

GPS Tropospheric Processing for NRT and Post-Processing Applications at ASI



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EUREF Symposium 2007, London, 6-9 June, 2007



Outline of the Talk

- *The History*
- *NRT and Post Processing Strategy: results*
- *NRT solutions with and without absolute PCV*
- *A Method for the Assessment of the Uncertainties of NRT Estimates*
- *Assimilation of ZTD in NWP: a case study*



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History

ASI has been involved in GPS data analysis of regional permanent network since September 1996 when its solutions are incorporated in EUREF.

GPS-Meteo Projects



1999 MAGIC *develop and test the capacity for meteo organizations to benefit from GPS as new data source*

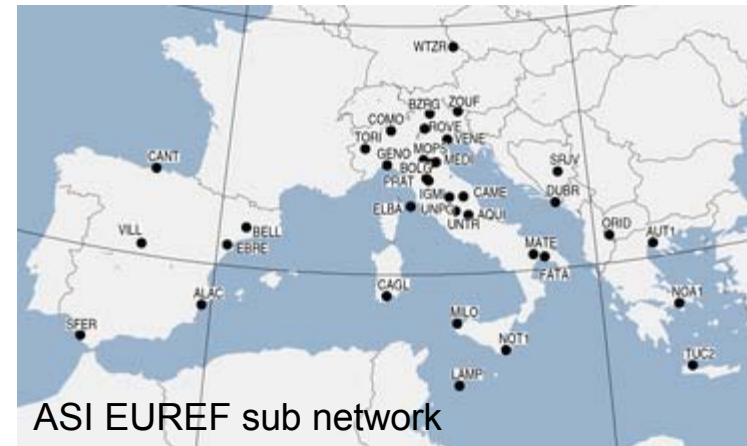
2001 COST-716 *NRT demonstration campaign*

2003 TOUGH *Targeting Optimal Use of GPS Humidity Measurements in Meteorology*

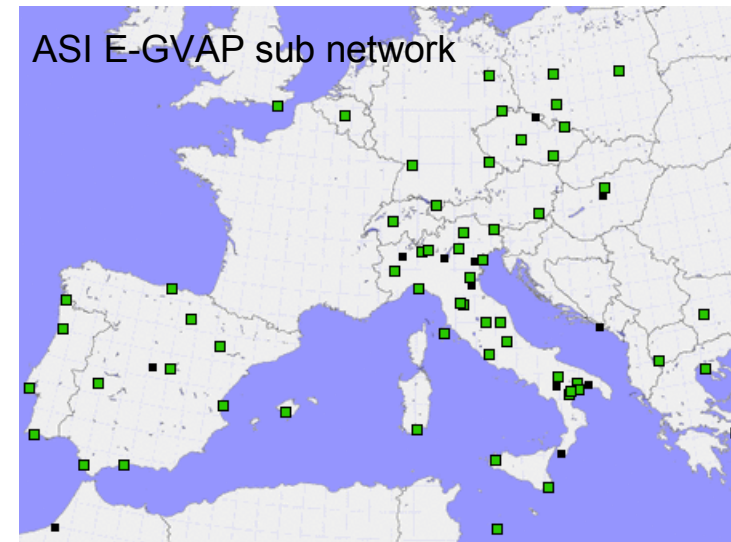
2005 E-GVAP *towards operational use and establishing a GPS delay observing system*



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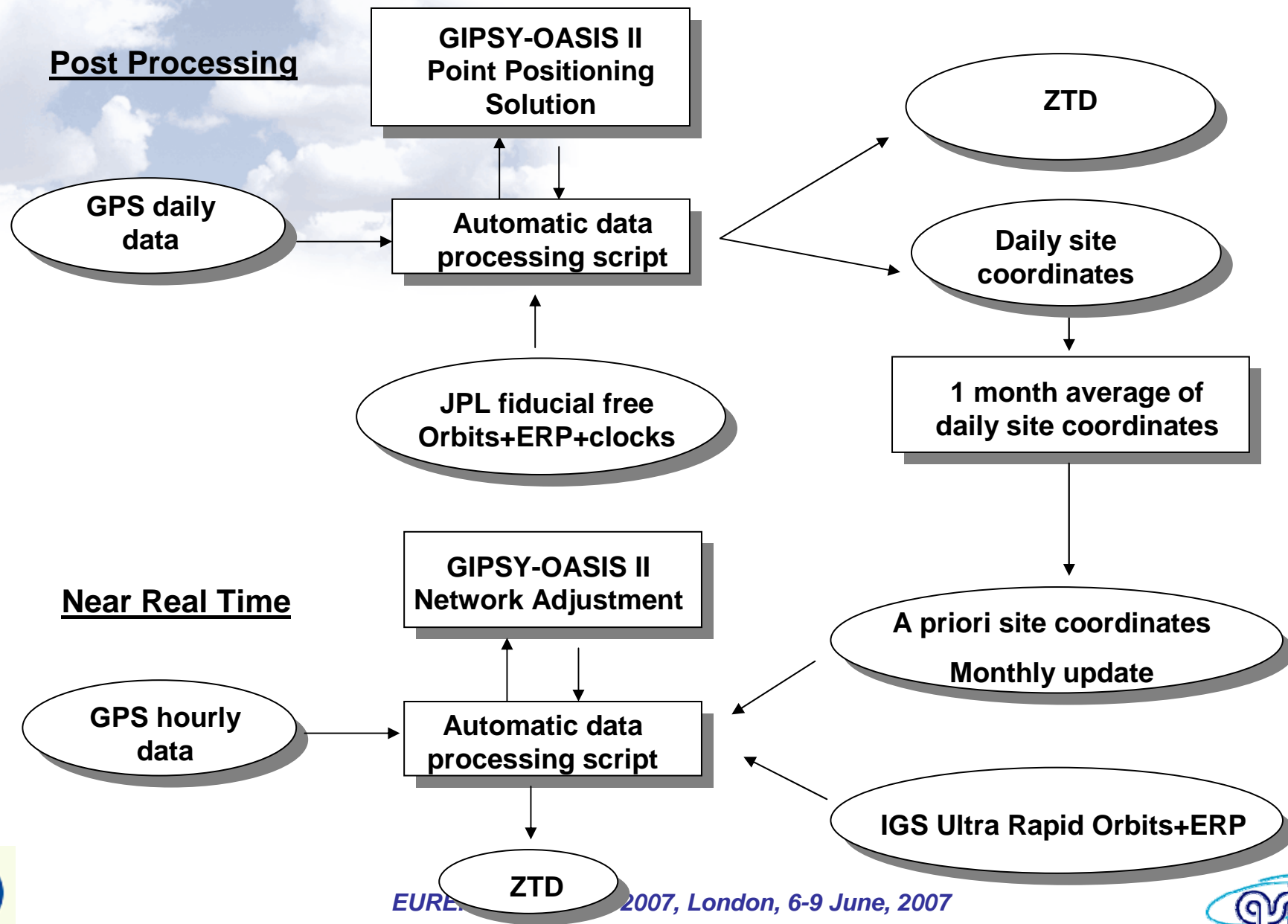
ASI EUREF sub network



