

Combination of Near Real-Time tropospheric parameters observed by GPS



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Outlook of the talk

- E-GVAP (The EUMETMET GPS Water Vapour Programme) Scenario.
- Motivation for a Combined Solution.
- Combined solution: its issues and characteristics w.r.t. the contributing solutions and independent techniques.
- Combination as a tool for Active Quality Control.
- IGS and tropo applications.

What is E-GVAP?



- **EIG EUMETNET GNSS Water Vapour Programme.**
- EUMETNET = organisation of European national meteorological offices (West European + number of East European, enlarging).
- E-GVAP is a separate observing programme under EUMETNET. Not all EUMETNET members are members of E-GVAP (currently 15). It is those members that finance E-GVAP.

<http://egvap.dmi.dk>

Purpose of E-GVAP

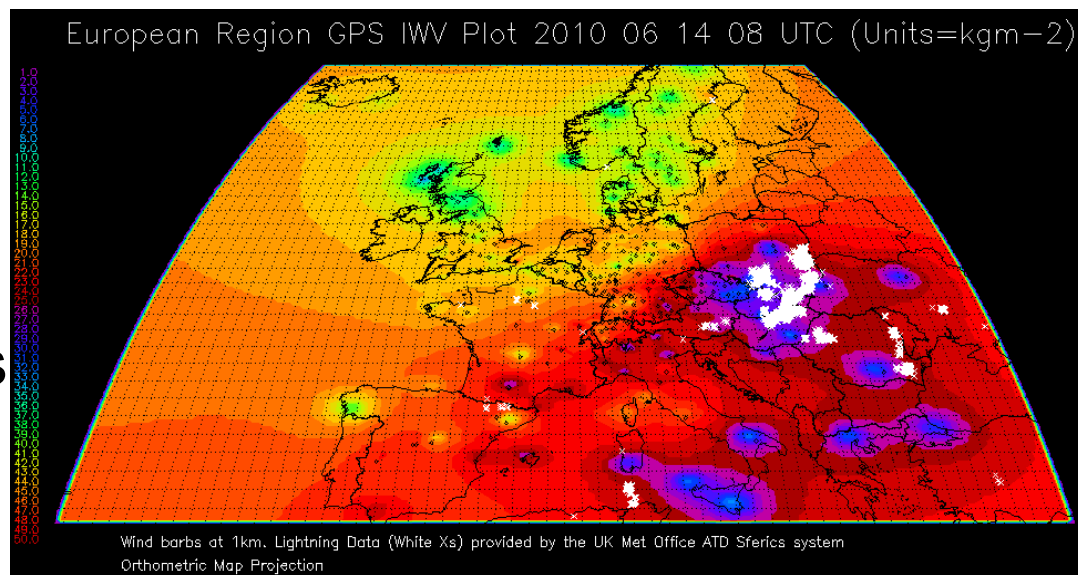
Goal:

- Provide quality checked, ground based GNSS ZTDs/IWVs in **Near Real-Time** (NRT) for use in **operational** NWP models and in now-casting to the participating EUMETNET members.
- Improve the NRT GNSS ZTD data quality and enlarge data coverage.
- Assist users in using the data for weather forecasting.

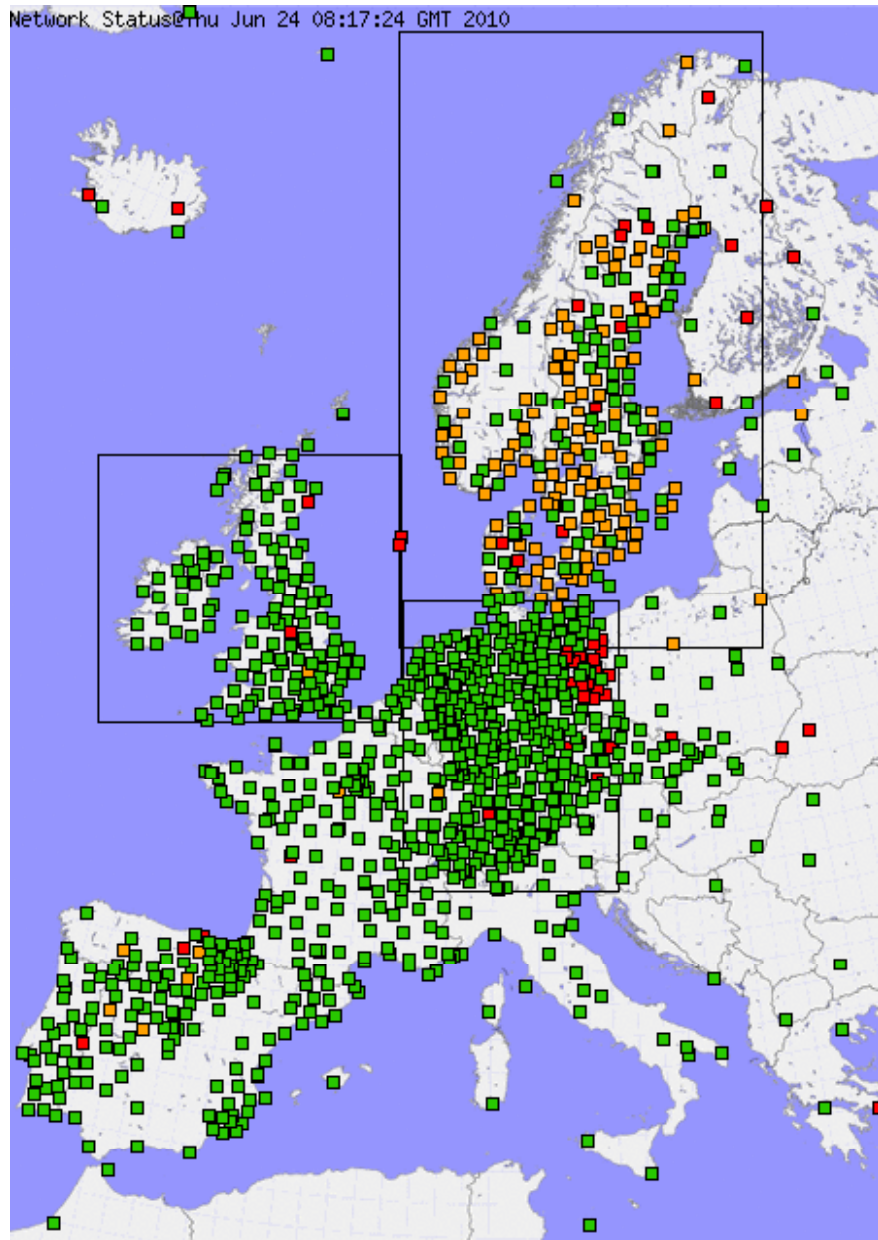
UK MetOffice and Meteo France are using NRT ZTDs in their operational forecasts.

Main Product:

- NRT ZTD of ~1200 European sites
- IWV maps** →
- Product delay < 90min



GNSS Water Vapour Network in Europe



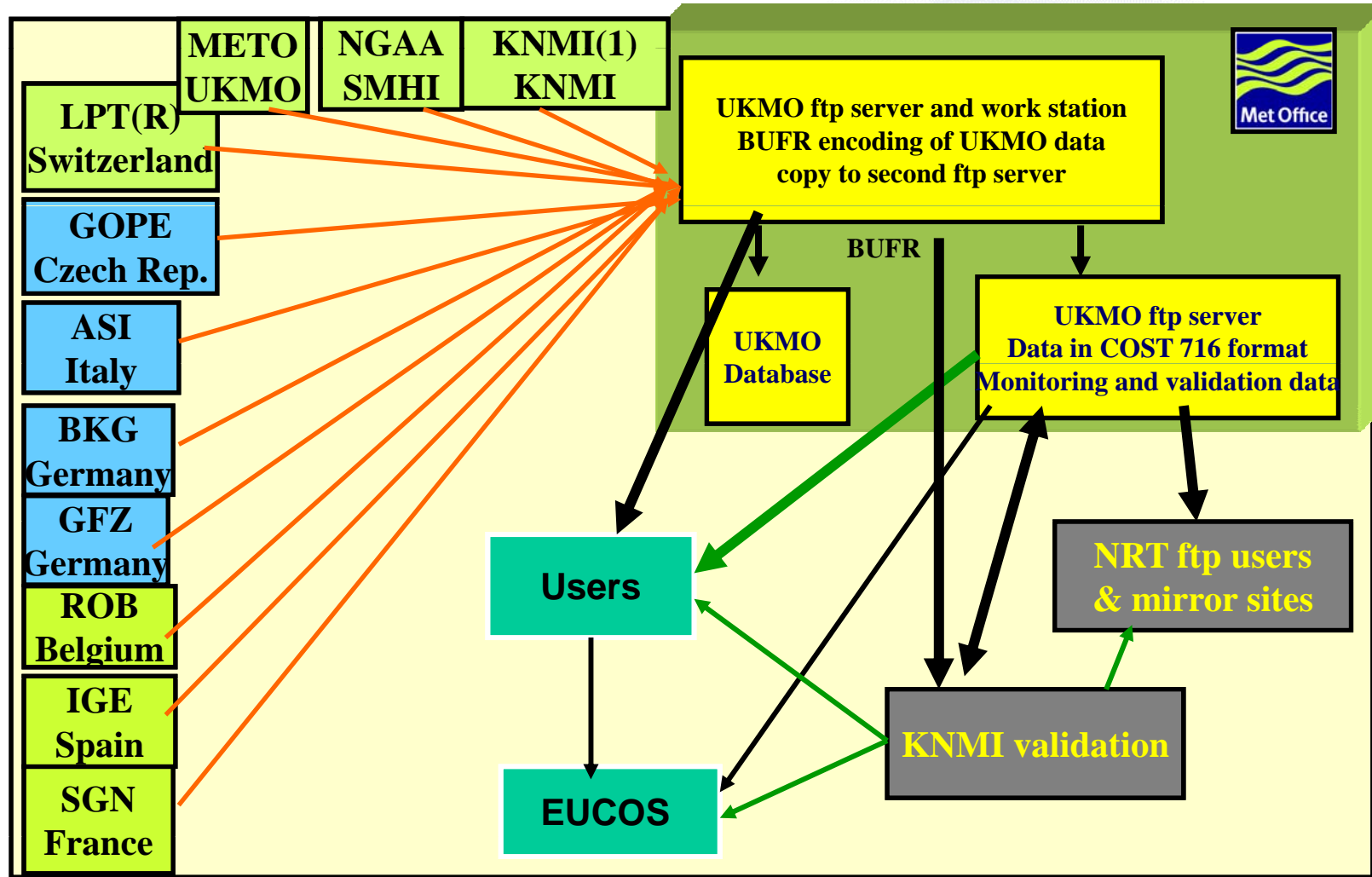
Data Coverage

- ~1250 unique GNSS sites
- ~1000 analyzed by 1 and 2 ACs
- ~250 analyzed at least by 3 ACs

Colour according to the latency.

