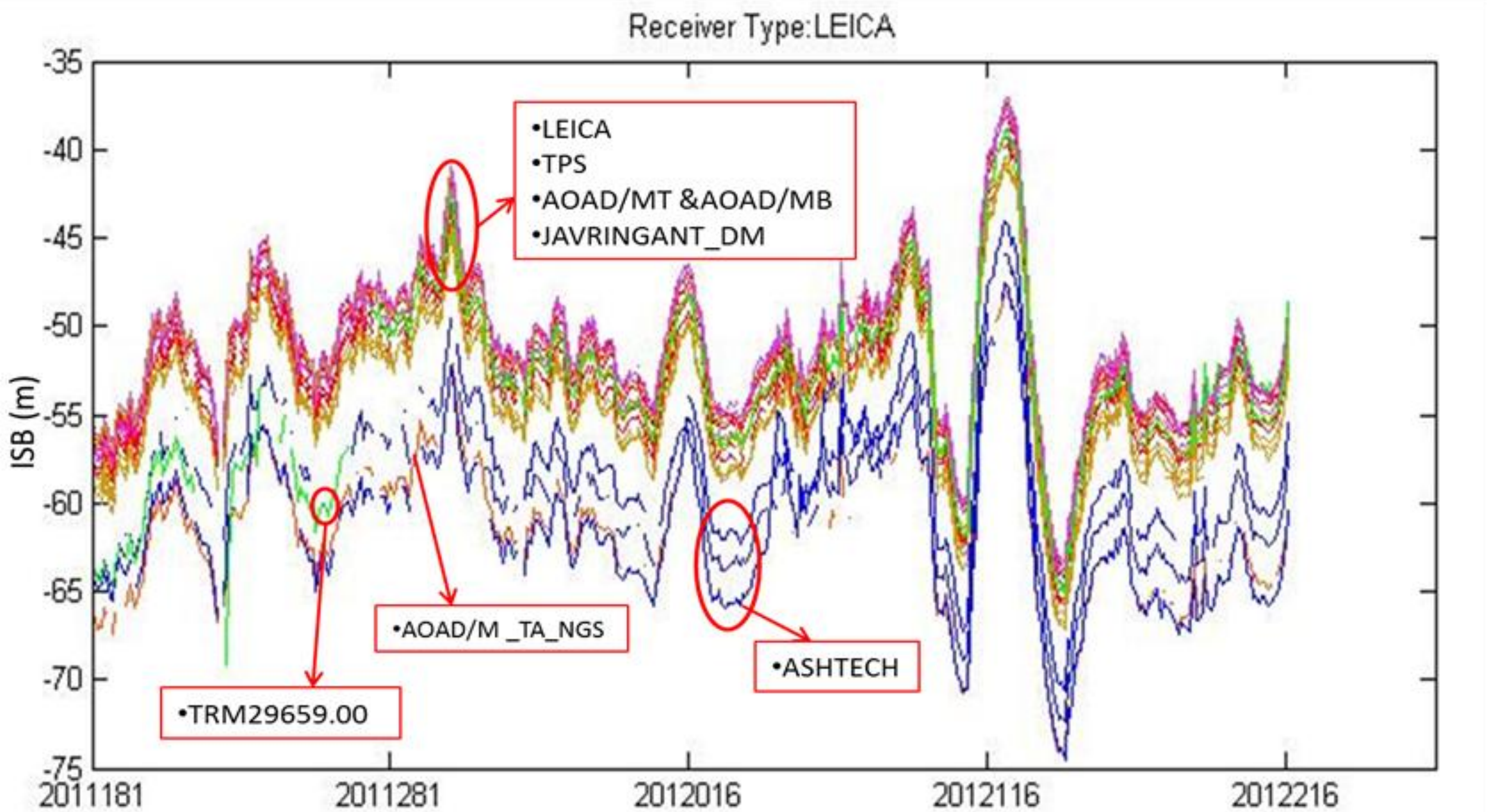
Receiver: LEICA GRX1200GGPRO



GPS/GLONASS inter-system bias

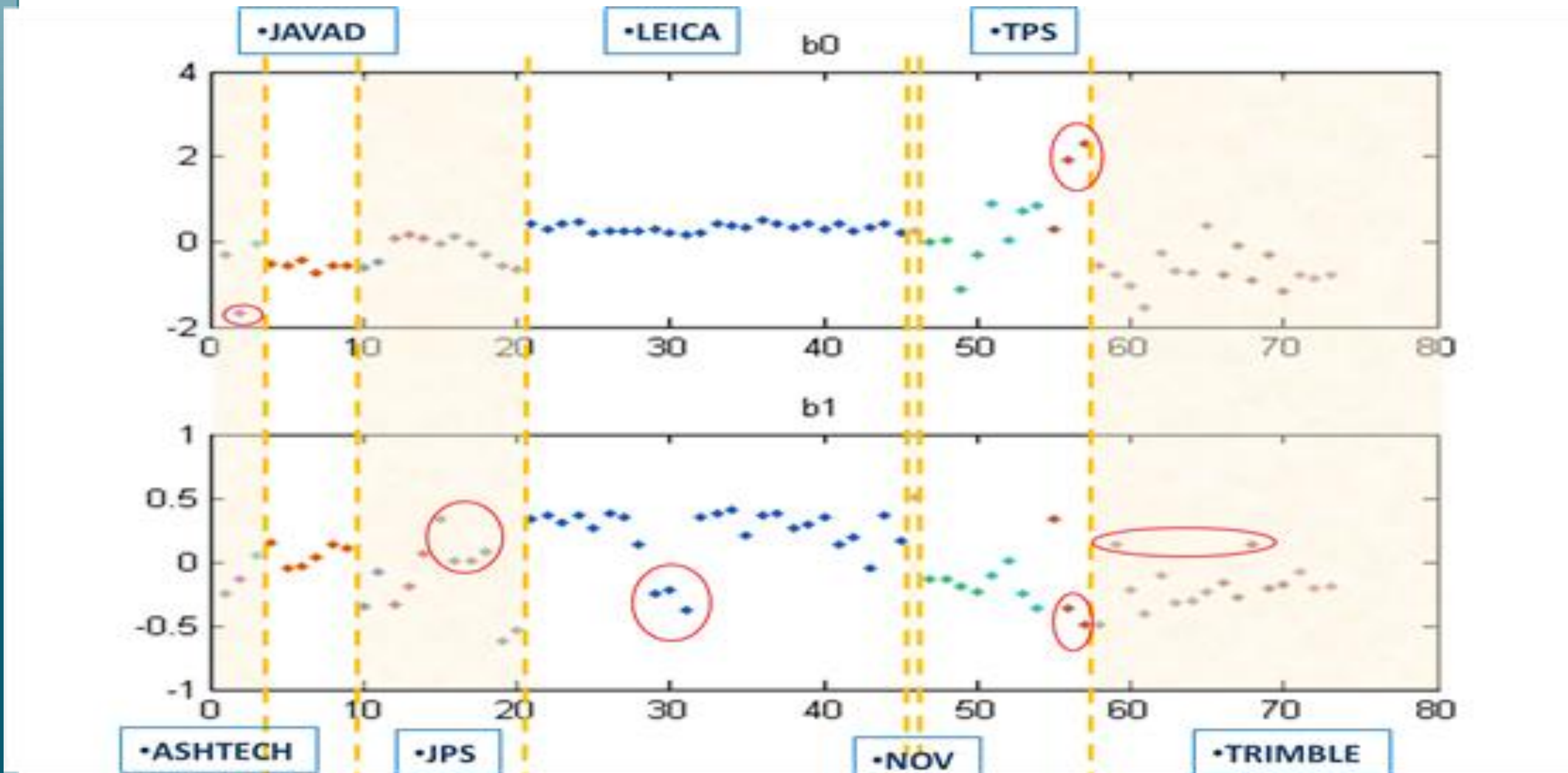
Receiver: LEICA

Spanning from: 2011 181 to 2012 240



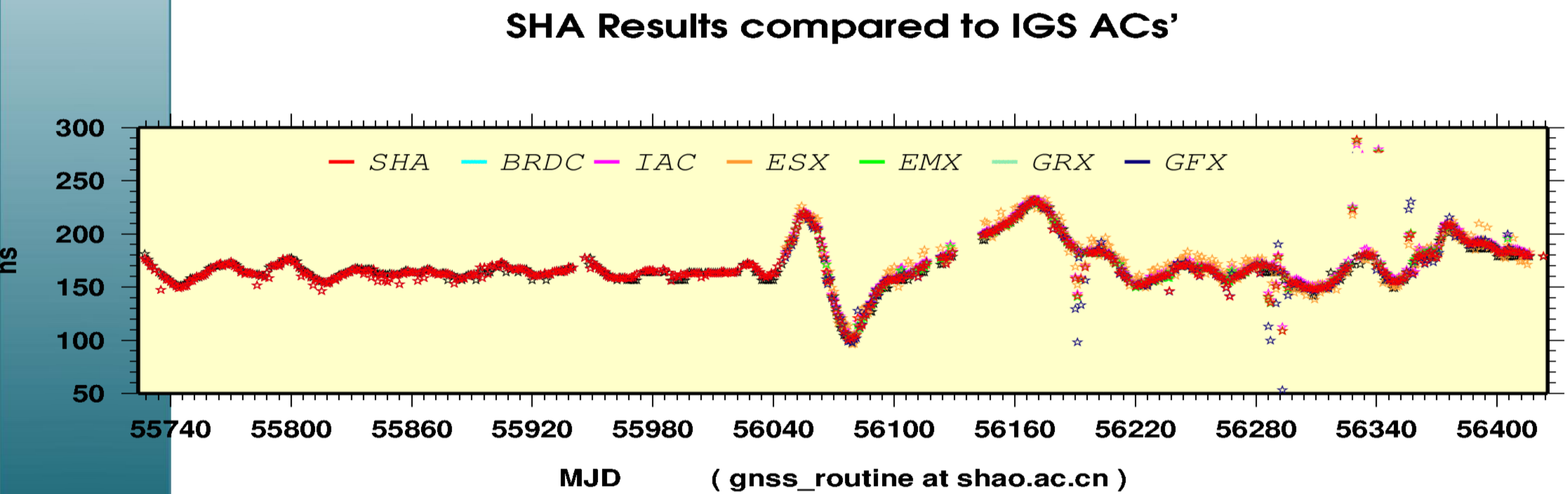
GPS/GLONASS inter-system bias

$$ISB_i^j - ISB_i^k$$
$$= \Delta DCB^{j,k} + IFB_i^{j,k}$$
$$= \Delta DCB^{j,k} + (f^j - f^k)\Delta h_i = b0 + b1 \cdot (f^j - f^k)$$



Other products of SHA

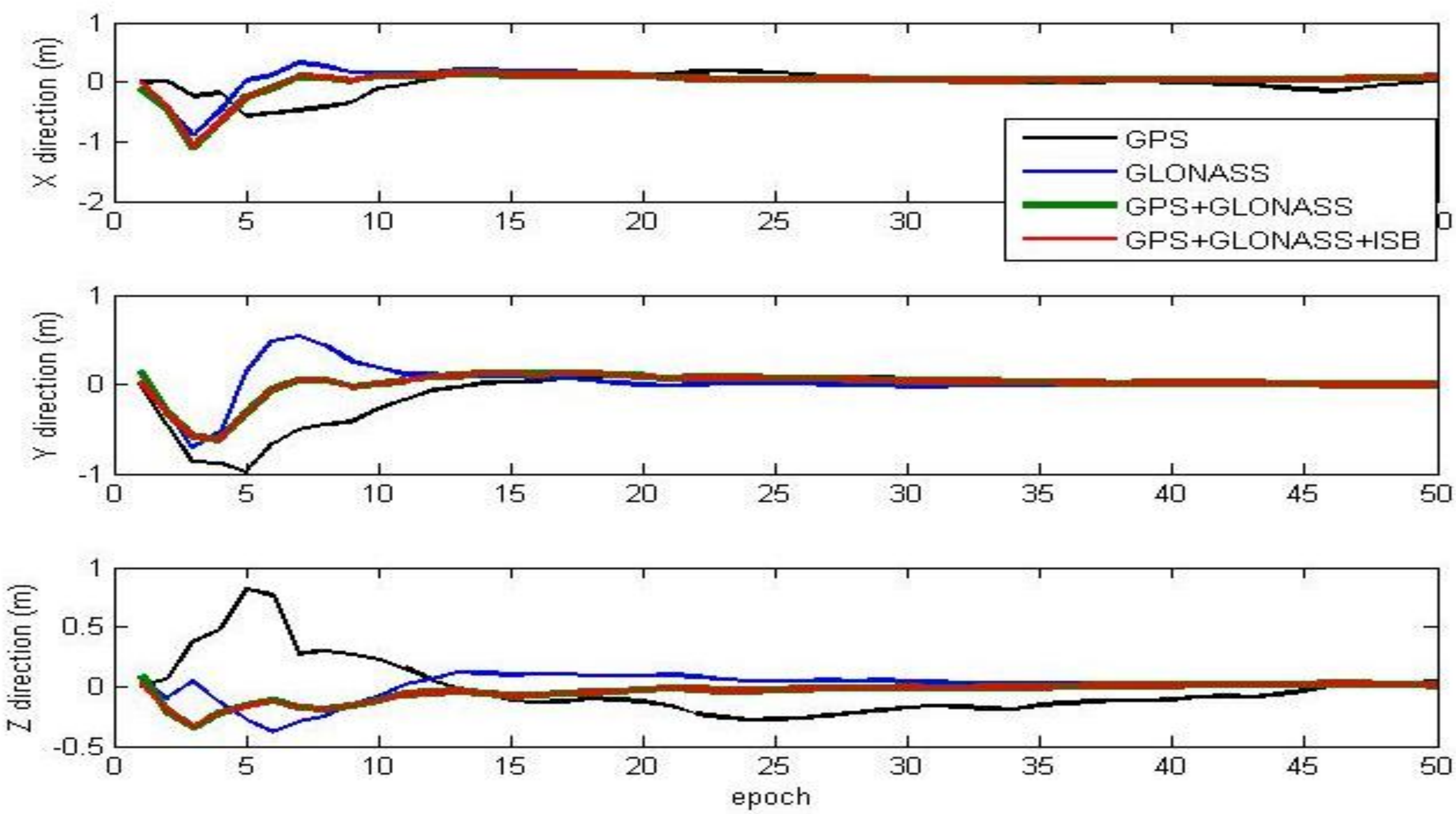
➢ **GPS/GLONASS Time Offset**



GPS/GLONASS inter-system bias in Multi-GNSS PPP

4 Scenarios: Single system, dual system (normal and IS
introduced)

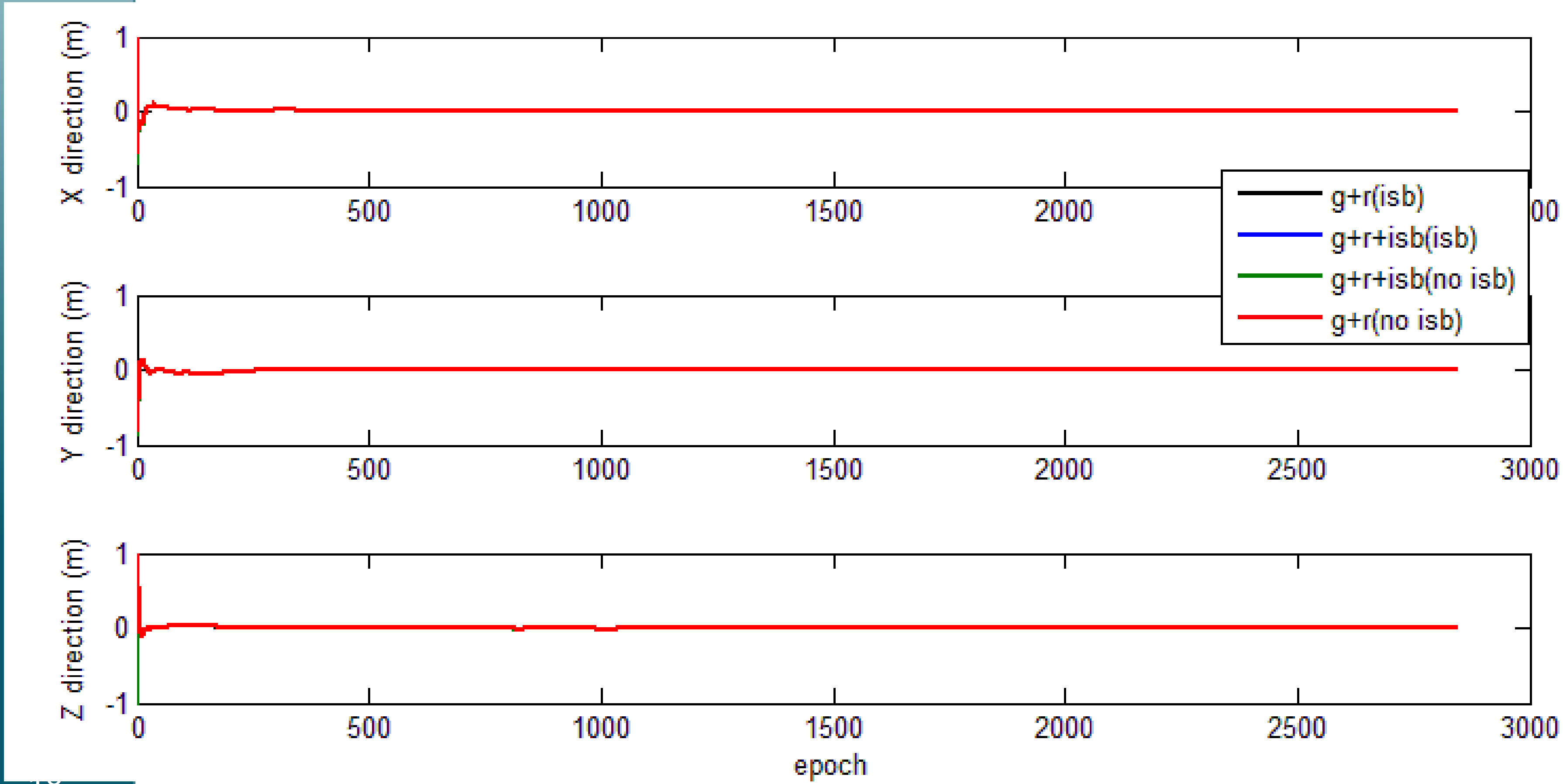
Software: User positioning client LTW_BS developed at SHA



GPS/GLONASS inter-system bias in Multi-GNSS PPP

4 Scenarios: Single system, dual system (normal and ISB introduced)

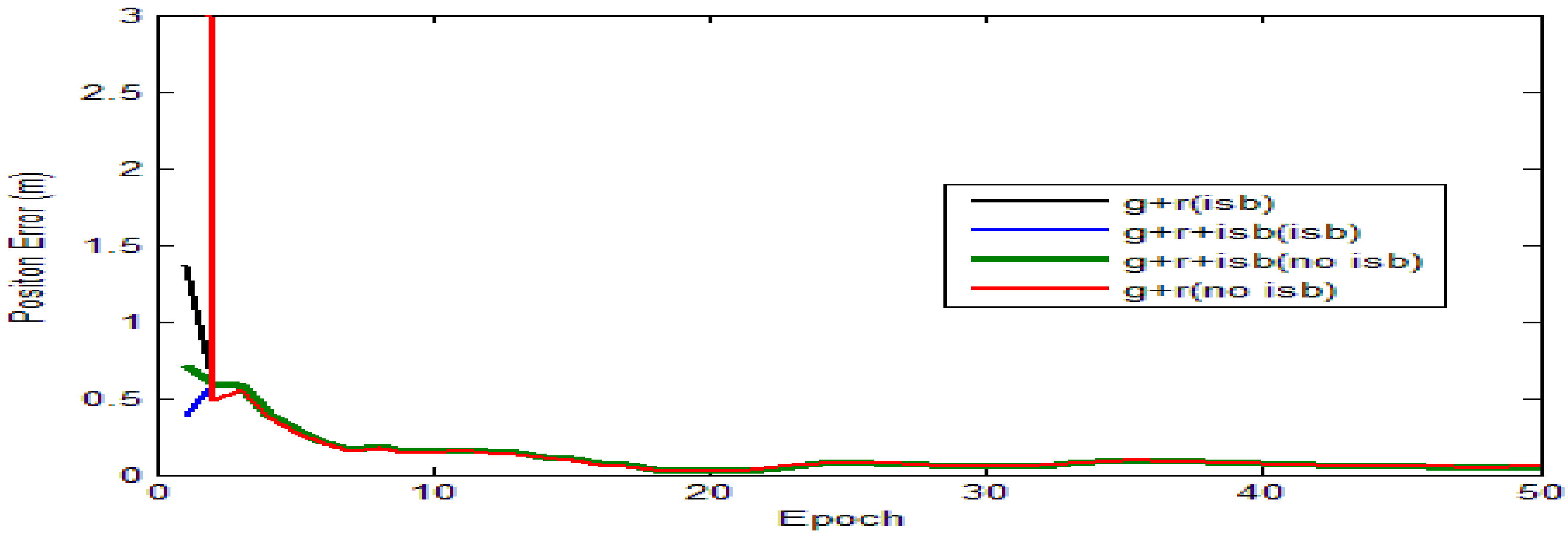
Software: User positioning client LTW_BS developed at SHAO



GPS/GLONASS inter-system bias in Multi-GNSS PPP

- ➢g+r(isb)：传统的GPS/GLOANSS组合精密单点定位
- ➢g+r+isb(isb)：在以上基础上，用SHA提供的GPS/GLONAS 时延偏差对GLONASS观测值进行改正，并进行偏差估计
- ➢g+r+isb(no isb)：同上,不进行偏差估计
- ➢g+r(no isb)：既不引入SHA提供的，也不估计ISB参数，即： 置一个接收机钟差参数

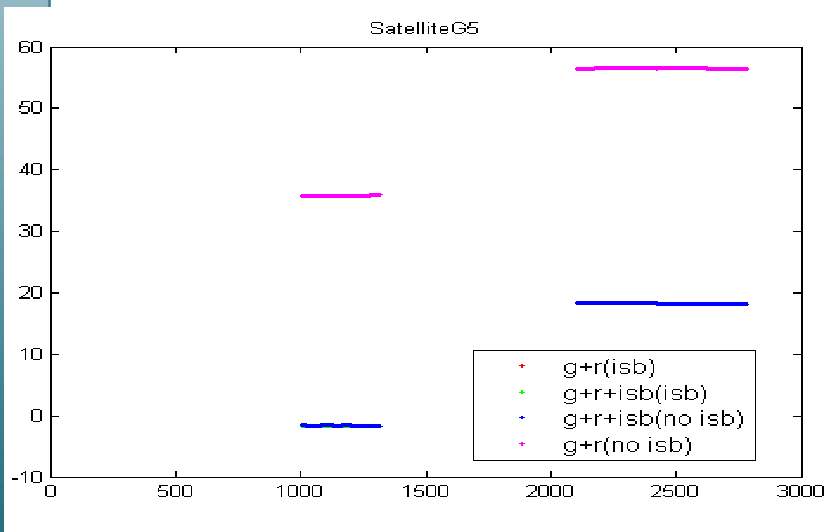
All 4 Scenarios come to the same result!!

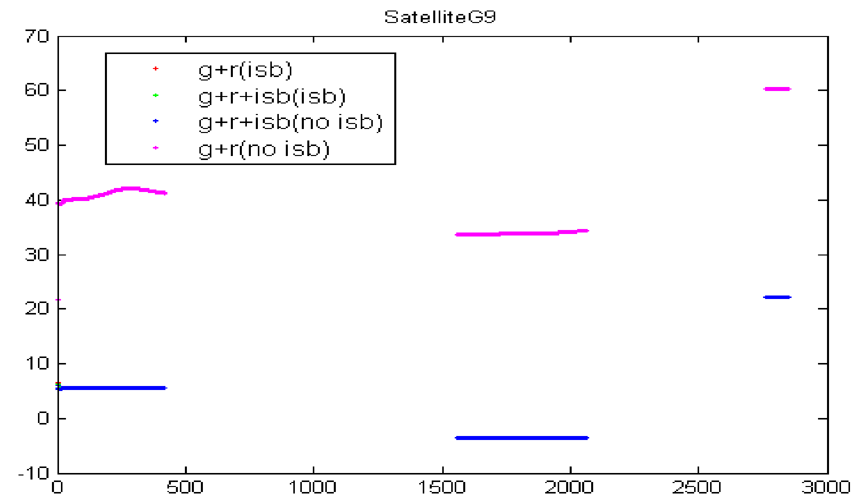


Multi-GNSS PPP: GPS ambiguities

Site: CHUR, GPS+GLONASS observations, 2012 318

Scenario 4 differs from the other three with a constant bias!!

