# Exploitation of IGS Real-Time Products for Tropospheric Monitoring

Rosa Pacione
e-GEOS S.p.A. ASI/CGS - Matera, Italy

Wolfgang Söhne
Federal Agency for Cartography and Geodesy (BKG) – Frankfurt am Main, Germany

# Outline

- Motivation

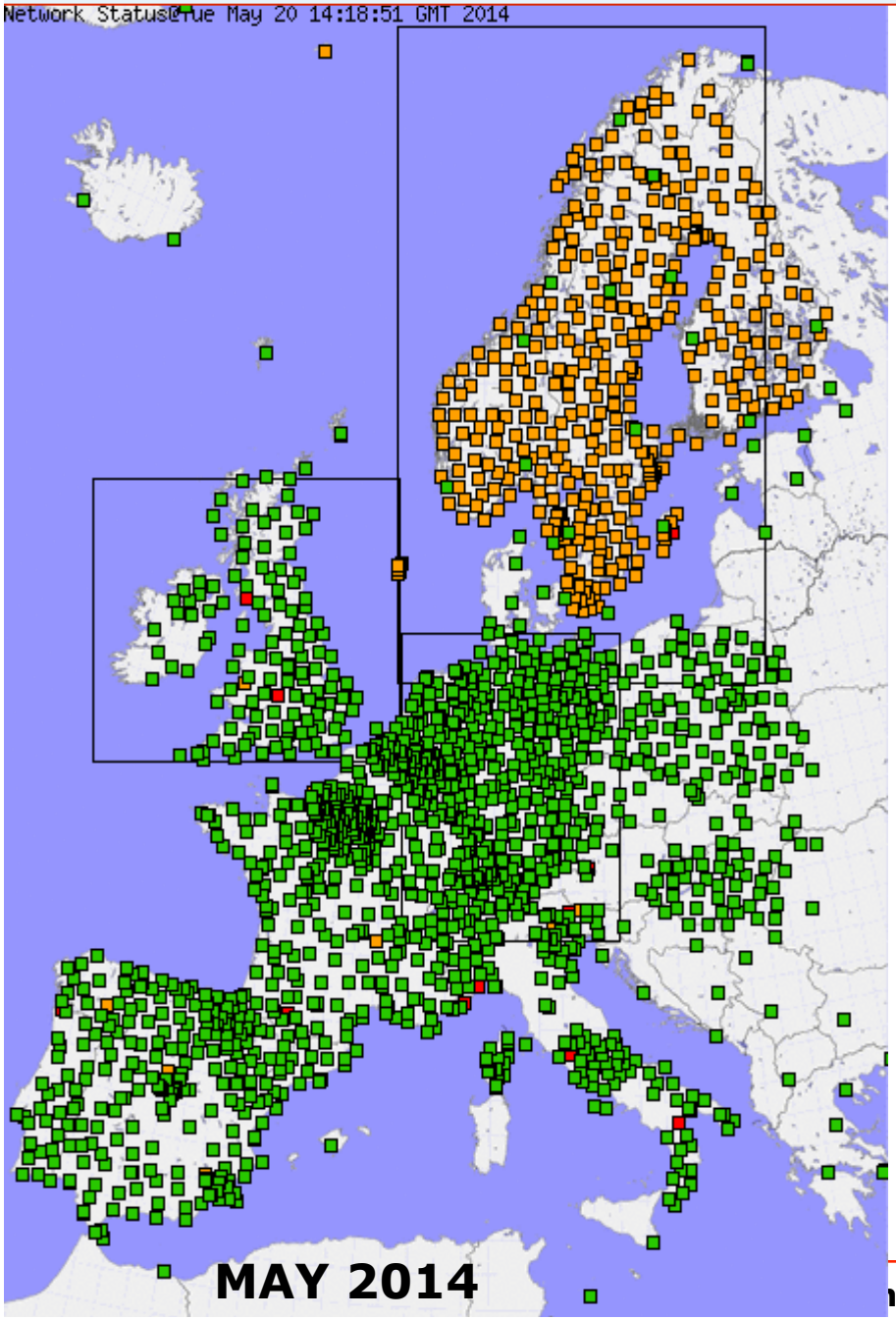
  from hourly to sub-hourly and real-time

  from network to PPP processing
- GNSS-Met product requirements
- Near real-time, sub-hourly, real-time processing modes
- Summary and conclusions

# Moving towards sub-hourly processing

- Estimation of ZTD on hourly basis (so-called **Near Real-Time**) and its assimilation in Numerical Weather Prediction models is well established since more than a decade (**E-GVAP** framework).
- There are still unforeseen events….for example related to heavy, local precipitation. A phenomena expected to increase due to global warming.

# EUROPEAN GNSS Water Vapour Network




E-GVAP http://egvap.dmi.dk

**EUMETNET EIG GPS Water Vapour Program**

-consortium of 18 National Weather Services working in close collaboration with 17 analysis centres, whereof the majority are national mapping agencies

-provide quality checked, ground based GNSS ZTDs and IWVs in **NRT** for use in **operational** numerical weather prediction models and in now-casting

-GNSS network composed of public & private stations and counts ~ 2000 unique sites world-wide delivering ~10M ZTDs per month.

-GNSS rinex data are processed by 17 ACs in NRT, i.e. latency < 1h45min.

-NRT ZTD disseminated by UKMO via GTS (BUFR files) and assimilated in NWP models by UKMO, Meteo-France, DMI, KNMI…

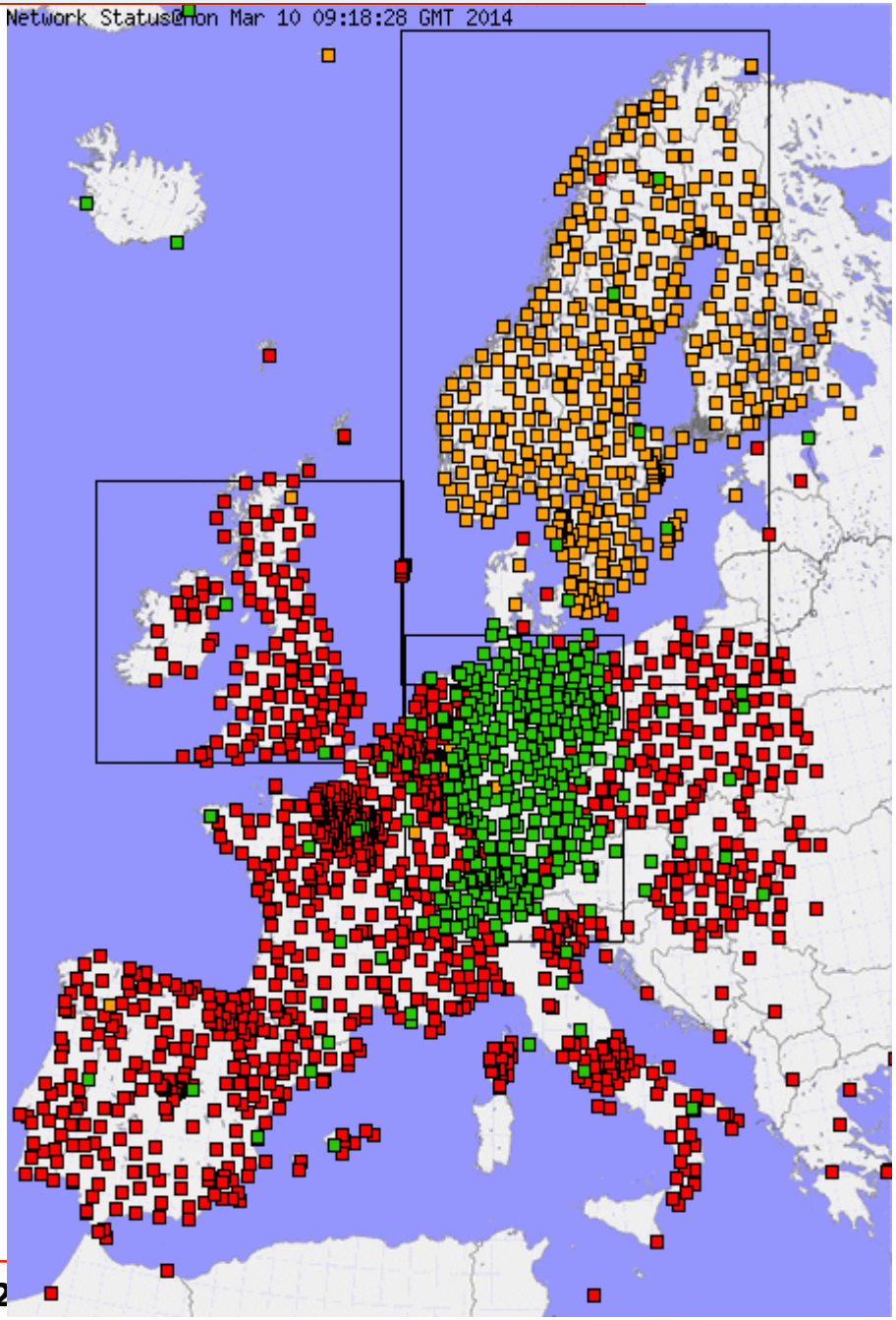
# IGS Outage March 2014

**Red** sites did not provide ZTDs, due to IGU orbits not being available.

**Orange** sites did provide ZTDs, based on ppp solution, but with a delay (not related to IGS outage)

**Green** sites processed by LPT (Swiss) using CODE orbits in a network mode and GFZ (Germany) using its own orbits and clocks in PPP.

**But …. IGS RT products were available**



# GNSS-Met Product Requirements

GNSS-Met Observational requirements for Regional NWP

| | IWV | | |
|---|---|---|---|
| | **Threshold** | **Breakthrough** | **Goal** |
| **Horizontal Domain** | Regional (e.g. Europe, N. America) | | |
| **Horizontal Sampling** | 250 km | 25 km | 3 km |
| **Observation Cycle** | 12 h | 6 h | 1 h |
| **Accuracy** | 5 kg $m^{-2}$ | 2 kg $m^{-2}$ | 1 kg $m^{-2}$ |
| **Timeliness** | 6 h | 30 min | 5 min |

GNSS-Met Observational requirements for now-casting

| | IWV | | |
|---|---|---|---|
| | **Threshold** | **Breakthrough** | **Goal** |
| **Horizontal Domain** | Sub-regional (a few 100 km) | | |
| **Horizontal Sampling** | 50 km | 10 km | 5 km |
| **Observation Cycle** | 30 min | 10 min | 5 min |
| **Accuracy** | 5 kg $m^{-2}$ | 2 kg $m^{-2}$ | 1 kg $m^{-2}$ |
| **Timeliness** | 30 min | 10 min | 5 min |