Negotiating access to global NRT ZTD data to be used in Global NWP model.

E-GVAP NRT GNSS ZTD Data Flow



ASI and KNMI
Combination Centers

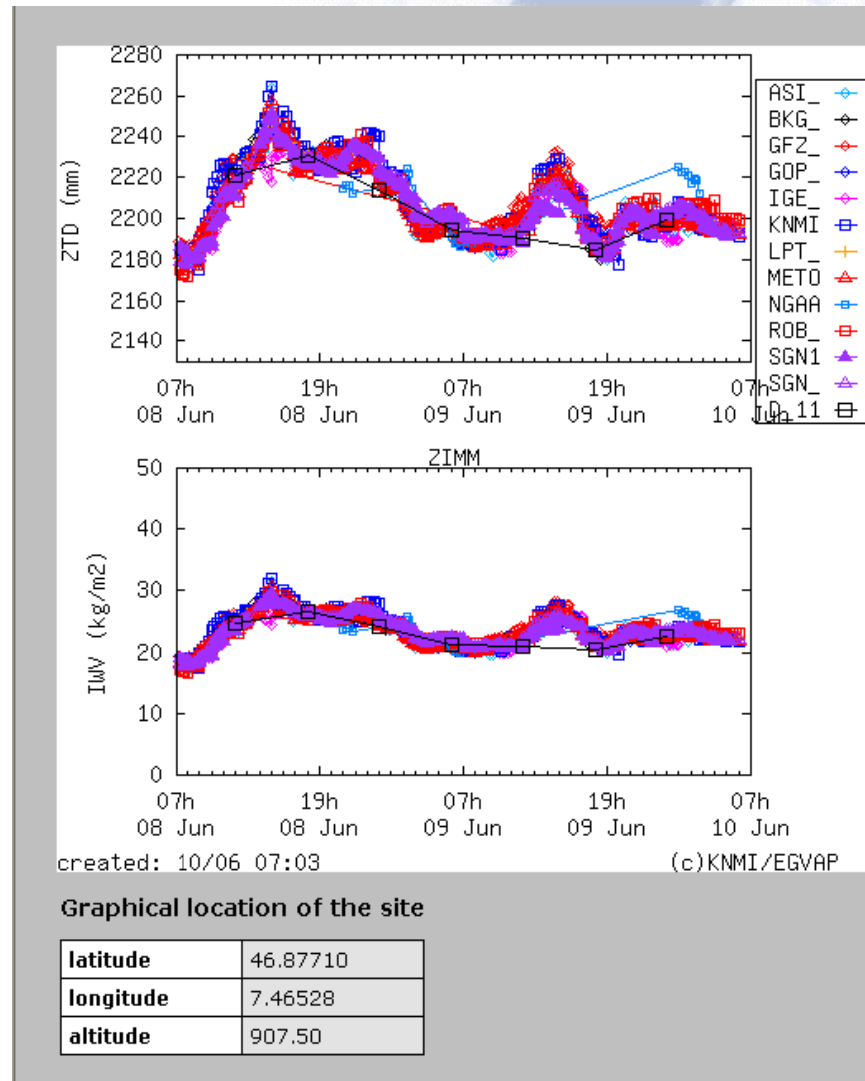
11 Analysis Centres (ACs), each processing raw GNSS data from many sites. In many cases only national AC can have access to the raw data.

Motivation for a Combined Solution

The driver of a *combined solution* is the need of having an internally consistent ZTD product on the basis of several individual solutions, obtained from parallel Near Real-Time processing.

Combining these solutions:

- allows to give feedback to the individual AC in case of problems,
- can be a promising tool for *Active Quality Control*.



HIRLAM(KNMI) AN - GPS ZTD
7day stat. 2010/06/02 - 2010/06/10

AC	num	bias	RMS	stddev
ASI	28	1.9	9.2	9.0
BKG	27	4.0	10.1	9.2
GFZ	26	9.6	13.7	9.8
GOP	28	4.3	10.2	9.3
IGE	28	2.9	9.0	8.5
KNMI	19	5.7	13.2	11.9
LPT	28	3.2	9.3	8.7
METO	28	1.9	9.8	9.6
NGAA	25	-5.1	23.7	23.1
ROB	27	2.2	10.8	10.5
SGN1	28	1.4	10.7	10.6
SGN	28	2.1	10.3	10.1

Notes

- Statistics are updated daily
- GPS ZTD are interpolated to NWP analysis time

ASI ZTD Combination Strategy

For a single site and each hourly batch ZTD is modeled as:

$$(1) \quad y_n^k = Y_n + b^k + e_n^k \quad \begin{array}{l} n = 1, \dots, N \quad \text{epochs} \\ k = 1, \dots, K \quad \text{ACs} \end{array}$$

where Y_n is the combined ZTD at epoch t_n , b^k is the analysis center bias and e_n^k is the misclosure error between Y_n and y_n^k .

Each contributing solution plays the role of an ‘observation’ whose error must be minimized.

The linear function model in (1) can be solved in the generalized least square sense by adding the constrain equation:

$$\sum_k b^k = 0 \quad (\text{barycentric equilibrium})$$

Input for NRT ZTD Combination

We consider the time series of GPS ZTD estimates obtained by different ACs for the same GPS site. Ideally the time series within each batch should have the same length and sampling interval but in practice

AC	# samples	@
ASI	4	00-15-30-45
BKG	1	30
GFZ	4	07-22-37-52
GOP	2	00-59
IGE	5	00-15-30-45-59
KNMI	5	00-14-29-44-59
KNM1	5	00-14-29-44-59
LPT	2	00-59
LPTR	11	02-07-12-17-22-27-32-37-42-47-52
METO	5	00-15-30-45-59
NGAA	4	00-15-30-45
ROB	5	00-15-30-45-59
SGN	5	00-15-30-45-59
SGN1	5	00-15-30-45-59

..... there is the need to specify a set of equidistant time tags at which to perform the combination (we choose **hh:00 – hh:15 – hh:30 – hh:45**).

Combination Steps

The first step in the processing is reading, checking hourly solutions coming from different ACs, removing gross errors (ZTD sigma \geq 30mm).

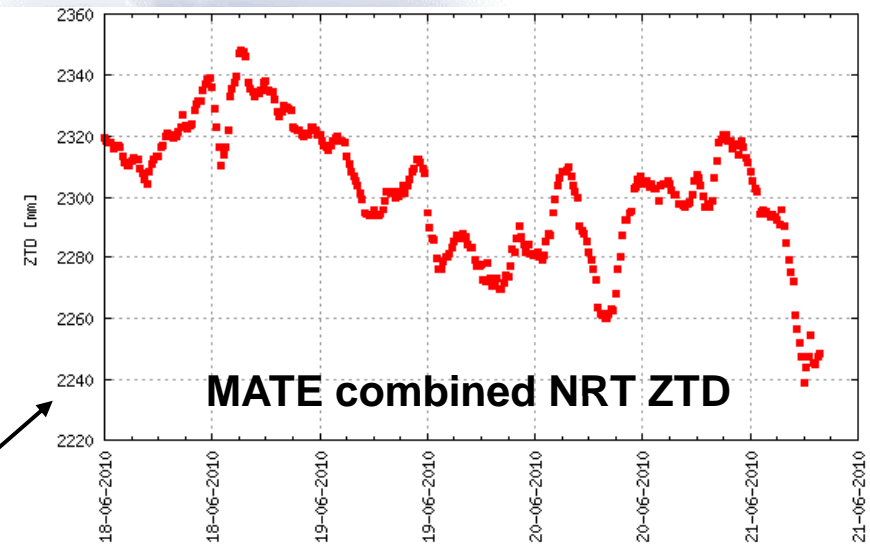
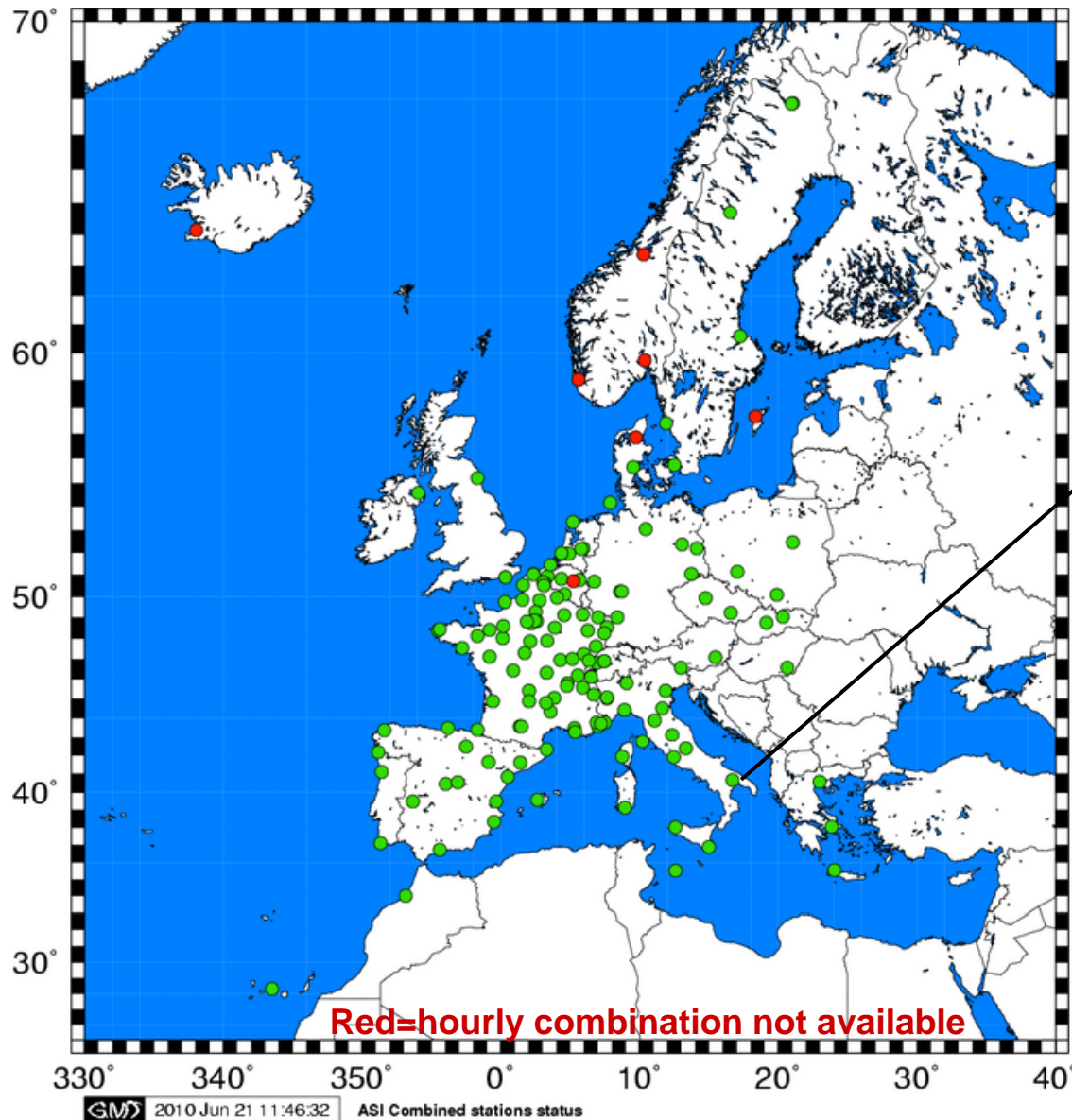


Data or processing problems are suddenly detected; they occurred more frequently in NRT than in post-processing.