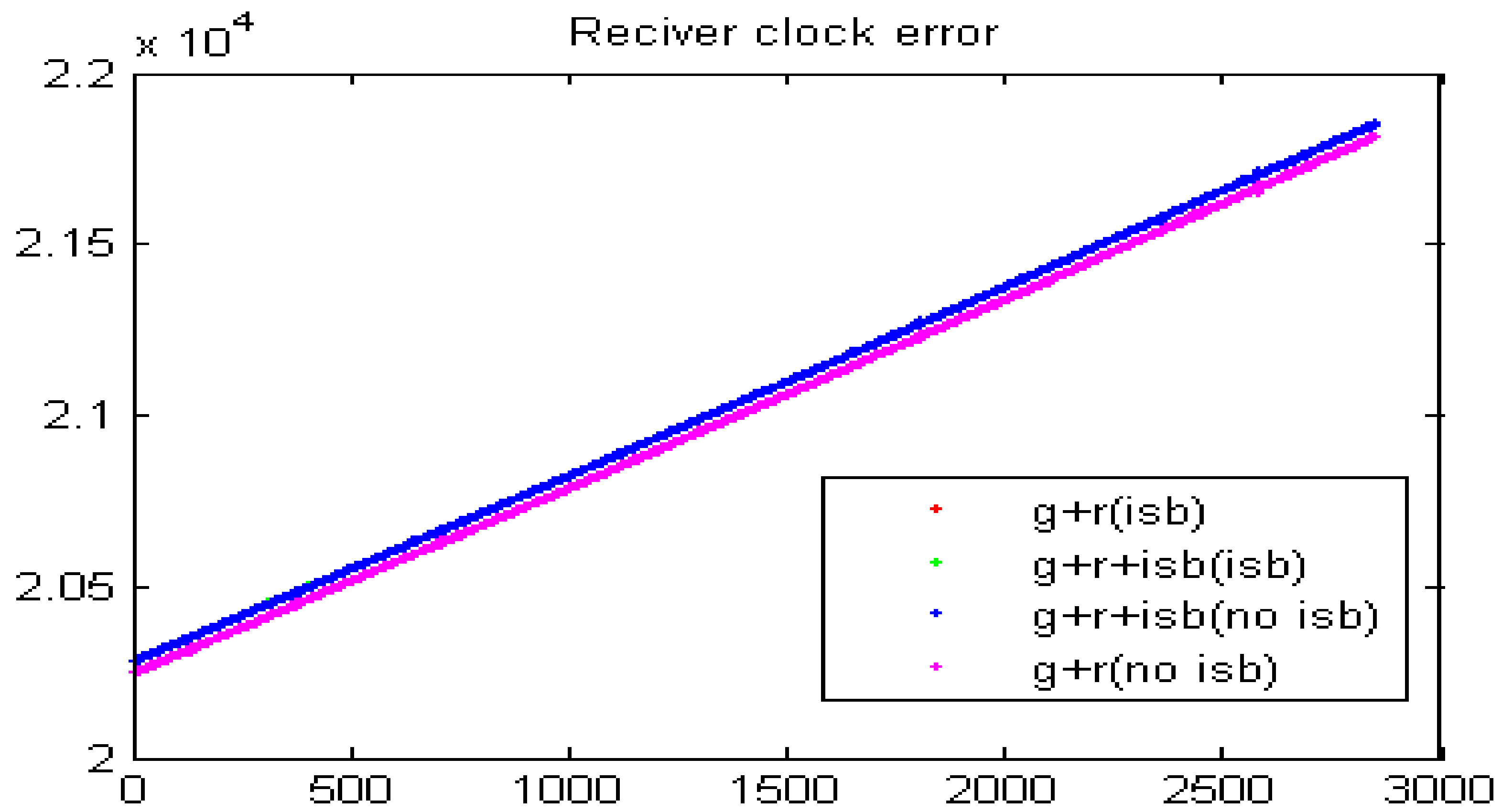




Multi-GNSS PPP: GPS clocks

Site: CHUR, GPS+GLONASS observations, 2012 318

Scenario 4 differs from the other three with a constant bias!!



Multi-GNSS PPP: GPS parameter mitigation

Site: CHUR, GPS+GLONASS observations, 2012 318

For GPS parameters: ambiguities and clocks are coupled

$$(c\cdot dt_i^G - c\cdot \overline{dt_i^G}) + (\lambda N_i^{jG} - \lambda \overline{N_i^{jG}}) = 0$$

Type	Average (mm)	STD (mm)	Type	Average (mm)	STD (mm)
G1	-0.01	0.03	G17	-0.01	0.02
G2	-0.01	0.02	G18	0.11	0.99
G3	0.42	4.02	G19	0.16	1.22
G4	-0.01	0.02	G20	-0.01	0.01
G5	-0.01	0.01	G21	0.20	1.62
G6	0.50	5.03	G22	0.49	4.55
G7	0.00	0.01	G24	-0.25	2.86
G8	0.00	0.01	G25	-0.01	0.01
G9	-0.25	2.90	G26	-0.58	6.79
G10	-0.01	0.01	G27	-0.01	0.01
G11	0.00	0.03	G28	-0.61	6.23
G12	-0.01	0.01	G29	-0.01	0.01
G13	-0.01	0.01	G30	-0.01	0.01
G14	0.66	6.35	G31	0.00	0.03
G15	-0.46	5.01	G32	0.00	0.01
G16	0.00	0.00			

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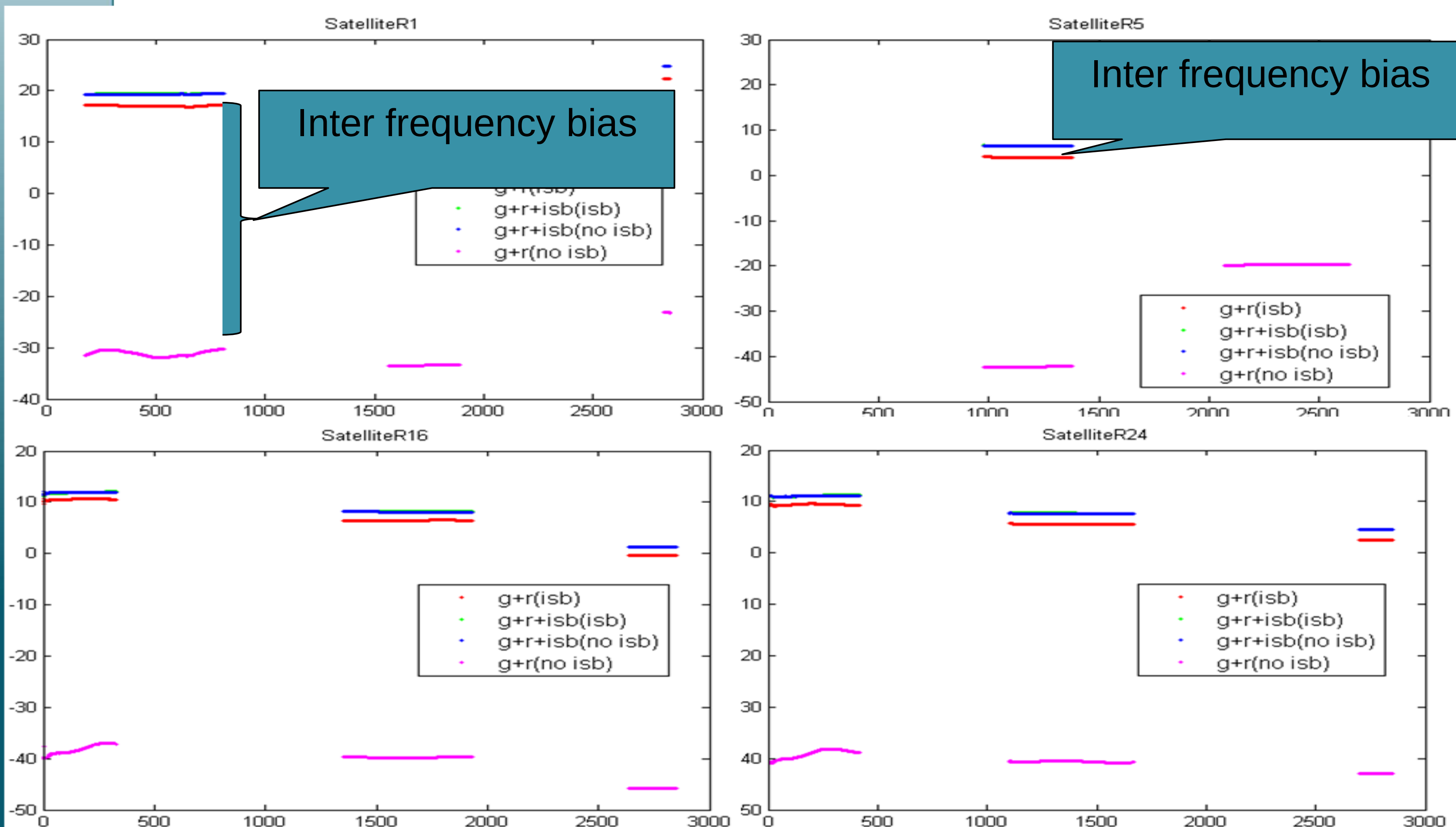
Multi-GNSS PPP: GLONASS ambiguities

Site: CHUR, GPS+GLONASS observations, 2012 318

Results sorted in three 3 groups!!



Multi-GNSS PPP: GLONASS parameter mitigation

All 4 Scenarios have the same results!!

For GLONASS parameters: ambiguities, clocks and system bias are coupled

$$\Sigma_{glonass1} = (c\cdot dt_i^G - c\cdot\overline{dt_i^G}) + ISB_i^{kR} + (\lambda\cdot N_i^{kR} - \lambda\cdot\overline{N_i^{kR}(4)})$$

$$\Sigma_{glonass2} = (c\cdot dt_i^G - c\cdot\overline{dt_i^G}) + ISB_i + (\lambda\cdot\overline{N_i^{kR}(1)} - \lambda\cdot\overline{N_i^{kR}(4)})$$

卫星	（ mm ）		（ mm ）	
	平均值	标准差	平均值	标准差
R1	0. 08	0. 05	0. 08	0. 07
R2	0. 09	0. 05	0. 04	0. 02
R3	0. 08	0. 05	0. 03	0. 01
R4	0. 07	0. 05	0. 02	0. 00
R5	0. 05	0. 04	0. 02	0. 00
R6	0. 02	0. 04	−0. 21	3. 82
R7	0. 03	0. 04	0. 27	1. 81
R9	0. 04	0. 04	0. 08	0. 21
R10	0. 07	0. 05	0. 08	0. 10
R11	0. 08	0. 05	0. 05	0. 05
…	0. 06	0. 03	0. 04	0. 03

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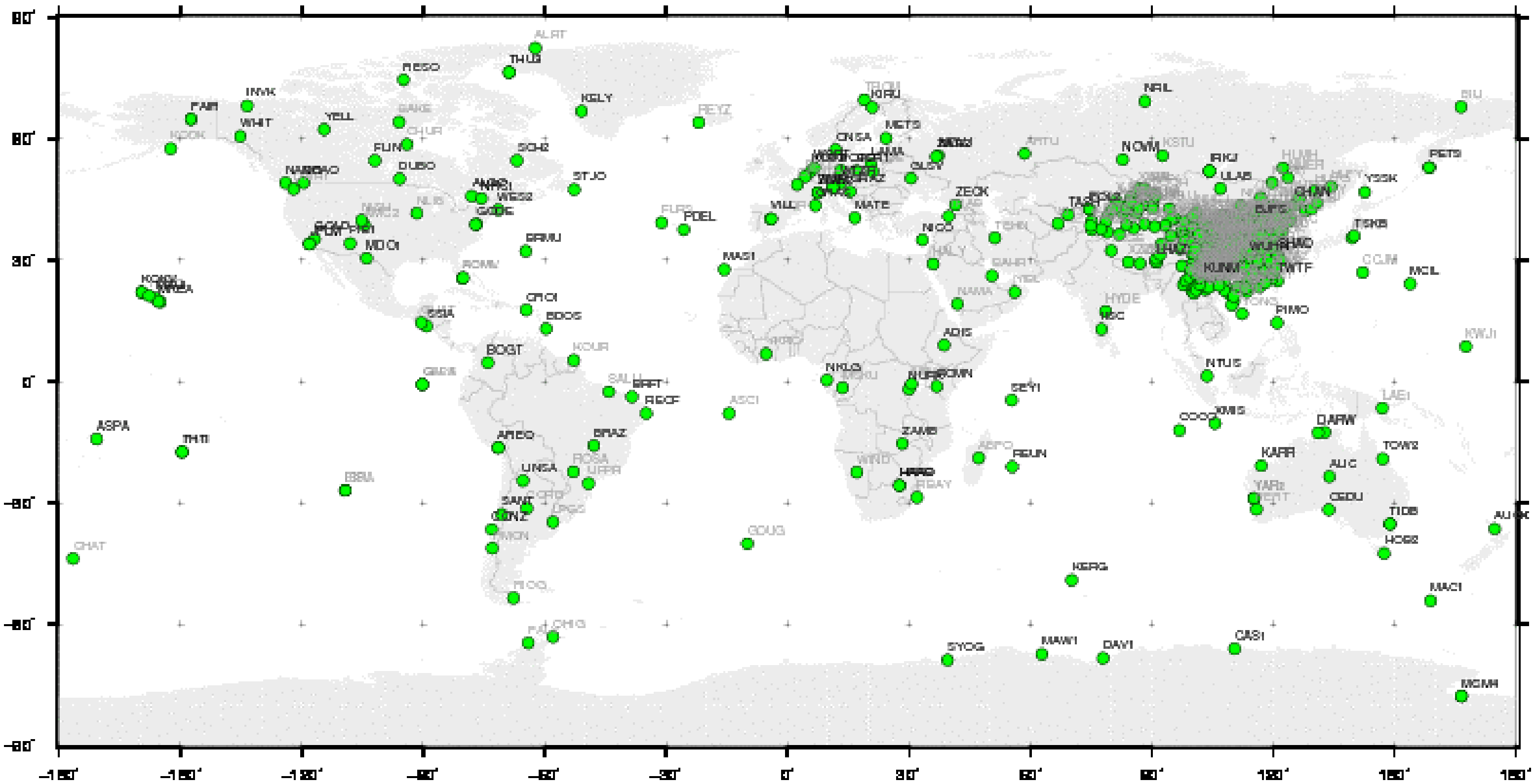
GNSS若干问题(3)

- 大网解算

- **Motivation**
- **Efficiency issue in Multi-GNSS data analysis**
- **Data sampling v.s. Product precision**
- **Summary**

Motivation

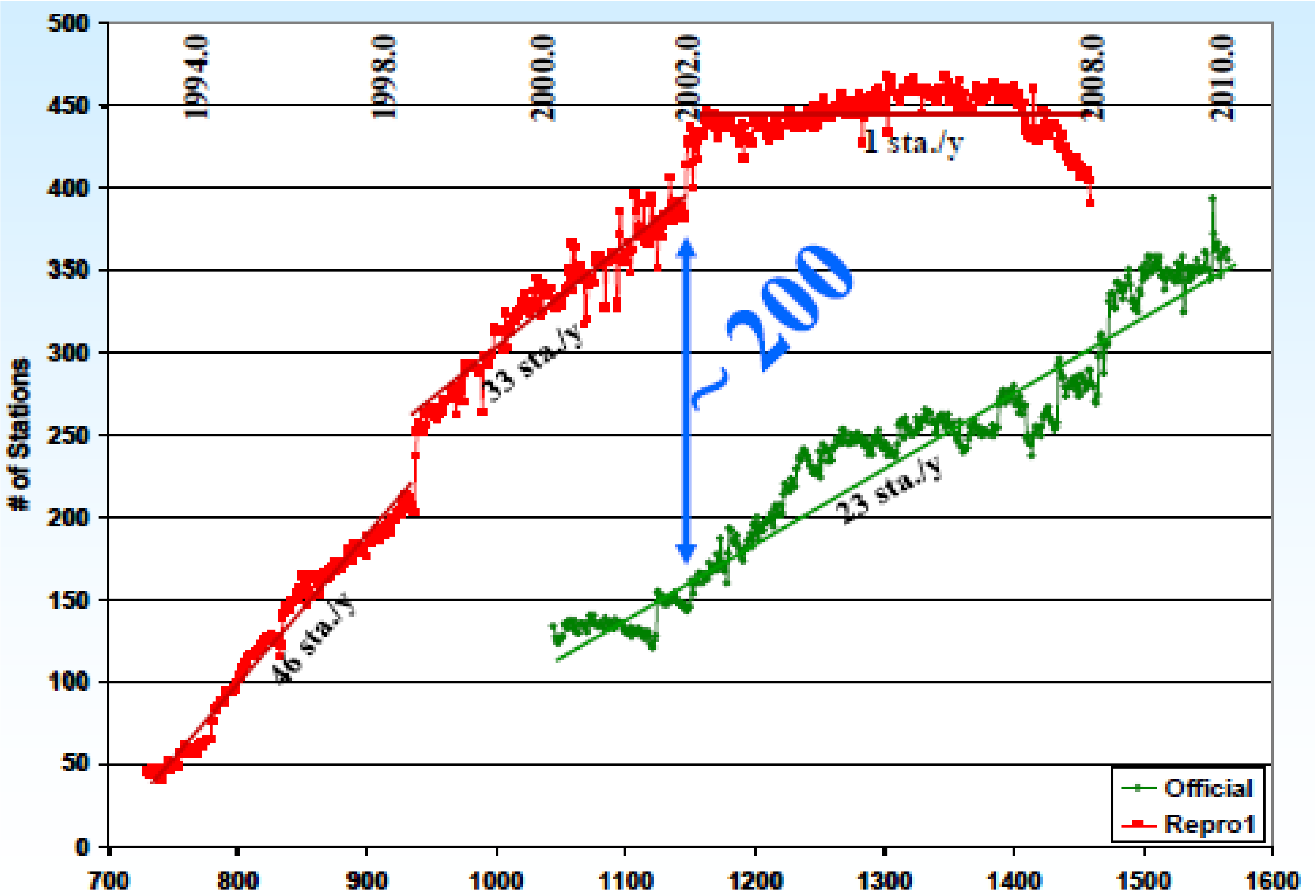


Huge network solution: Crustal Movement Observation Network of China (CMONOC): 260+ ~100 IGS stations

- To get consistent coordinates time series
- Daily GPS solution: takes ~12 hours!!

Challenges in Huge network solution

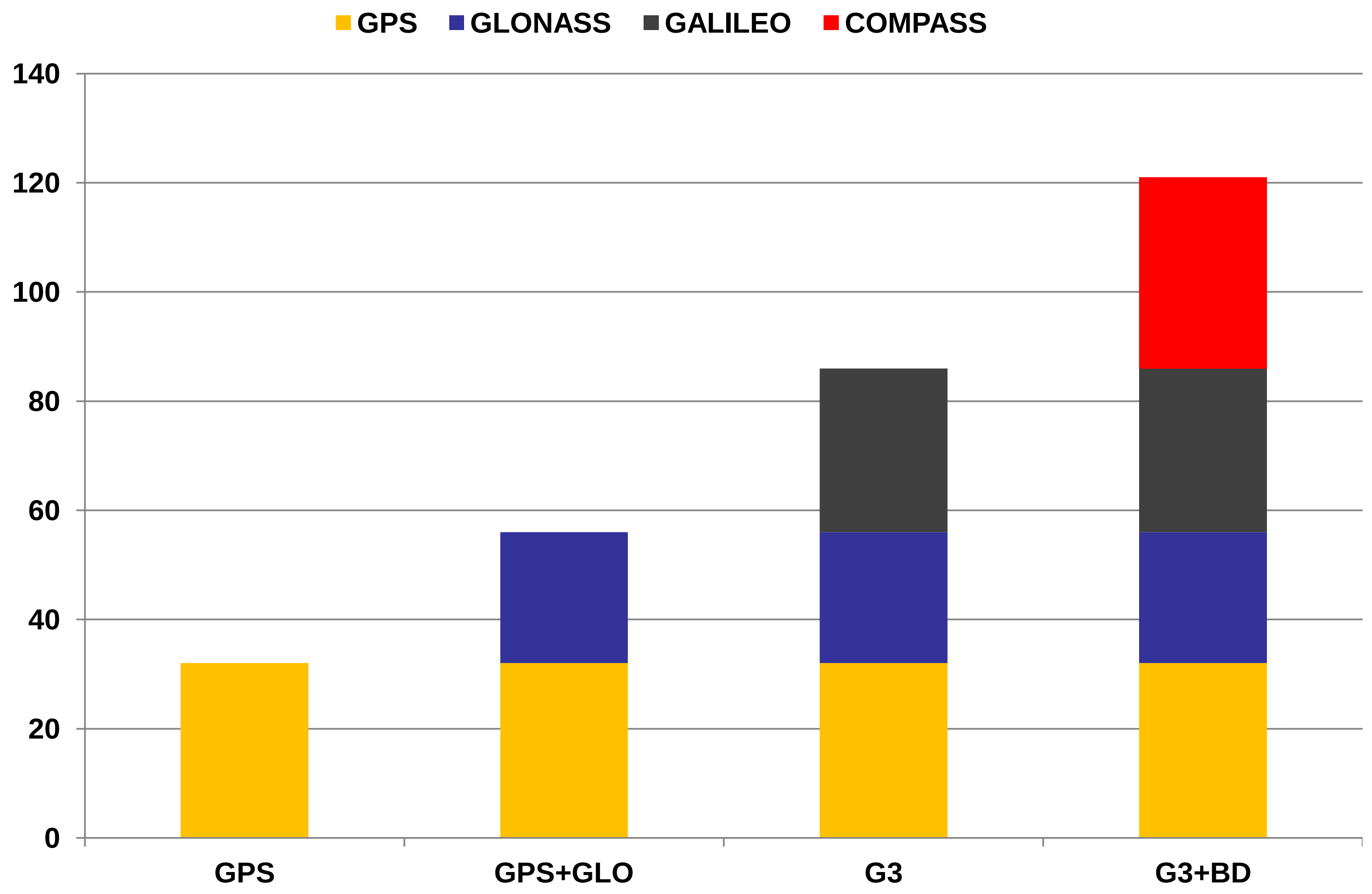
Huge network solution: Number of stations



R. Ferland. 2010

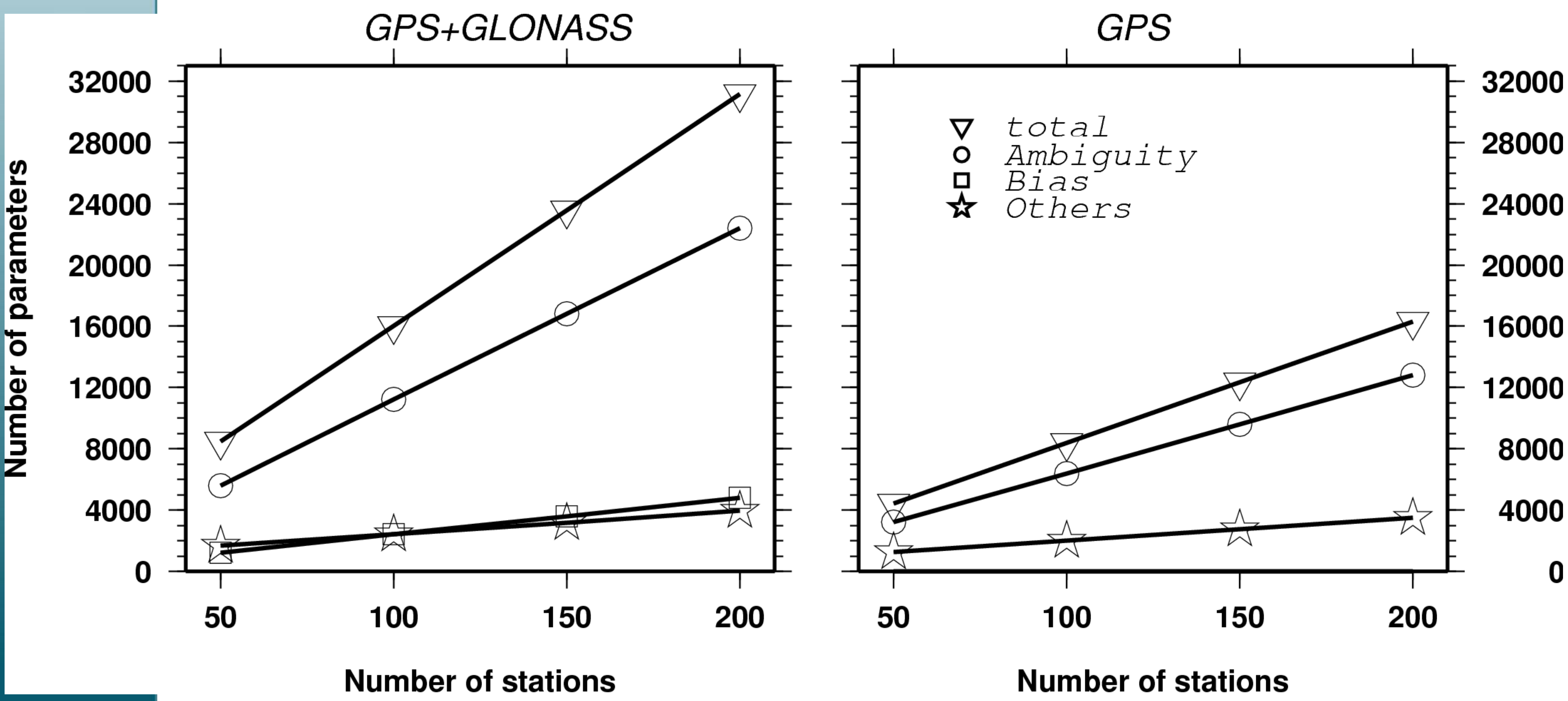
Challenges in Huge network solution

Huge network solution: Number of satellites



Challenges in Huge network solution

Huge network solution: Number of parameters



➢**Parameter number linearly increased, but processing time expands more dramatic!!**

Challenges in Huge network solution

- **Parameter elimination performed epoch-wisely .and.**

Station number v.s. processing time

Station Number	100	300
Processing time	25 min	720 min

Factor of 30 !!