E-GVAP II Product Requirements Document

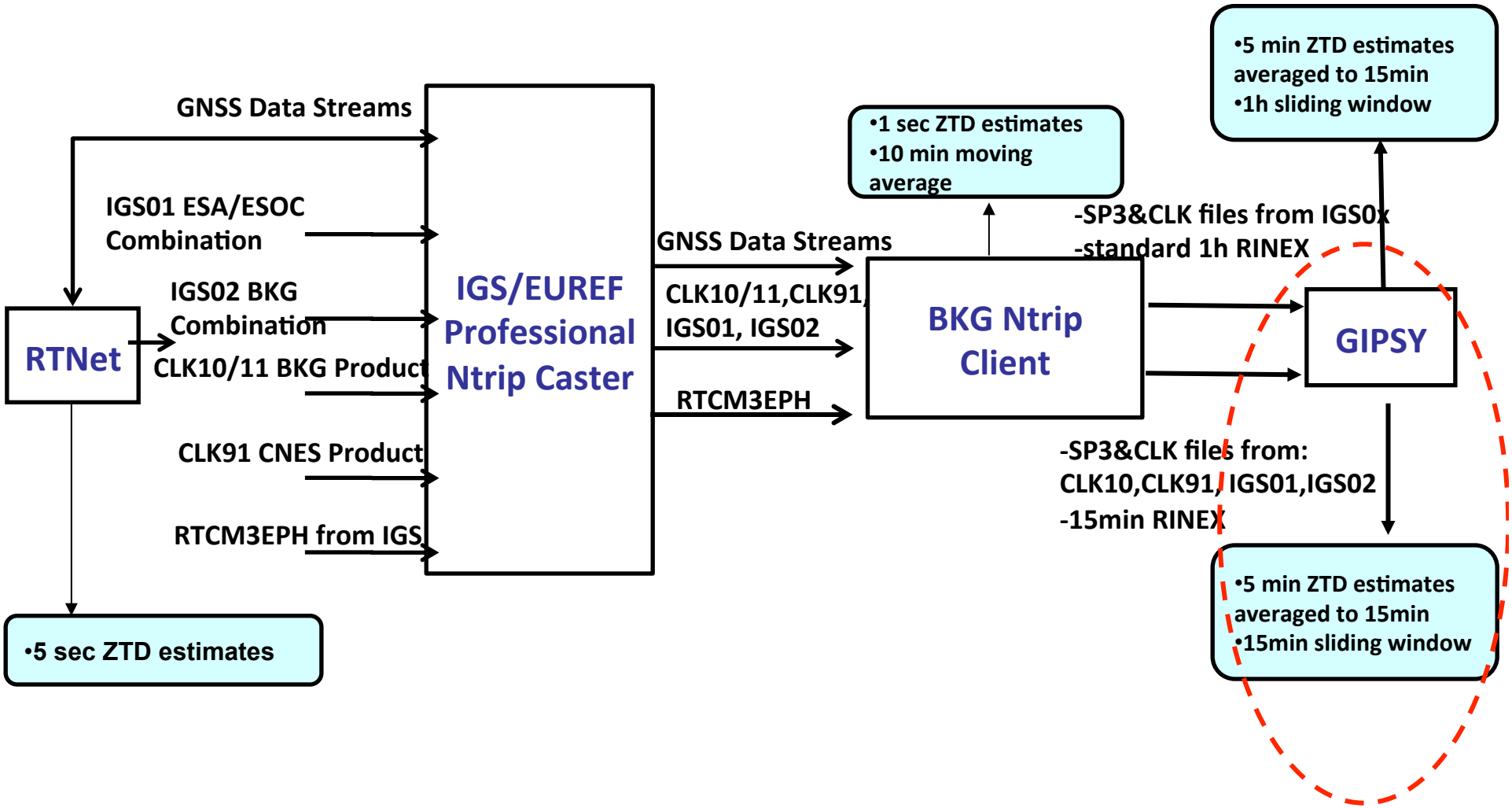
# Motivation

- Demand for smaller horizontal sampling leads to increase the number of stations
- Demand for shorter timeliness asks for solutions beyond "classical" NRT
- Sub-hourly or even real-time processing necessary for now-casting applications
- PPP is a very promising strategy for efficient GNSS Meteorology

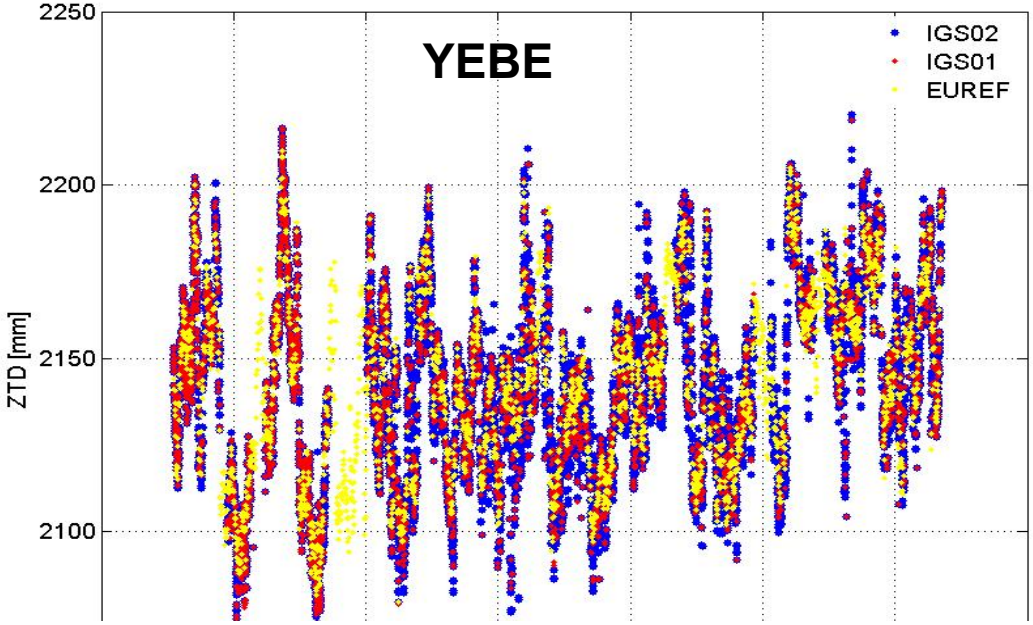
Orbit and clock correction products, within certain timeframe and with acceptable accuracy, are necessary input for PPP.

# Processing Mode

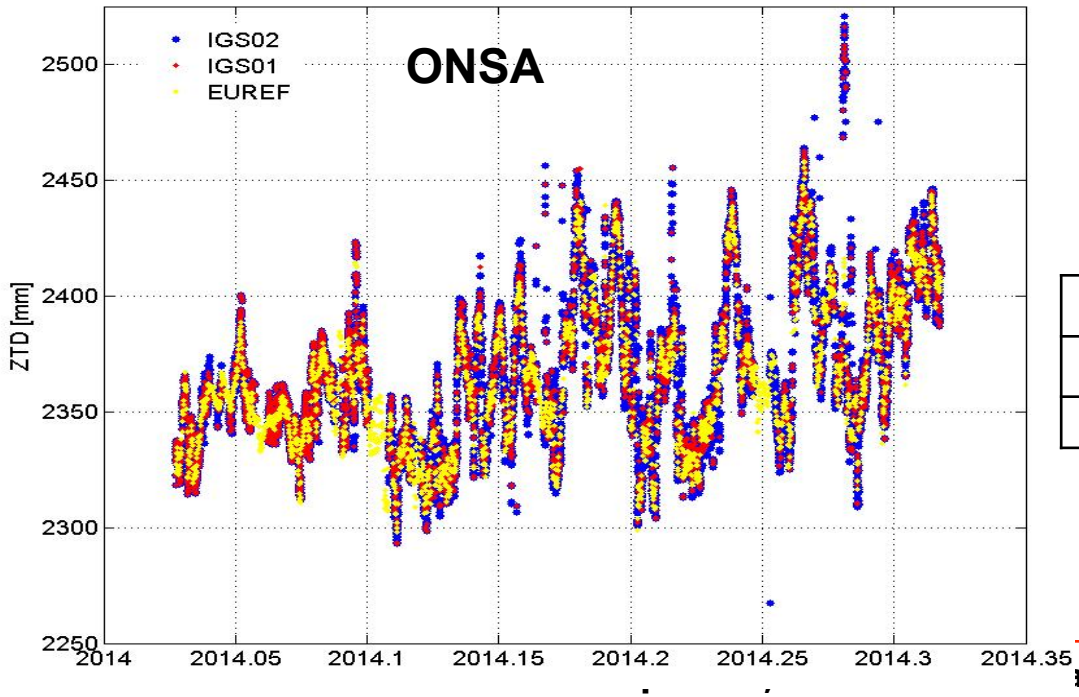
## Real Time, sub-hourly, hourly PPP system architecture