Then, **a first combination** is performed to compute proper weights for **the final combined solution** which will provide combined NRT ZTD estimates, their std and site/analysis centre specific bias.

The method has a low computational cost but it does not consider the last time series biases and weights as a priori information for the next hourly combination.

Combined E-GVAP Network



Every hour the contributing solutions are fetched from UKMO database for the combination.

It takes a couple of min for ~250.

Quality of the combined product

The quality of the combined product depends on different factors as:

data analysis:

- Poor satellite orbit predictions or clock error predictions (AC doing PPP solution).
- Movement of the GNSS antenna by a GNSS site owner, without notification to the AC processing the data long ahead (this causes widespread problems when AC is doing network solution).
- Different set of sat. & rec. antenna phase center.
- Using the wrong antenna type in the processing, or fixing the coordinates to the wrong values (e.g. after an earthquake), may result in gross-errors of occasionally up to 1–2 cm in ZTD.
- Different cut-off angles and mapping functions may result in small systematic effects

combination:

- Balance in the contribution of all the AC solutions, in order that none of the solution dominates the combined product.
- Constraint equation (*barycentric equilibrium*).
- Gross-error removal, which affects the following computation.

E-GVAP Processing Strategies

➤ *PPP approach:*

- GFZ (EPOS)
- NGAA (GIPSY)

➤ *Network approach:*

- ASI (GIPSY)
- BKG, GOP, KNMI, LTP, ROB, METO, SGN (Bernese)

➤ *Real Time Solution:*

- LPTR (GPSNET_2.0)



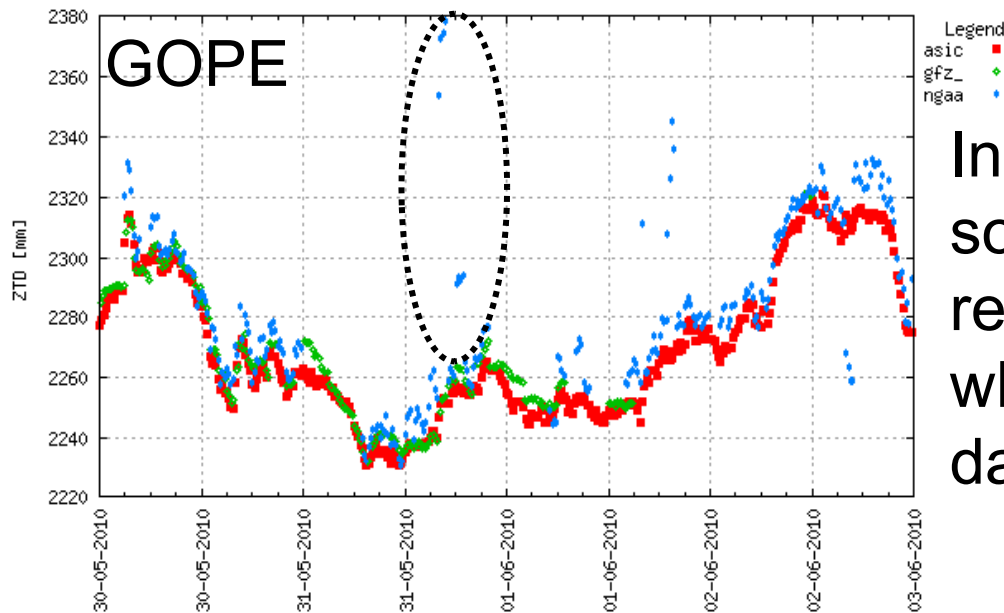
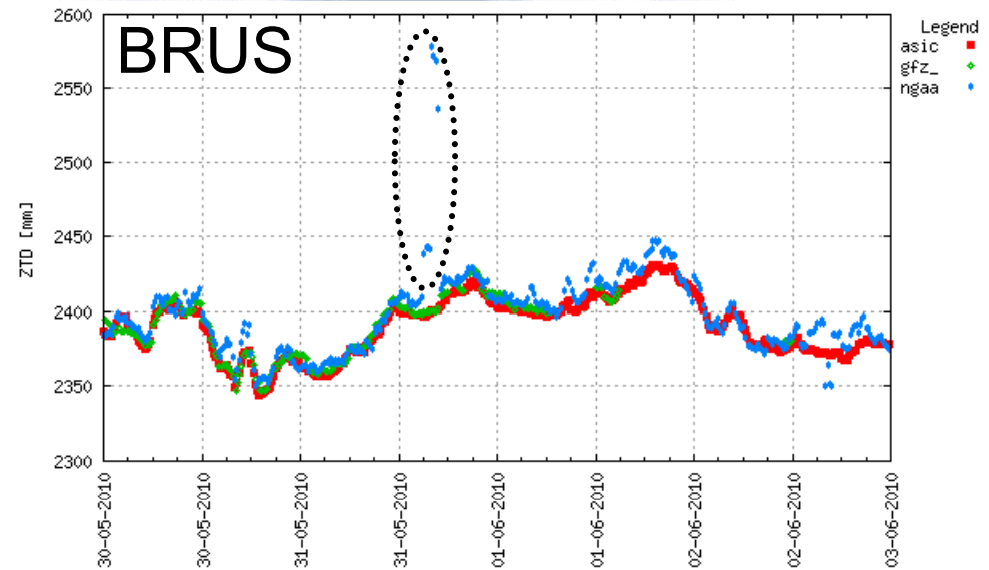
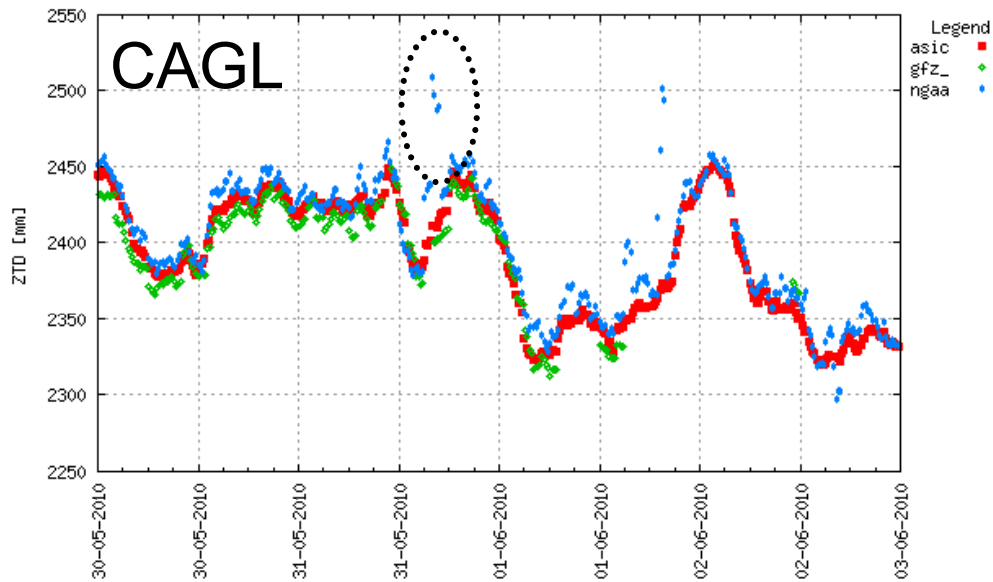
Motivation for PPP

	PPP	Network
Advantages	<ul style="list-style-type: none">• Small NEQ• Keeping CPU with increasing number of sites / parameters (e.g. ZTD every 15 min, estimation of gradients)• Investigations of site dependent effect	<ul style="list-style-type: none">• Correlations between parameters of all stations are taken into account• Independence of external products (except for small networks)
Disadvantages	<ul style="list-style-type: none">• Correlations btw stations are ignored• Use of external products (orbits, clocks)	<ul style="list-style-type: none">• Large NEQ• Increasing CPU with incr. number of sites/parameters

==> Main reason for switching to PPP :
efficient operation of large networks (>100 sites) within short computation time