- **Data sampling increase, Less processed epochs**
- **Way to reduce processing time**
- **But how about product precision??**

Data sampling v.s. processing time

GPS/GLONASS network: 110 stations, ~55 have GLONASS

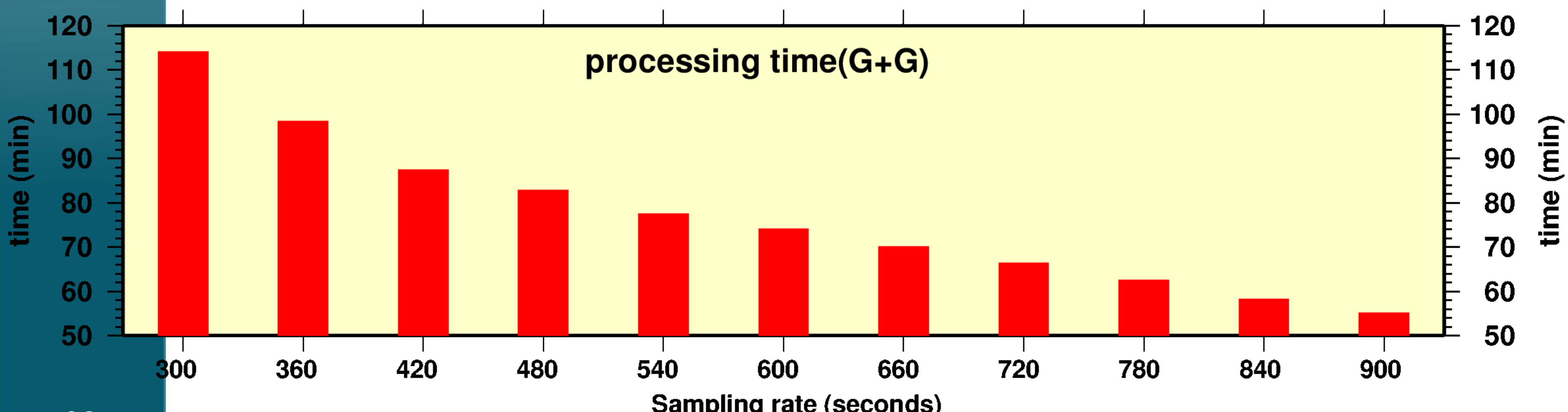
➢iGPOS developed at SHAO

➢**GPS week 1686-1689 4 weeks' data**

➢Personal computer (CPU：Intel Core i7-2600，3.4 GHz；RAM：8*2.0G=16.0G)

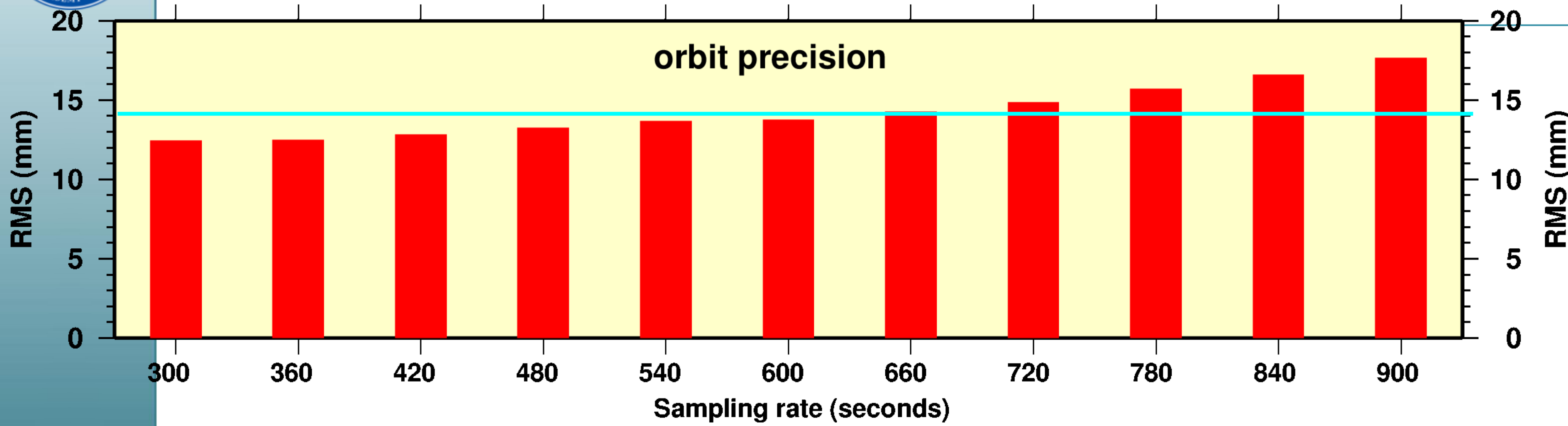
➢data sampling setting ranges from 5 minutes to 15 minutes

➢**Mean processing time for daily jobs**



From 15 to 5 min, reduced by a Factor of 2 !!

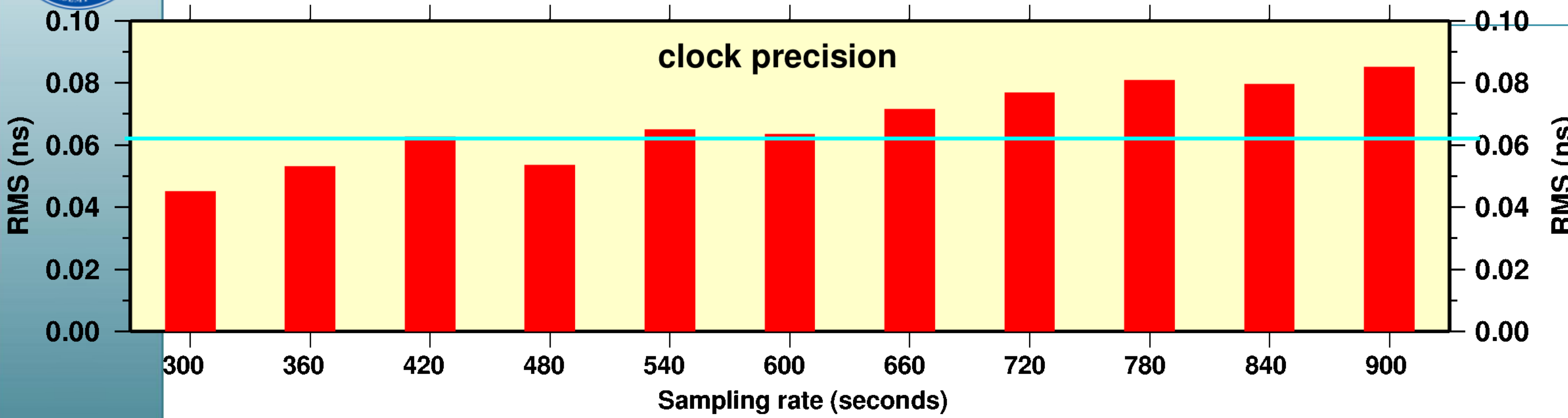
Data sampling v.s. orbit precision



- **Worst still better than 2 cm**
- **Precision better than 1.4: sampling within 5-10 minutes**

- data sampling could set to10 minutes

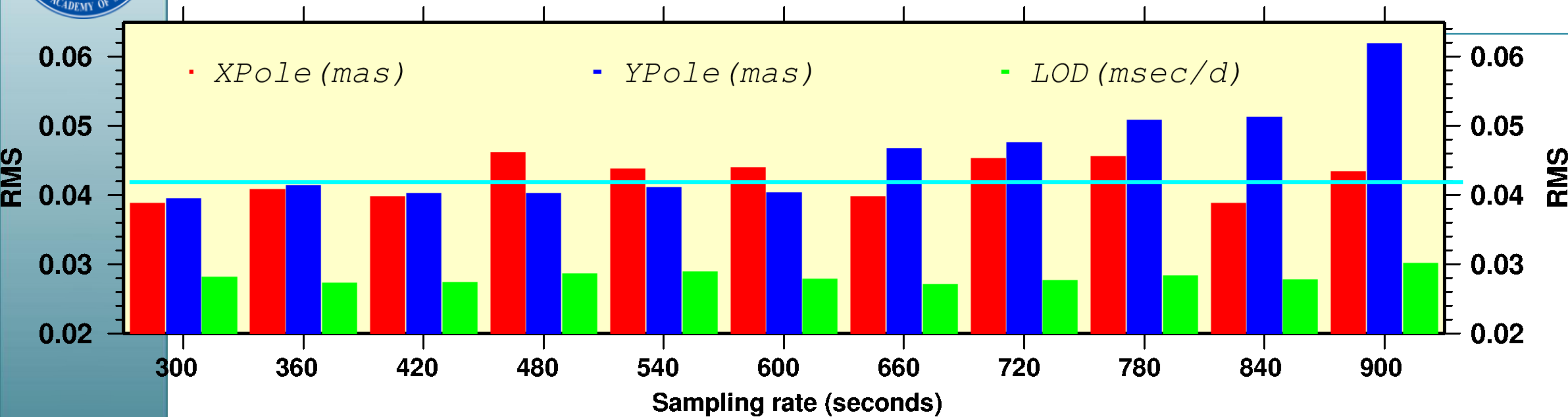
Data sampling v.s. clock precision



- **Worst still better than 0.08 ns**
- **Precision better than 0.06: sampling within 5-10 minutes**

- data sampling could set to10 minutes

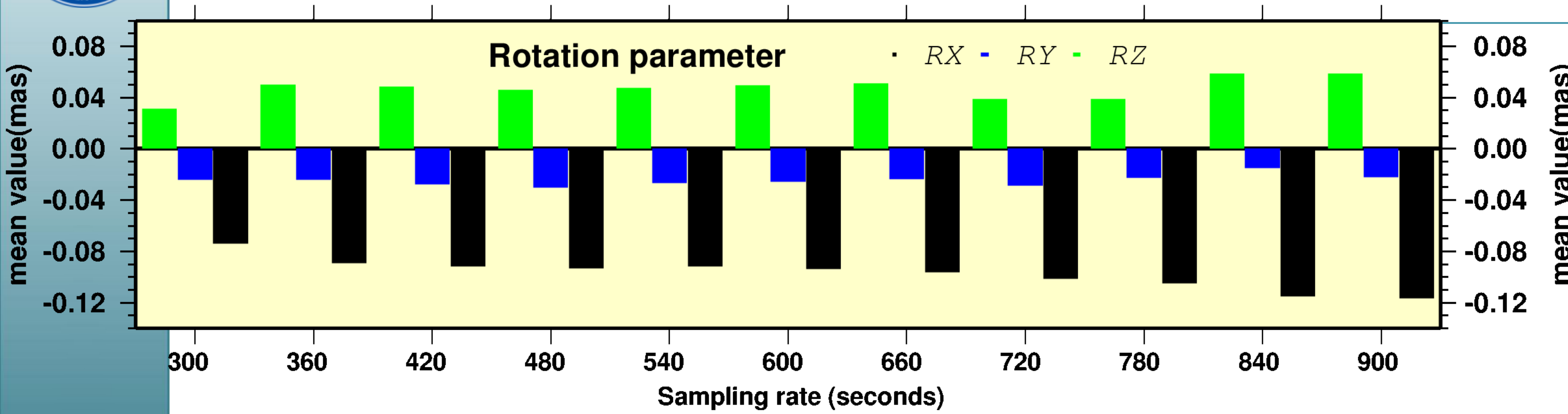
Data sampling v.s. ERP



- **Defined as daily constants**
- **Pole precision better than 0.04 mas: sampling within 5-10 minutes**
- **LOD not affected by data sampling**

- data sampling could set to10 minutes

Data sampling v.s. reference frame



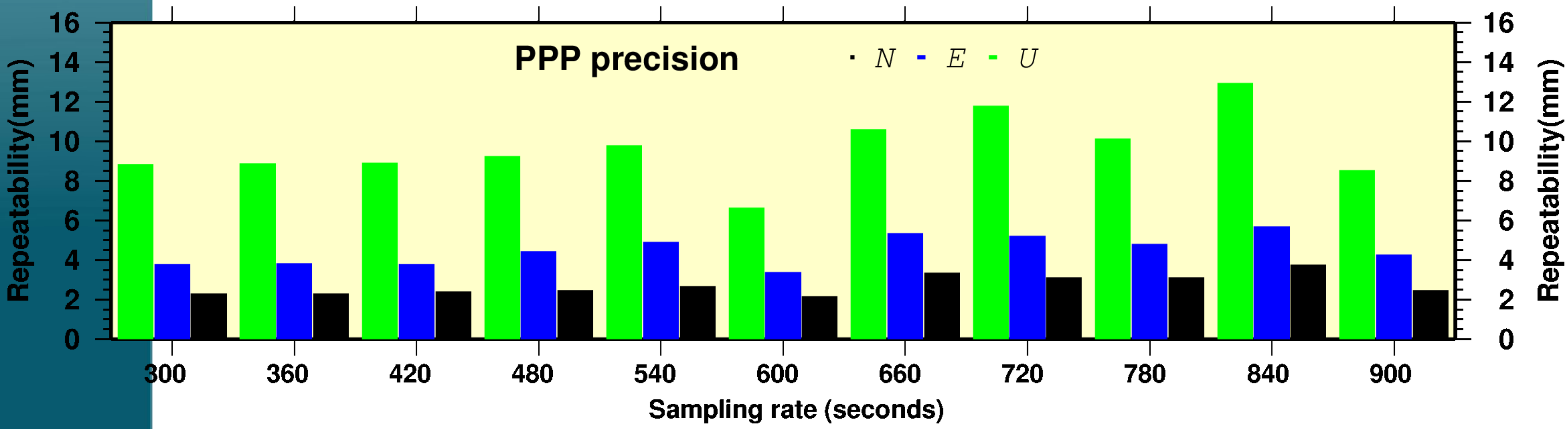
- Scale difference less than 0.01ppb
- translation parameters difference less than 0.4mm
- **RX turns out to gradually increase with sampling becomes bigger**

- data sampling could set to10 minutes

Data sampling v.s. USER static PPP

22 GPS/GLONASS stations

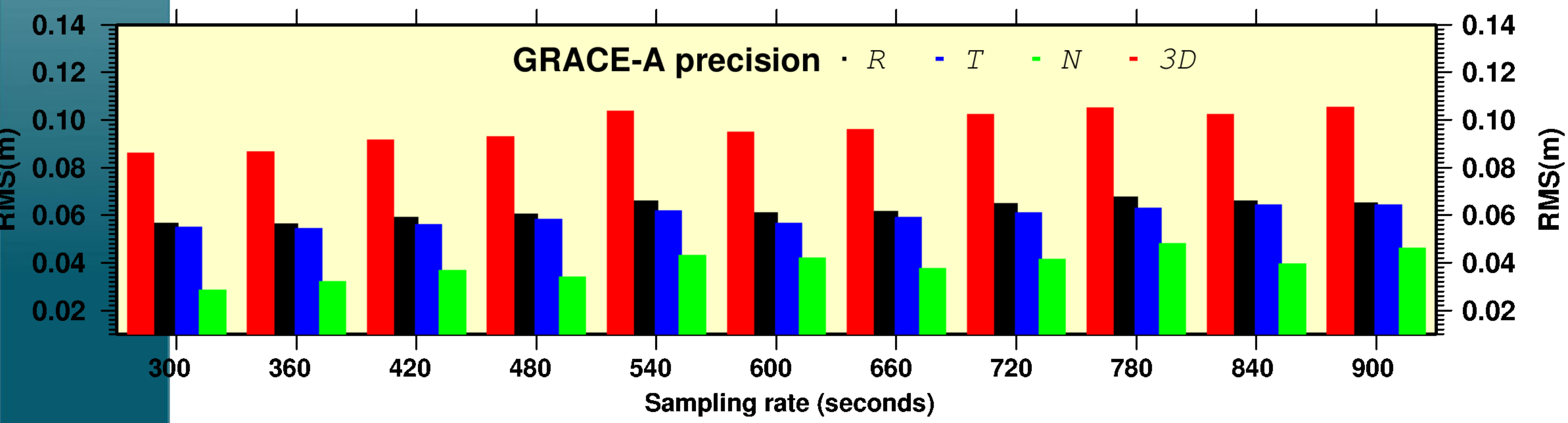
- USER positioning client LTW_BS developed at SHAO
- **GPS week 1686-1689 4 weeks' data**
- ImOrbits and clocks based on net-solution with data sampling changes from 5 minutes to 15 minutes
- pact on repeatability: Horizontal less than 2mm, height less than 6 mm



Data sampling v.s. USER static PPP

GRACE-A and GRACE-B, 2010 doy 94-100

- LEO pure kinematic POD client developed at SHAO
- **Orbits and clocks based on net-solution with data sampling changes from 5 minutes to 15 minutes**
- Kinematic orbits compared to JPL PSO
- RMS difference: less than 2 cm



Summary

- Data analysis using Zero-difference strategy is a bottleneck with the development of the observing network and inclusion of multi-GNSS systems.

- We discuss the impacts of changing data sampling on product precision and user application.

- Using the GNSS data analysis platform of SHAO, big amount of data from the 110 IGS globally distributed stations are analyzed.

GNSS若干问题(4)

- 实时数据处理

Motivation

Sensor data needs to be available in near real-time, as a tsuami may have very short travel times.

How can GPS improve a Tsunami Early Warning System?

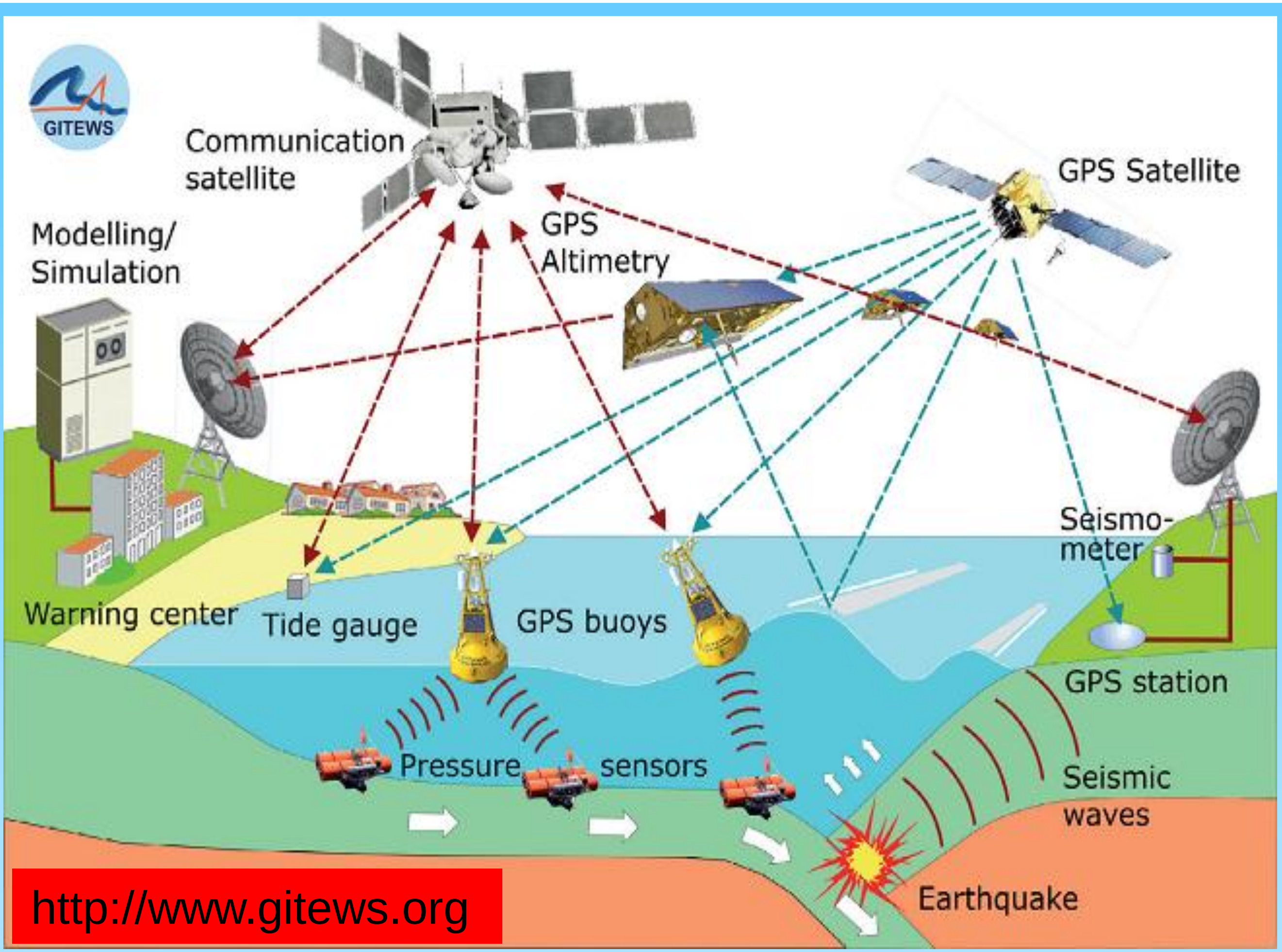
GPS can detect movements of stations on land (in land and at tide gauges) and on buoys

Thus, it can help to understand an earthquake‘s mechanism and to detect tsunami waves on- and off-shore.

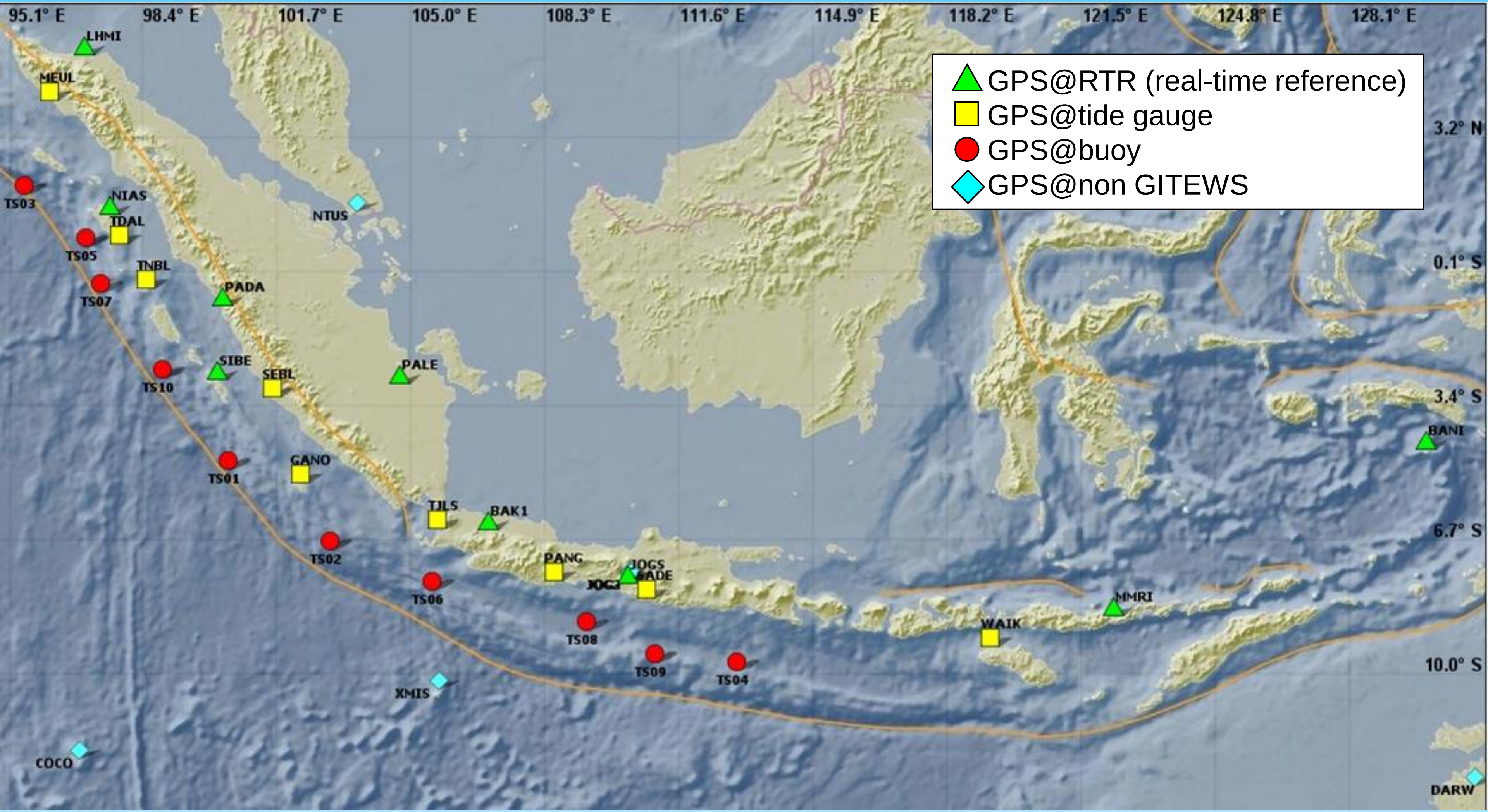
http://www.gitews.org

GITEWS Concept

Data from different sensor systems is transmitted to the warning center located in Jakarta / Indonesia, where it is processed and analysed. The Products are used to distinguish between thousands of pre-calculated scenarios. The best fitting one is used for tsunami prediction and warning dissemination.