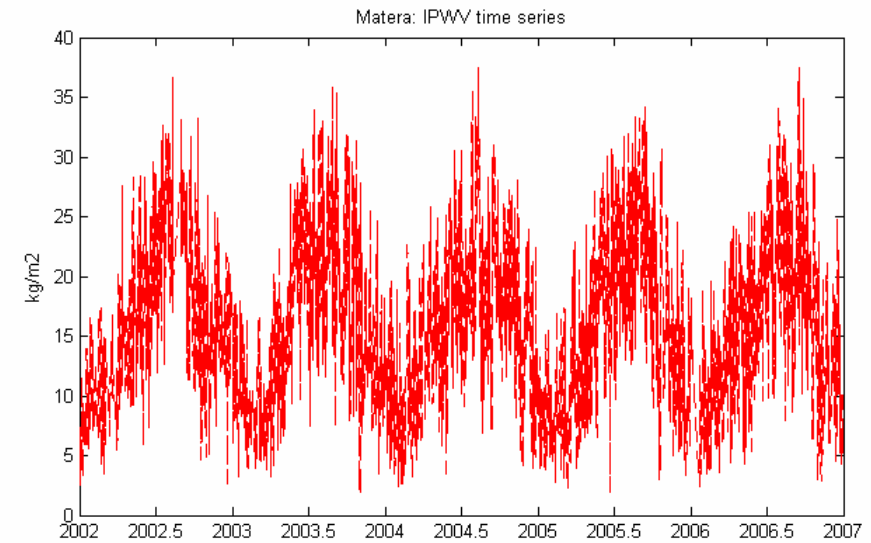
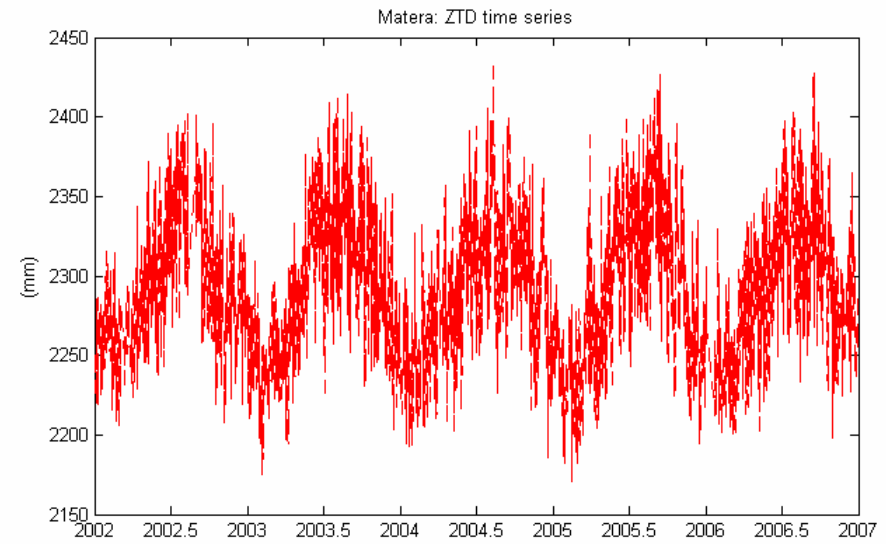
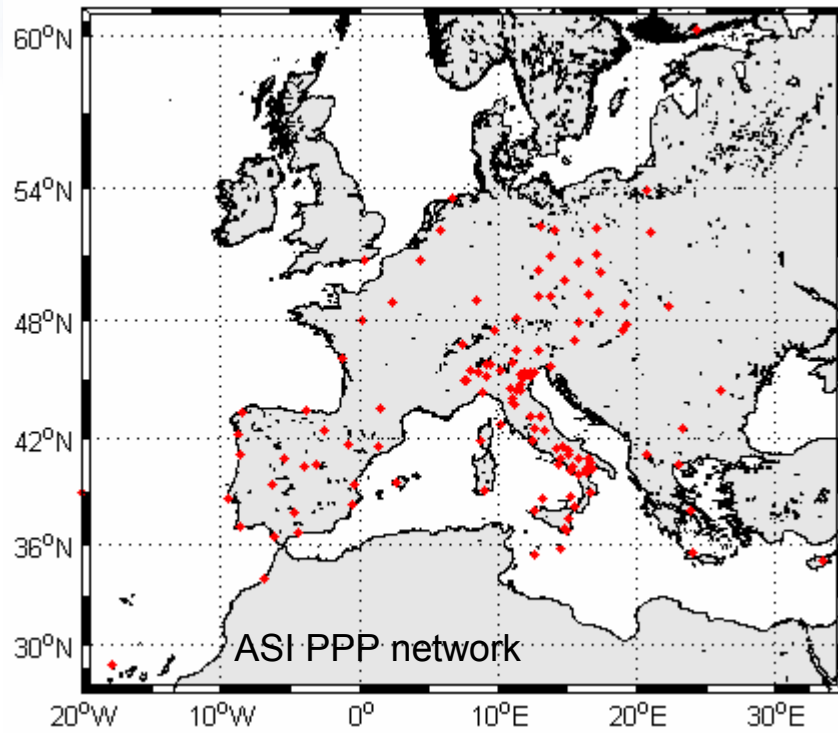
ASI E-GVAP sub network