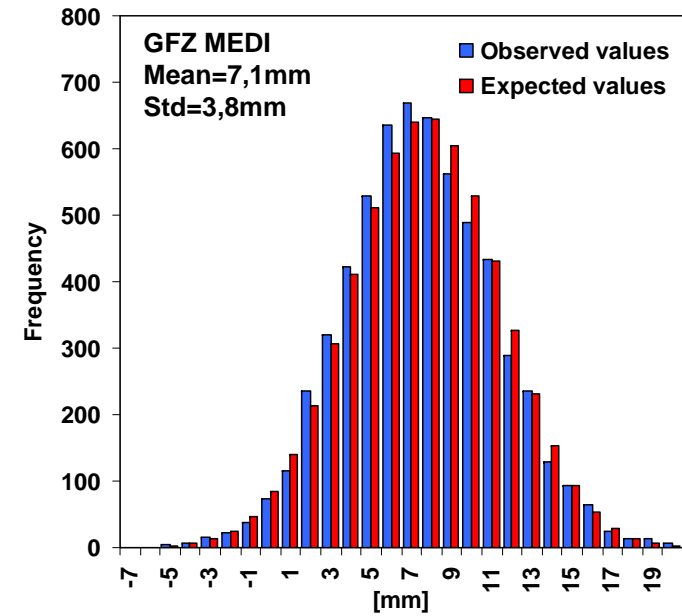
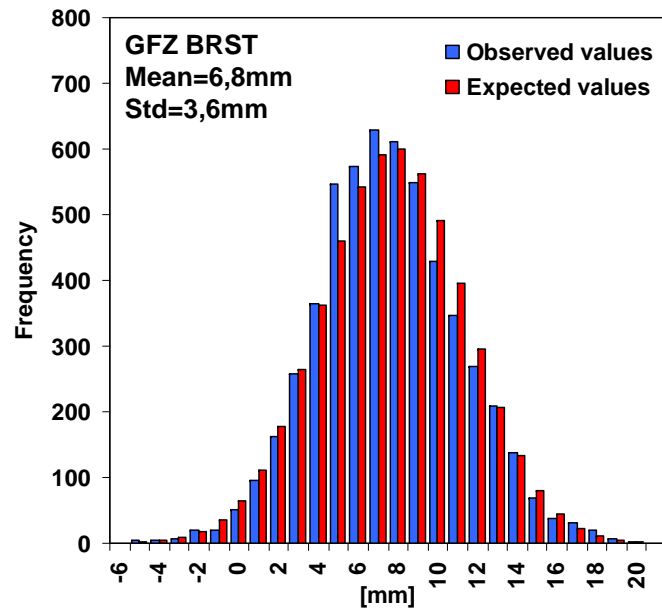
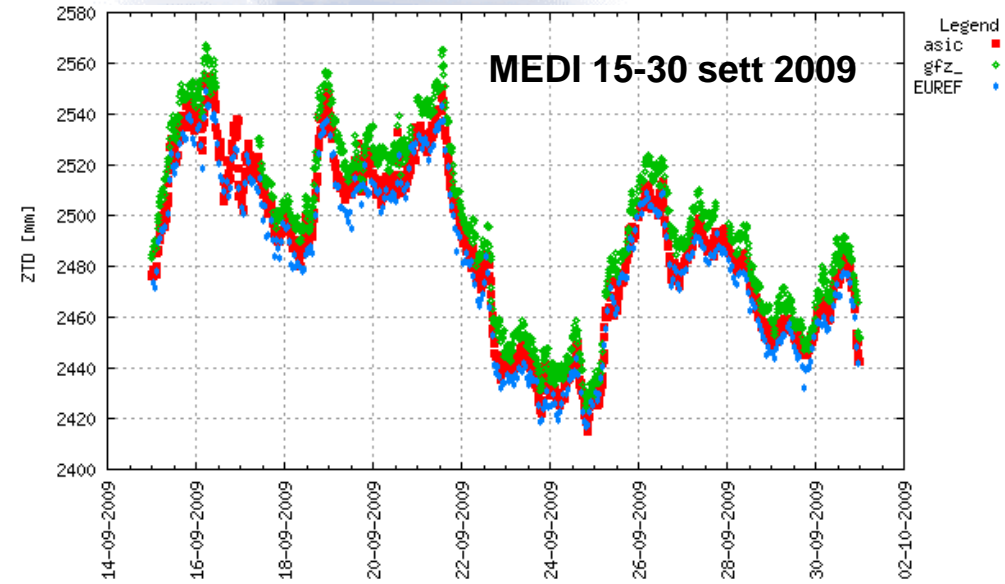
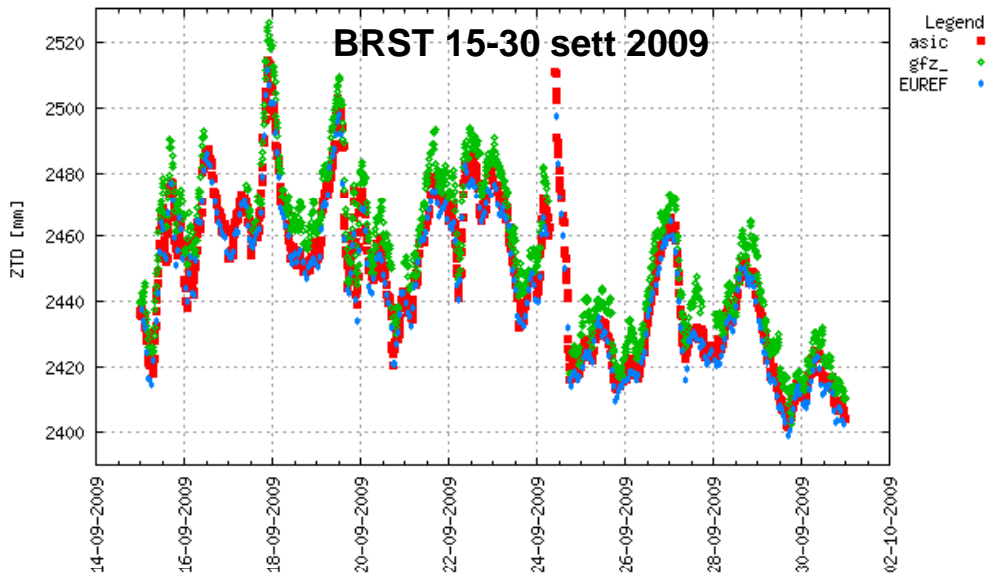
REQUIREMENT: GPS orbits & clocks should be given with sufficient accuracy

NRT Processing Problem related to GPS Clocks



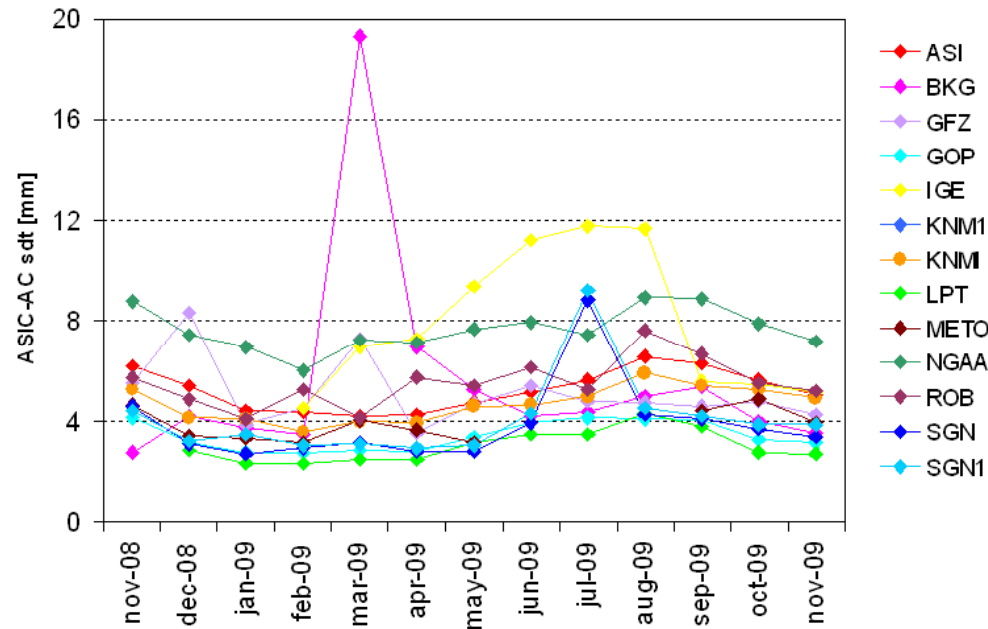
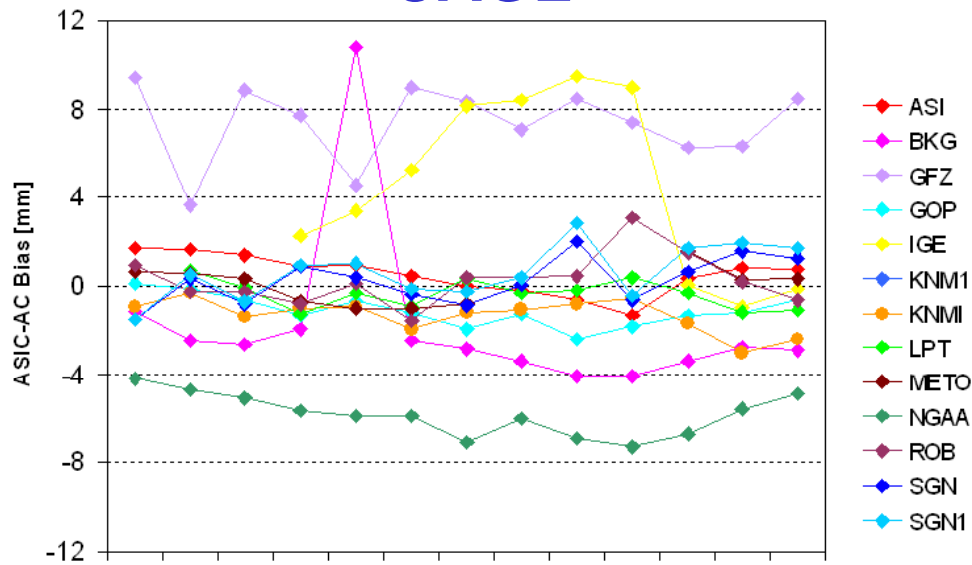
Intermittent problem with NGAA solution (based on PPP processing) related to the orbit and clock analysis which sometimes fails due to global data collection problems.