# Sub-Hourly ZTD with IGS0x Products

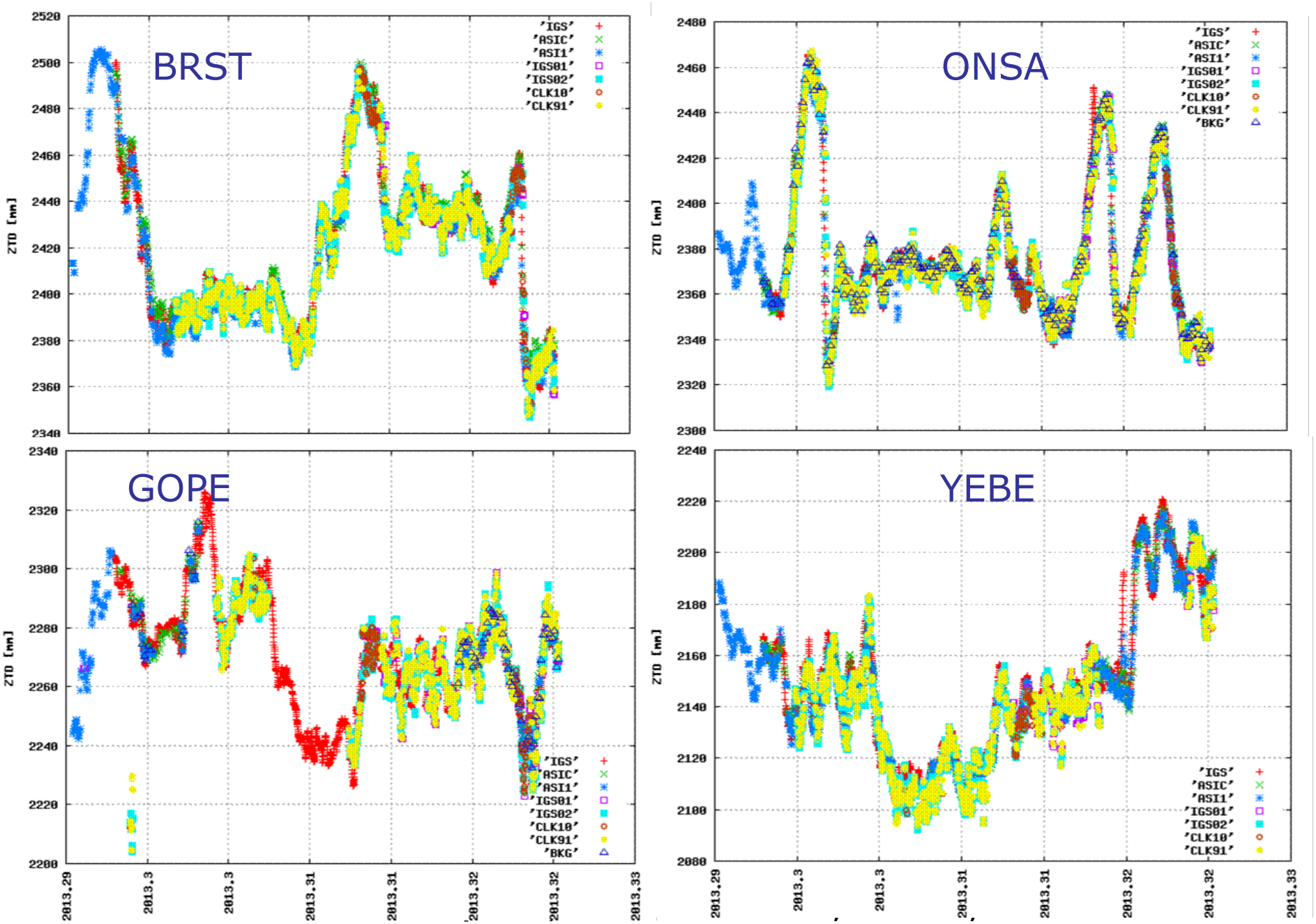



| | EUREF-IGS01 | EUREF-IGS02 |
|---|---|---|
| MEAN [mm] | 0.59 | 0.30 |
| STD [mm] | 8.27 | 8.26 |

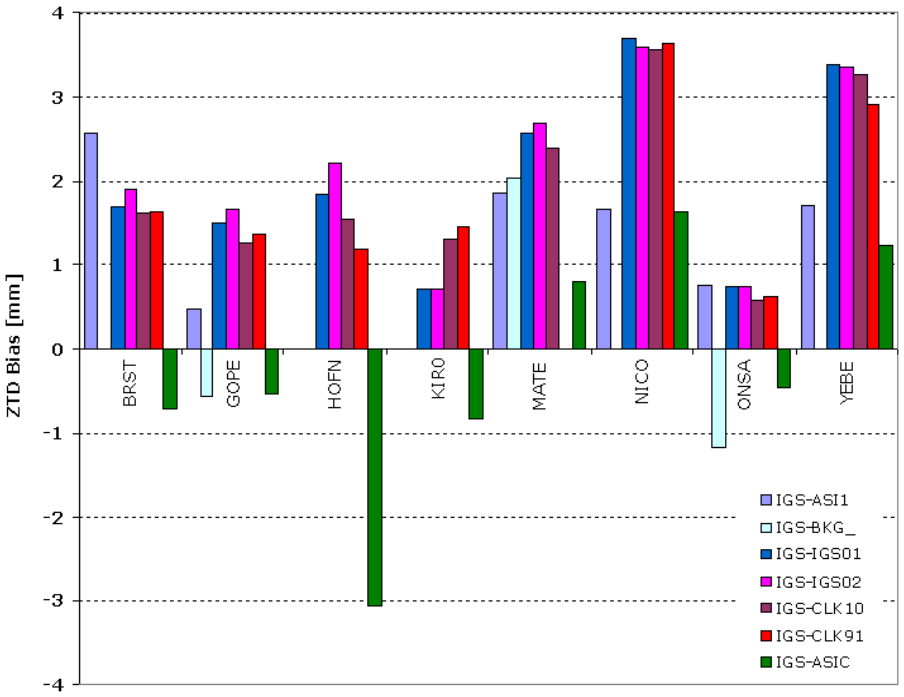


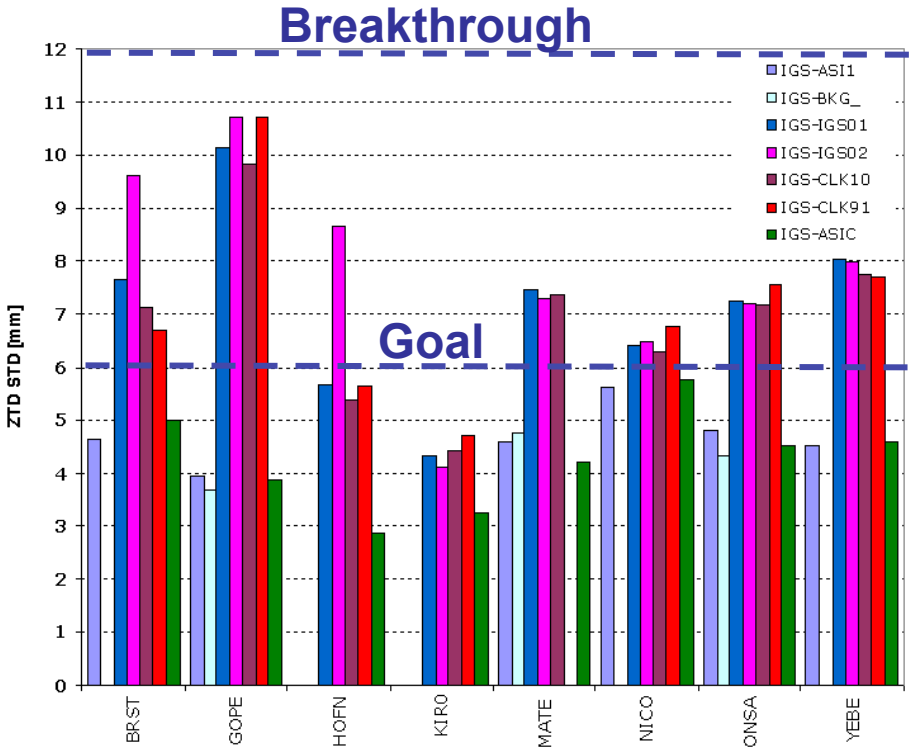

| | EUREF-IGS01 | EUREF-IGS02 |
|---|---|---|
| MEAN [mm] | -0.66 | -0.66 |
| STD [mm] | 5.66 | 6.33 |