Analysis scheme for ZTD generation: Post Processing and NRT

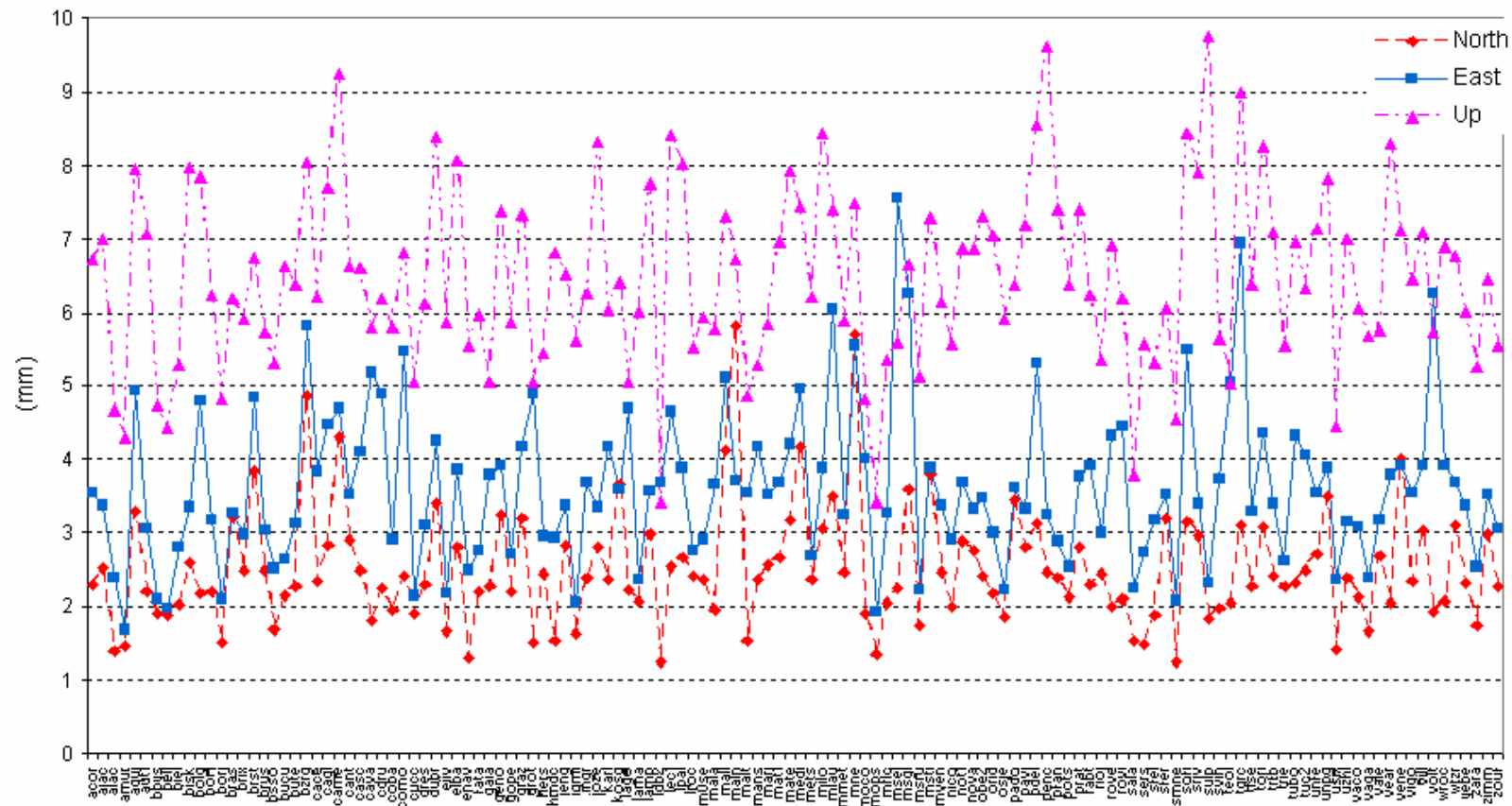


Post Processing ZTD/IPWV time series



Post Processing: site coordinate repeatability

Heights coordinate repeatability as indicator for ZTD quality



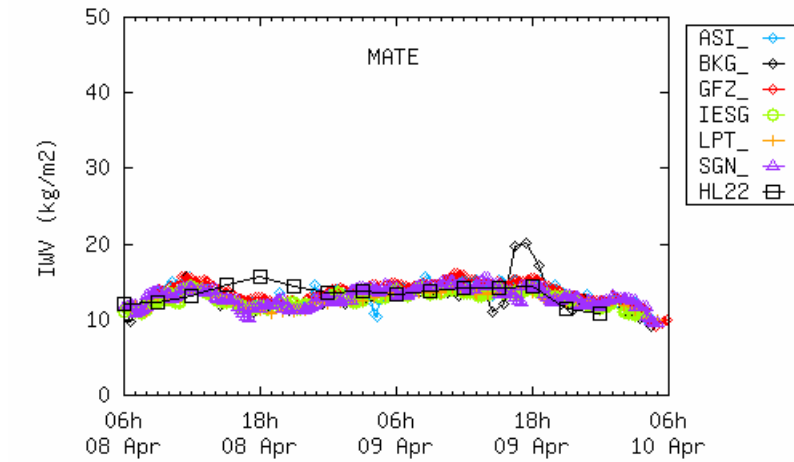
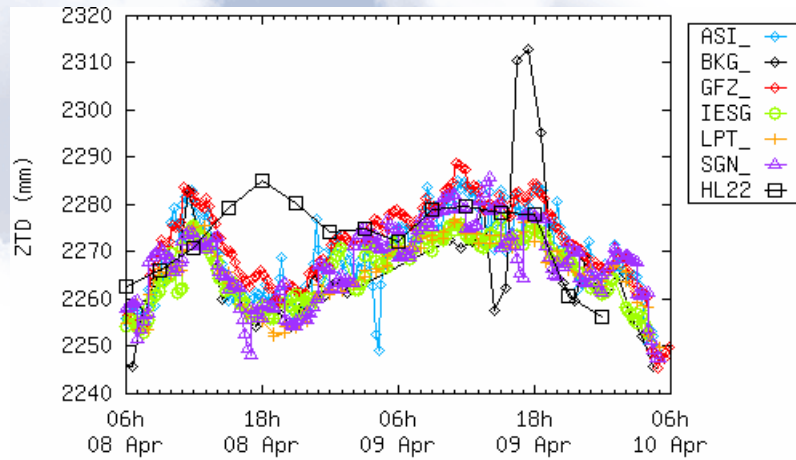
To get 0.45mm IPWV we need 3mm ZTD that is 9mm H



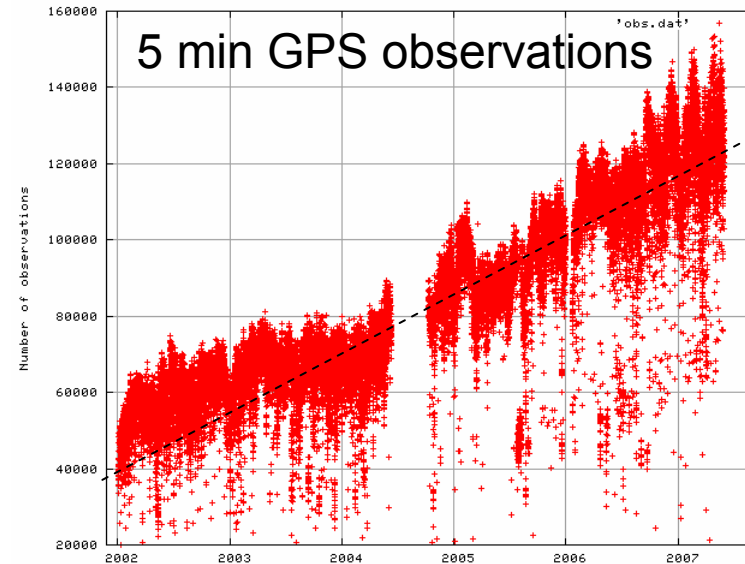
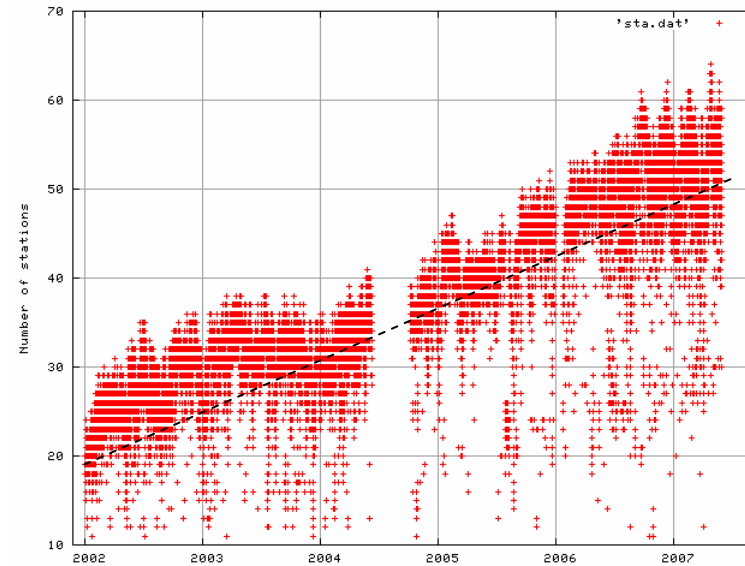
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NRT Processing: evolution with time



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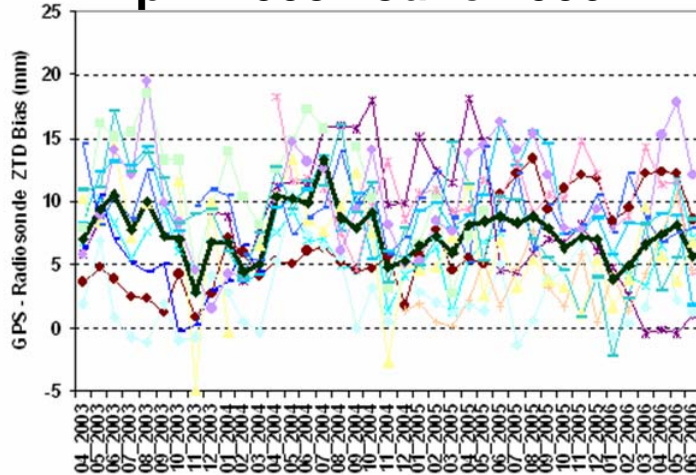