GPS Network Topology



RTR site installation (Maumere)

- preference for major island, inland locations
- mostly co-located with seismic sensor station
- shared, permanent VSAT satellite link

GPS RTR station installation, co-located with seismic station (Maumere,Indonesia)

Real-time Precise Positioning Service (PPS)

- **RTK** (and VRS etc.): precise local positioning. Observation domain. ~100km distance, ~2 cm accuracy
- **Network solution**: Global/regional network, station parameters estimated together with satellite parameters. Time consuming
- **PPP** based real-time positioning service: parameter domain. More efficient in time and space, 50-100 stations globally, ~10 cm accuracy
- IGS Real-time Pilot Project (**IGS-RTPP**)

Real-time GNSS

Real-time Data streaming and products dissemination

BNC,BNS from BKG

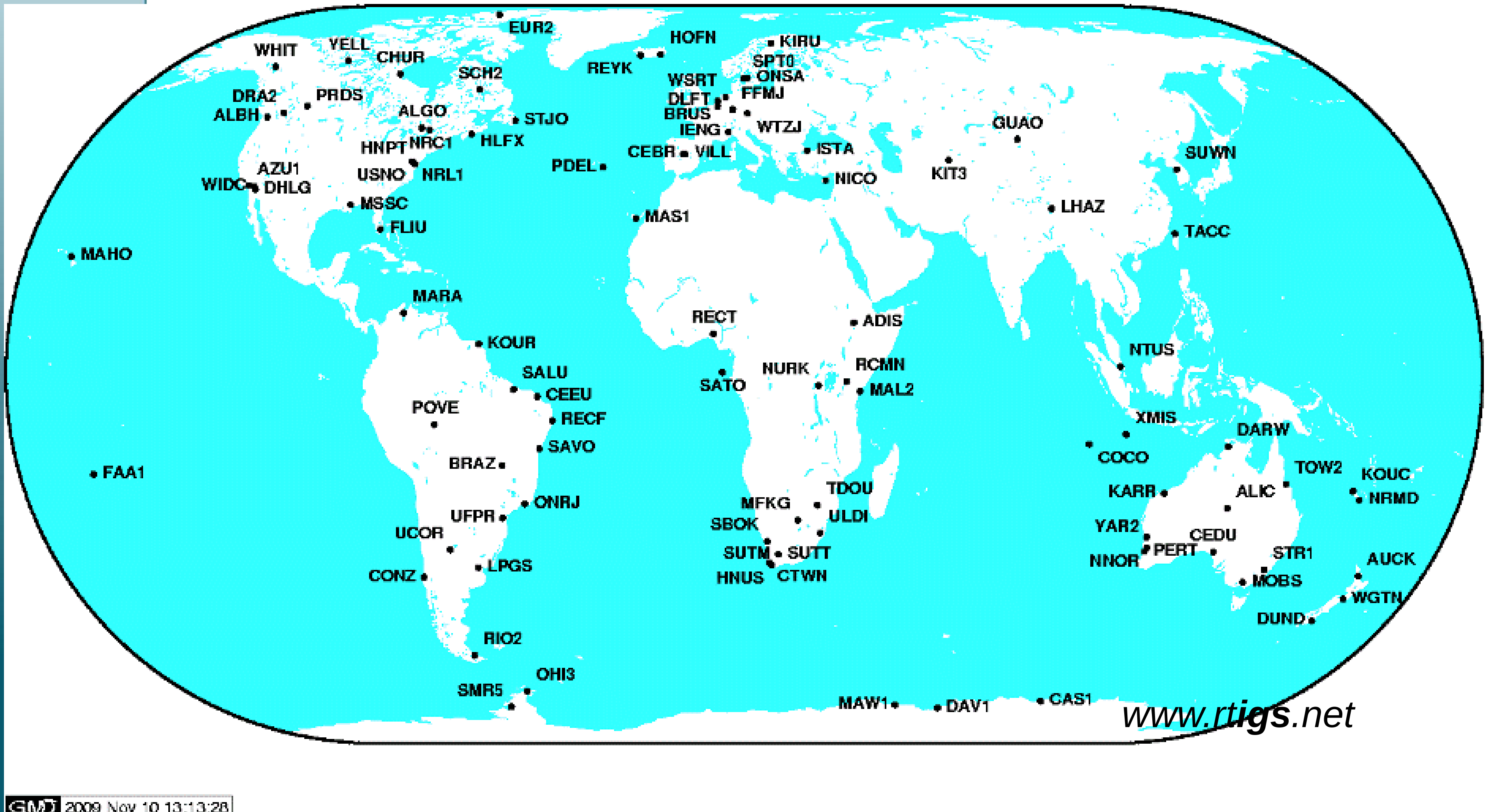
Existing real-time data analysis system

GDGPS (Global Differential GPS): dm accuracy

Commercial system : OmniSTAR (FUGRO),

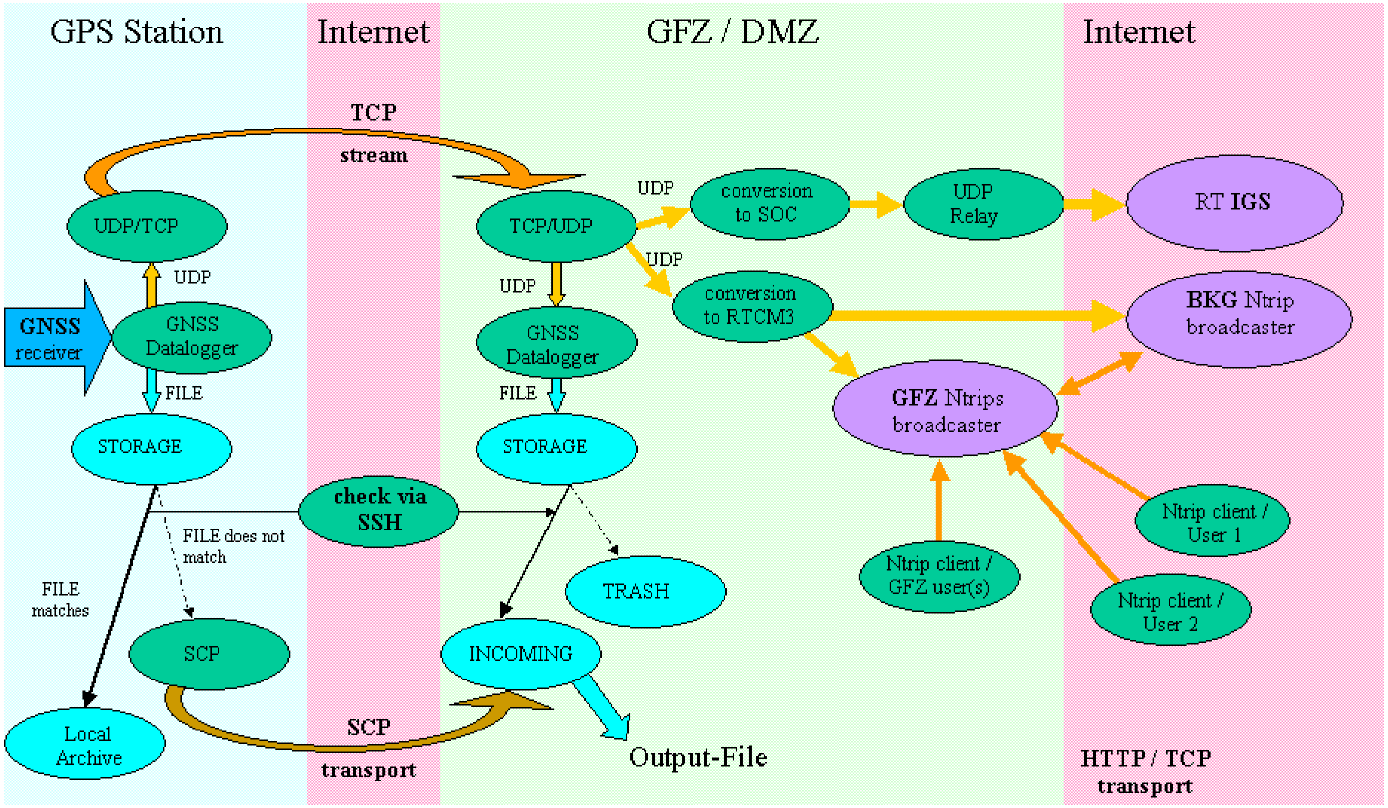
StarFire (NavCom)

Real-time GNSS Network



More than 100 stations from the IGS Network
~100 stations from the EUREF network

GNSS Real-time Streaming

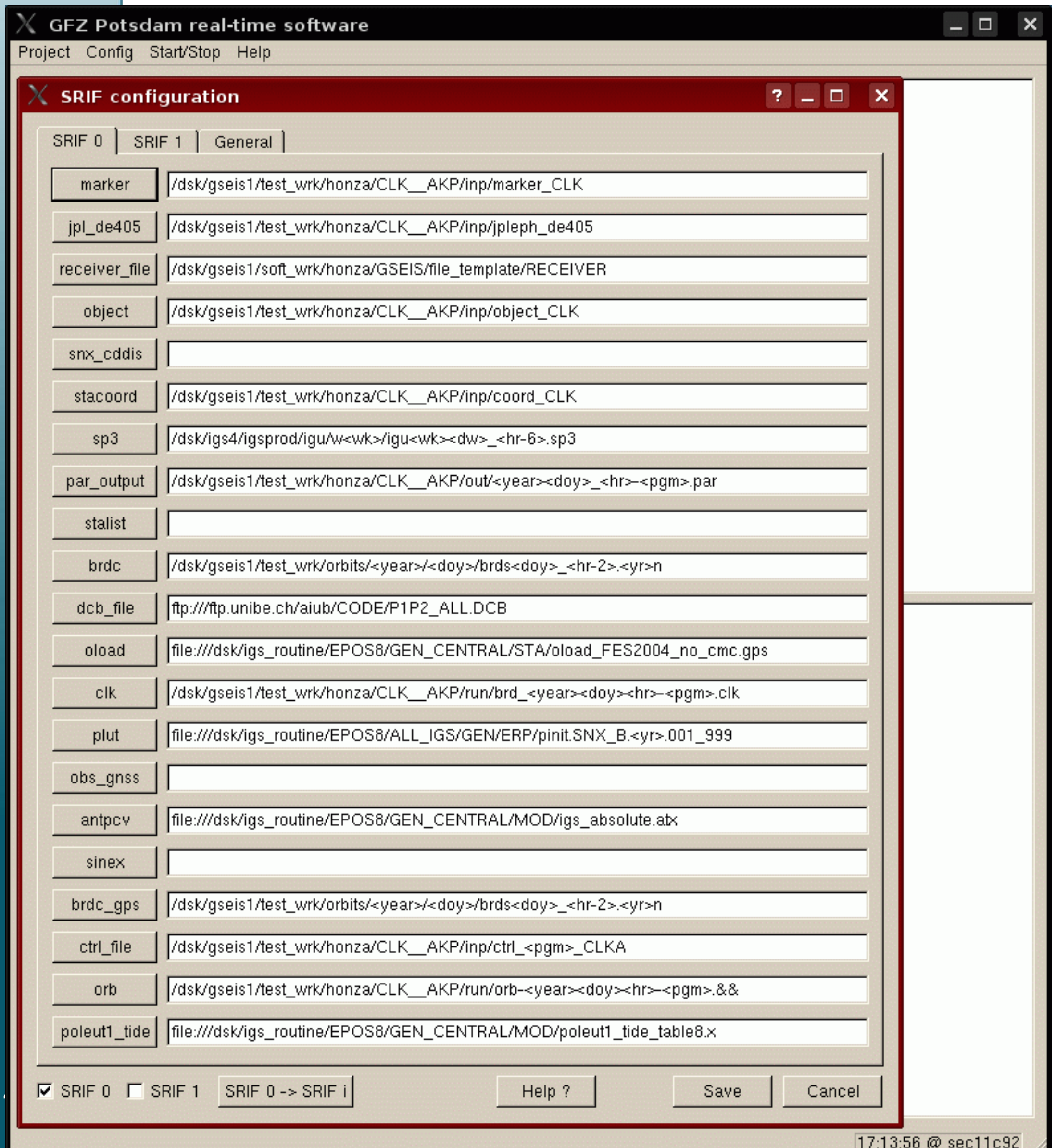


GNSS data streaming with 1-hz data rate

-Based on UDP (User Datagram Protocol) / TCP (Transmission Control Protocol) and Ntrip (Networked Transport of RTCM via Internet Protocol)

-Up to 100 data streams processed in parallel without problems

Software Interface

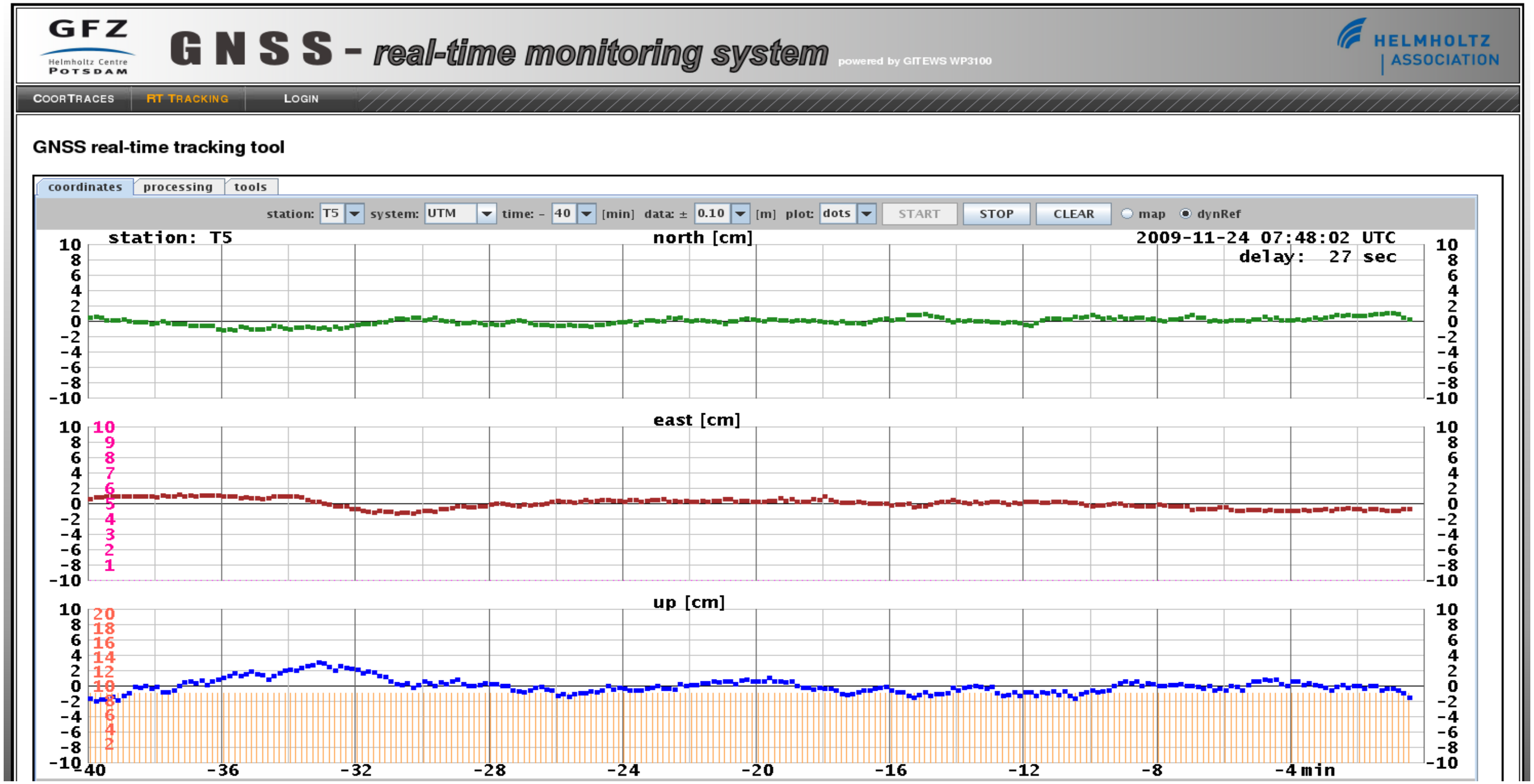


Central Control Unit:

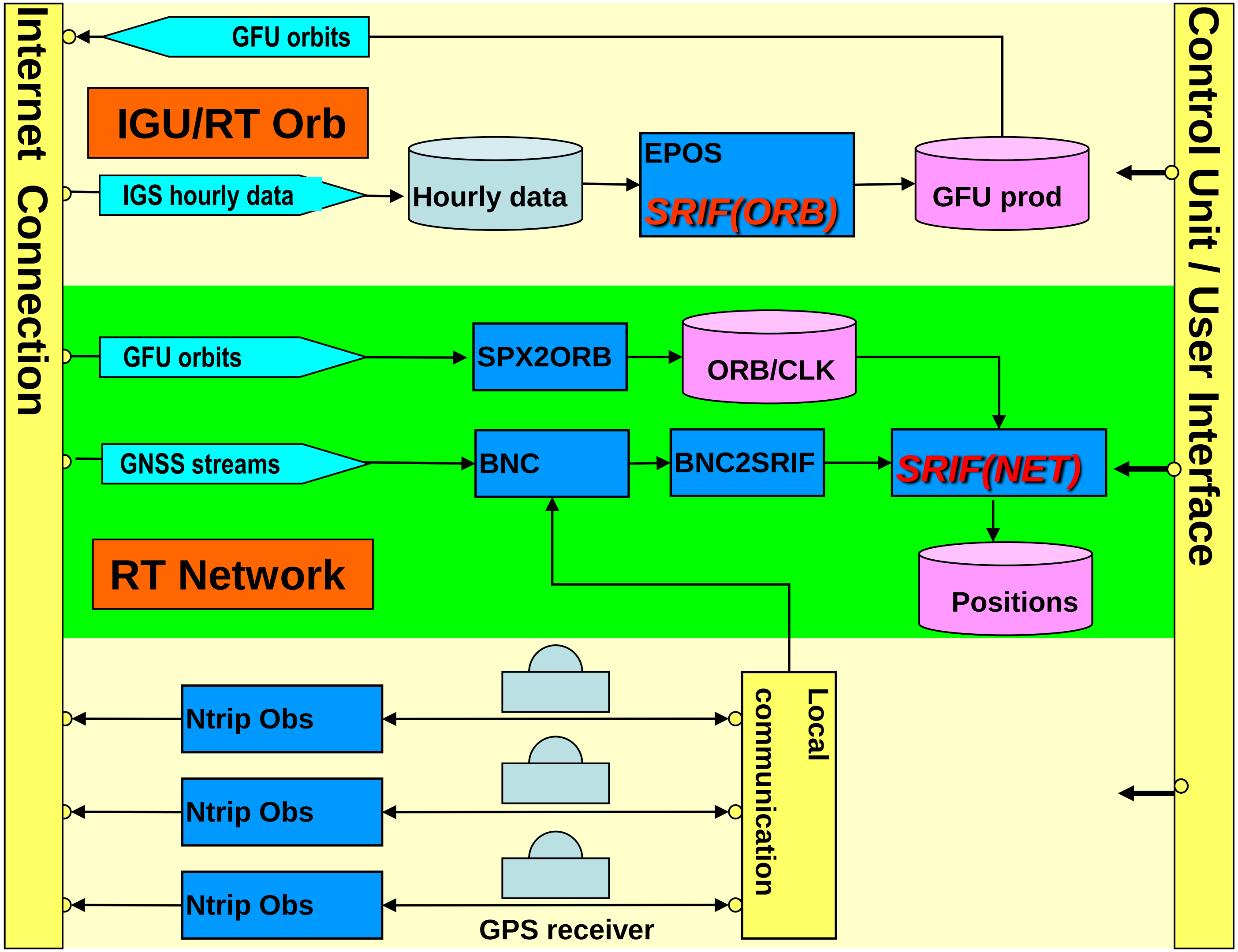
- Configuration and control of the EPOS-RT processing unit
- Providing UDP,TCP,NTRIP and shared memory input/output
- Providing monitoring and e-mail warning system
- Providing job scheduler for other external programs
- Checking and downloading important input files
- Providing graphic user interface

Software Interface

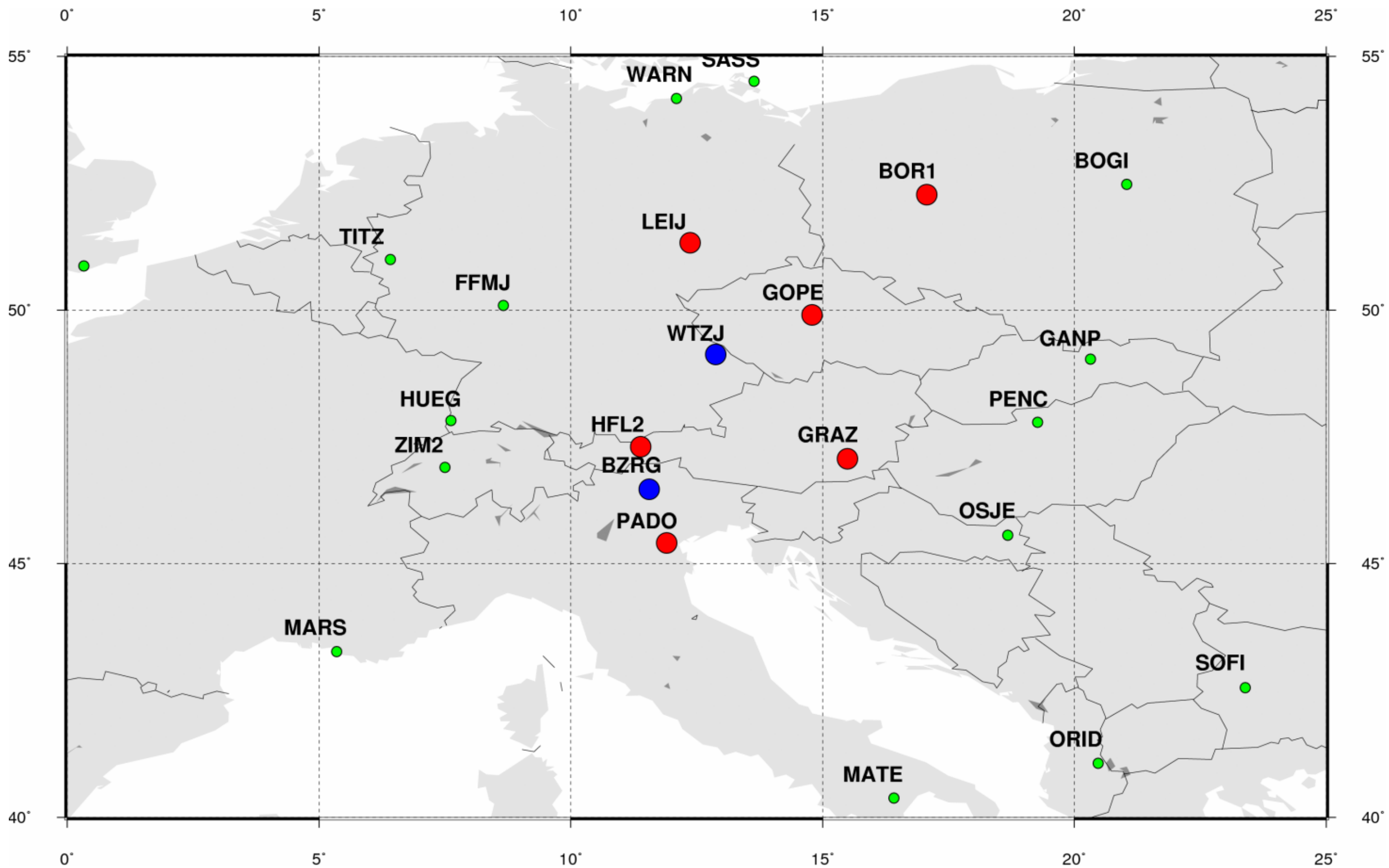
Web Monitoring:



Network Solution

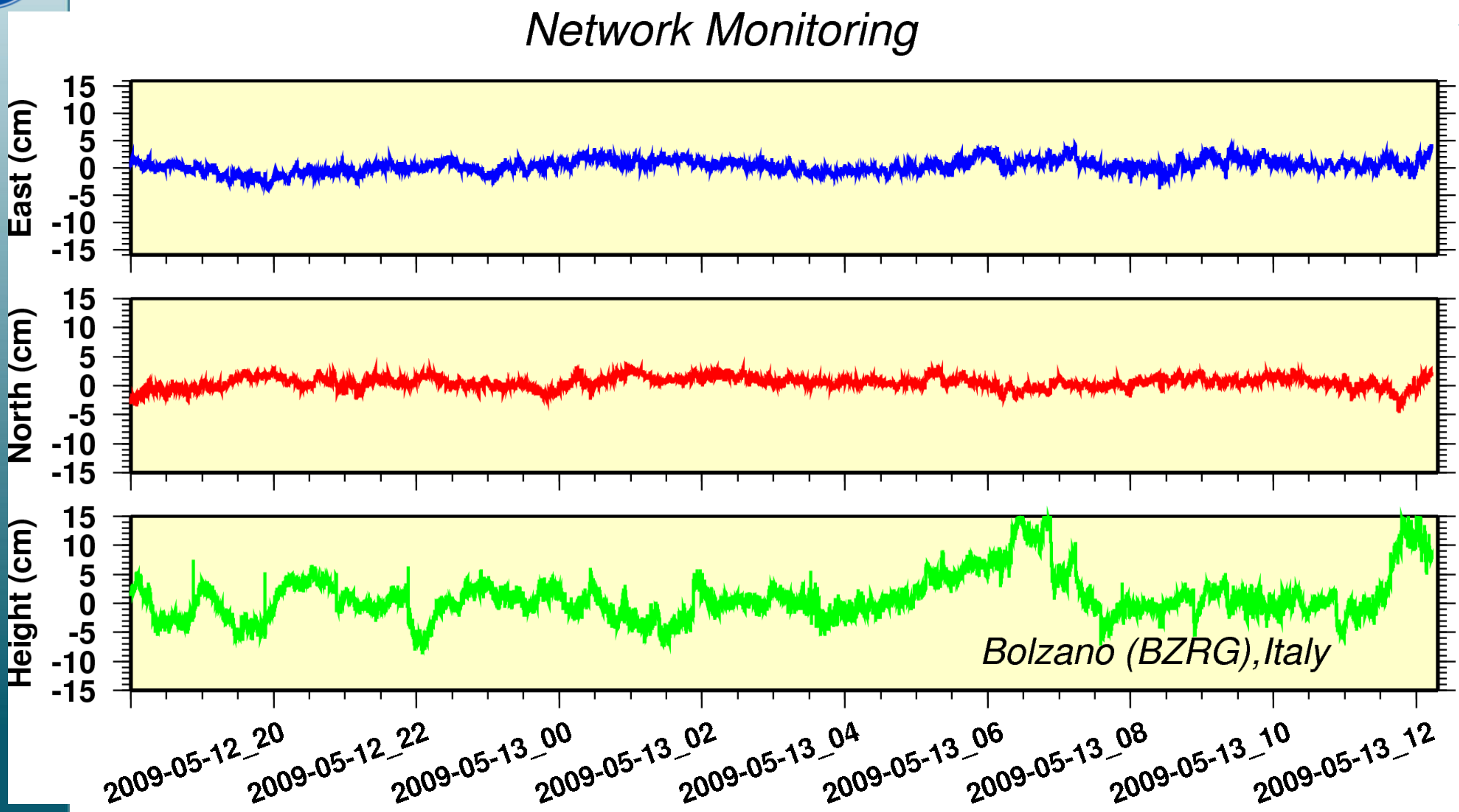


Real-time Network solution



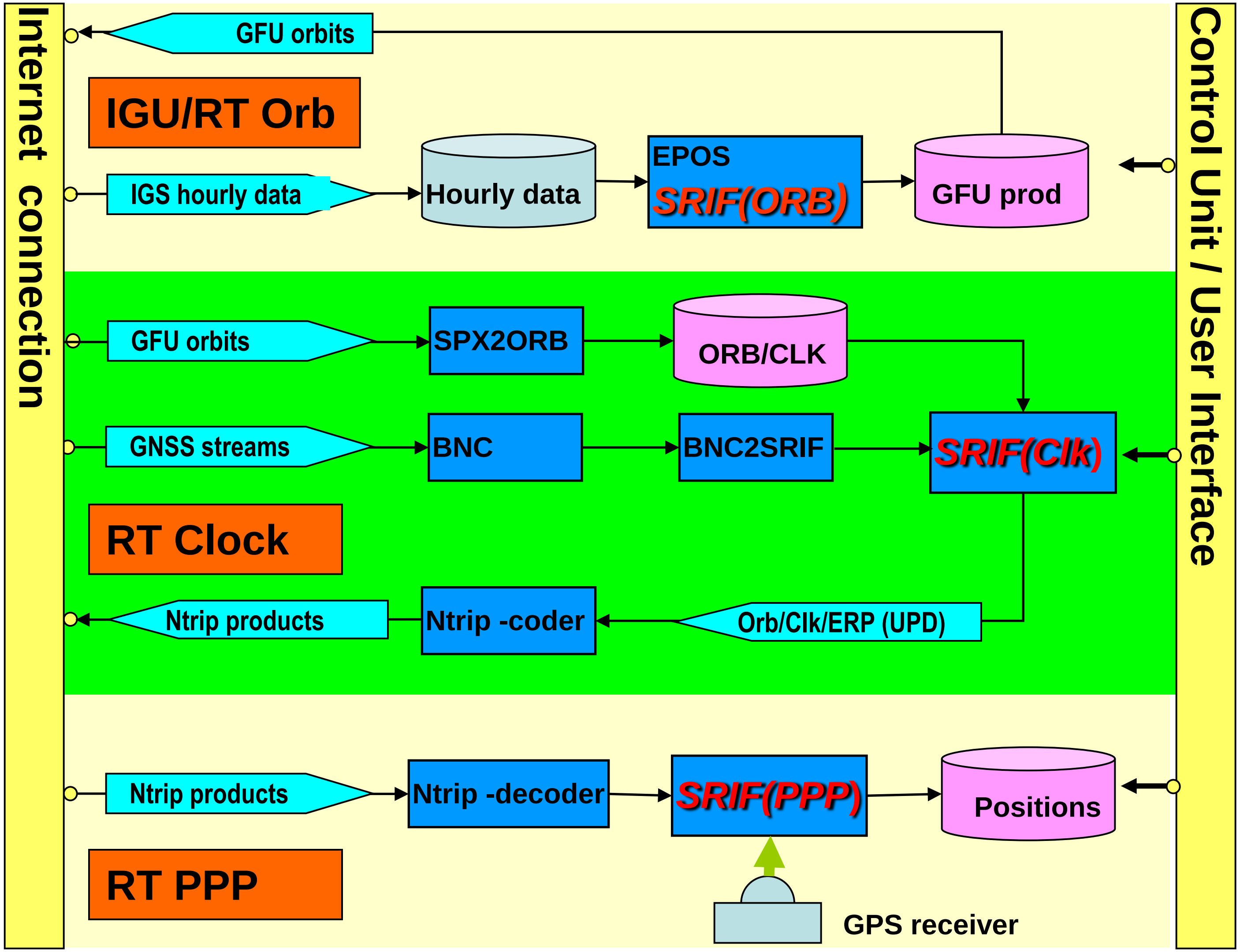
- Data from Ntrip caster :1-hz, 8 stations(6 fixed, 2 kinematic)16-17 April, 2009
- Ambiguity fixing with Lambda method (Teunissen et al, JG, 1995)

Real-time Network solution

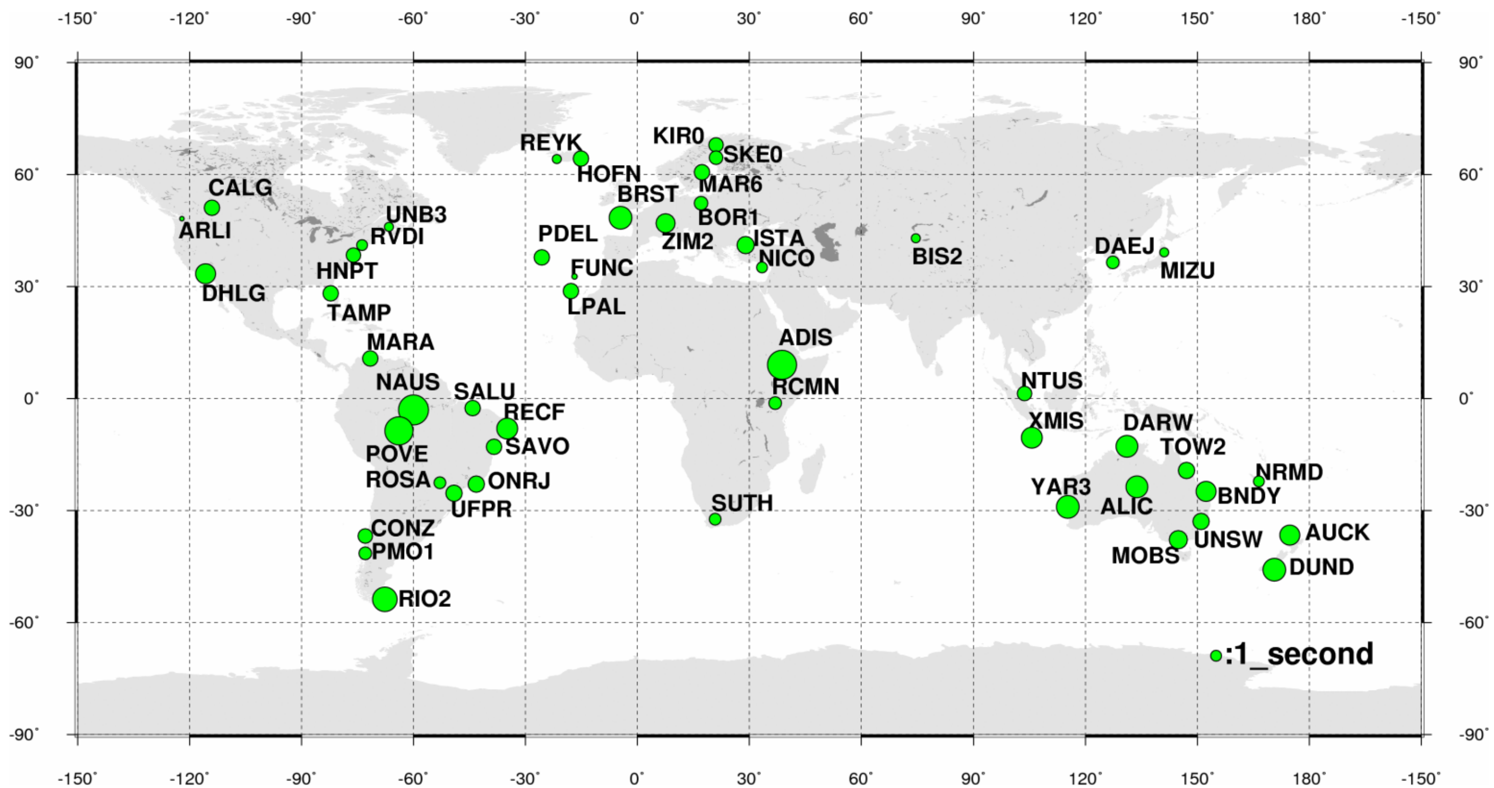


precision: (1.1,1.2,3.6) cm

PPP Based Positioning Service



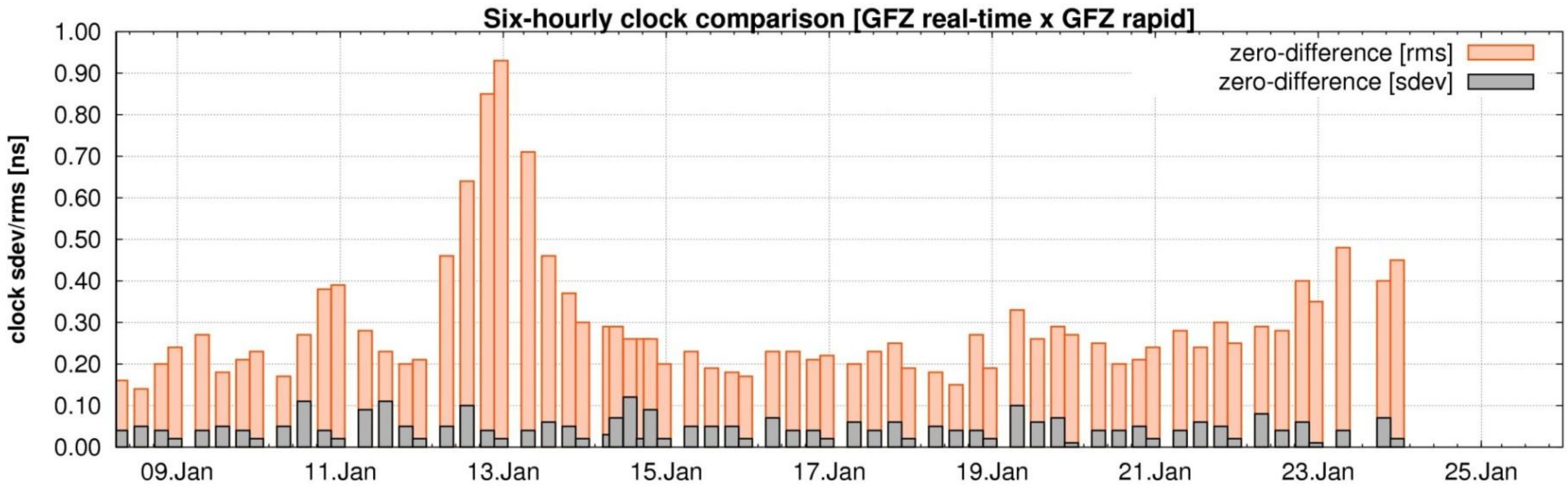
Real-time Clock Estimation & PPP

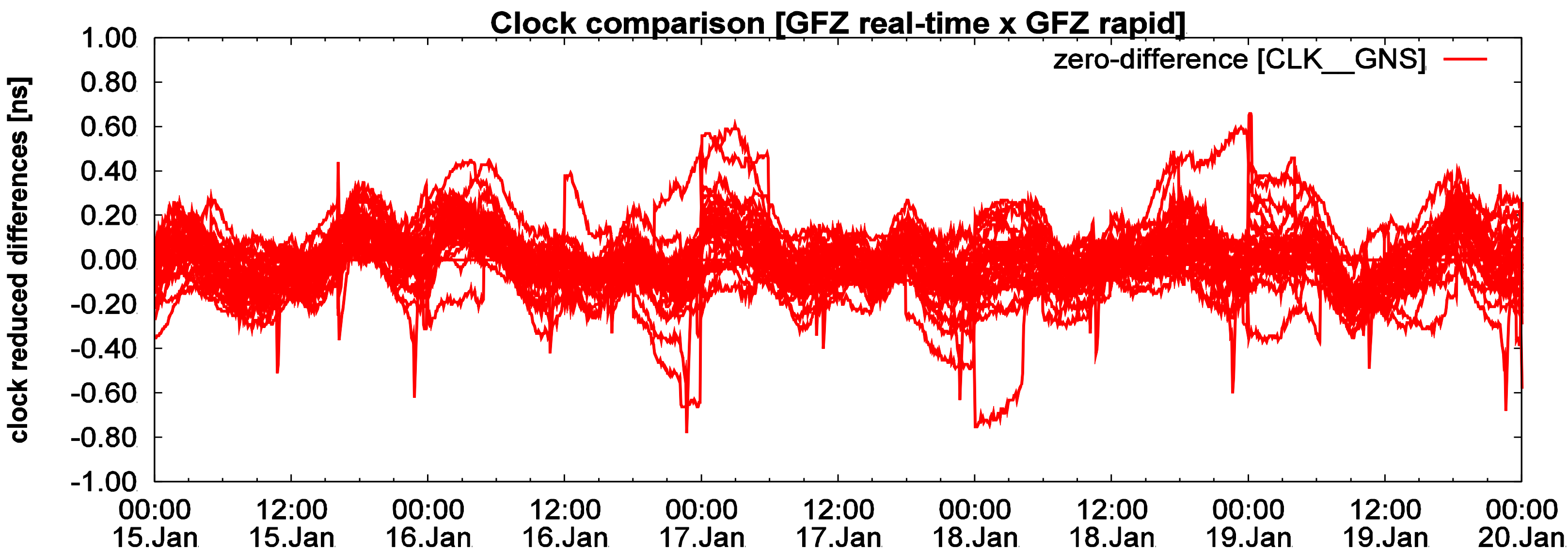


- IGS real-time network from GFZ Ntrip caster, about 50 stations
- **Orbits & ERP fixed to GFZ ultra-rapid products (6h update)**
- Station coordinates fixed to our PPP results
- Zero- and epoch-differenced observations
- Estimated satellite & receiver clocks and ZTDs

Real-Time Clocks (Comp)

UD-Method: RMS=0.3 ns, STD=0.08 ns

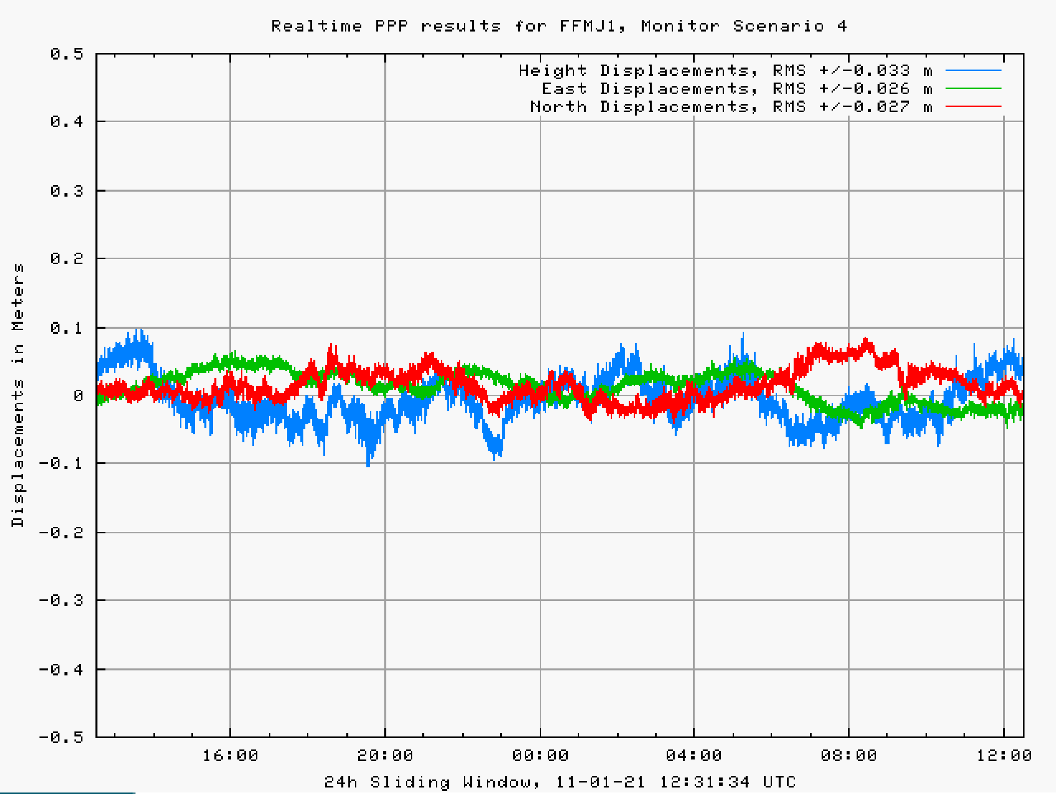


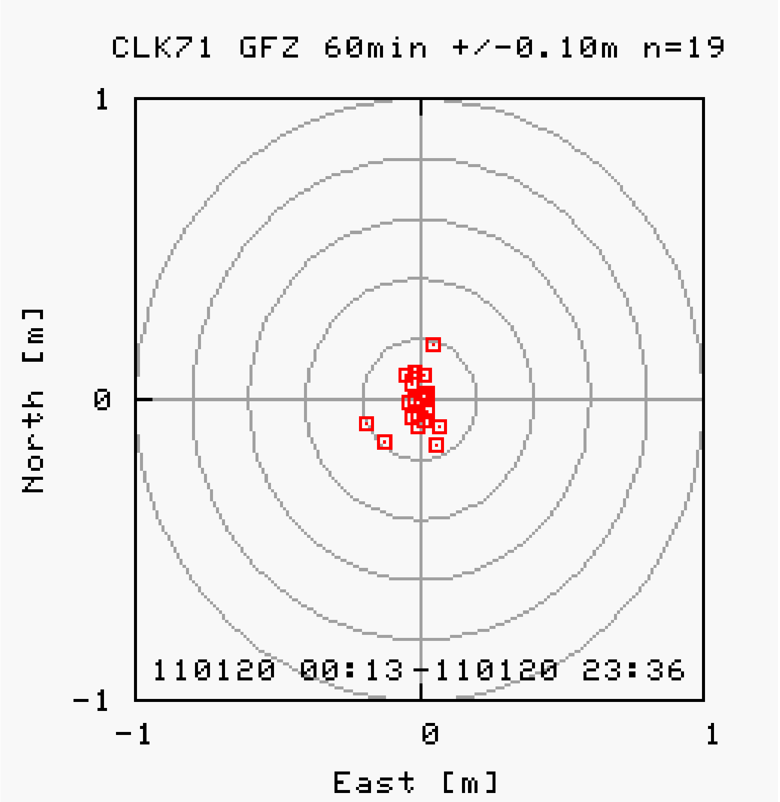


Real-Time Clock (Valid)