# Sub-Hourly ZTD with IGS RT Products



# Sub-Hourly ZTD w.r.t. IGS Final ZTD

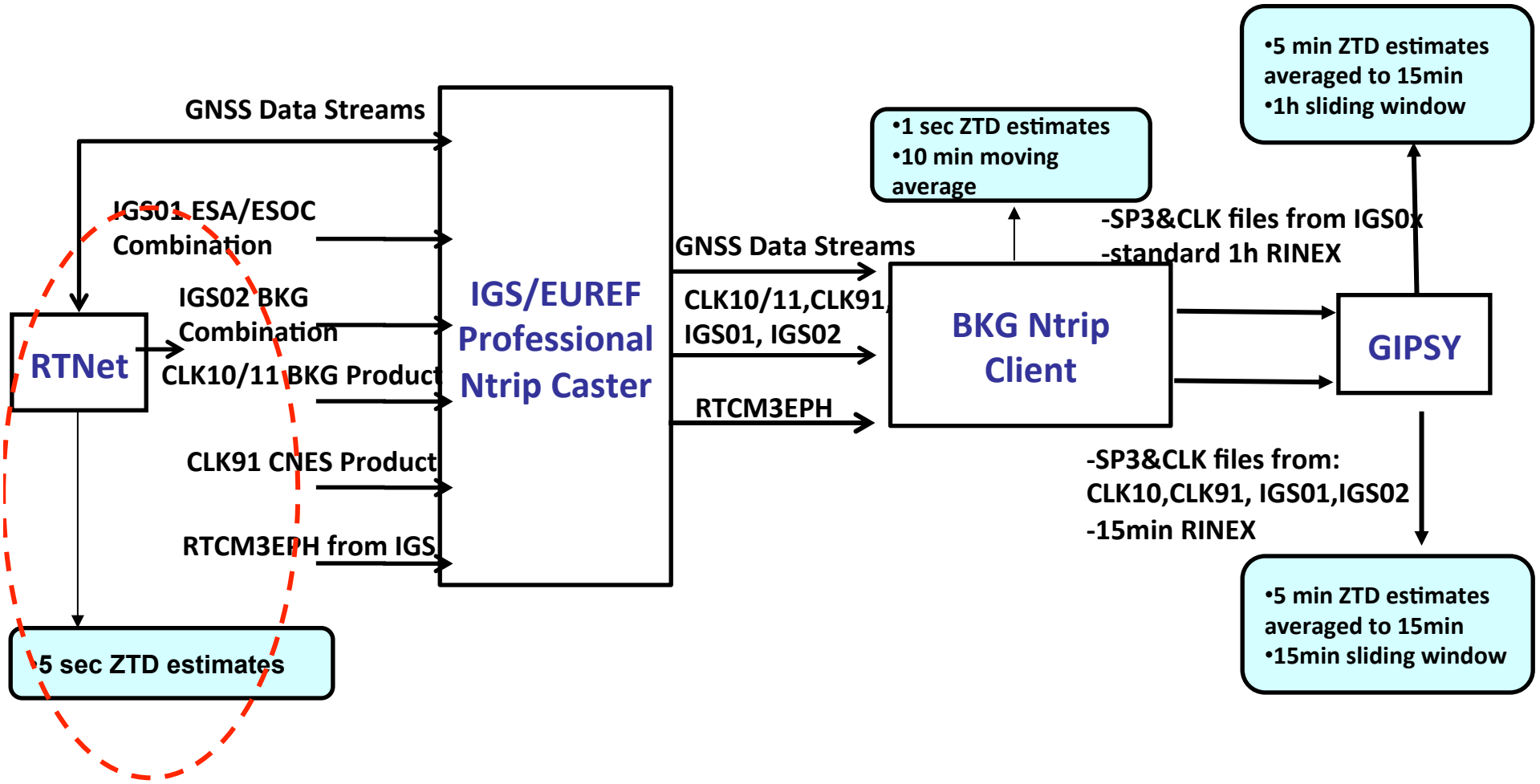


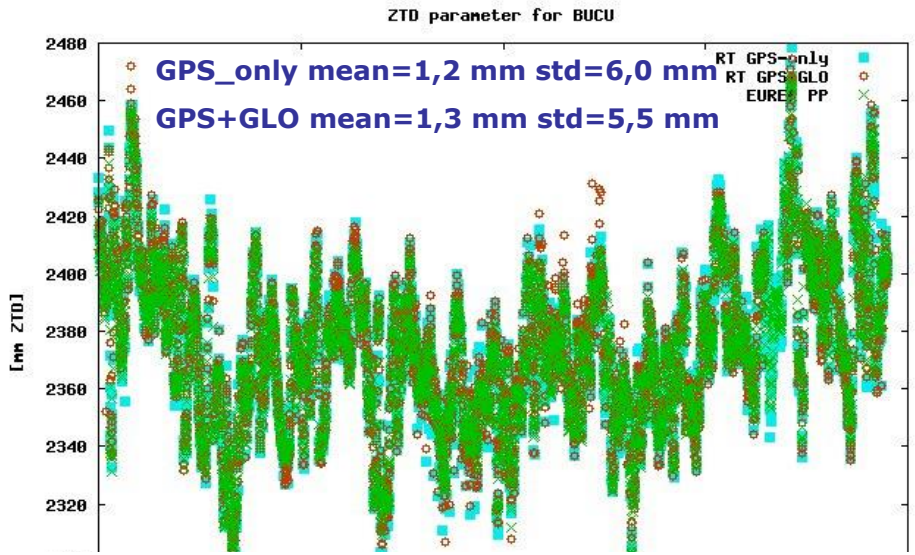

## E-GVAP NRT and sub-hourly ZTD w.r.t. IGS Final ZTD

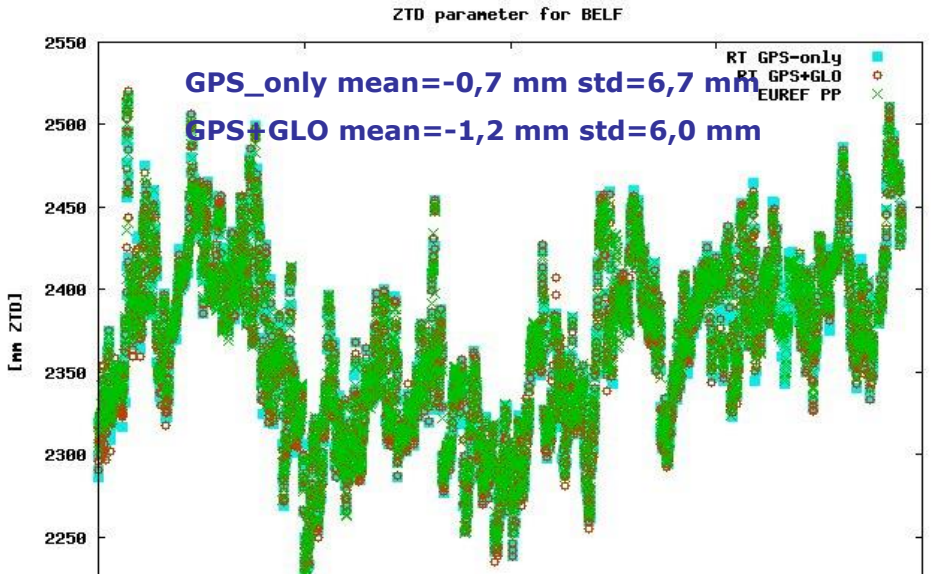
# Processing Mode

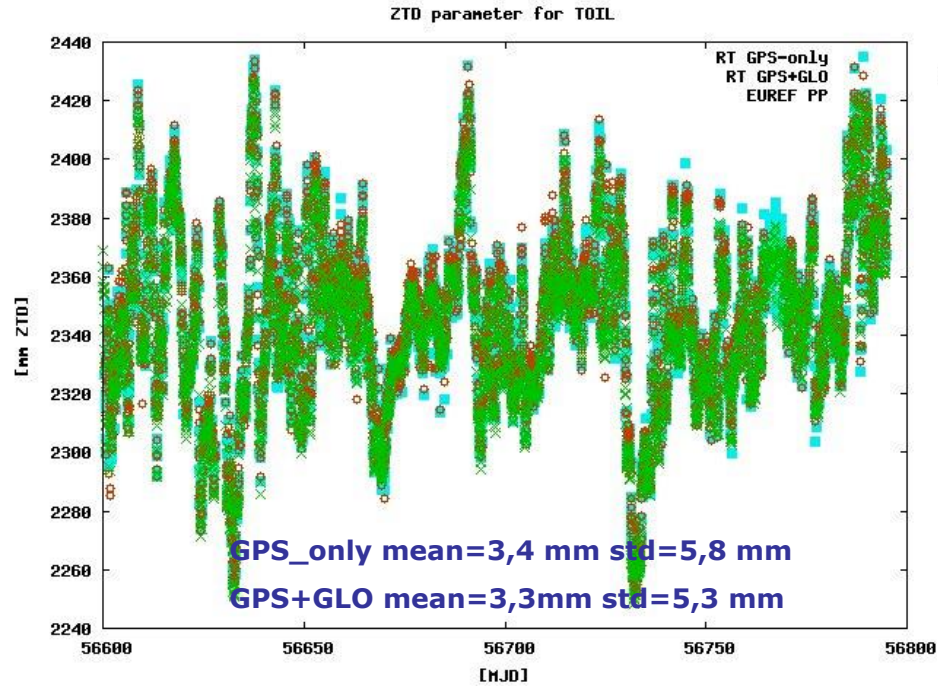
## Real Time, sub-hourly, hourly PPP system architecture