A linear increase in the number of the stations and of the observations

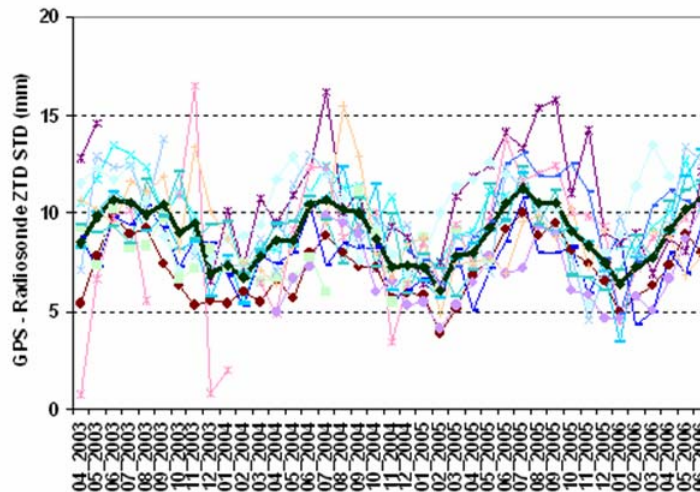


NRT validation: GPS vs Radiosonde

April 2003 - June 2006



- Bias: radiosonde are dryer than GPS.



- STD: seasonal dependence which seems to fit the atmospheric thermal cycle. It is about 10 mm in summer and 7 mm in winter.

— CAGL — CANT — GOPE — HERS — MEDI — MILO — OBE2
— VILL — WROC — ZIMM — MOSE — TORI — YEBE — ALL

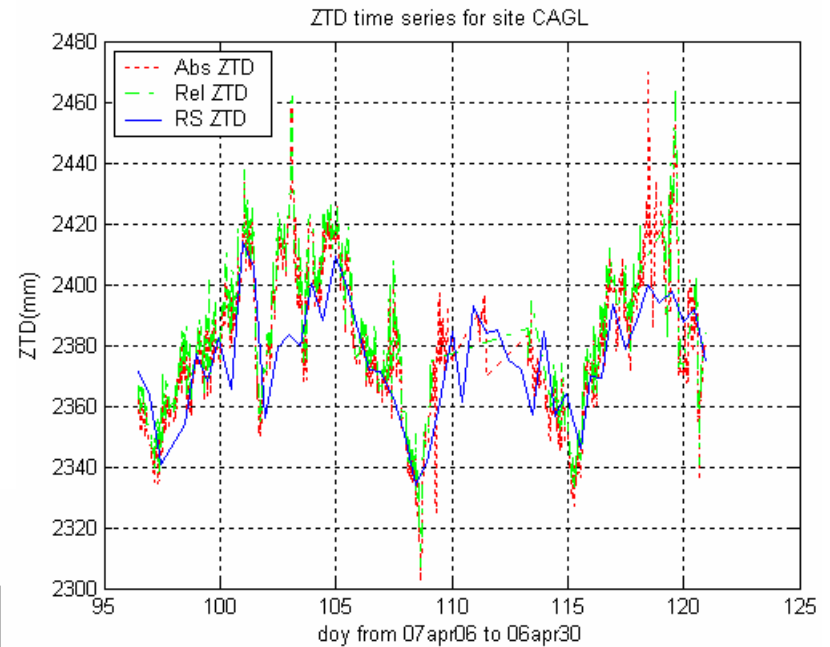


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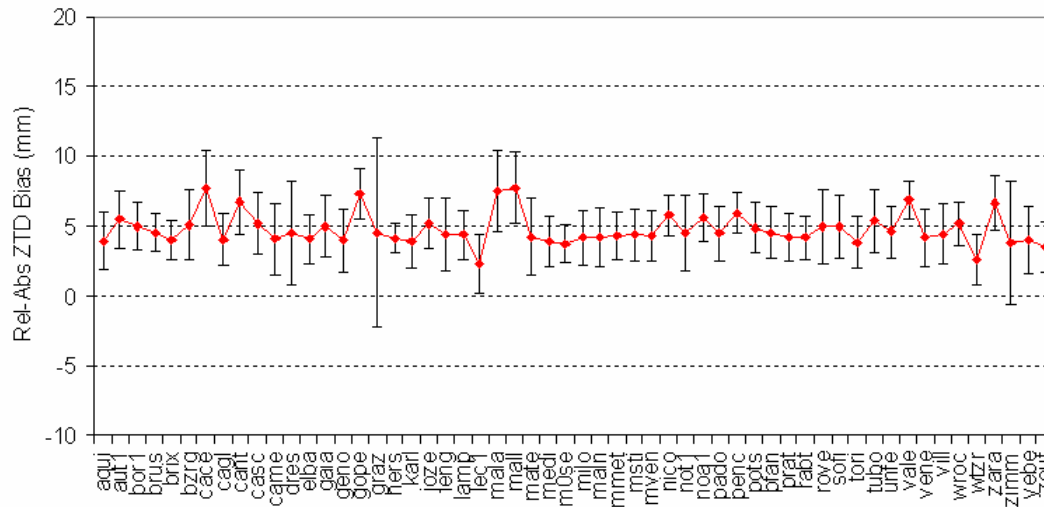


NRT ZTD absolute versus relative PCV (1/2)

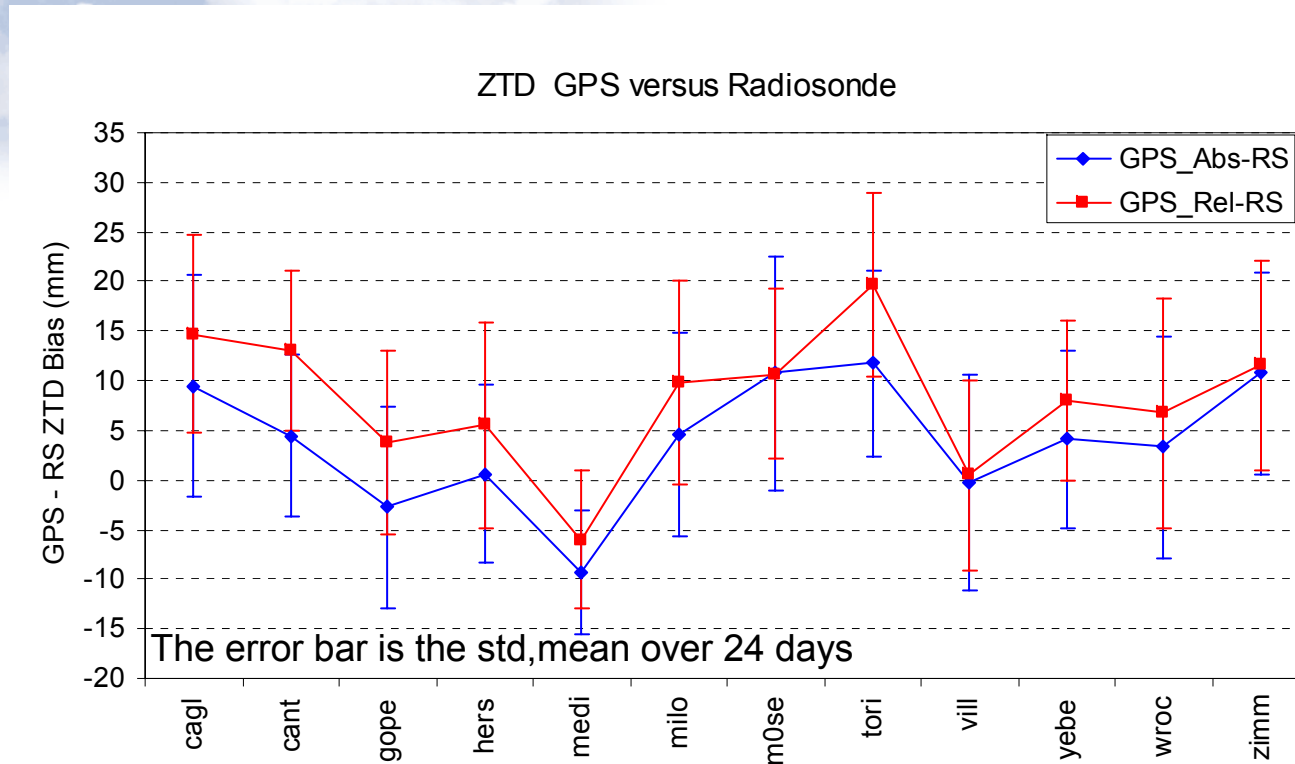
- 2 NRT parallel runs one with absolute and the other with relative PCV are set-up.
- For the period 07apr06-07apr30 (gps week 1421-1425) NRT ZTD estimates for 56 stations from both products lines are compared. A mean bias in 'relative minus absolute ZTD' of about 5mm is detected.