Absolute & Relative Antenna Phase Center

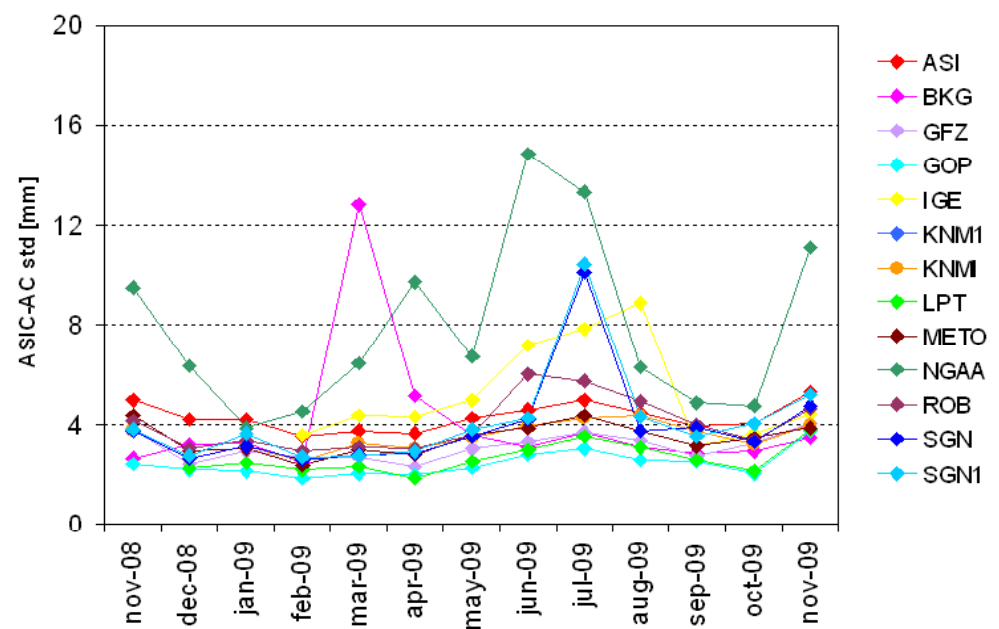
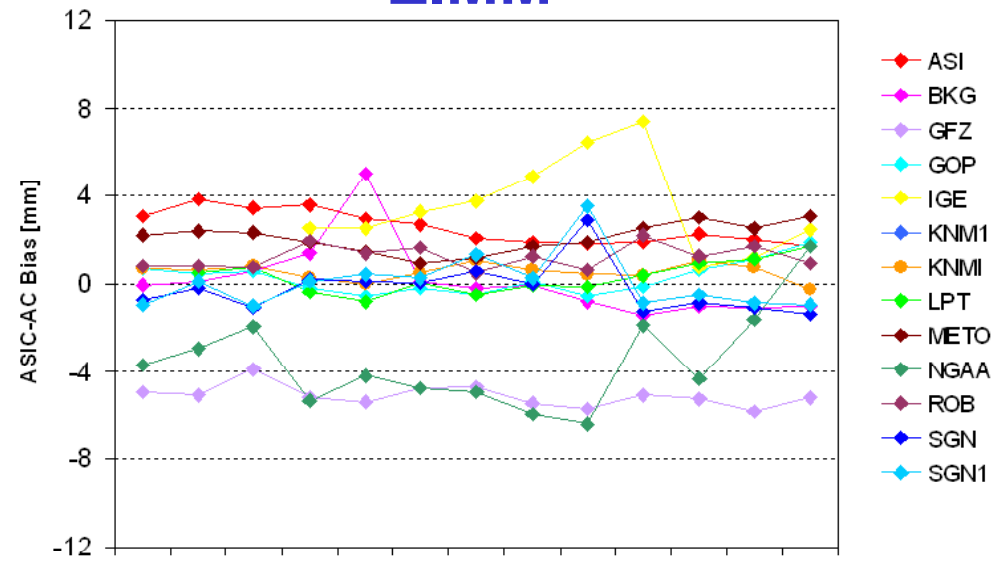


Combined versus individual monthly mean and std

CAGL



ZIMM



E-GVAP Combination Centers: ASI and KNMI

Within E-GVAP two combinations are performed:



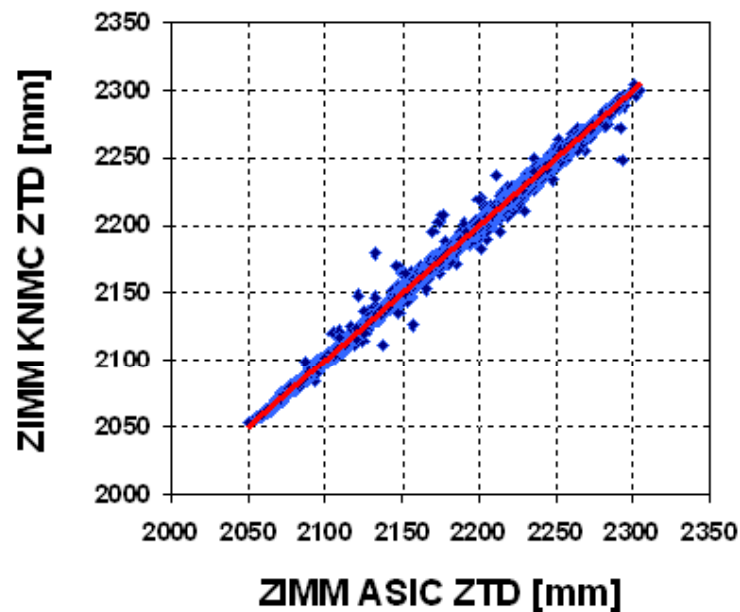
@ ASI/CGS

based on generalized least square approach

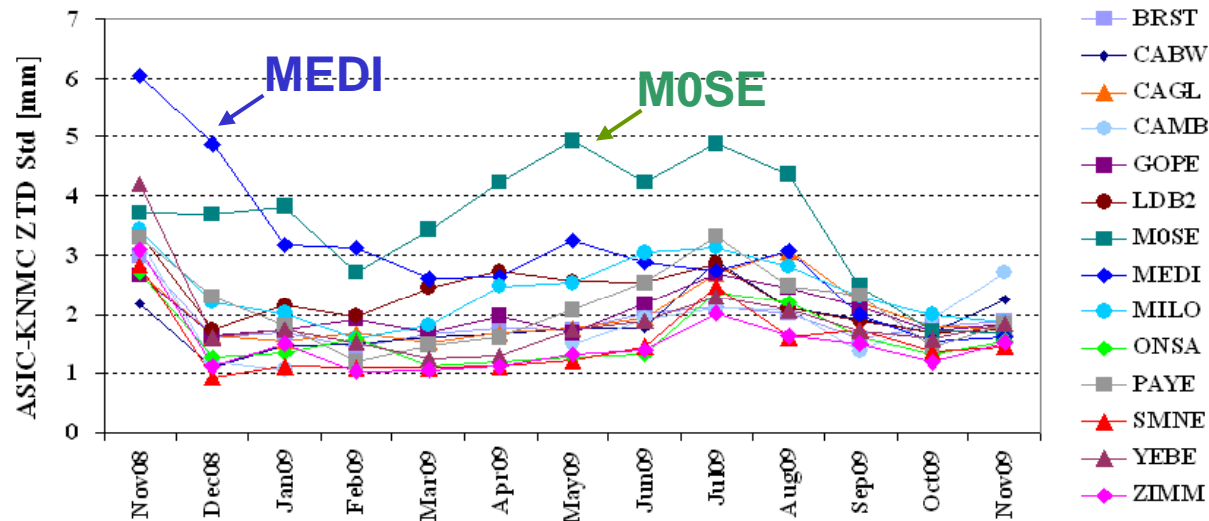
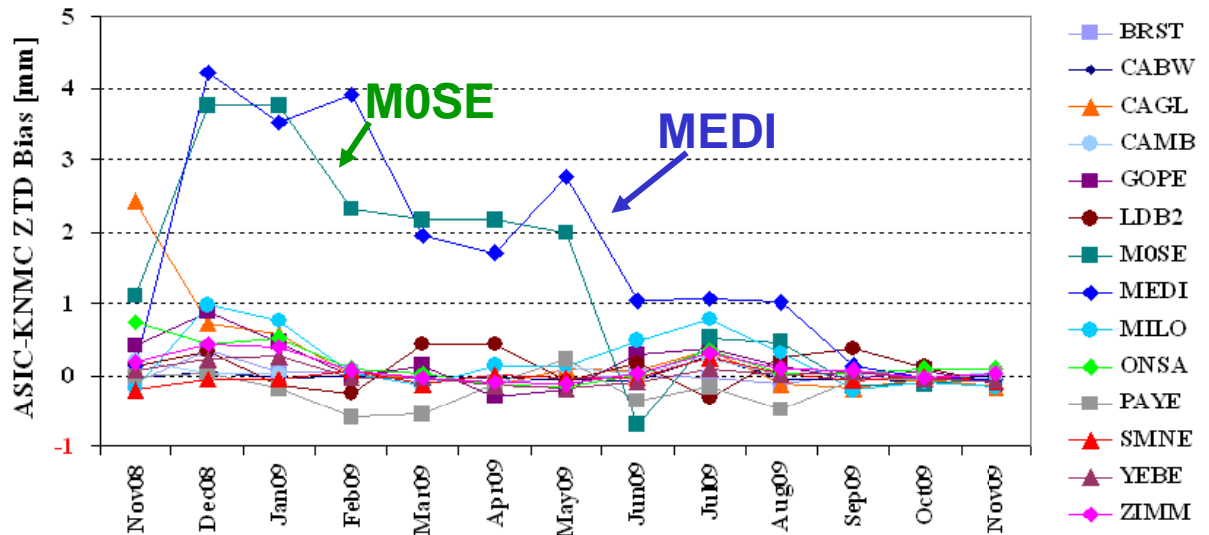


@ KNMI

based on a Kalman filtering method



Comparison between ASIC and KNMC



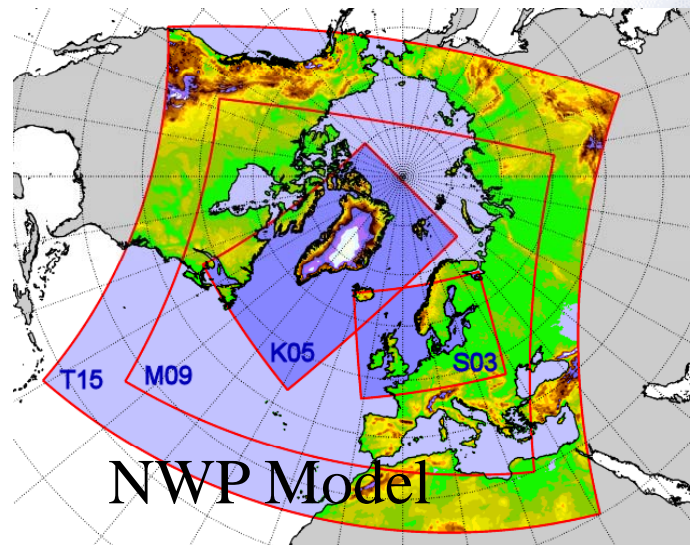
The absolute value of the bias is < 1 mm.

MEDI and **MOSE** biases are due to the combination of a new AC with a large bias over Italy and KNMI does not apply gross-error rejection. NRT processing is prone to certain type of errors rarely seen in post-processing.

The std is of the order of 1-3 mm for most of the stations.