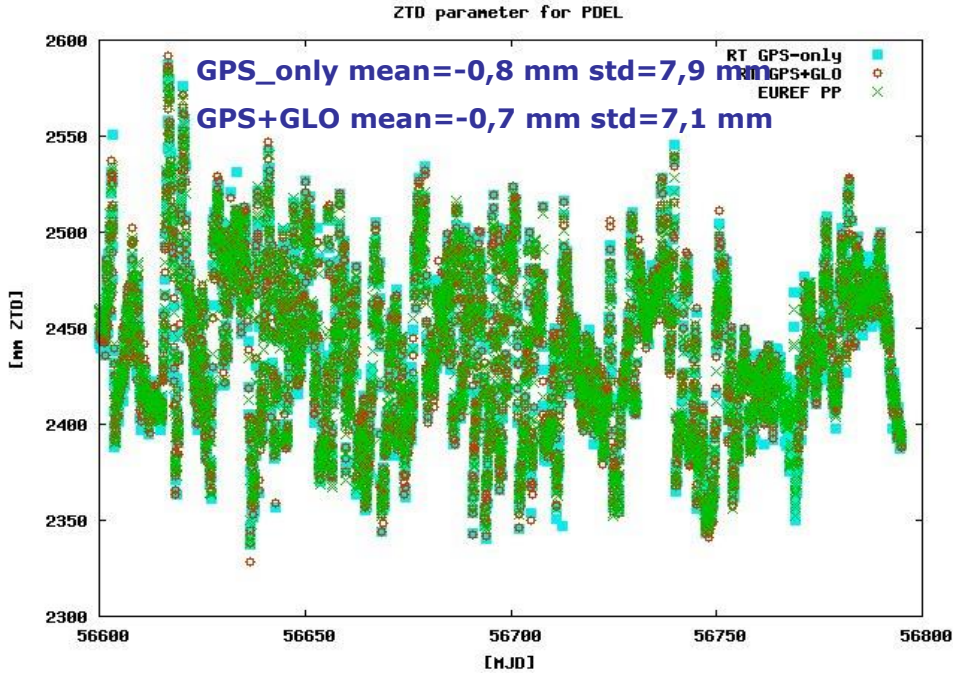


# Real Time Net ZTD time series

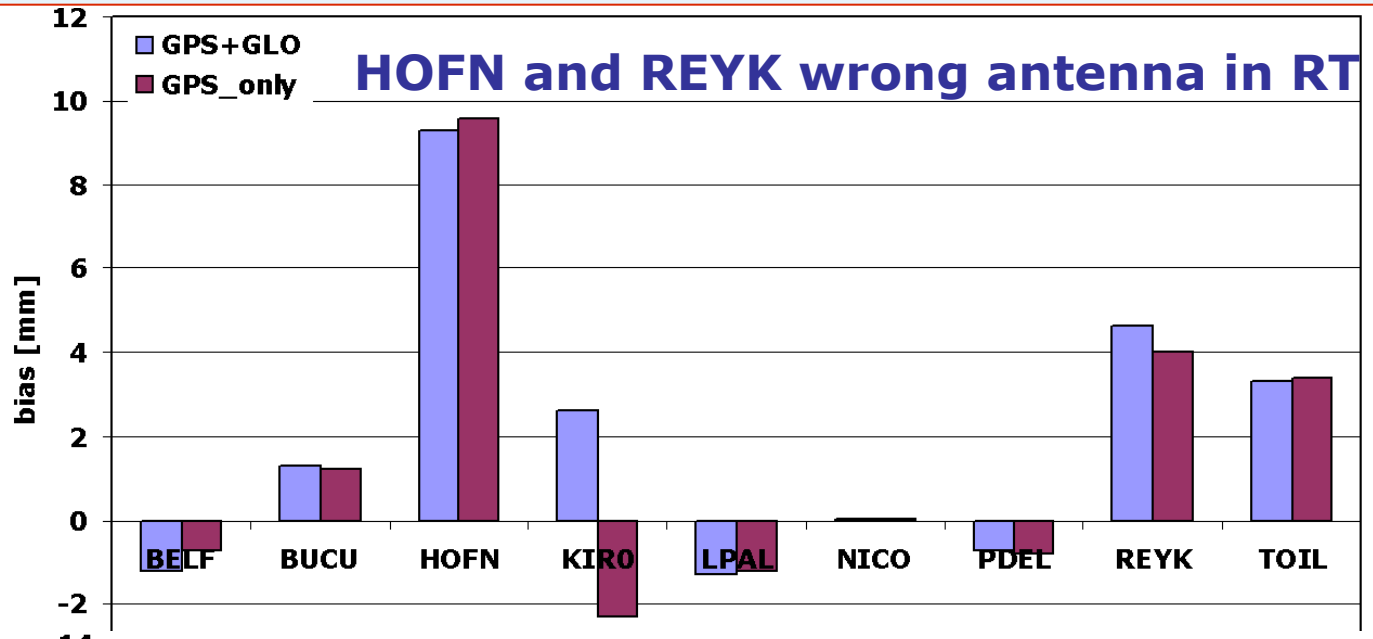


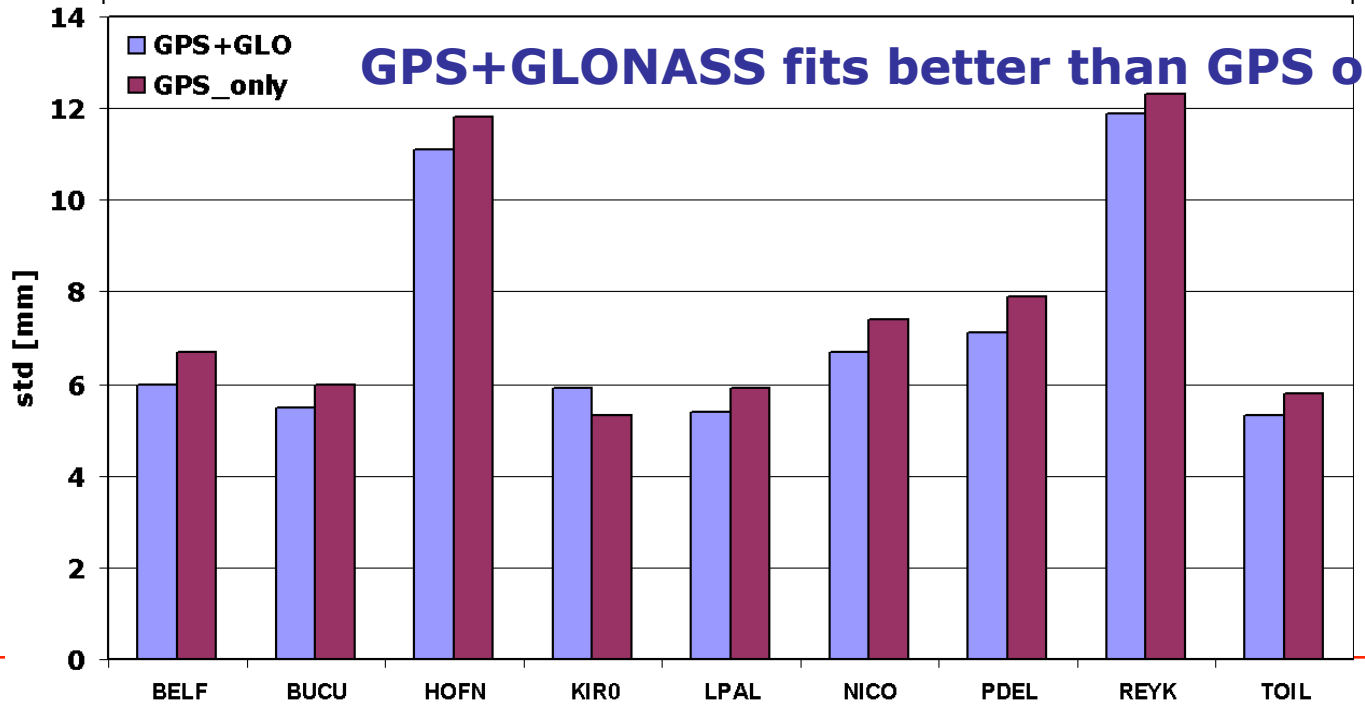



# Real Time Net ZTD w.r.t. EUREF



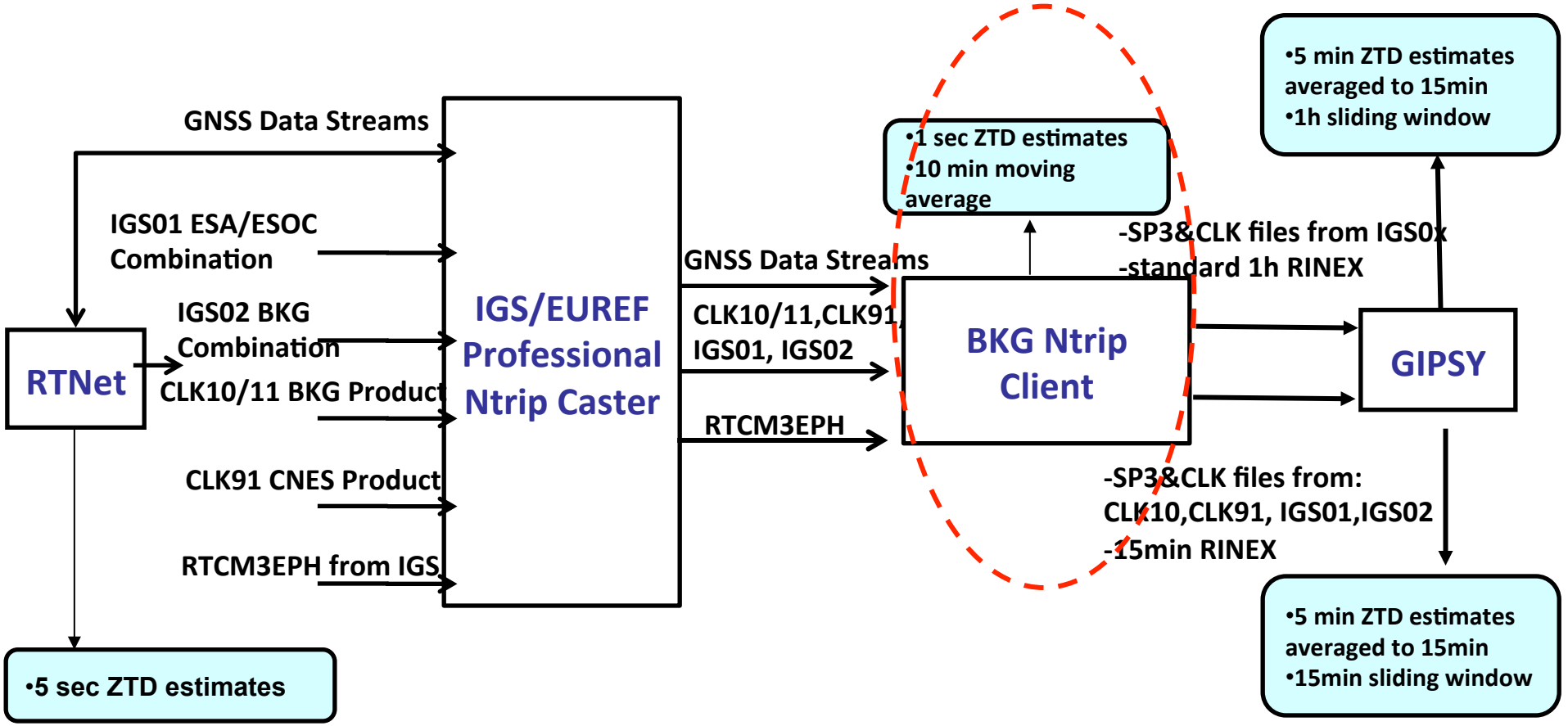

**HOFN and REYK wrong antenna in RT solutions**



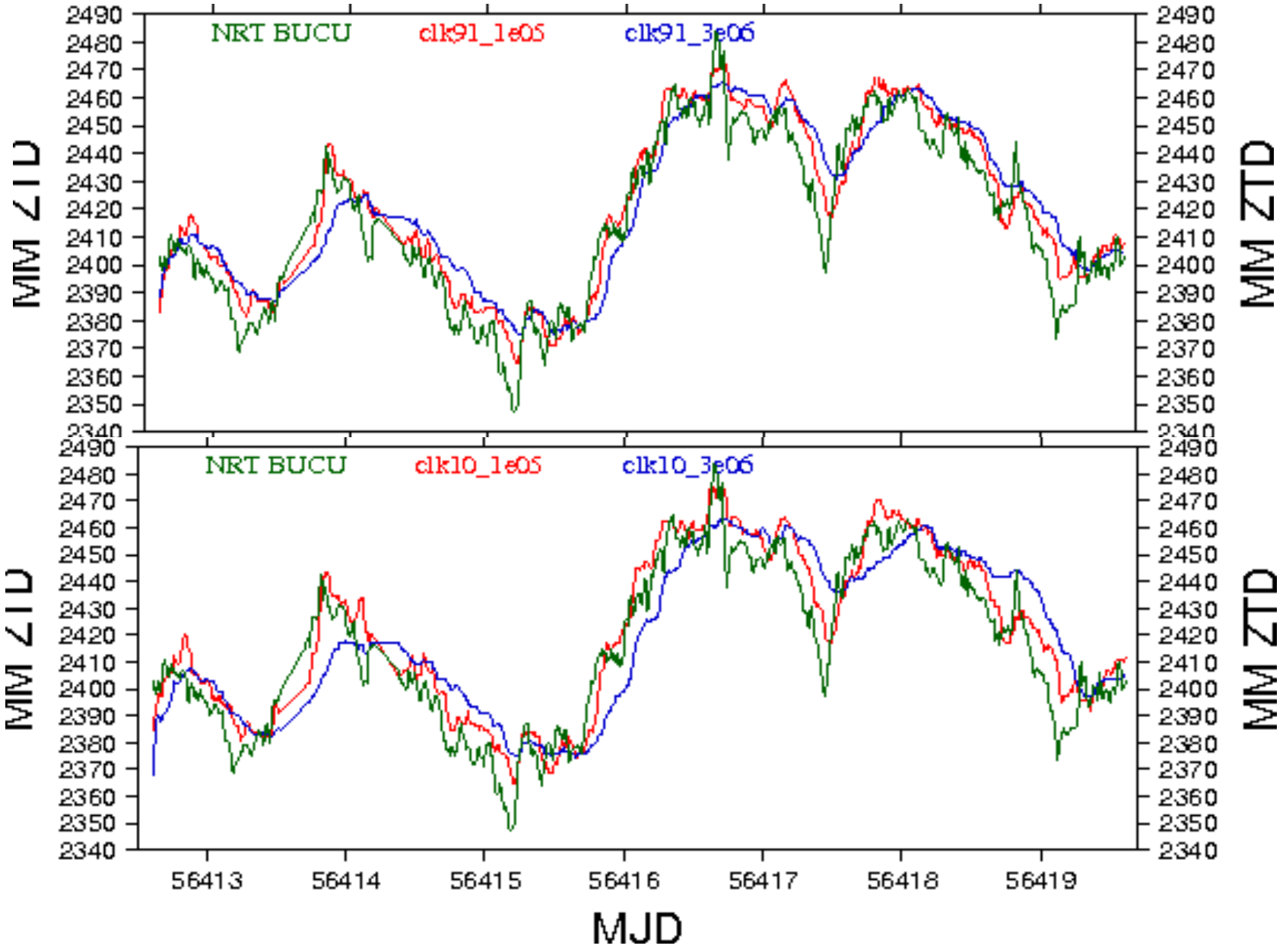

**GPS+GLONASS fits better than GPS only**

# Processing Mode

## Real Time, sub-hourly, hourly PPP system architecture

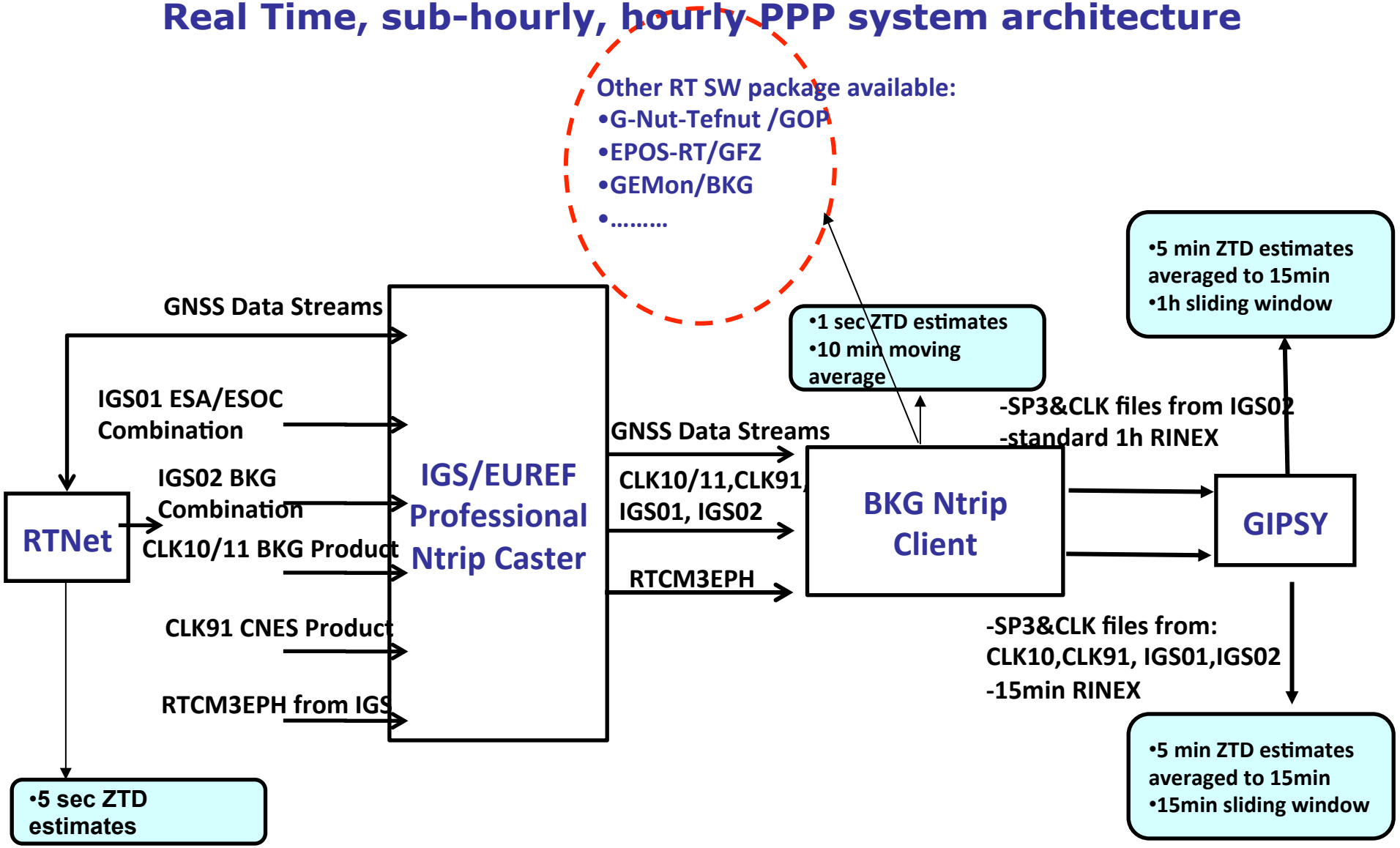


# Real Time PPP Time series with BNC



# Processing Mode

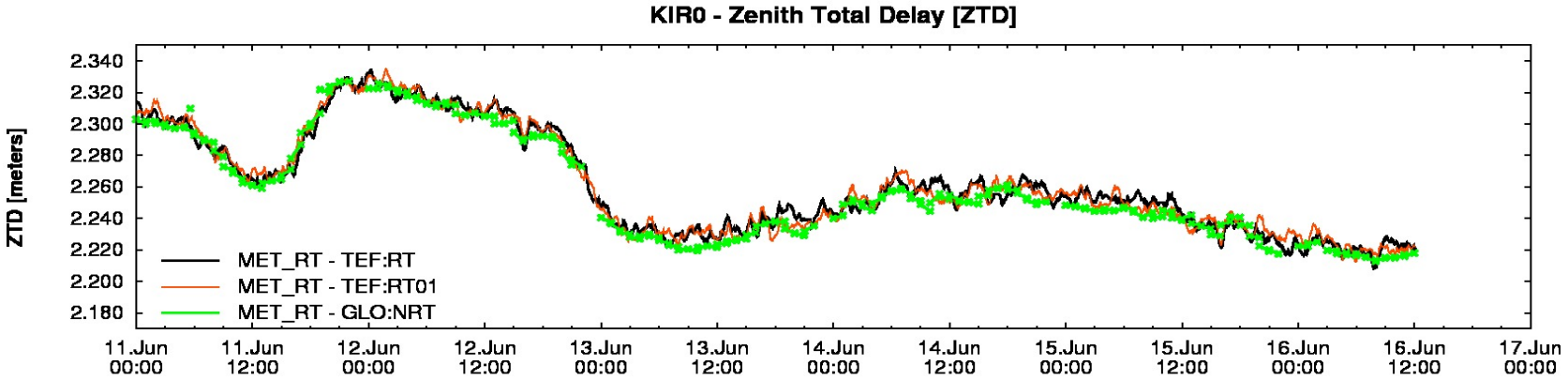