IGS RT PPP Online Validation:

http://igs.bkg.bund.de/ntrip/ppp

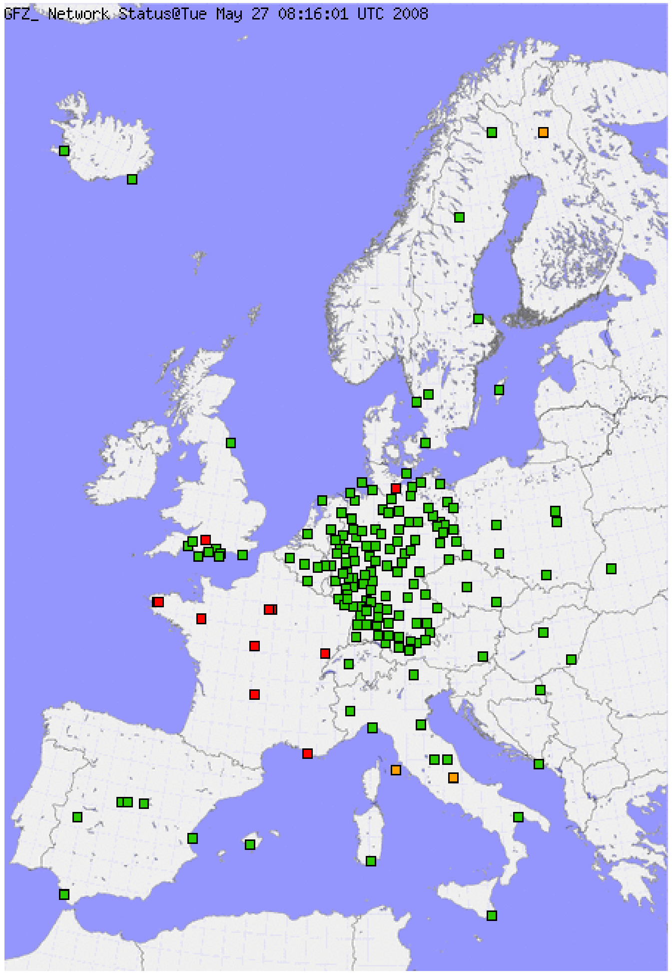




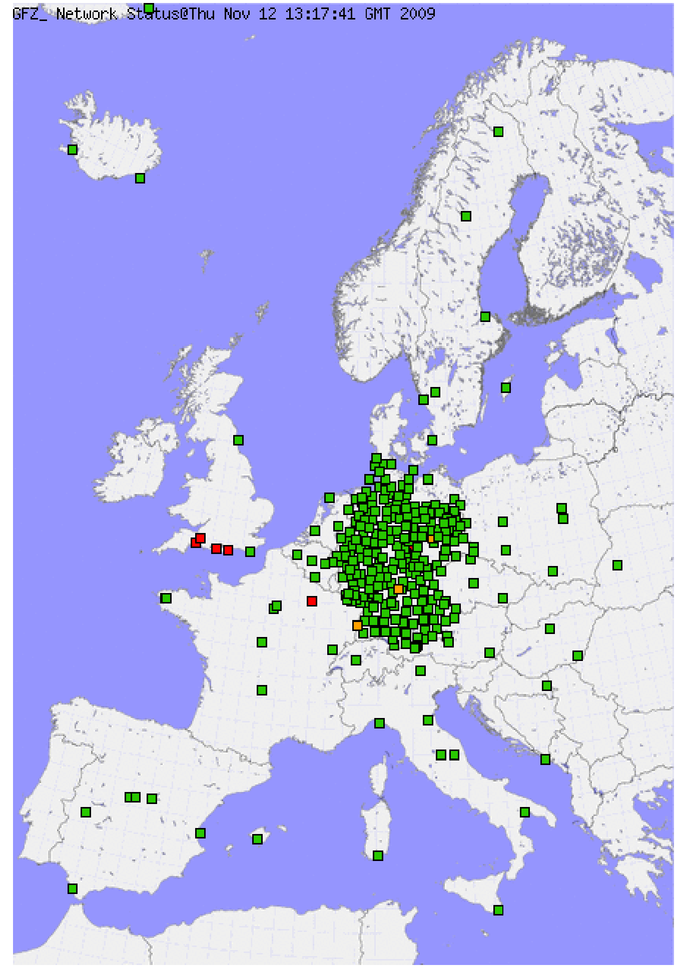
GNSS Atmosphere Sounding

E-GVAP Analysis Center

2008: aprox. 220 Stations



Since Nov. 2009: aprox. 350 Stations

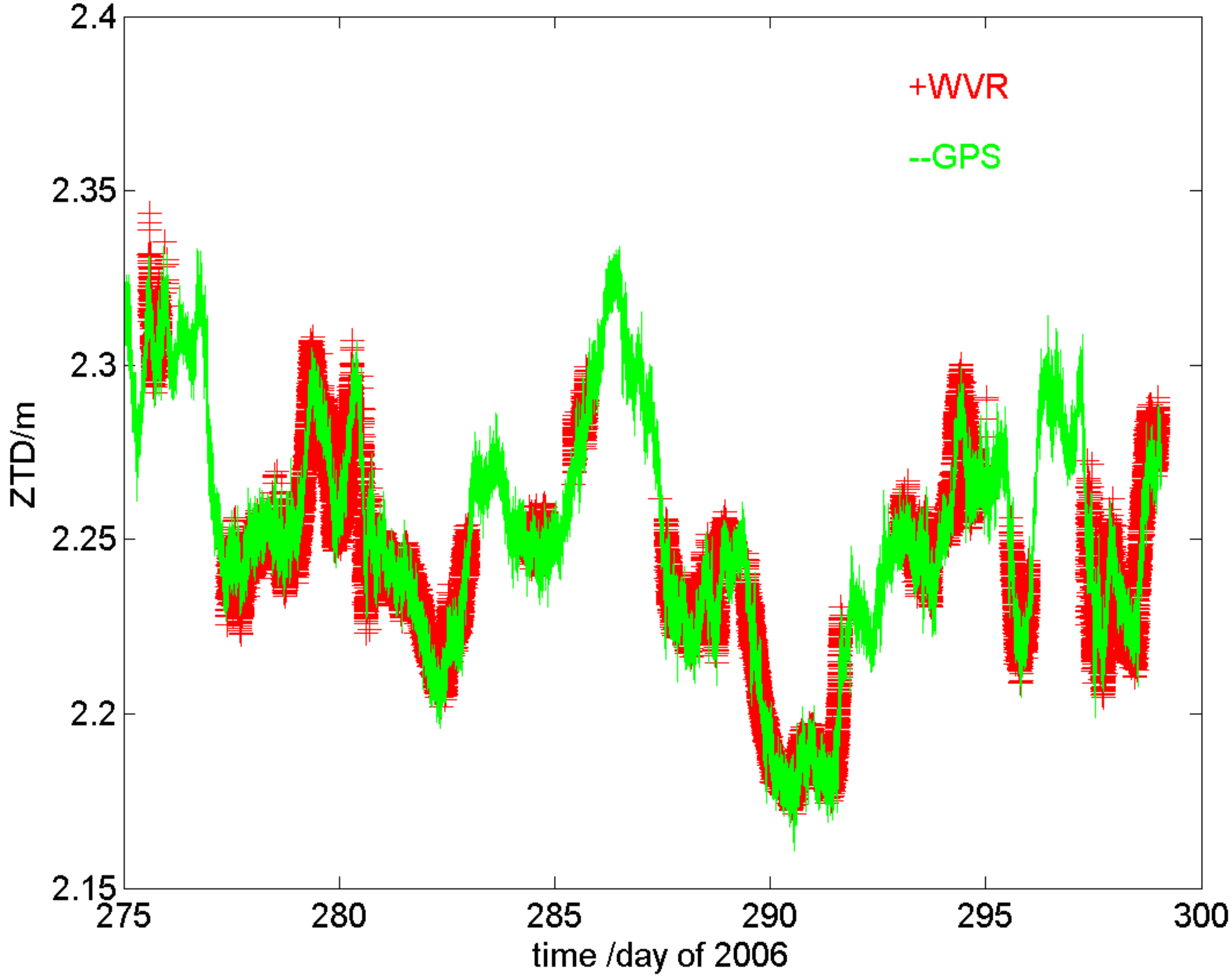


Dick et al., GFZ

Operational Near real-time. ~1-2 hours delay

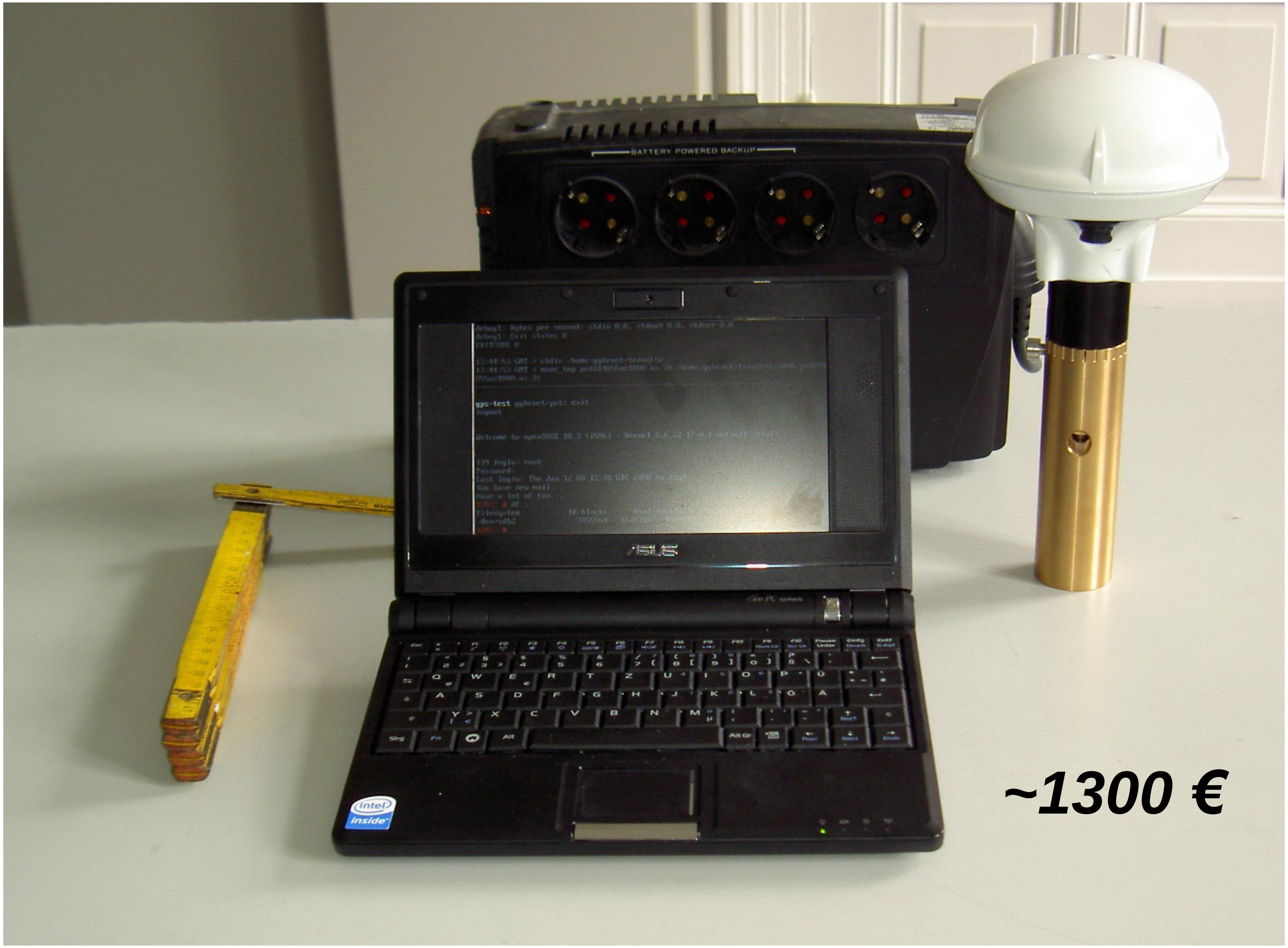
ZTDs for Meteorological modeling in weather monitoring and forcasting

ZTD Validation with WVR



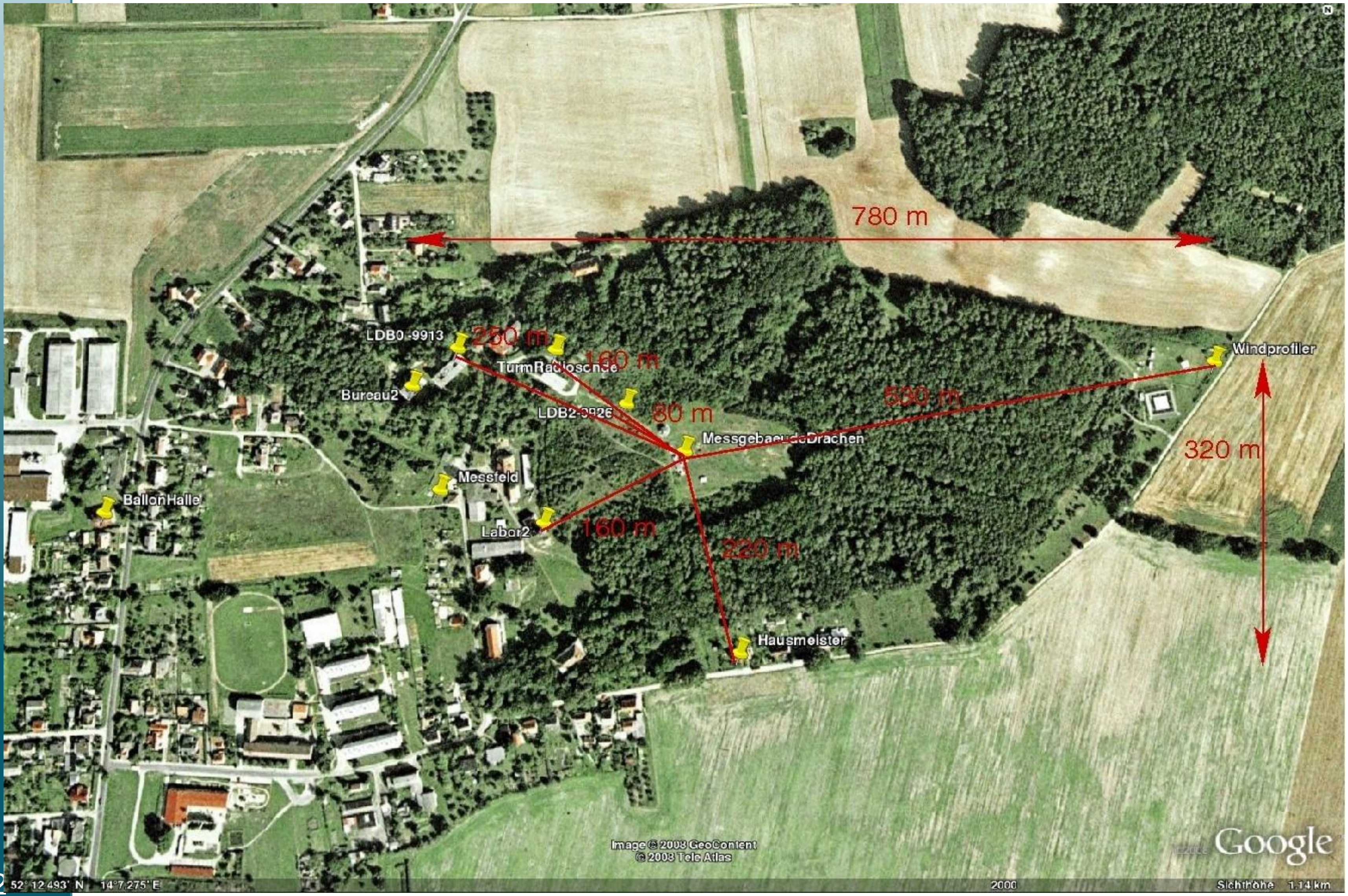
ZTD-comparision GPS/Water Vapor Radiometer in Wettzell (Oct.2006)

1-Freq. GPS Station with ASUS PC

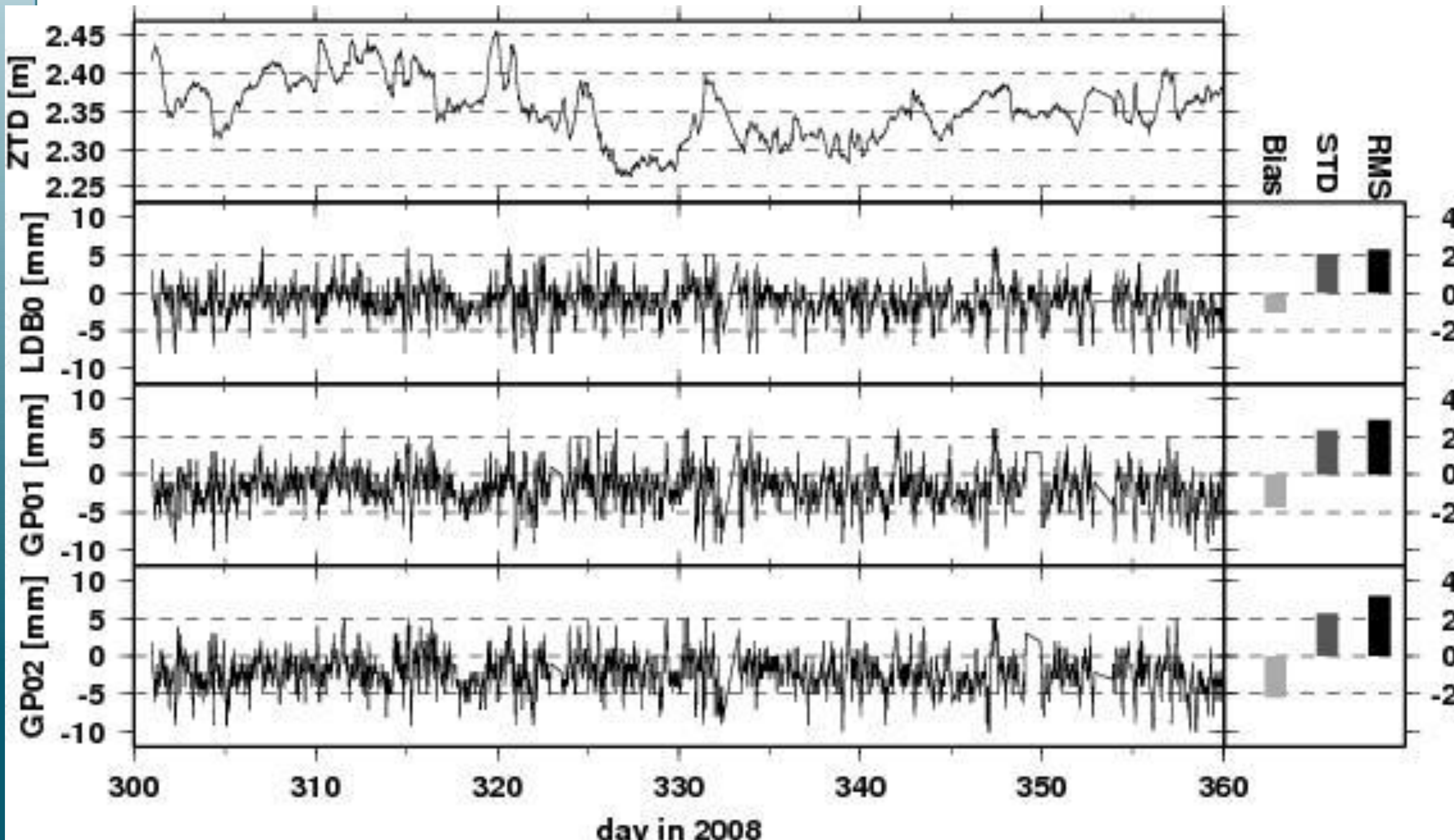


~1300 €

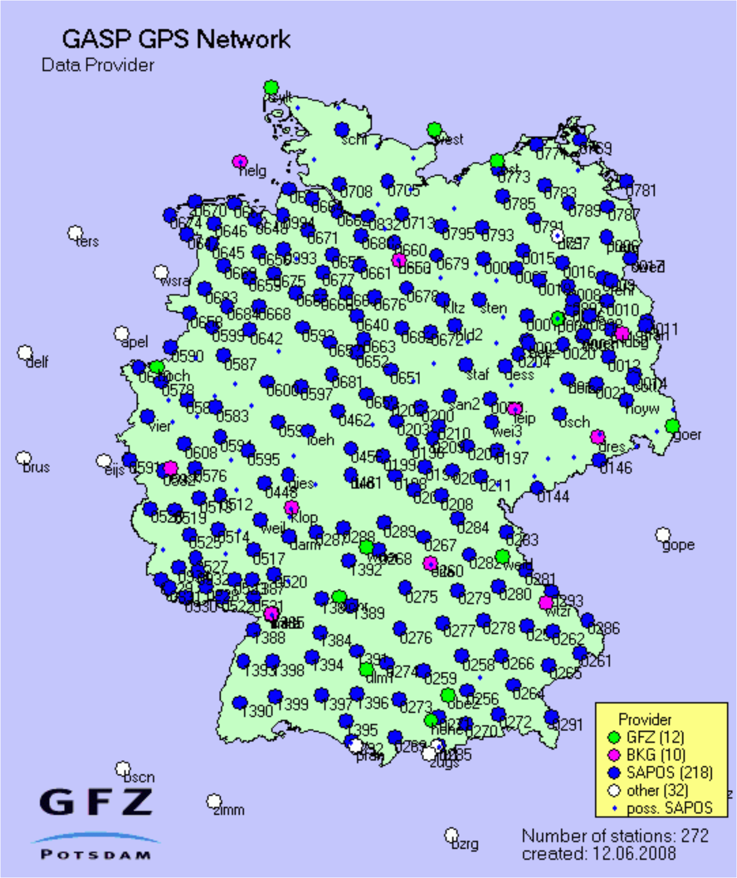
Lindenberg Upper-air Method Intercomparison (LUAMI)