NRT ZTD Relative versus Absolute PCV



NRT ZTD absolute versus relative PCV (1/2)



The use of Absolute Phase Center values reduces the 'GPS versus Radiosonde' bias



Assessment of the uncertainties of GPS NRT estimates (1/4)

If we have different data sets x_i and y_i , which are measurements of the same variable in time and space, we can assess the real uncertainties of one of the measurements that is that intrinsically less precise.

If y_i is more precise than x_i , we can define the non-dimensional data set z_i as:

$$z_i = \frac{(x_i - y_i)}{\sqrt{\sigma_{x_i}^2 + \sigma_{y_i}^2}}$$

If x_i and y_i are unbiased and if their internal error is not underestimated, z_i behaves according to a Gaussian distribution with $\mu=0$ and variance $\sigma_z^2=1$. The error on the mean σ_μ should behave according to a normal distribution

$$\sigma_\mu = \frac{\sigma_z}{\sqrt{n-1}}$$

If μ is significantly different from 0 (i.e. more than 3 sigma) it means that the x dataset is biased. The variance behaves according to the χ^2 function with $n-1$ degrees of freedom.

We must check if the value $\sigma_z^2=Dz=1$ is within the variance interval that is determined by fixing the confidence level to 90%.



Assessment of the uncertainties of GPS NRT estimates (2/4)

We consider $V = \frac{\tilde{D}(n-1)}{D}$

where D is the variance for which we want to know the confidence interval, and \tilde{D} is the estimated variance of the “z” dataset.

V behaves according to the χ^2 distribution with $n-1$ degrees of freedom

The confidence interval of the parameter V is $X_1 \leq V \leq X_2$ with $\chi^2(X_1) = \frac{1-\beta}{2}$

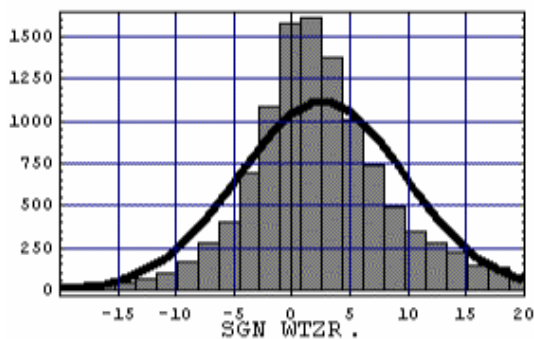
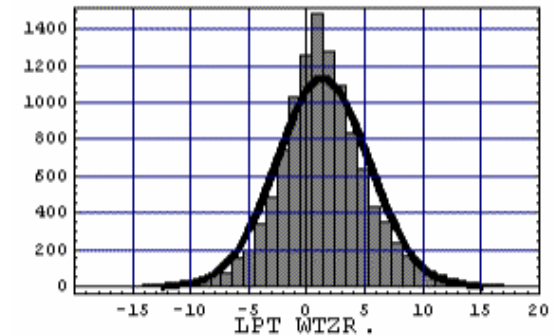
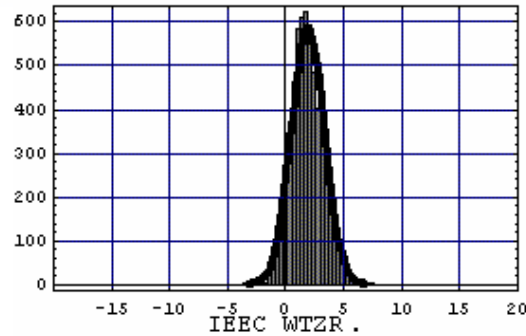
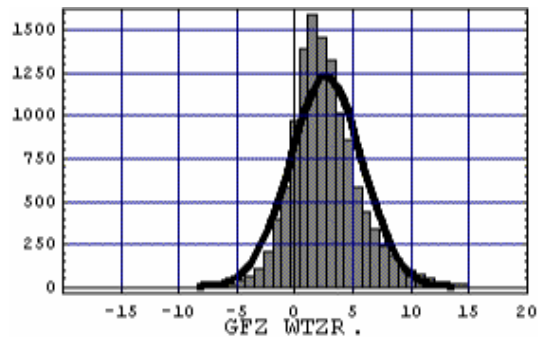
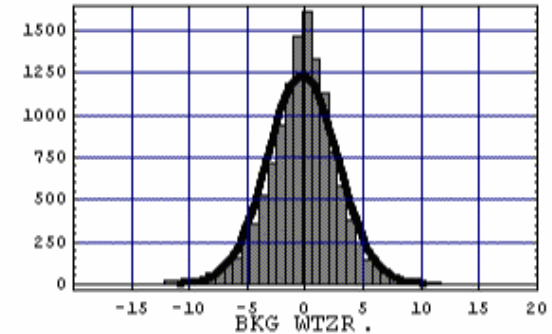
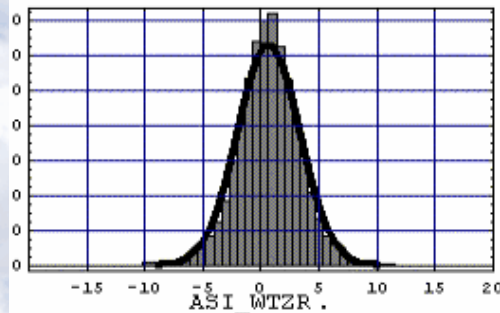
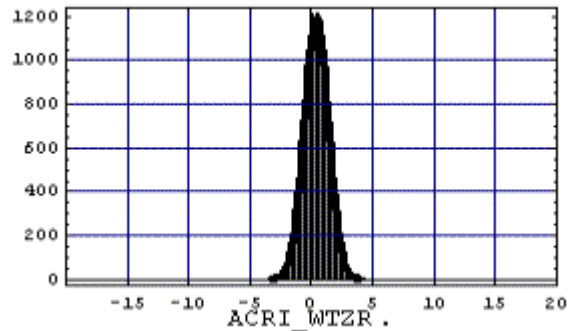
Thus $\frac{\tilde{D}(n-1)}{X_2} \leq D \leq \frac{\tilde{D}(n-1)}{X_1}$ $\chi^2(X_2) = \frac{1+\beta}{2}$

If the nominal value of $Dz = 1$ is outside the range set with the previous equation, then the variance is biased, either underestimated or overestimated.