The Combined Solution versus Independent Techniques

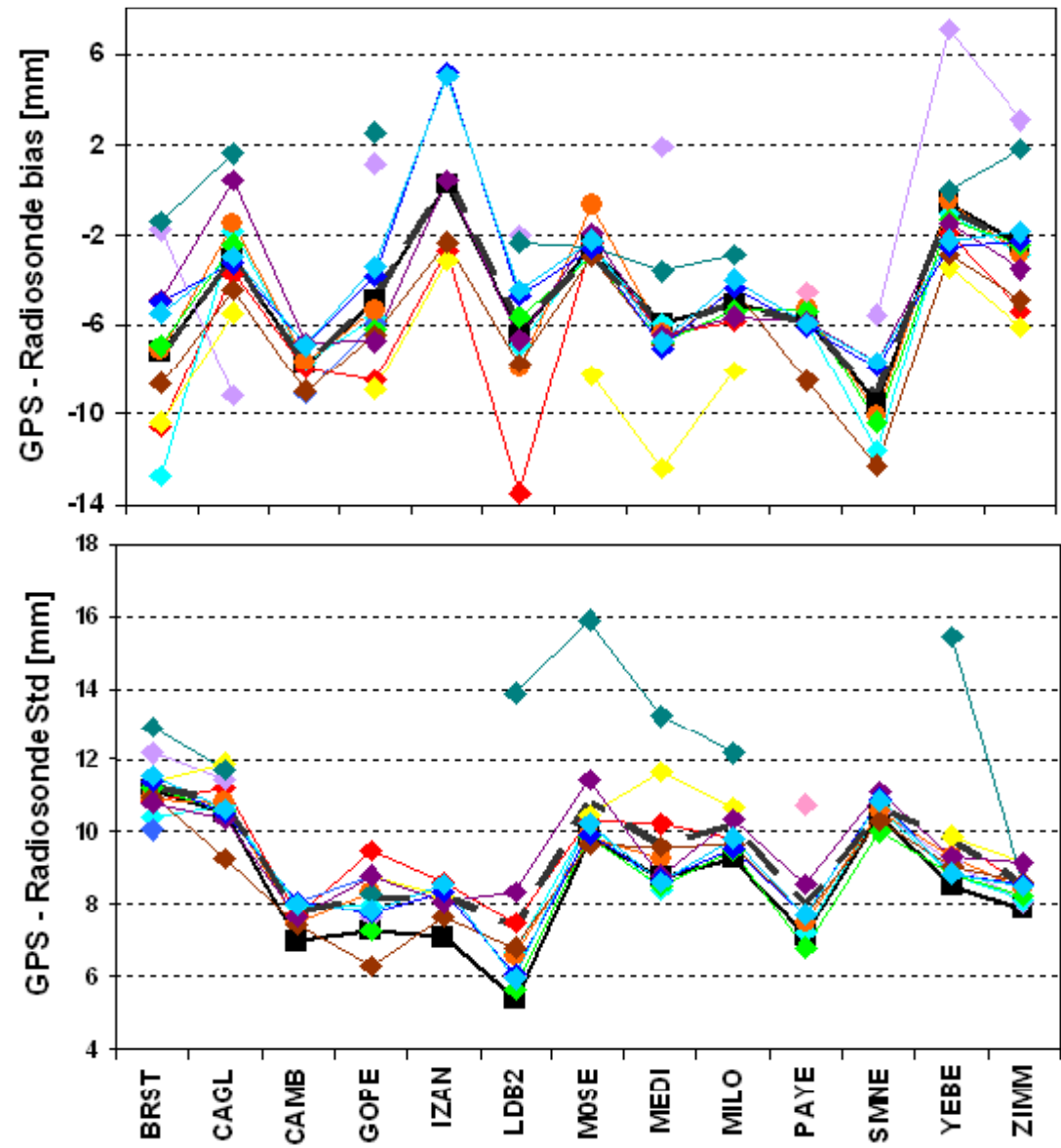
The performance of ASI combined solutions has been tested on 1-yr dataset, by comparing them versus Radiosonde, NWP Model and VLBI on Super Sites.



E-GVAP Super Site Network

- sites geodetically stable and with high installation standards,
- sites collocated with meteorological equipment (radiosonde and/or WVR) for validation.

The Combined Solution versus Radiosonde



The bias of the combined product is the equal to mean bias value for all the Super Sites.

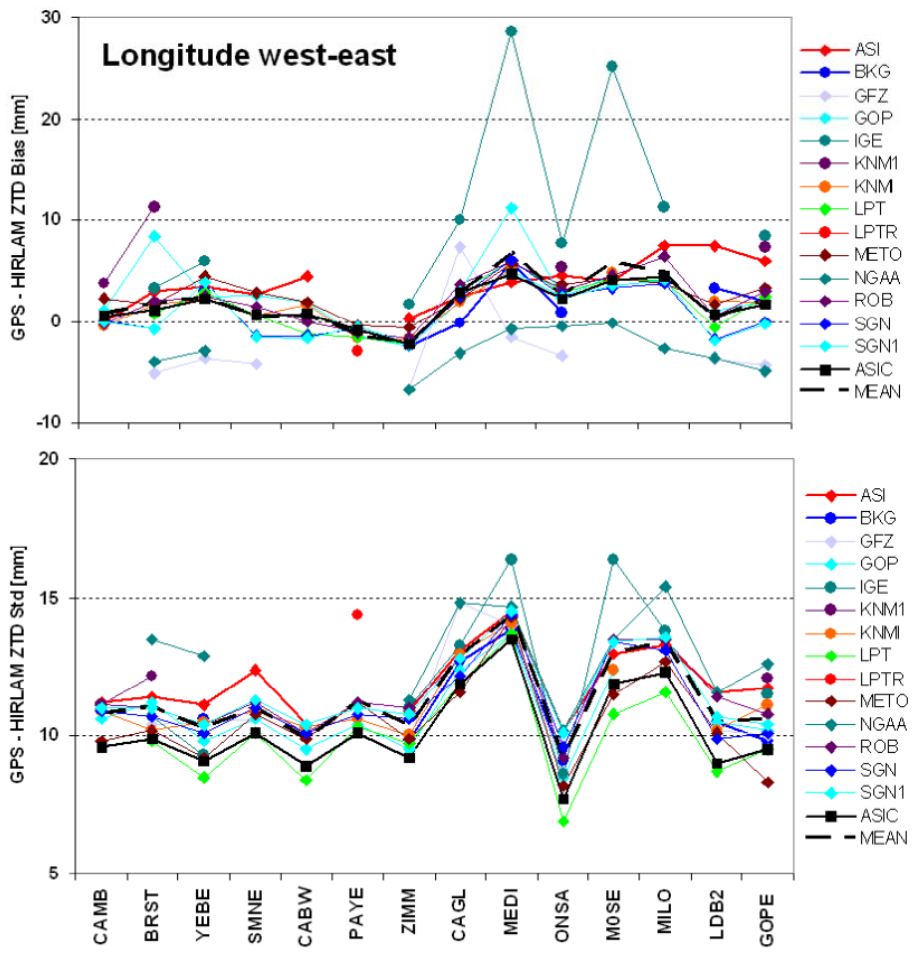
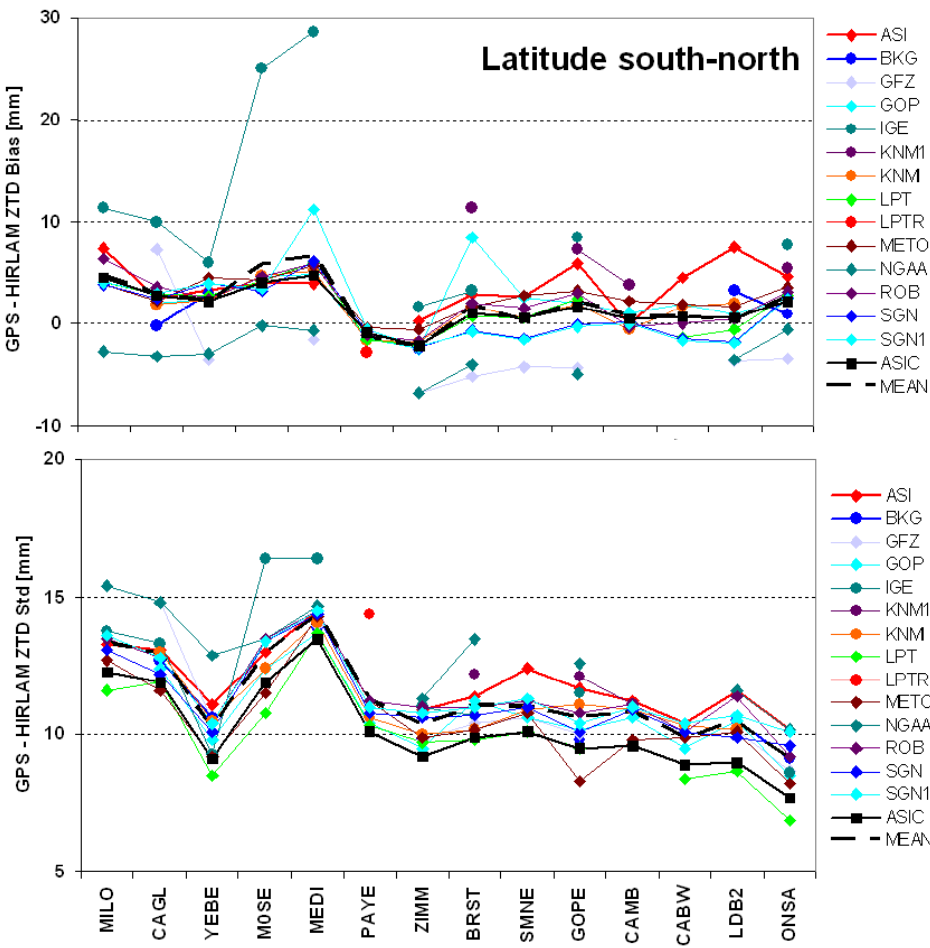
- ASIC
- ASI
- GFZ
- GOP
- IGE
- KNM1
- KNMI
- LPT
- LPTR
- METO
- NGAA
- ROB
- SGN1
- SGN
- MEAN

The std of the combined product is lower than the mean std value for all the Super Sites.