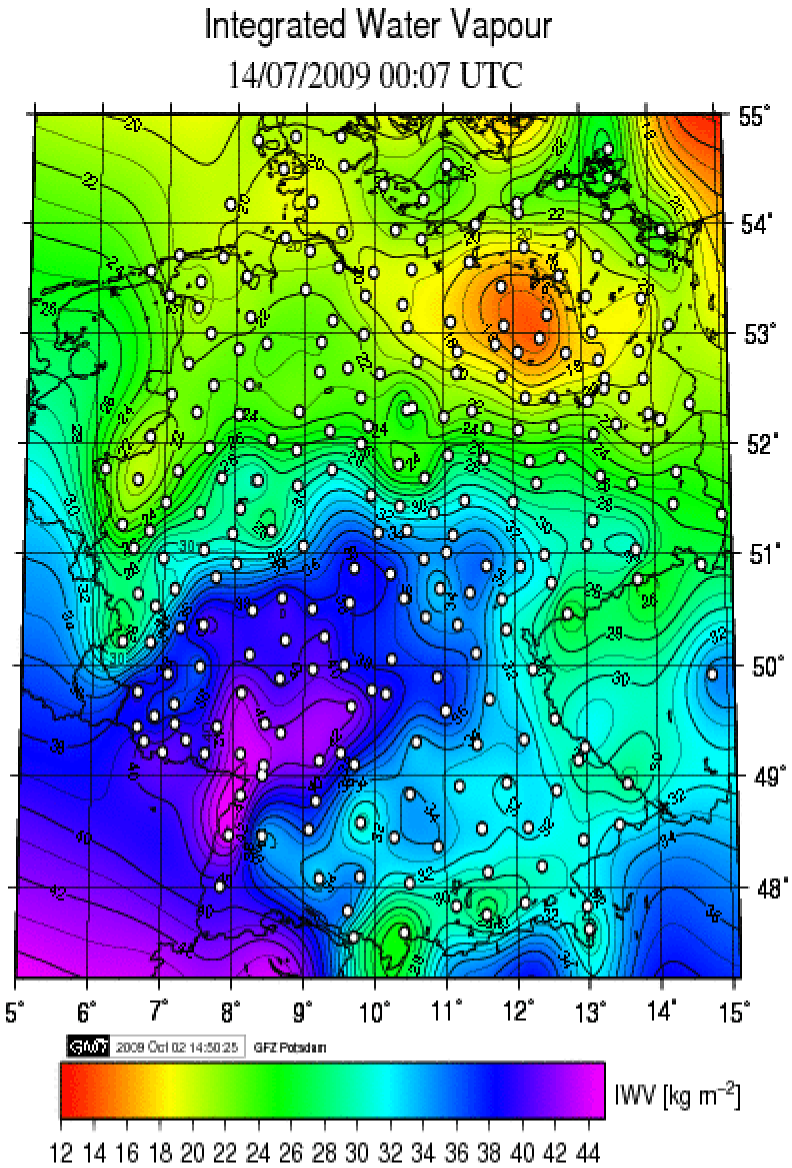


ZTD Results for LUAMI



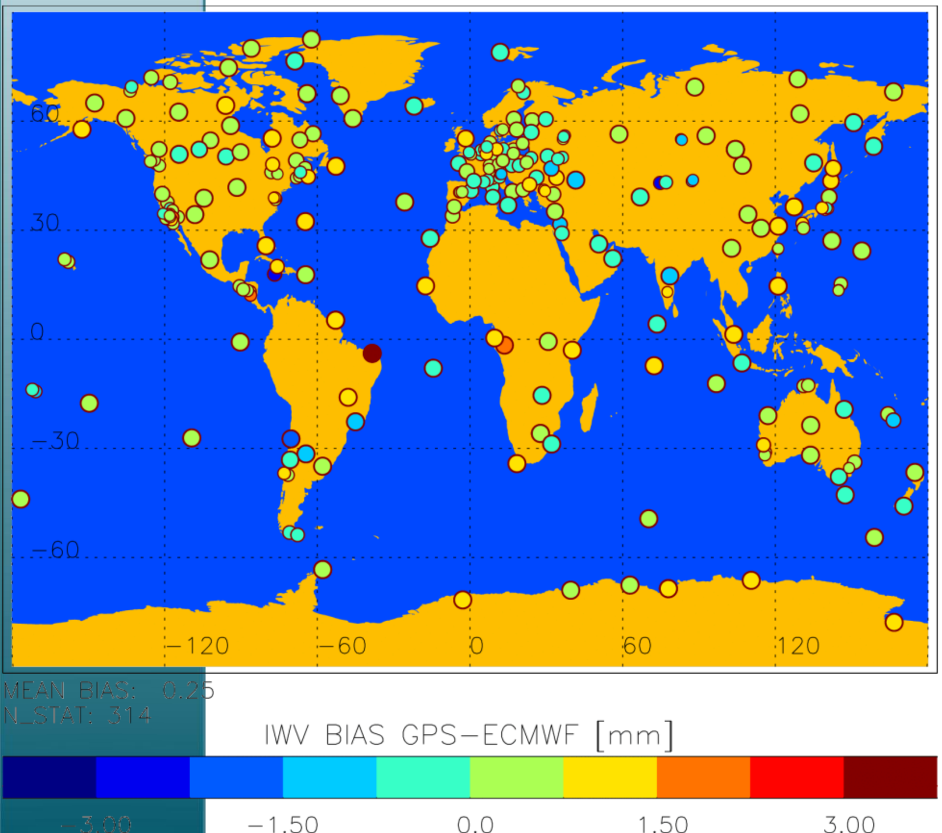
Regional IWV Monitoring

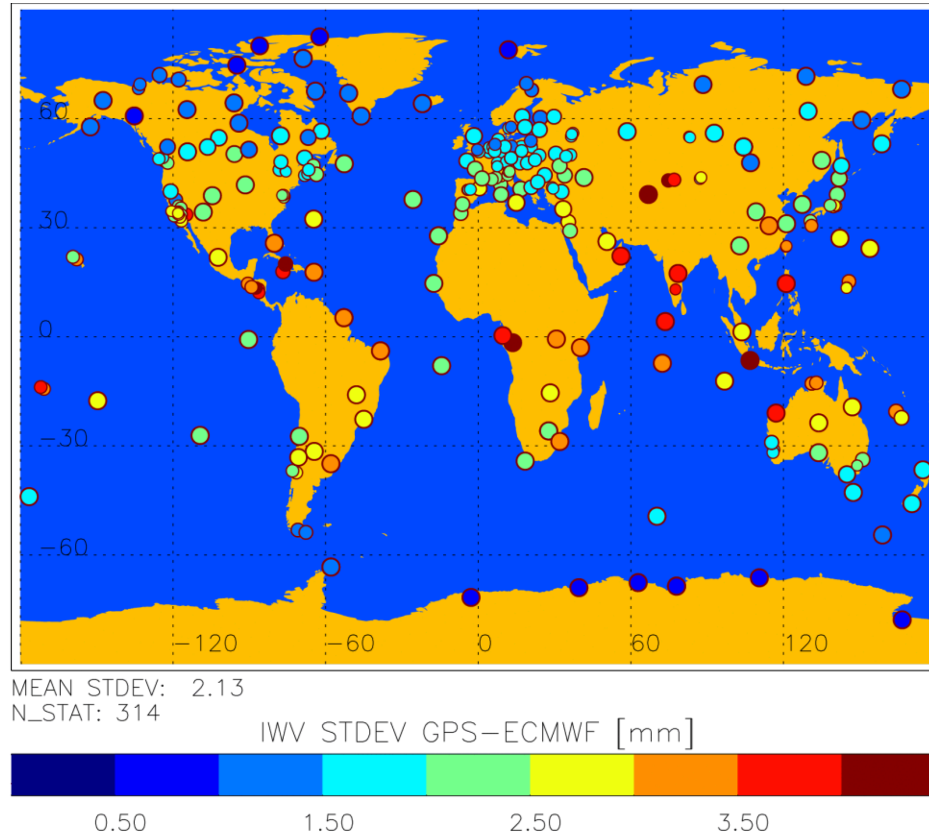




Global IWV Monitoring

GPS IWV comparison with ECMWF

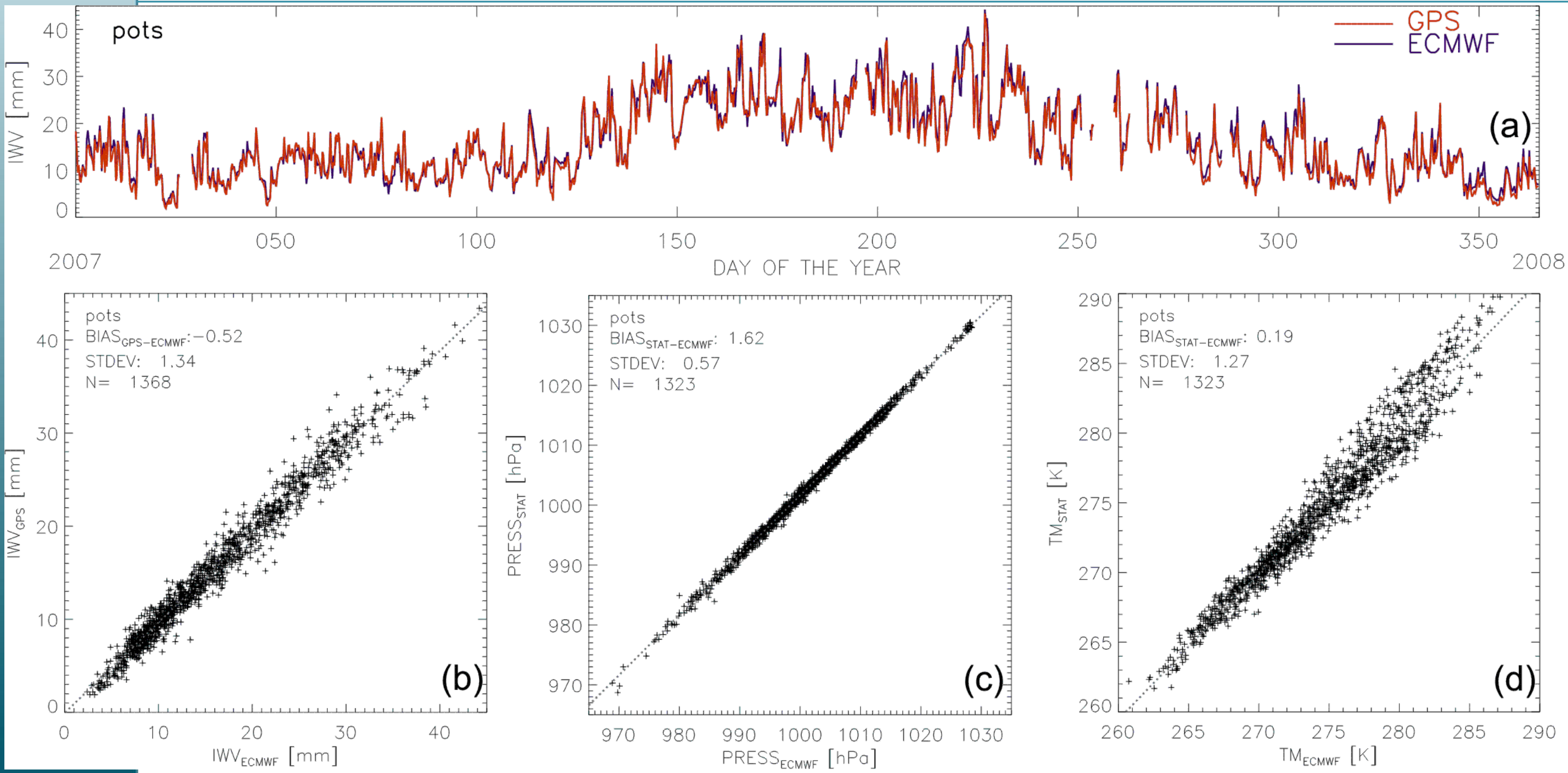




GPS IWV results 2000-2007 in comparison with ECMWF
only stations with more than one year of data
left: bias, right: standard deviation

Global IWV Monitoring - Potdam

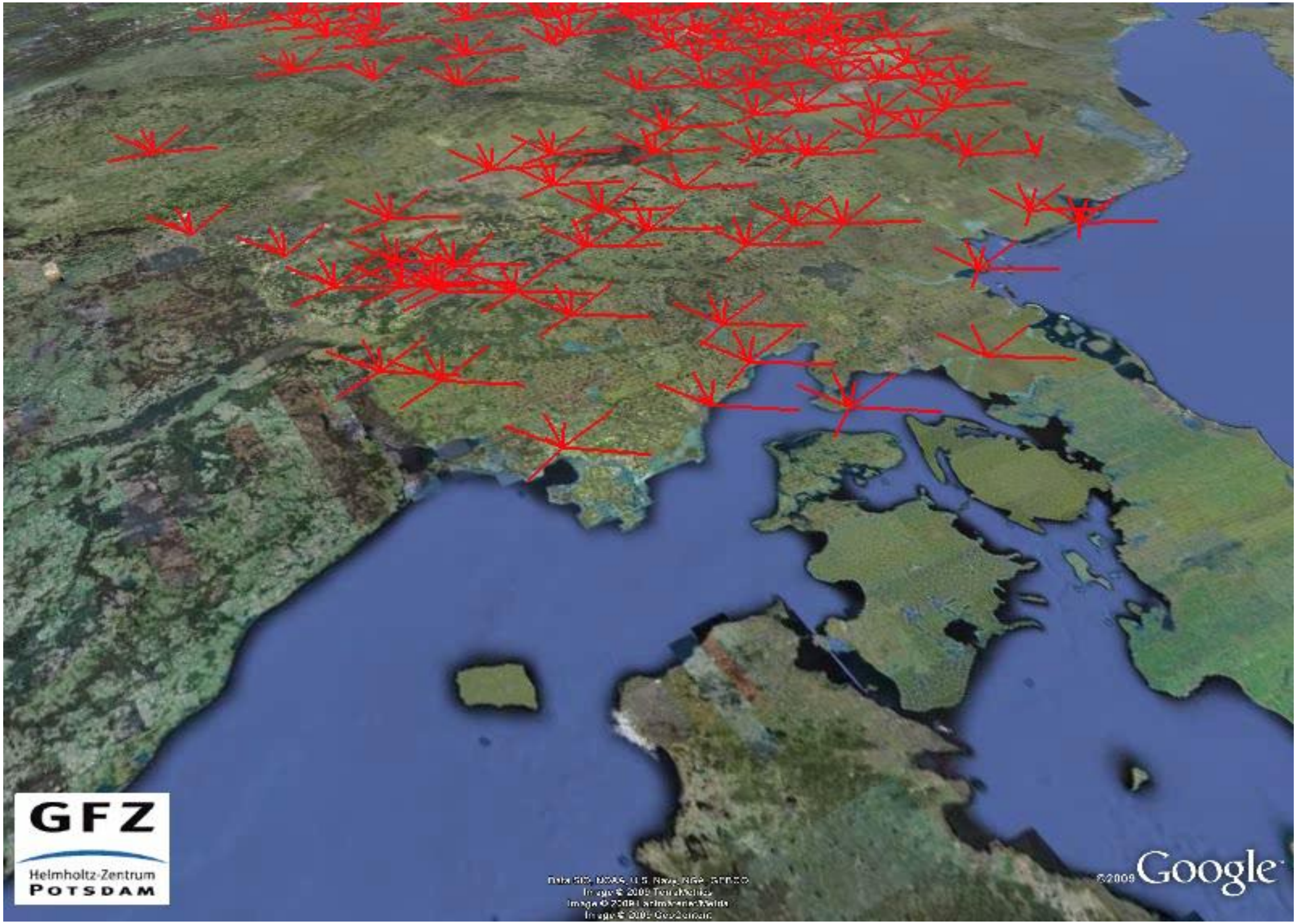
GPS IWV comparison with ECMWF



a) GPS IWV results of Potsdam in comparison with ECMWF in 2007
b) Scatter plot corresponding to (a), Bias:-0.5mm, Stdev:1.34 mm
c) Comparison of station pressure from local sensor and ECMWF
d) as (c) but for Tm

Slant Delays for Tomography

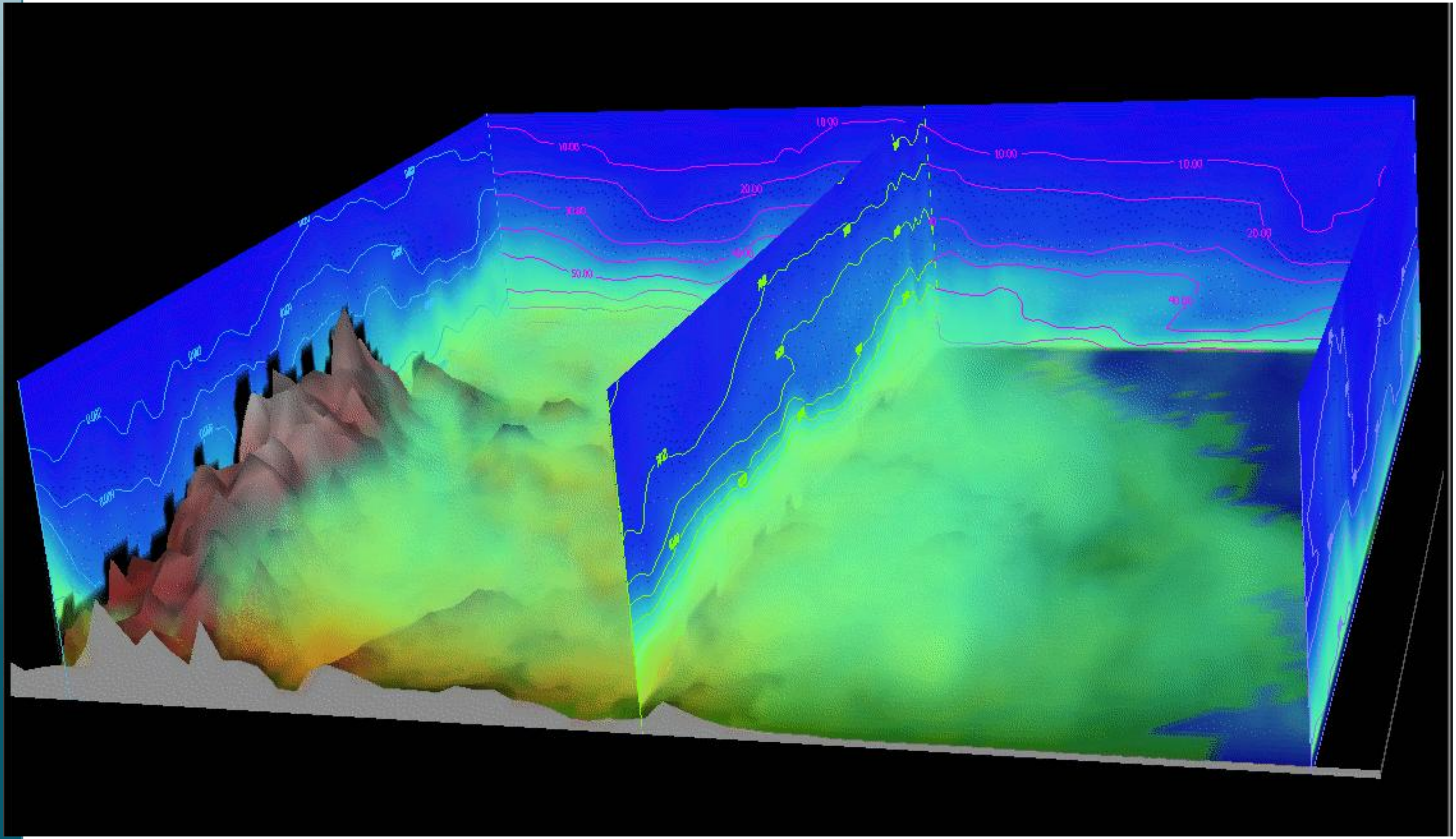
Geometric view of observations



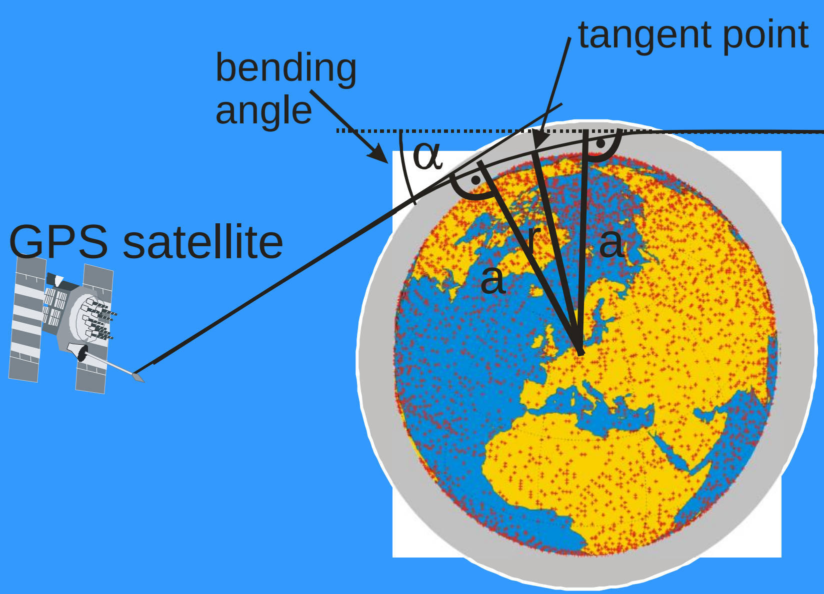
GNSS Tomography – Wator Vapor

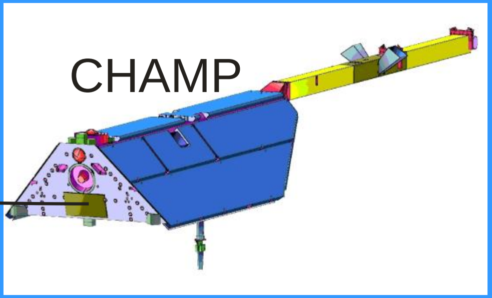
Water vapor predicted by the German meteorological weather model

Observed by the GNSS tomography



GPS Radio Occultation(RO) Measuring- Principle





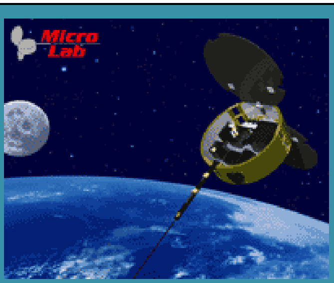
$$\ln n(r) = \frac{1}{\pi} \int_a^{\infty} da' \frac{\alpha(a')}{\sqrt{a'^2 - a^2}} \qquad n = n(r)$$

$$N = (n-1) \times 10^6 = 77.6 \frac{p}{T} + 3.73 \times 10^5 \frac{p_w}{T^2}$$

n: refractive index
a: impact parameter
N: refractivity

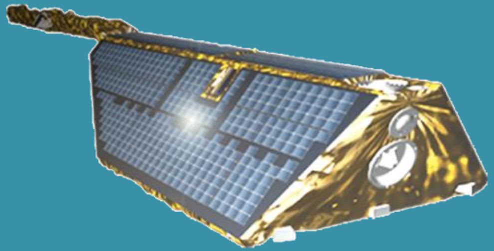
p: pressure
T: temperature
p_w: water vapour pressure

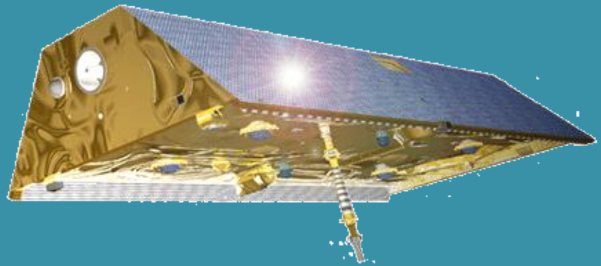
RO Satellites



Pioneering experiment: GPS/MET (1995-1997)

SAC-C (2001-)

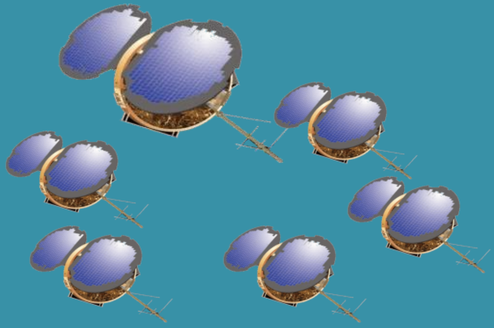


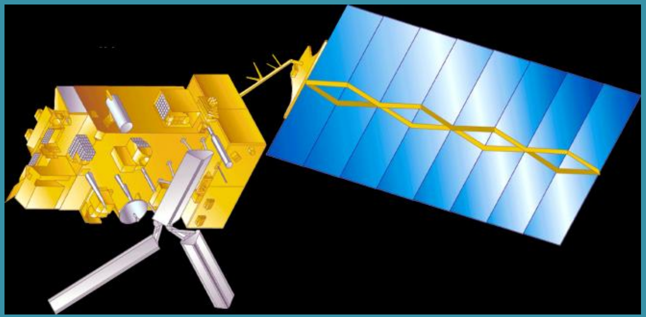


CHAMP (2001-2008)

GRACE (since 2006)

TerraSAR-X (since 2007)



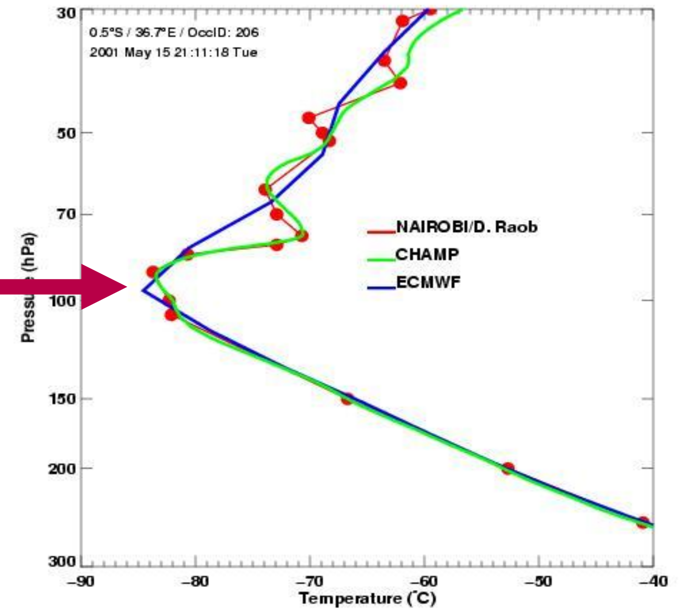


COSMIC (since 2006)

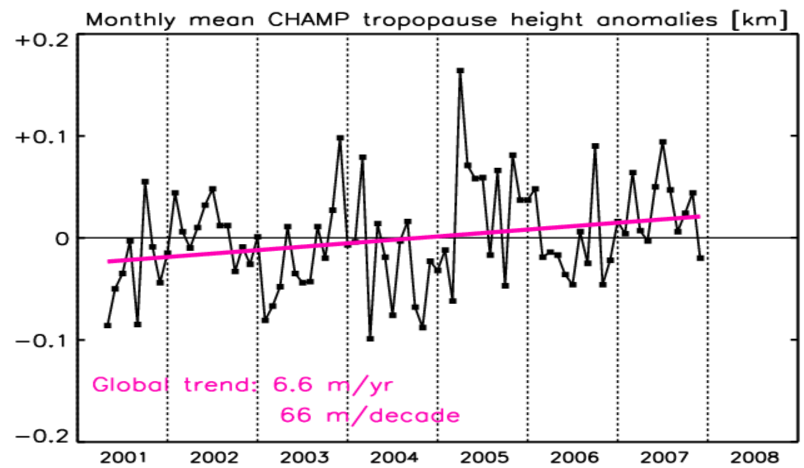
Metop (since 2006)