## Real Time, sub-hourly, hourly PPP system architecture

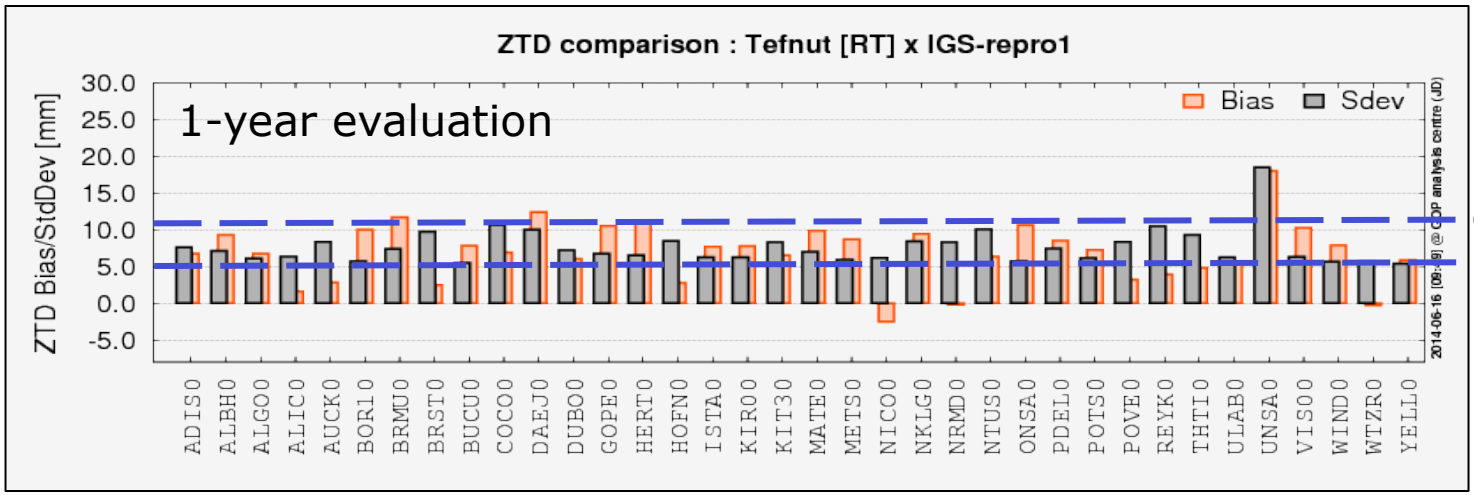


# G-Nut-Tefnut/GOP Tropo Monitoring

***G-Nut/Tefnut*** *developed at Geodetic Observatory Pecny (GOP) using* ***G-Nut sw library***

- ✓ ***real-time****, near real-time & offline processing mode*
- ✓ *supports* ***GPS****+****GLONASS*** *(other GNSS whenever available relevant precise products)*
- ✓ *real-time* ***ZTD*** *(since Feb 2013) +* ***horizontal tropospheric gradients*** *(since Feb 2014)*
- ✓ *Kalman filter (since Feb 2013) + back-smoothing algorithm (currently testing)*
- ✓ *Additional details:* ***Václavovic and Douša @ PS05 – Tropospheric poster session***