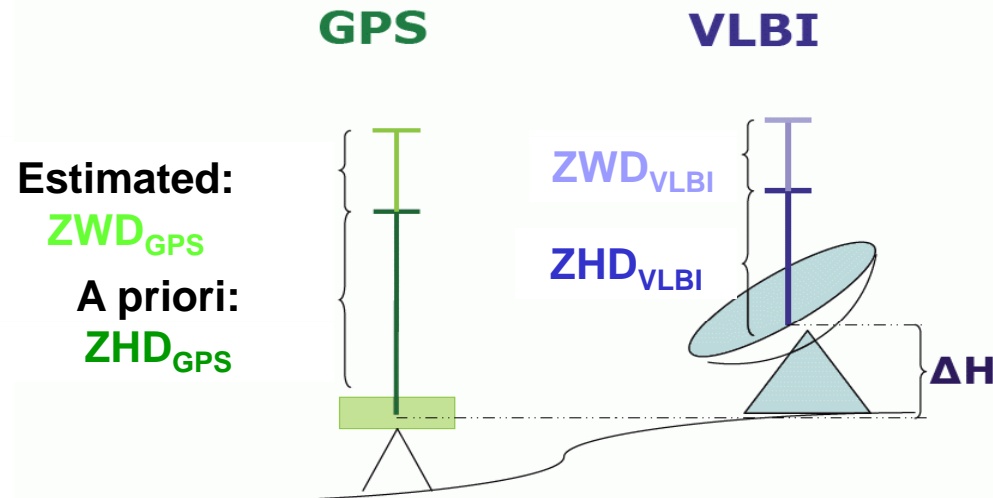
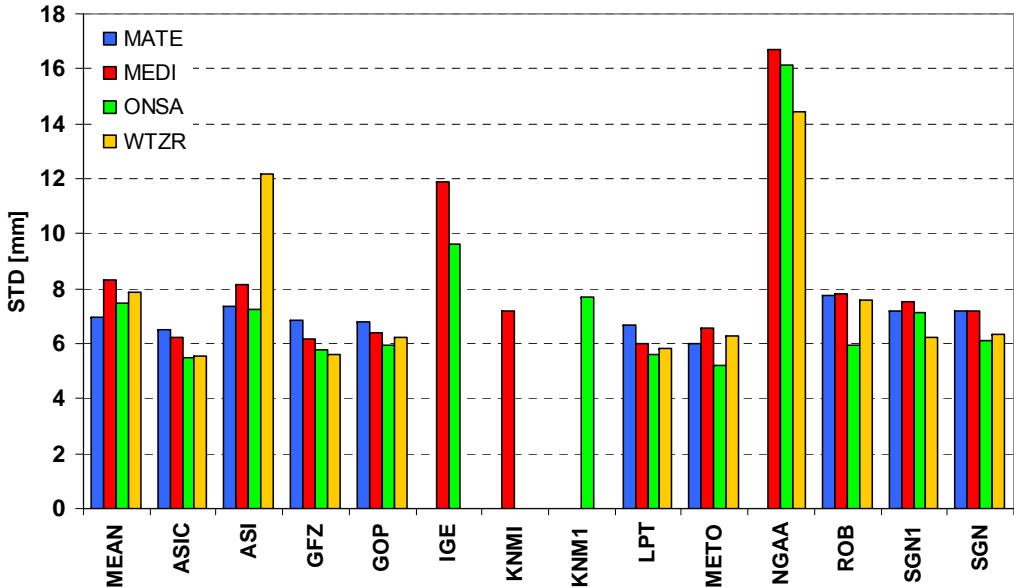
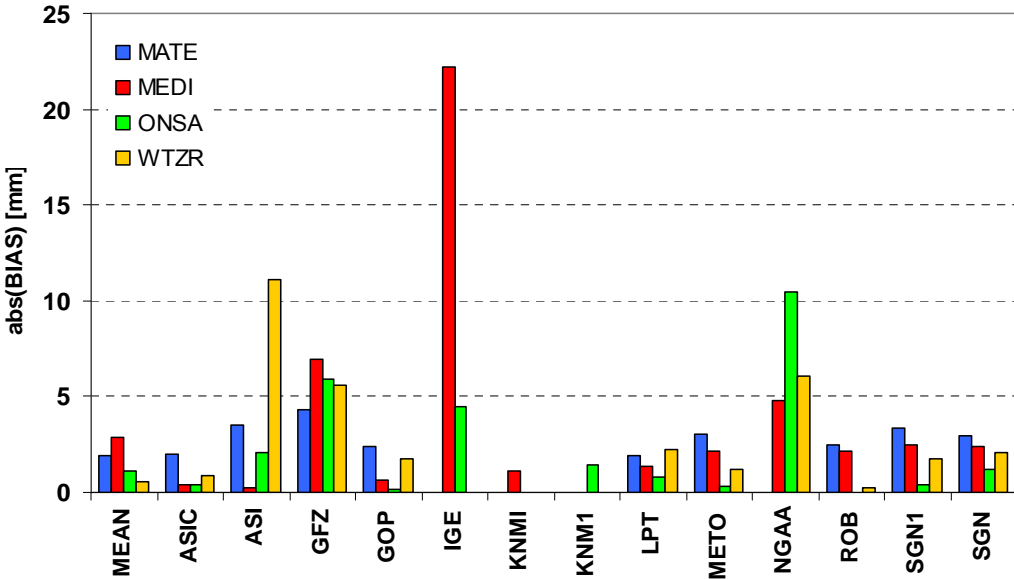


The Combined Solution versus NWP Model

Sites are sorted for increasing latitude (left) and longitude (right).
 Worst agreement for sites in south Europe where temperature and humidity are higher.



The Combined Solution versus VLBI

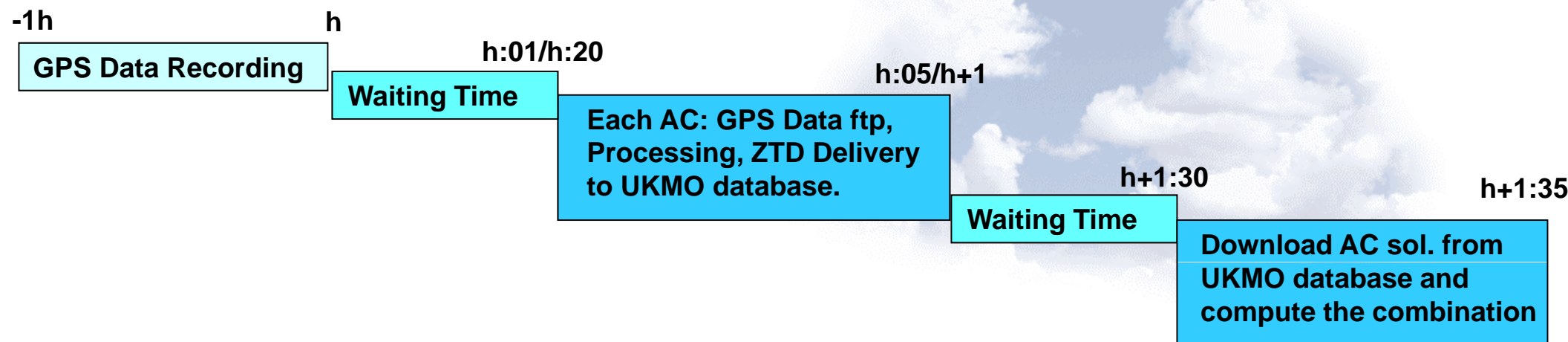


Because of ΔH , $ZHD_{GPS} > ZHD_{VLBI}$
 $\Delta H = 10m$ is ΔZHD of about 3mm

- Theoretical bias [mm]:**
- MATE 2.31mm
 - MEDI 5.31mm
 - ONSA 4.11mm
 - WTZR 0.93mm



Schedule of the Combined Solutions



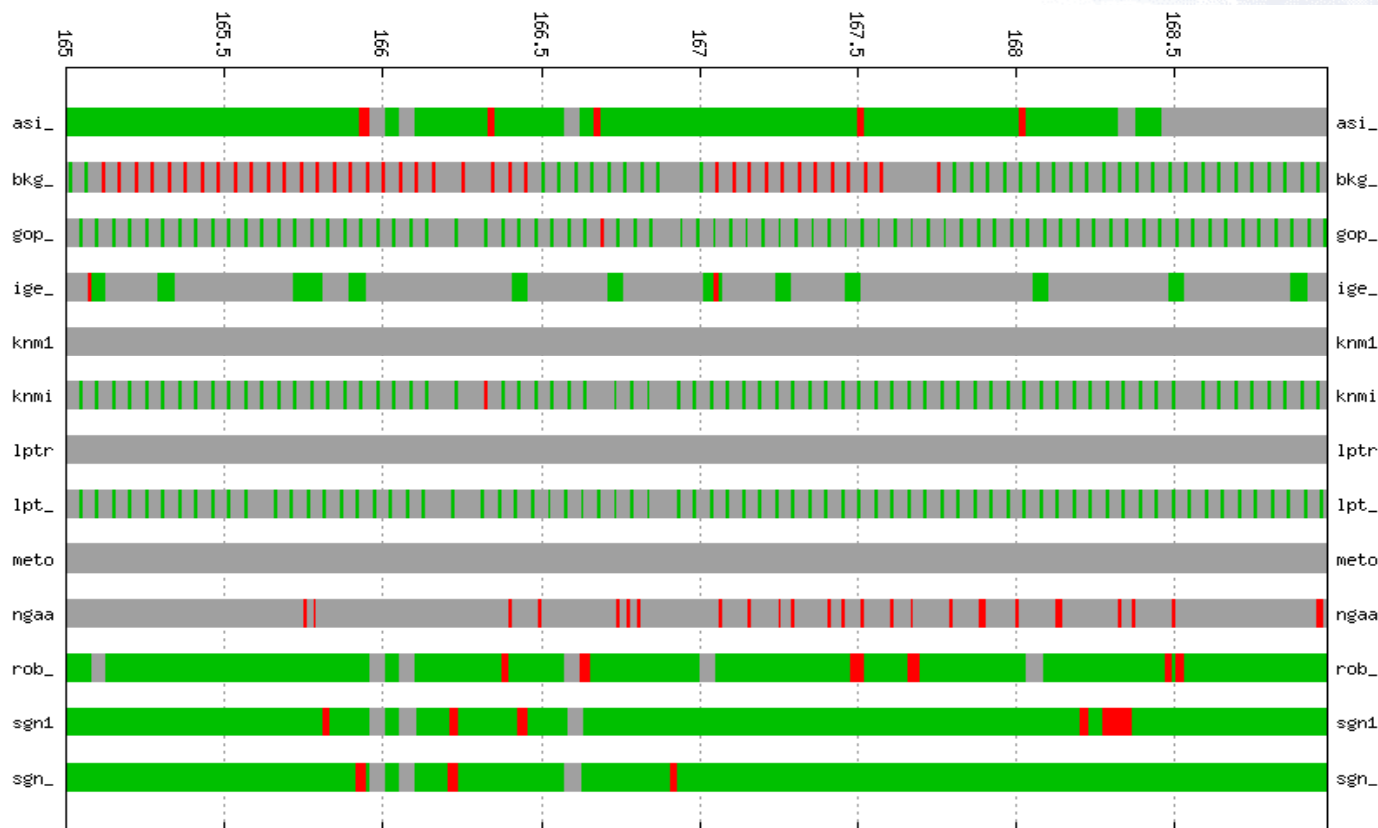
Operational drawbacks:

- The Combined Solution is available with about 1.5h delay w.r.t. the last hourly solutions available covering the interval [-1h:h],
- The Combined Network too sparse (~250 sites) w.r.t. the Operational Network (~1250 sites),

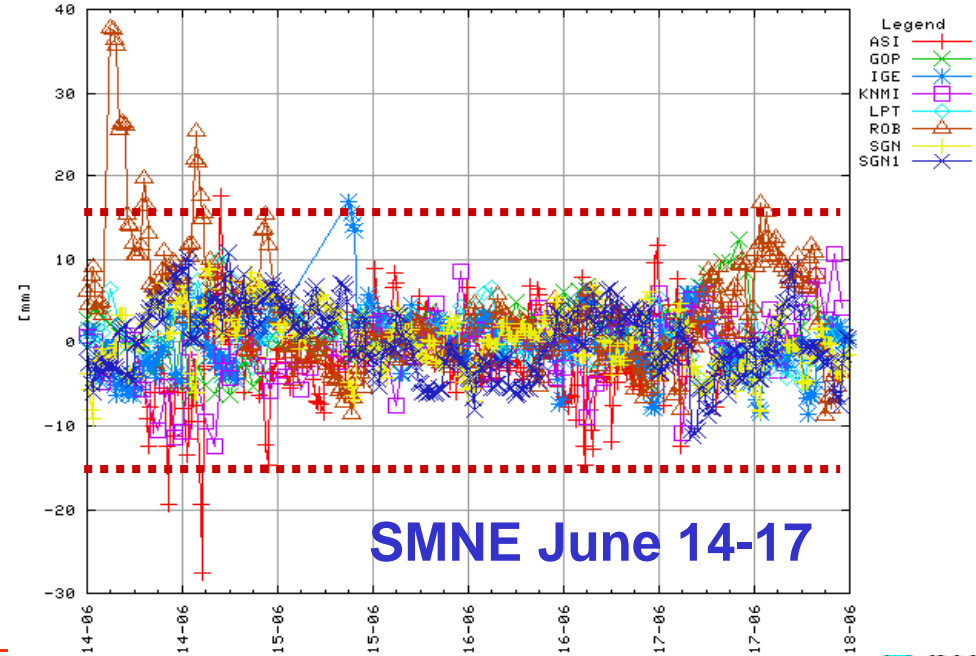
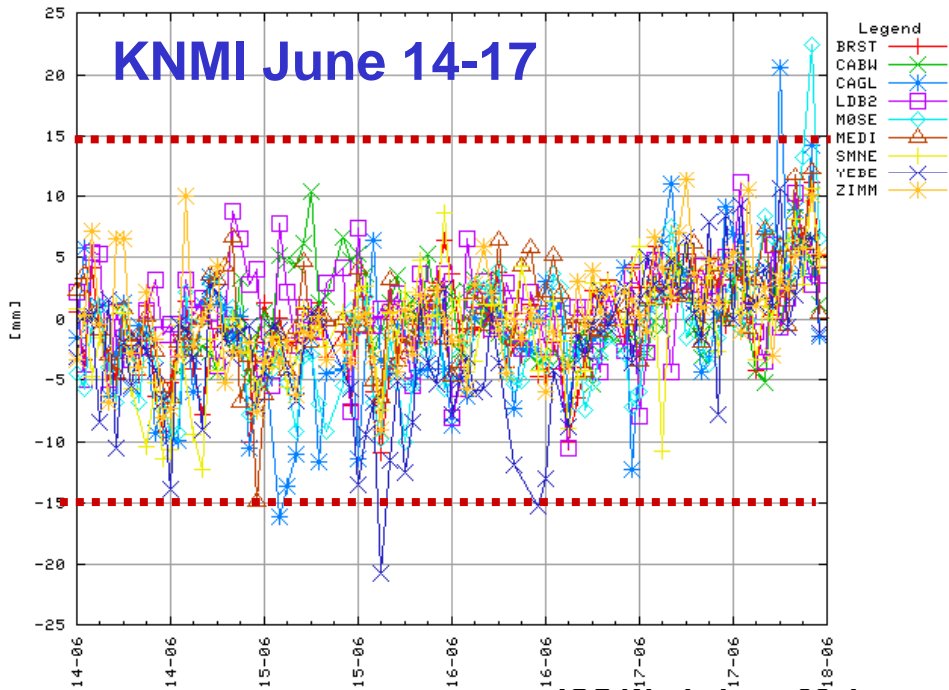
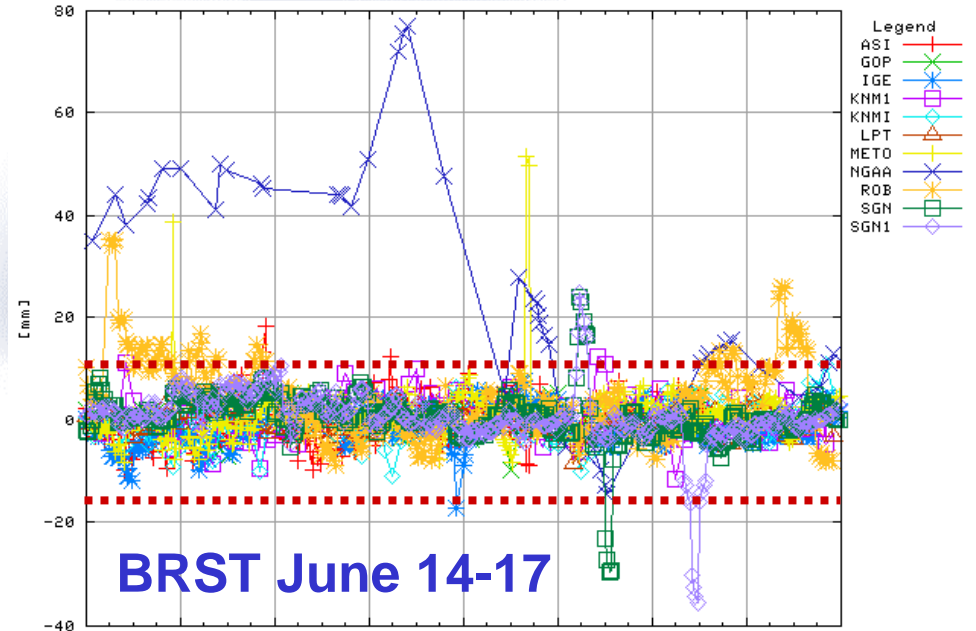
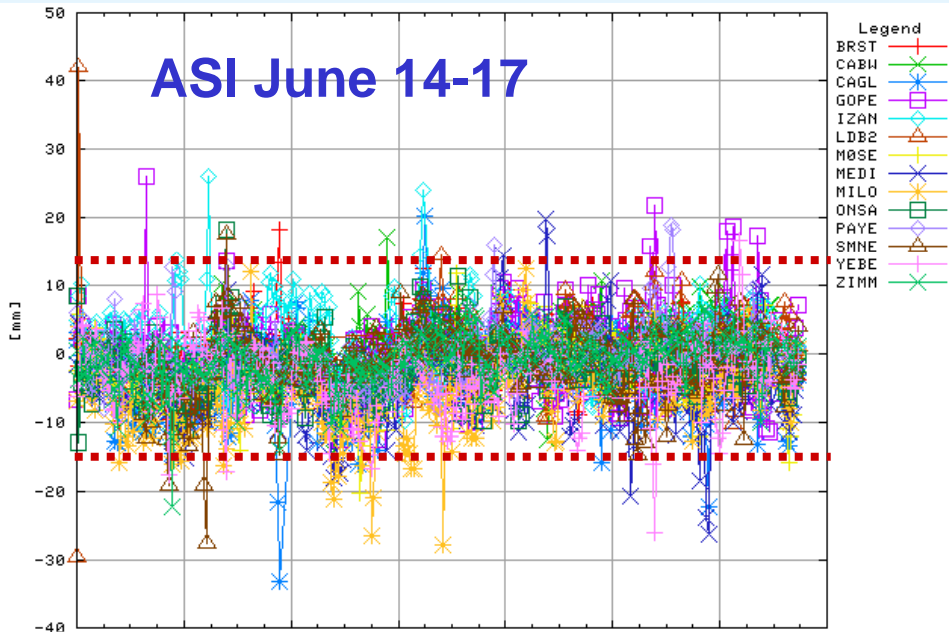
.....but it can be useful for **Active Quality Control**.

Active Quality Control

- Pre-operational phase
- Quality evaluation from June 14 00:00 to June 17 23:59 @ CAGL
- Time Resolution = 15min
- **OK**=|obs-combi|<15mm, **Not OK**, No Info



Active Quality Control per AC and per Site



E-GVAP and IGS (1/2)

- GPS derived ZTDs are used operationally in Europe and E-GVAP is very thankful for the services that IGS provides. Almost all the E-GVAP ACs use IGS Ultra Rapid Products which are vital to NRT ZTDs used in meteorology.
- For weather forecasting ZTD data must be available fast and of a quality which is both good and does not fluctuate strongly in time. Timeliness is an important issue.
- Due to steadily increasing number of operational GNSS sites, PPP strategy is very promising for future efficient GNSS-meteorology. E-GVAP recommends IGS to support PPP strategy with high quality products and to deliver NRT clock products.
- For now-casting applications sub-hourly ZTD products are required and E-GVAP recommends IGS to deliver and support the use of RT products.
- For Global NWP users Global ZTD in NRT are required and IGS might deliver them.



E-GVAP and IGS (2/2)

- With the availability of GLONASS and, in the near future, Galileo IGS should support their use in operational meteorology by providing high quality products as done so far for GPS.
- More than 10 years of data covering all Europe and analyzed in NRT are available @ E-GVAP. There are many requests to use them for climate, but they are not adequate since long-term stability is not guaranteed. IGS (and EUREF) should provide ZTD time series for climate applications.
- Should IGS look at new potential users?

SAR product geolocation error is highly correlated to tropospheric refraction, which is not negligible if 1m accuracy in geolocation is required.

We acknowledge all E-GVAP ACs for providing the ZTD data used in this work and all the GNSS site owners providing raw data for processing by the ACs.