GPS RO Application –Tropopause Monitoring

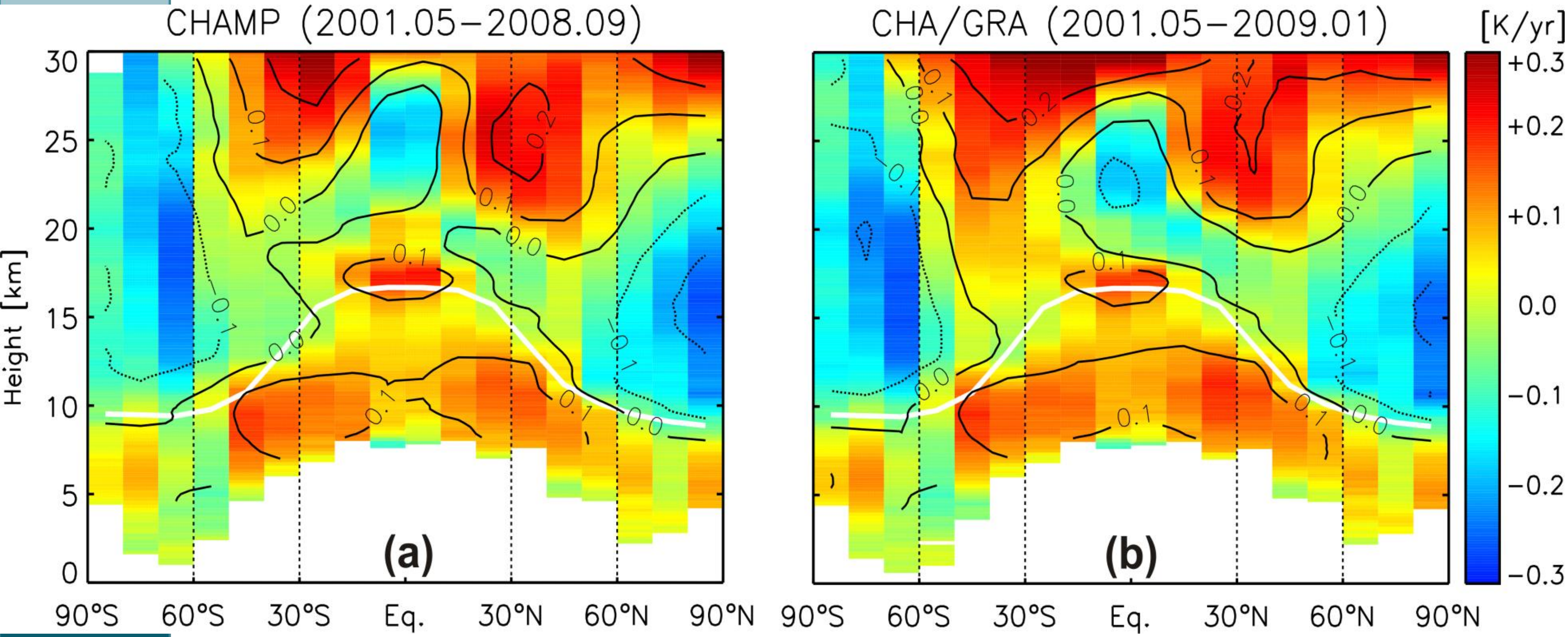
- **Tropopause height, indicator for climate change**



- **GPS RO: Monitoring of the tropopause**
- **Height trend: +6.6m/year**



GPS RO Application – Global Temperature Monitoring



Temperature trends derived from CHAMP and CHA+GRA

GNSS Reflectometry

GNSS– Reflectometry (GNSS-R)

- GNSS-R uses GNSS as signal source of opportunity in a bistatic configuration(Uplooking antenna for direct signals, downlooking antenna for reflected signals)
- The reflections are received by a GNSS receiver on, e.g., a LEO satellite that is capable to track reflections(firmware modifications needed)

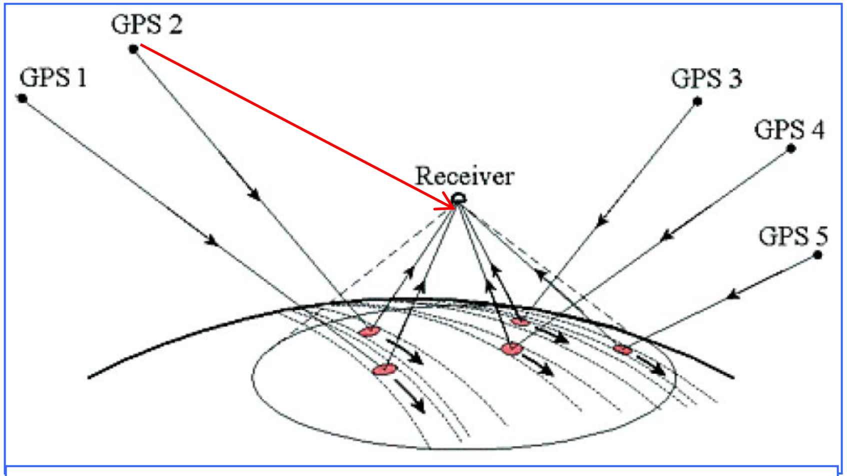
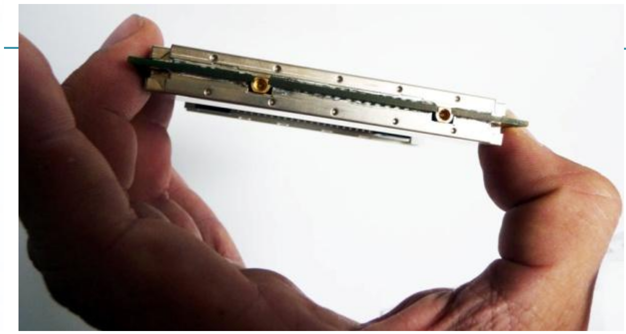
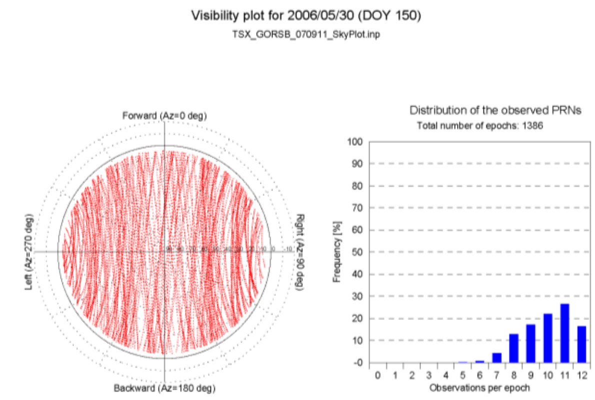


Figure from: Altimetry precision of 1 cm over a pond using the wide-lane carrier phase of GPS reflected signals, M. Martin-Neira, P. Colmenarejo, G. Ruffini, and C. Serra, Can. J. Remote Sensing, Vol. 28, No. 3, pp. 394–403, 2002

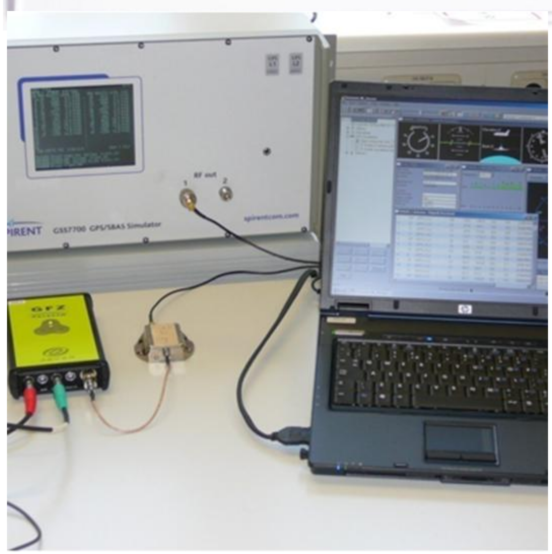
GNSS-R Receiver Development

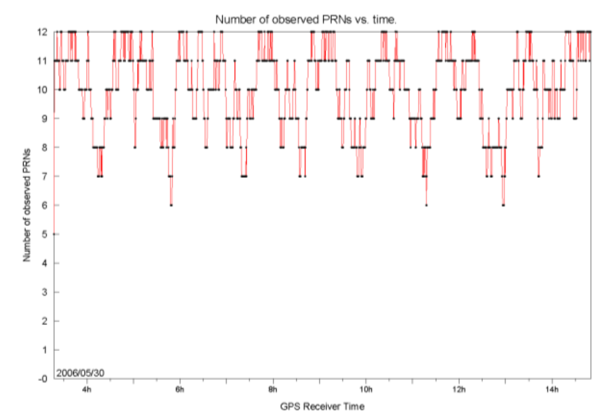
- New Generation JAVAD COTS Receivers



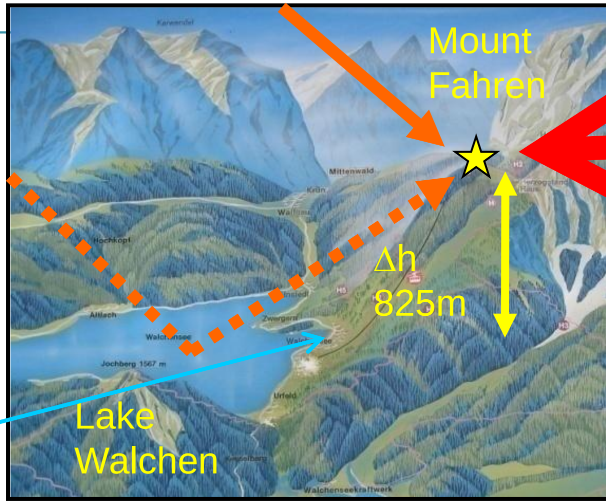


- Space Simulator tests



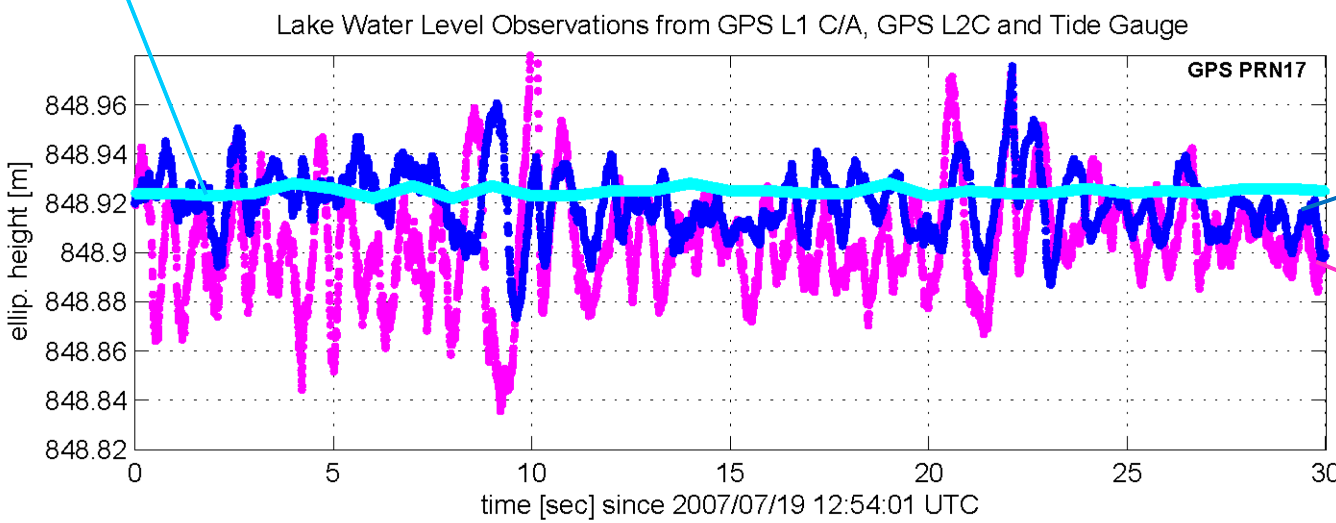


GNSS-R with Commercial Receiver



~ 2 cm accuracy for water surface monitoring

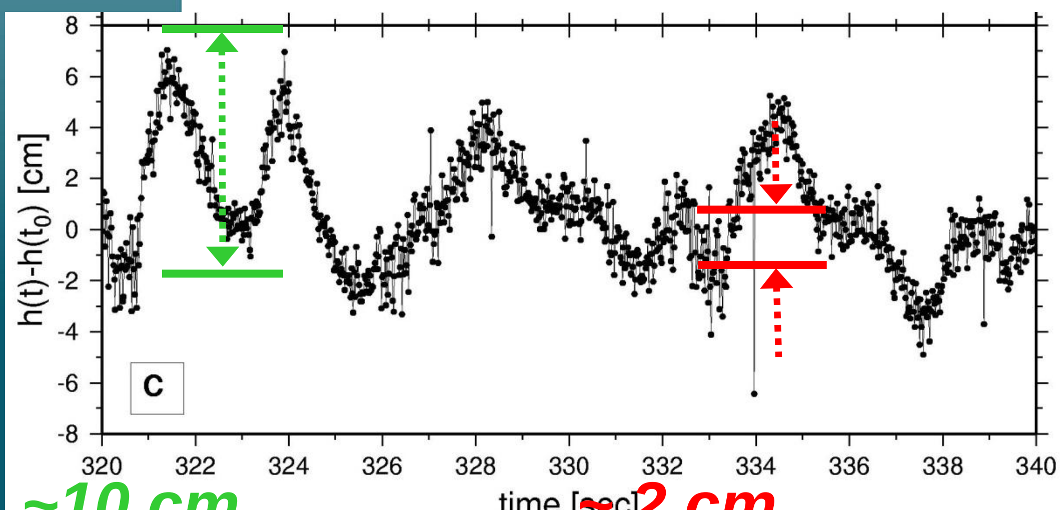
Tide Gauge



GPS L1

GPS L2C

GNSS-R with In-house Receiver



~10 cm wave height

~2 cm accuracy

Instrument

GFZ receiver (in-house development)

Possible applications

Sea level rise (global scale)

Tide gauges

Atmospheric/Ionospheric sounding

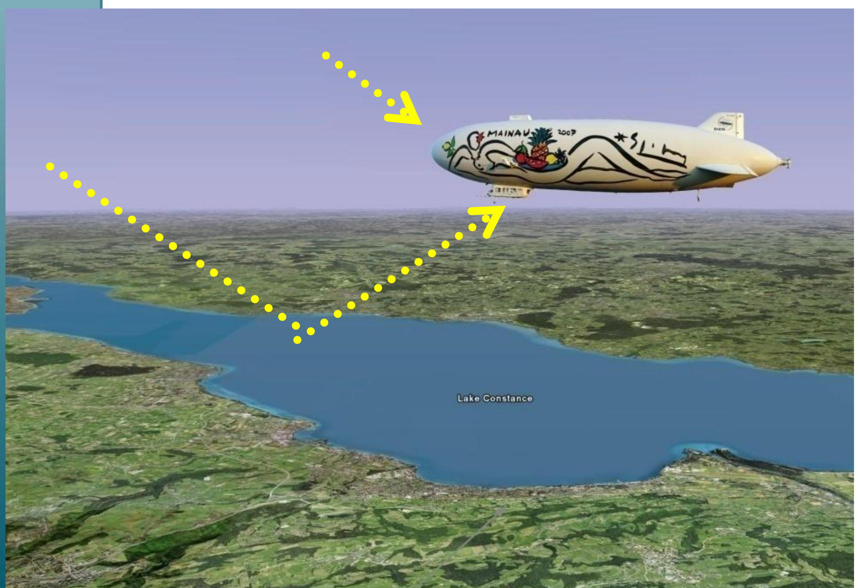
Wind velocities/directions above oceans (wave forms)

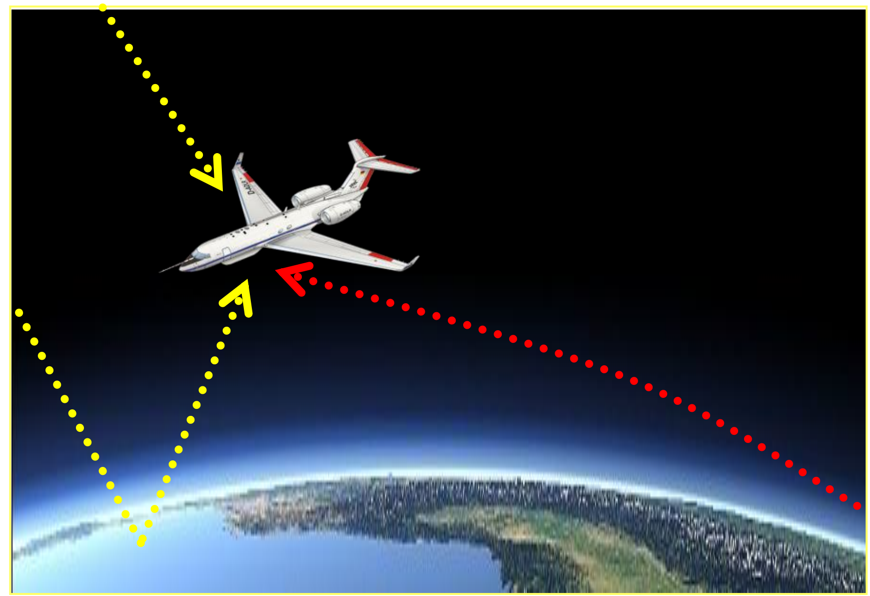
Soil moisture

Airborne Platforms

Zeppelin NT, 2010

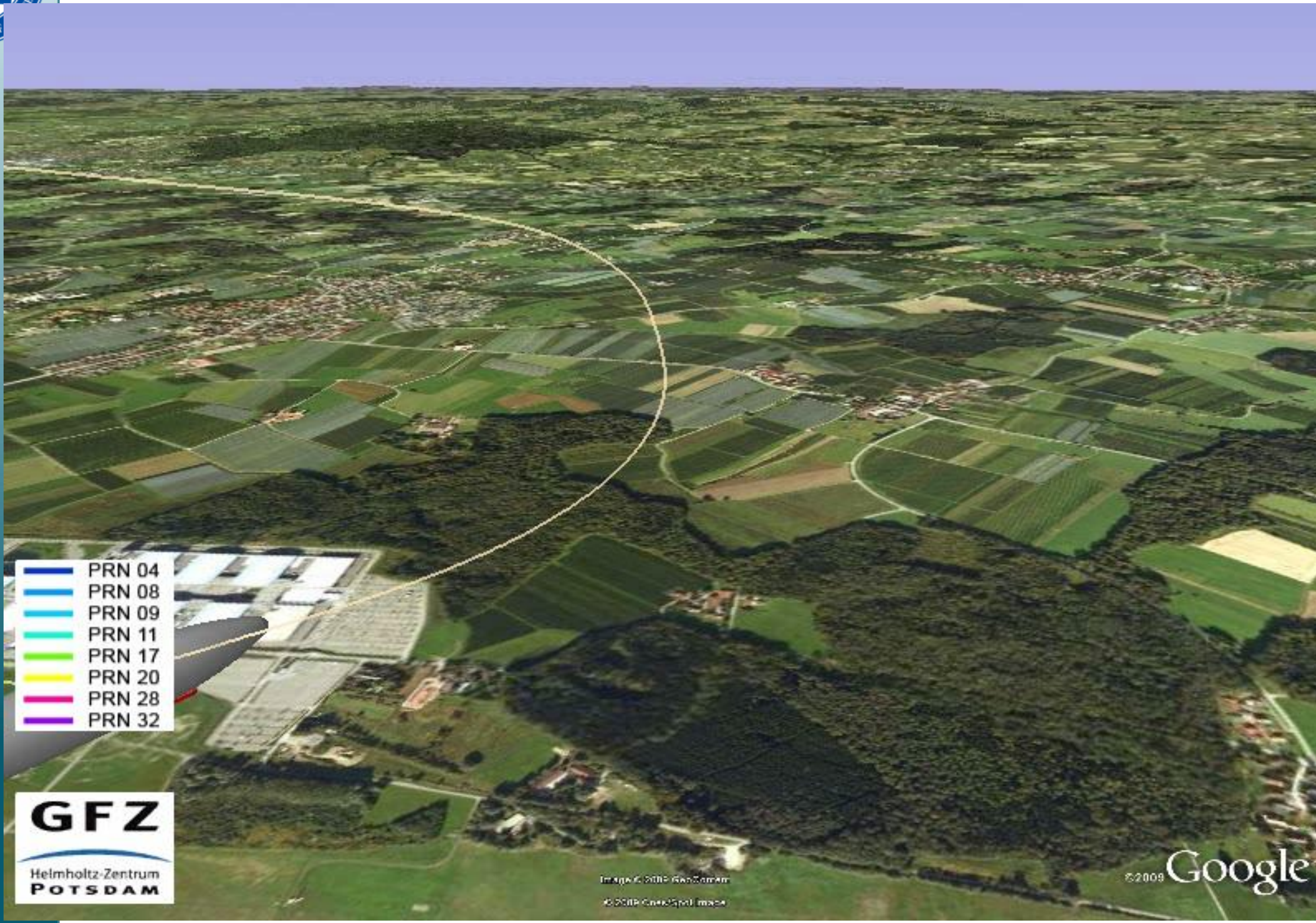
*Research HALO (*High Altitude and LOng Range Research*) aircraft ,2011*





Reflectometry/Scatterometry; Occultations (HALO)

Zeppelin NT


PRN 04
PRN 08
PRN 09
PRN 11
PRN 17
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PRN 28
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GFZ
Helmholtz-Zentrum
POTSDAM
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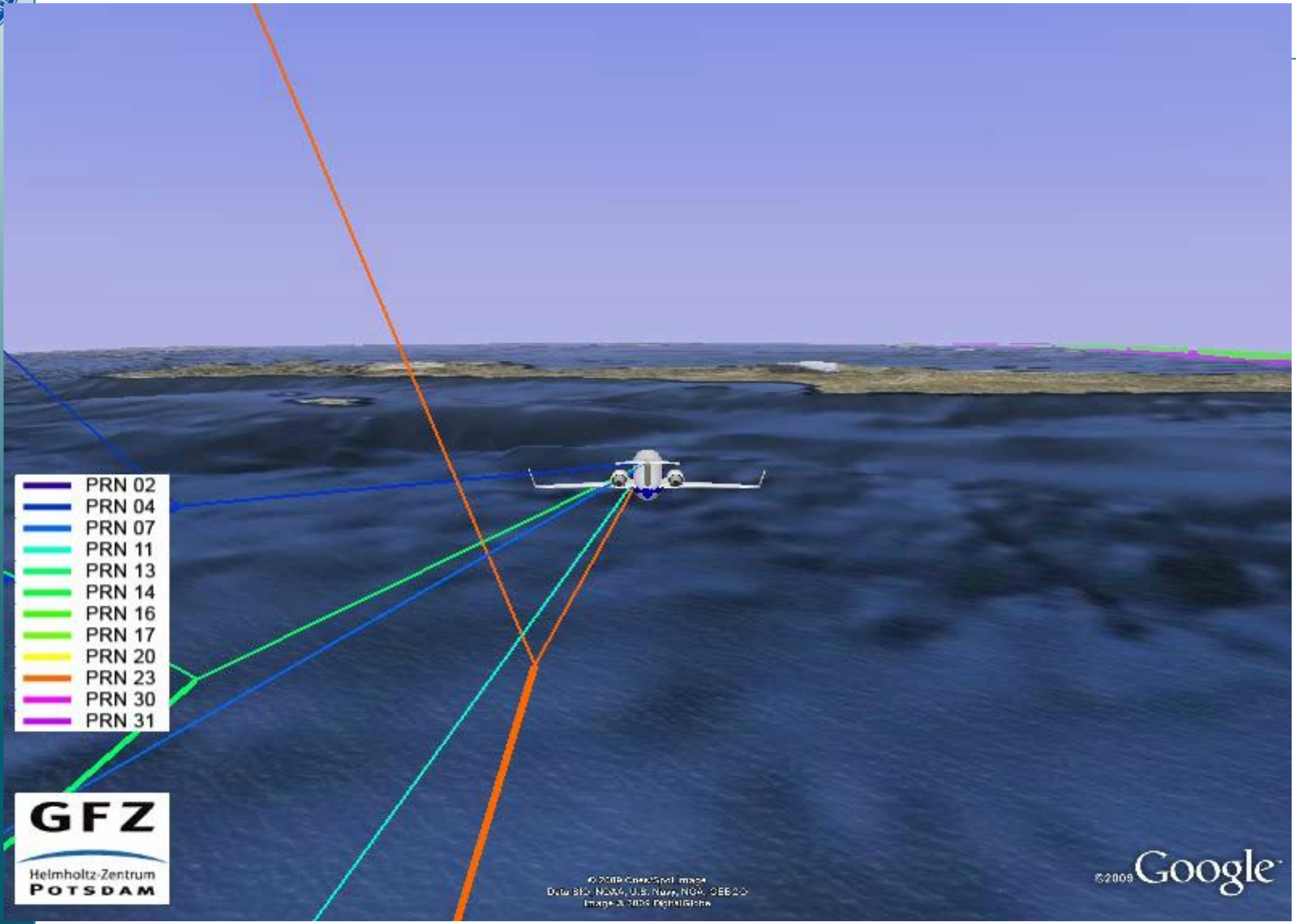
HALO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PRN 20
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PRN 30
PRN 31
GFZ
Helmholtz-Zentrum
POTSDAM
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在研热点(7)

- 导航系统时空基准统一
  - 模型
  - 姿态
  - 光压
  - 海量数据处理

- 导航系统性能指标提升
  - 轨道
  - 钟差
  - 电离层
  - 广播星历拟合
  - 广域差分
  - 完好性

中科院上海天文台

THANK YOU FOR YOUR ATTENTION!

www.shao.ac.cn/shao_gnss_ac