We apply this method considering the less accurate “x” dataset the NRT ZTD time series coming from the different TOUGH analysis centres, and considering the “y” dataset the EUREF combined tropospheric solution.

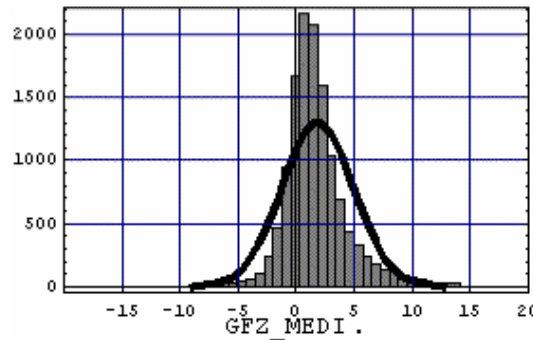
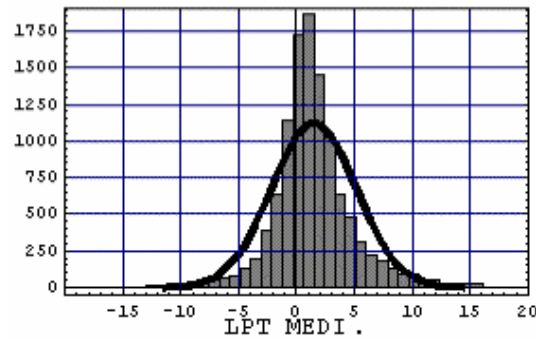
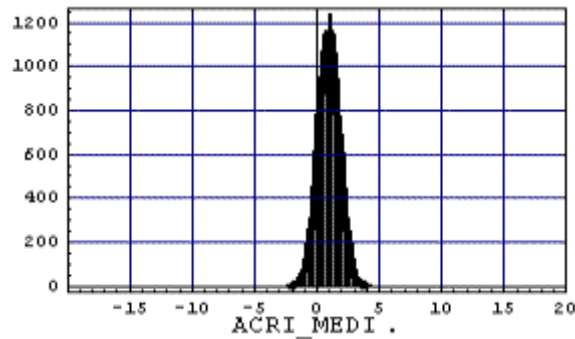


Assessment of the uncertainties of GPS NRT estimates (3/4)

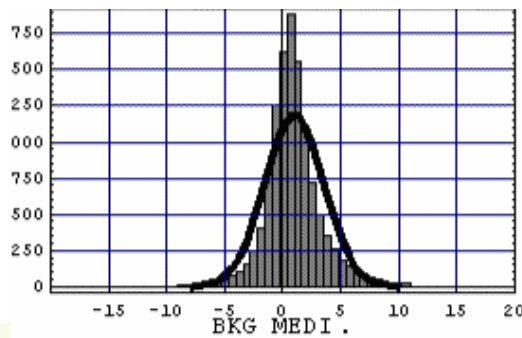


The y datasets are the EUREF combined ZTD solutions for WTZR while the x datasets are ACRI, ASI, BKG, GFZ, GOPE, IEEC, LPT, SGN NRT solutions. The black line represents the Gaussian function having the same mean and variance of the x dataset. The non-dimensional values of the combined z dataset and the number of the estimates are reported along the x and y-axis respectively.

Assessment of the uncertainties of GPS NRT estimates (4/4)



| | Scaled Factor | Scale Sigma (mm) |
|------|---------------|------------------|
| ACRI | 0.9 | 8.3 |
| ASI | 2.4 | 5.6 |
| BKG | 2.7 | 3.2 |
| GFZ | 2.8 | 2.9 |
| GOP | 2.8 | 3.0 |
| IEEC | 1.4 | 7.7 |
| LPT | 3.5 | 3.9 |
| SGN | 5.8 | 3.6 |



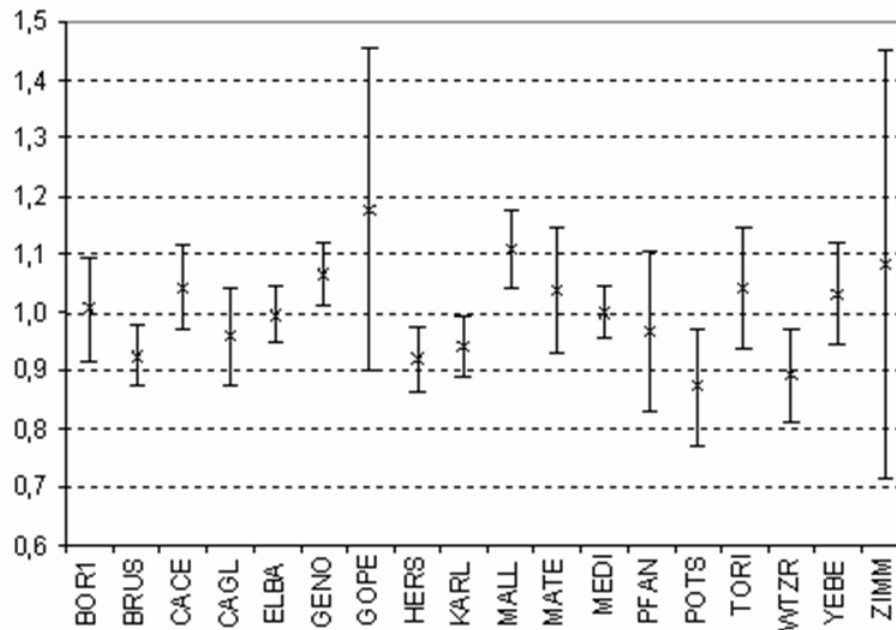
All Bernese and GIPSY solutions (BKG, GOP, LPT, SGN, ASI and IEEC) have underestimated uncertainties and their statistical distribution is not exactly Gaussian; while ACRI solutions using the GAMIT software have over-estimated uncertainties and their statistical distribution is nearly Gaussian. The uncertainties seem to be correlated more to the analysis strategies (troposphere modelling and estimation process) than to the quality of the stations.