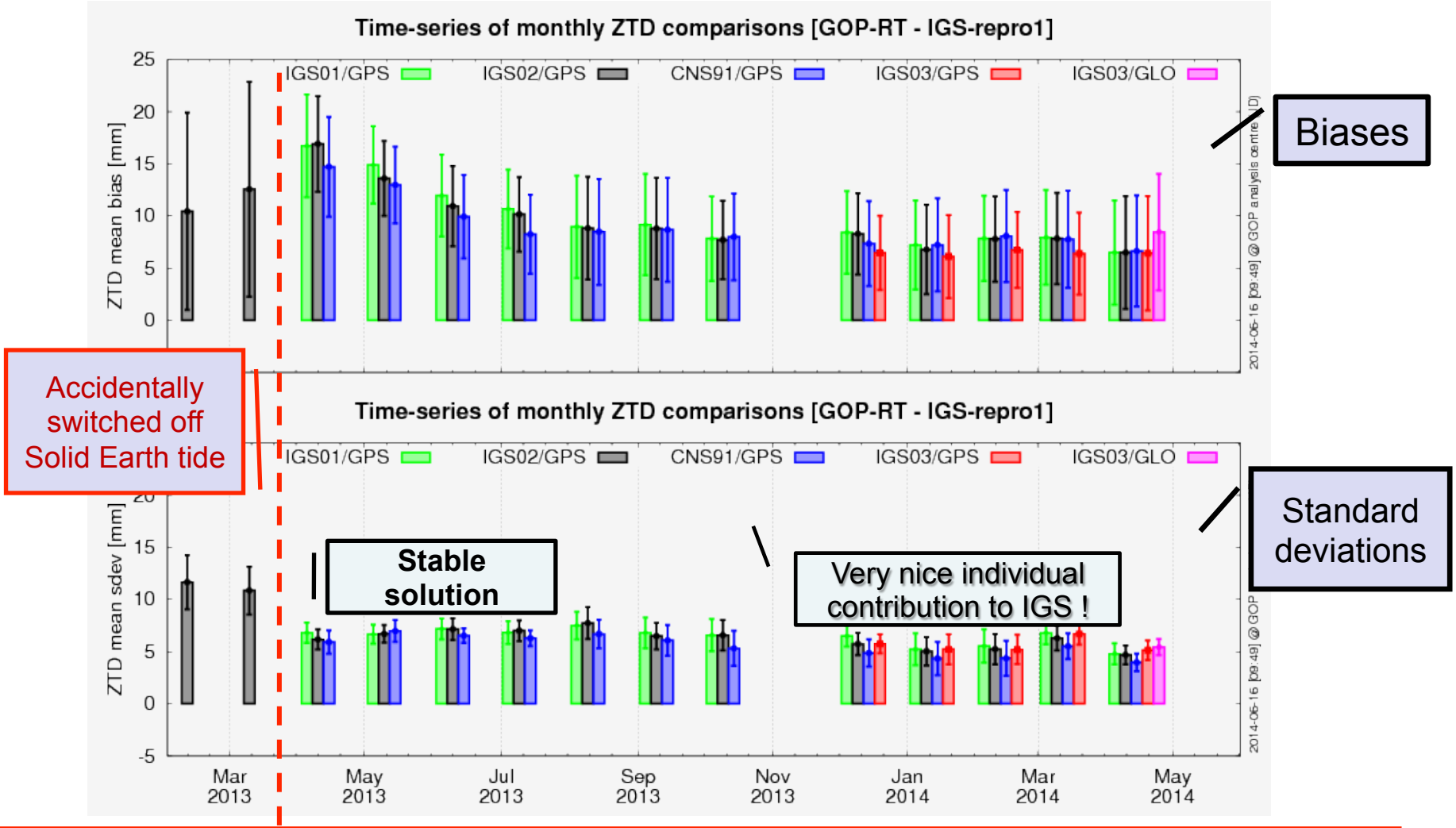

**Breakthrough**

**Goal**

***J.Dousa and P.Vaclavovic, ASR, 53, 2014***

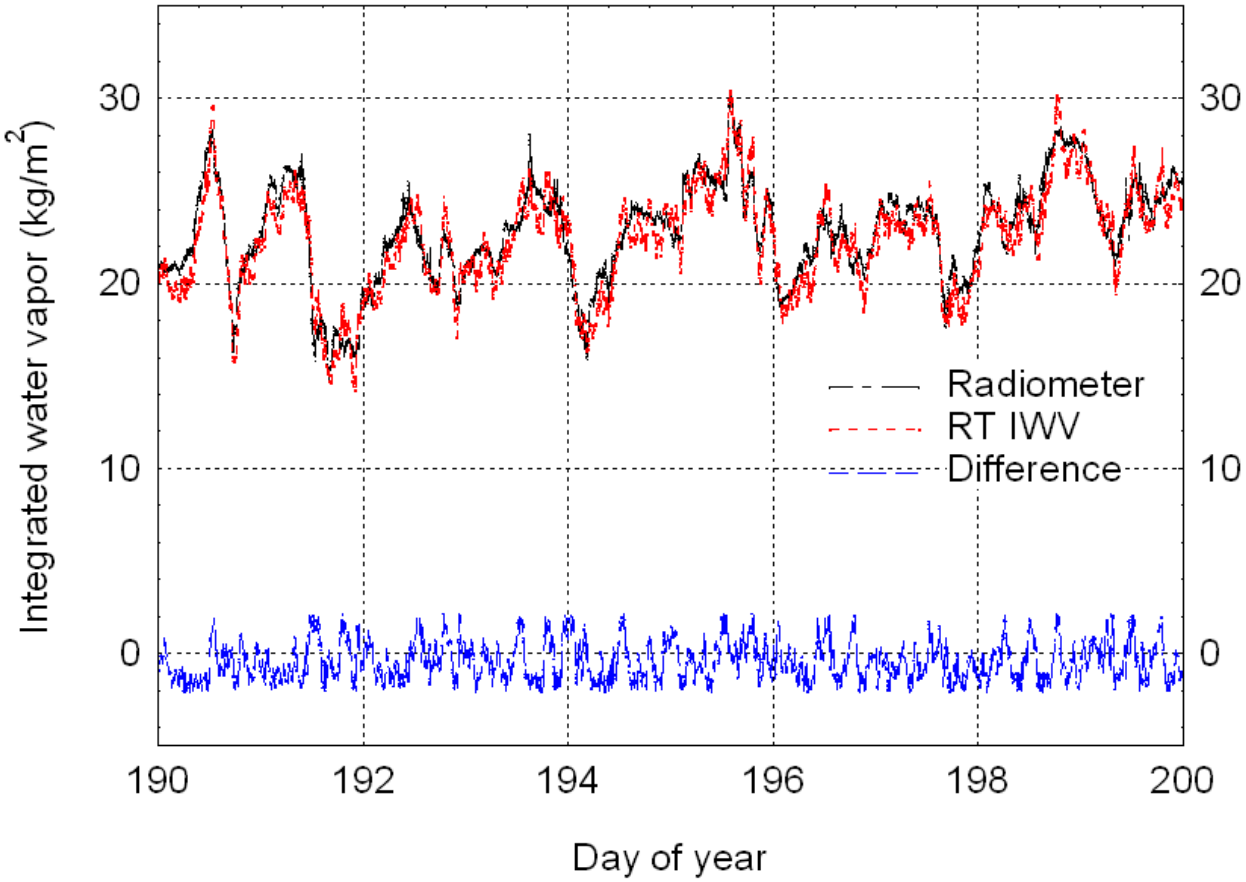
# G-Nut-Tefnut/GOP Real Time ZTD

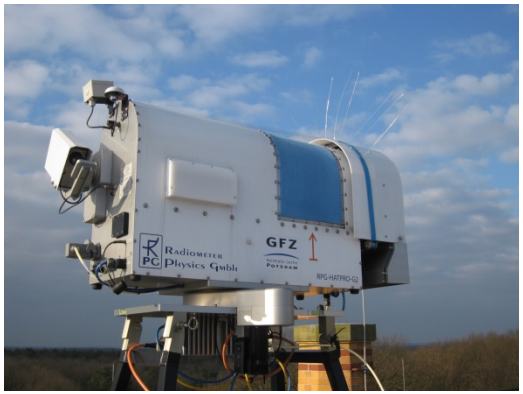
- *Evaluation campaign - **Feb 2013 – May 2014** testing **DIFFERENT** precise RT products*
- *Monthly comparison to IGS final ZTD products*
- *Means (and uncertainties) over 18 global + 18 European stations*



# EPOS-RT/GFZ Real Time PPP ZTD/IWV

**PPP with GFZ RT orbits and clocks, computed for IGS RT service**



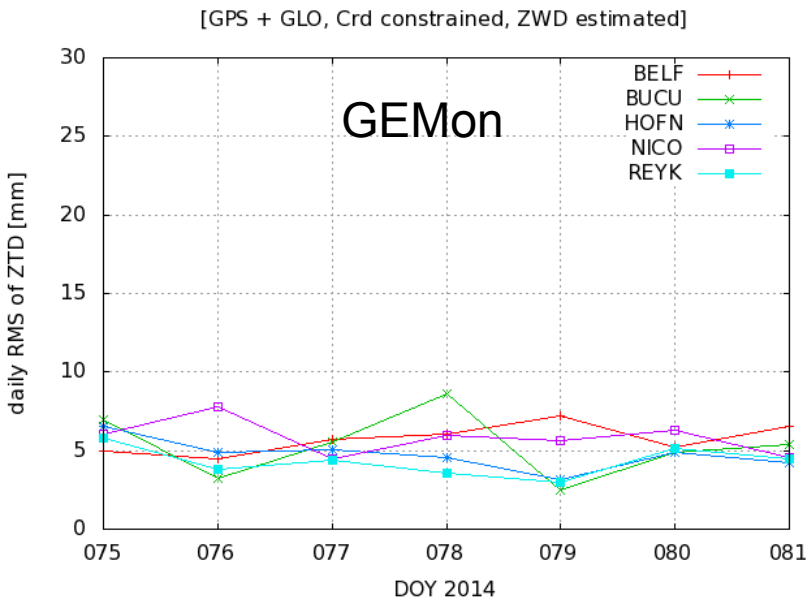

***Li et al., GRL, 2014***

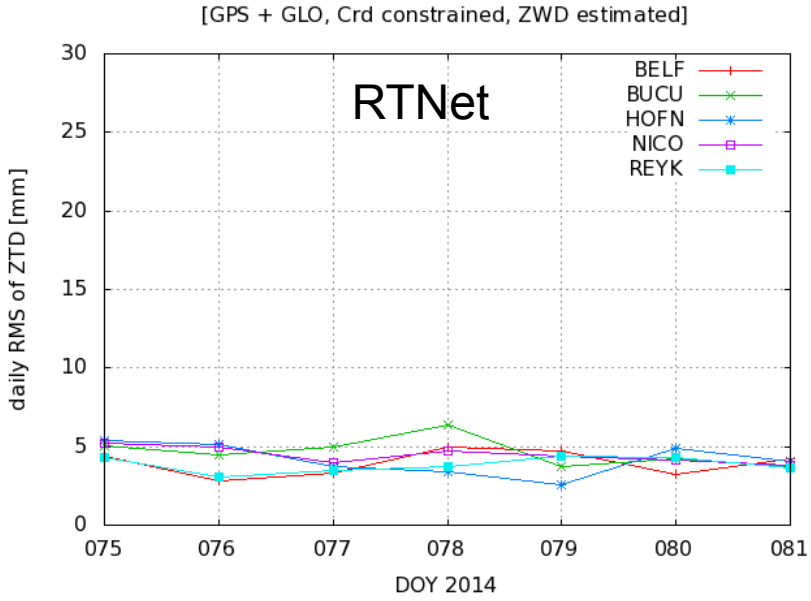
**RT IWV and IWV from microwave radiometer (HATPRO, GFZ) show a good agreement (time period of 10 days, DOY 190-200 of 2013)**

# GEMon/BKG Real Time PPP ZTD

**GEMon (GREF EUREF Monitoring)** under development in co-operation with the Technical University of Darmstadt

- ✓ *retrieves real-time data from BNC*
- ✓ *is able to process GPS + GLONASS observation and IGS RTS product data streams and files in PPP mode using Kalman filter or Normal equation stacking*
- ✓ *several state-of-the-art troposphere models are implemented*
- ✓ *estimation of zenith wet delay (and gradients)*
- ✓ *possibility to process several stations in parallel in real-time mode*