Station Quality

A measure of the quality of the i station is given by the non-dimensional quantity

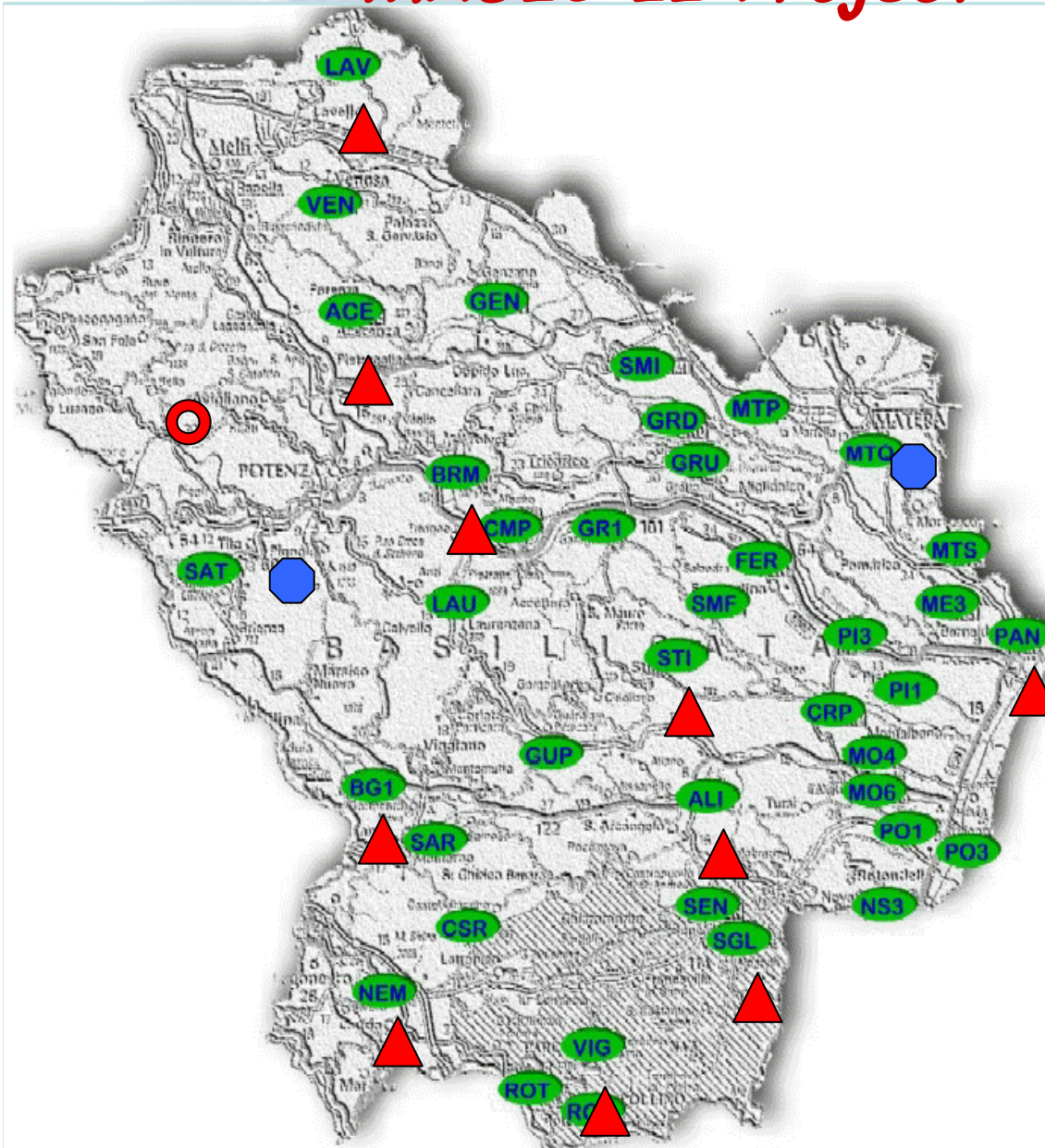
$$v_i = \sum_{j=1}^k \frac{\sigma_{ij}}{\sigma_j}$$

where σ_{ij} is the mean value of the σ estimated by the j analysis center AC_j for the station i ; while σ_j is the mean of the σ estimated for each station by the AC_j . The station i is considered 'good' or 'bad' if v_i is significantly lower or greater than 1.



The approach has been very helpful in singling out stations which have problems that require attention.

MAGIC II Project



Siti ALSIA selezionati ▲

| | | | |
|----------------------|-------|--------|--------|
| Lavello | (LAV) | q.s.m. | 300 m |
| Brindisi di Montagna | (BRM) | q.s.m. | 900 m |
| Marsico Vetere | (BG1) | q.s.m. | 1000 m |
| Aliano | (ALI) | q.s.m. | 600 m |
| Nemoli | (NEM) | q.s.m. | 700 m |
| Viggianello | (VIG) | q.s.m. | 550 m |
| S. Giorgio Lucano | (SGL) | q.s.m. | 400 m |
| Metaponto | (PAN) | q.s.m. | 30 m |
| Stigliano | (STI) | q.s.m. | 1000 m |
| Acerenza | (ACE) | q.s.m. | 300 m |

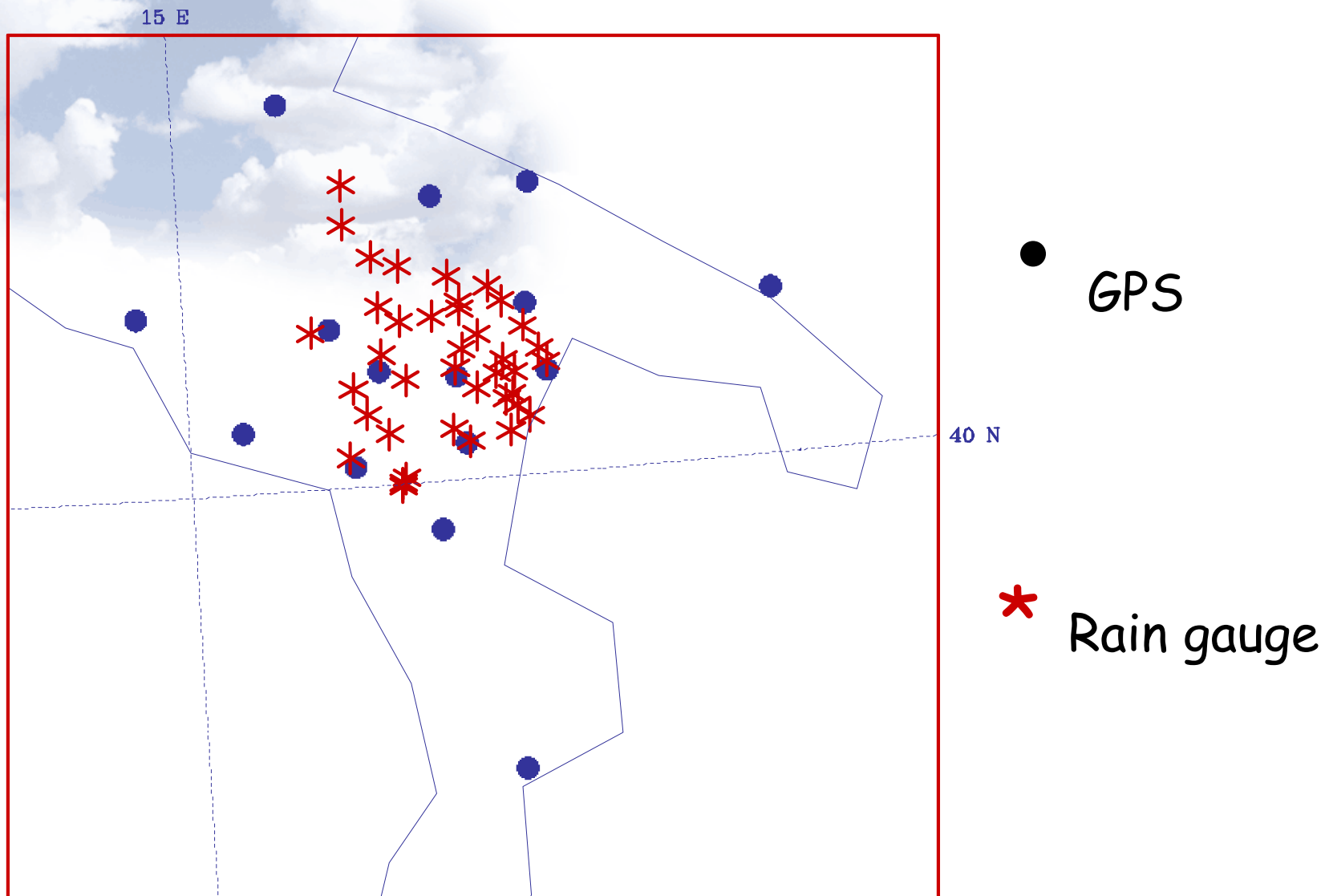
Ulteriori siti disponibili ●

| | | | |
|--------|-------|--------|-------|
| Matera | (CGS) | q.s.m. | 500 m |
| Tito | (TIT) | q.s.m. | 600 m |