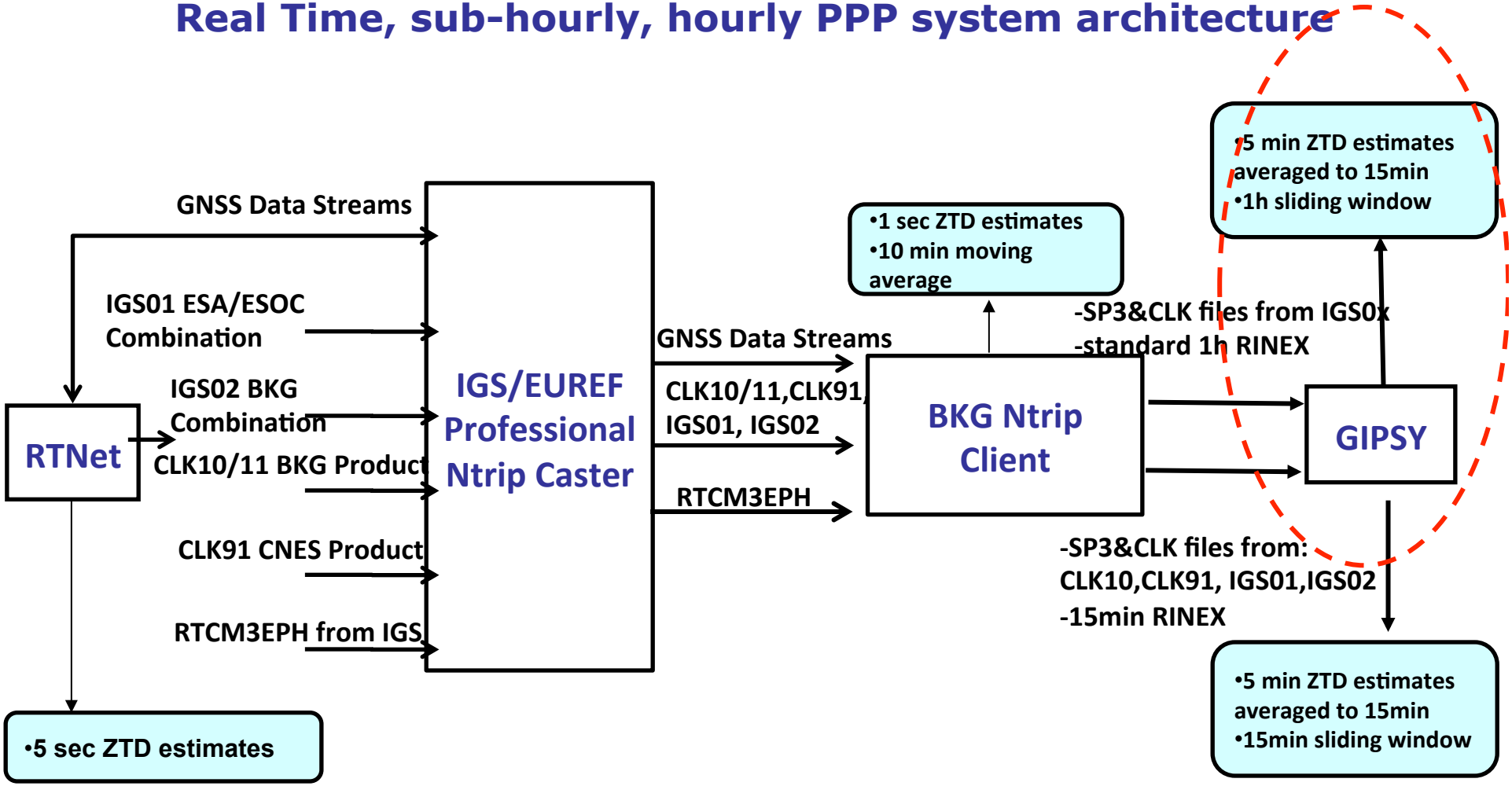


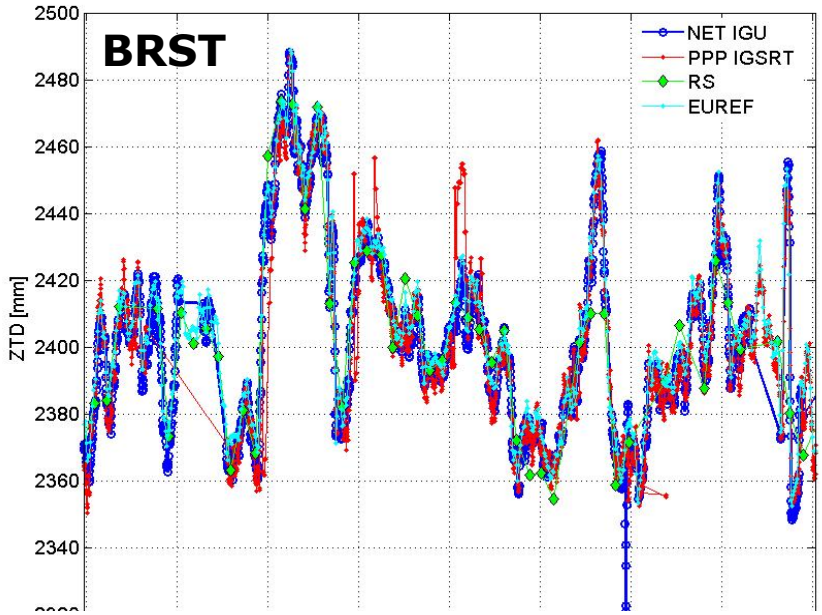

***A. Stürze et al., EGU 2014 talk***

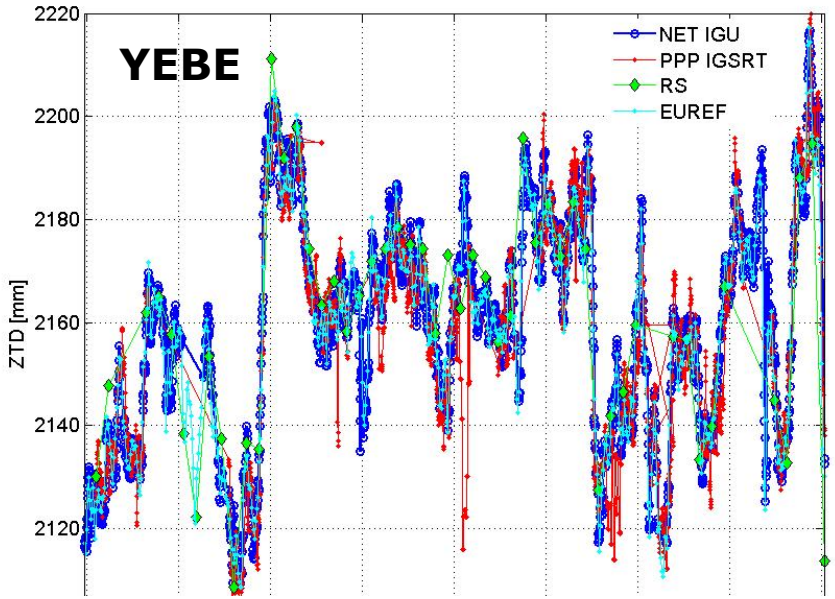
# Processing Mode

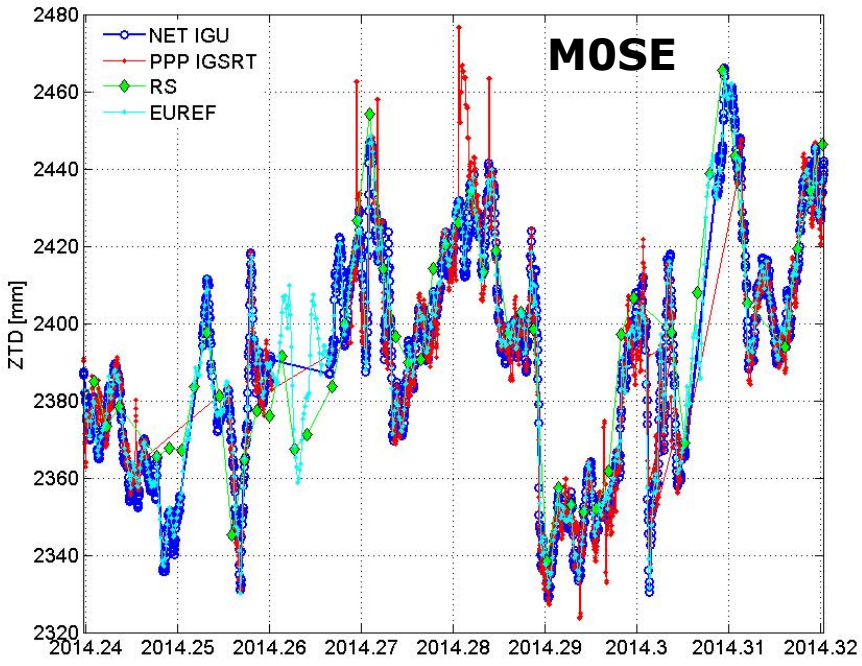
## Real Time, sub-hourly, hourly PPP system architecture

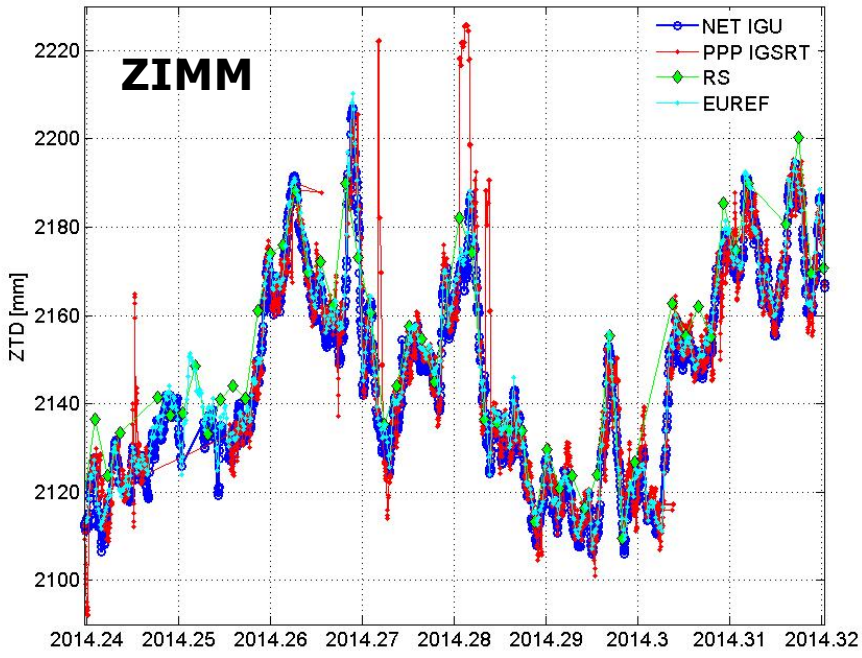


# Hourly Net IGU and PPP IGS RT

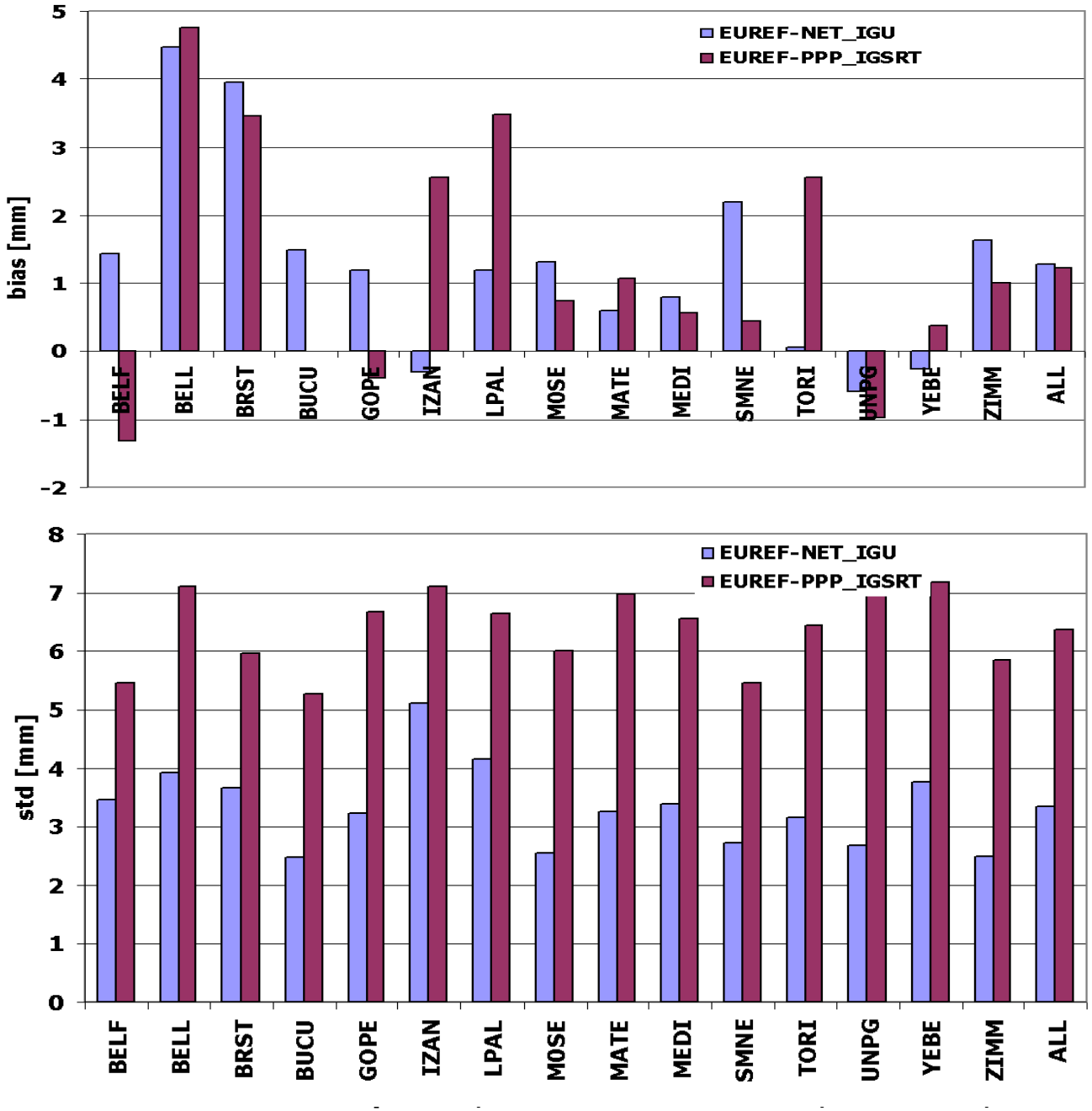


# Hourly Net IGU and PPP IGS RT vs EUREF



# Summary and Conclusions

- **Thanks to the availability of Real Time IGS Products, NRT users are no longer depending on the IGS Ultra-Rapid products only, since it is possible to store RT products in standard formats (clk, sp3) with short latency.**

- **RT processing depends on the production and dissemination of RT observations from the receiver and on the availability of RT global precise orbit and clock products and an overall robustness of the processing strategy.**

- **Different groups are working on Sub-hourly and RT tropospheric processing for now-casting of severe weather events. The results show that the ZTD quality is between the ‚breakthrough' and the ‚goal' as specified in the E-GVAP product requirements for nowcasting.**

- **RT network results show good agreement and accuracy but the number of stations is limited. The GPS+GLONASS solution has better std w.r.t. the GPS only solution.**

- **IGS RT products are promising for NRT PPP processing. Improvements are necessary to reduce the scattering.**

# Thank you for your attention

We are thankful to the IGS and EUREF communities for providing data and products used in this work

**Further we acknowledge**

European ESSEM COST Action ES1206 "Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)"

JPL for GIPSY/OASIS Software License

E-GEOS work is done under ASI contract I-014-10-0