Siti completamente da installare ○

Toppo di Castelgrande

Rete di stazioni GPS e Pluviometri



3DVAR

A variational data Assimilation technique not depending in time (3DVAR) has been used to assimilate the GPS ZTD on the NCEP analysis used as First Guess. 3DVAR produces improved initial conditions by minimizing the function

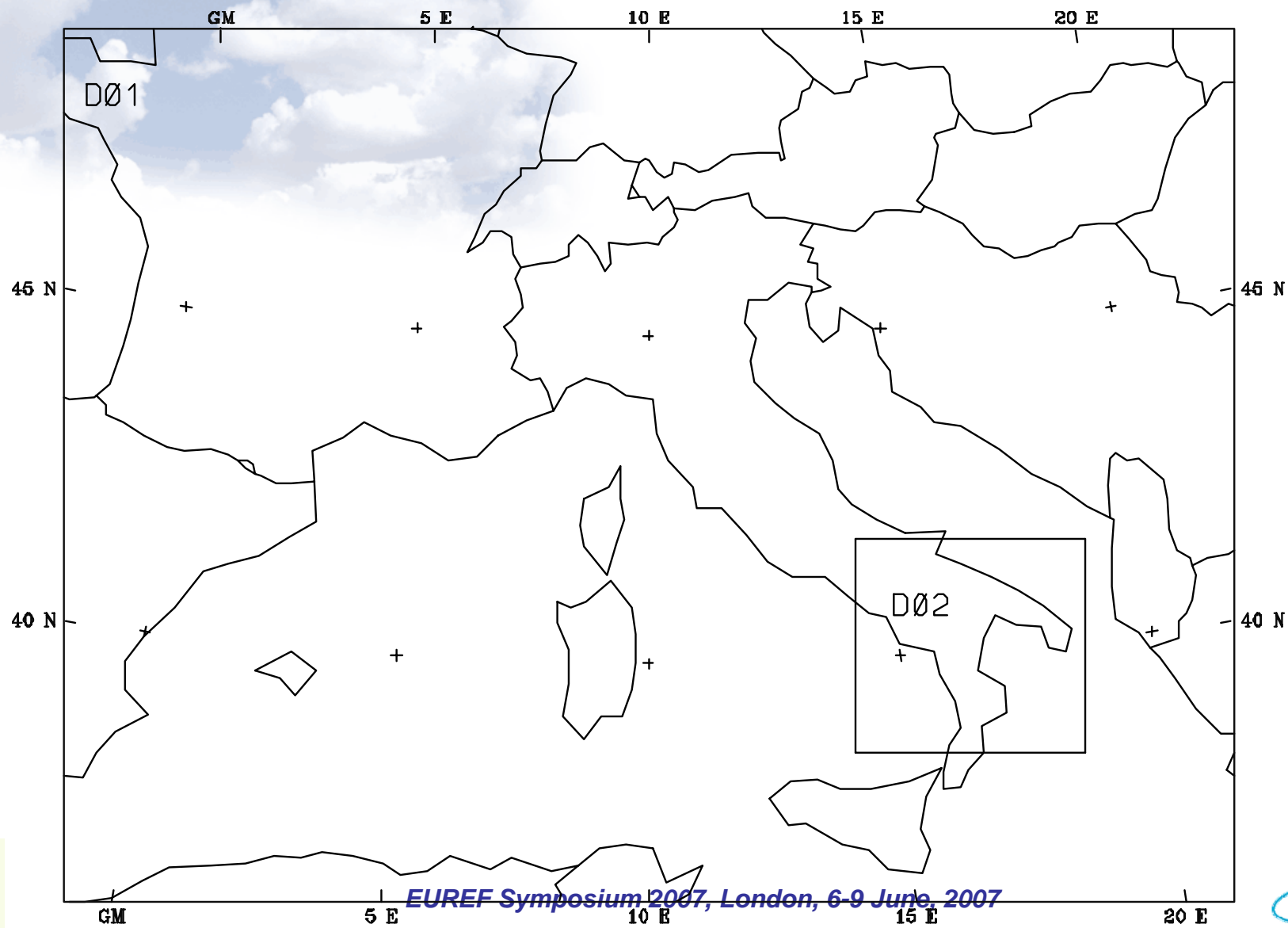
$$J = \frac{1}{2} (x^b - x)^T B^{-1} (x^b - x) + \frac{1}{2} (y^o - H(x))^T (R)^{-1} (y^o - H(x))$$

where x^b is the generic variable of a priori state (first guess), y^o is the observation, and H is the operator that converts the model state variables to the observed variables at the observation location. B and R are the error covariance matrices for the first guess and for the errors, respectively.



MODEL SETUP

Fig.2



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Model Used: **MM5 version 3**

Parameterizations:

- **Kain-Fritsch for cumulus**
- **Reisner for explicit moisture scheme**
- **MRF for PBL**

2 nested domains (27km D1, 9km D2)

29 σ levels

Initial Conditions: **1200UTC of each day**

Forecast: **36 hours.**

2 experiments per day: **CNTR with no assimilation and
EXP with GPS ZTD assimilation by 3DVAR**



RESULTS

The validation of the results has been evaluated using the Mean error and the RMS defined as

$$M = \frac{\Sigma(\text{Mod} - \text{obs})}{N} \quad \text{RMS} = \sqrt{\frac{\Sigma(\text{Mod} - \text{obs})^2}{N}}$$

where OBS is the observation and IC is the analysis at the *i-th* station location. The observation used for validation is the precipitation. The distribution of the pluviometers which provided the data are the dark grey asterisks in Figure 1. Average mean errors and RMS have been evaluated for the winter season, from December 2003 to the end of February 2004, and the spring season, from March to the end of May 2004. They are showed in Figures 3, 4, 5, and 6.

The Mean error shows that during December 2003 (Fig.3a,b) CNTR produces an underestimation (orange in Fig.3a) of the precipitation close to the west side of the Apennines (bottom left). This error is reduced and shifted eastward if ZTD from GPS is assimilated into the model (EXP, Fig.3b). Moreover it reduce the underestimation on the top of the domain. On the other hand, EXP overestimate (blue areas) the precipitation on the southern and eastern domain. On January (Fig.3c,d) EXP produces improvements on the top of the domain only, and no remarkable changes are found for February (Fig.3e,f). In March (Fig.4a,b) the assimilation of ZTD from GPS reduces the

overestimation on the bottom of the domain (Fig.4b) respect to CNTR (Fig.4a), and reduces the underestimation area on the bottom left corner, showing a great agreement with the observations. This is probably due to the increasing amount of humidity available during this month (passage from winter to spring) that it is not correctly reproduced by the NCEP analysis, but it can be provided to the model by assimilation of GPS ZTD. April (Fig.4c,d) and May (Fig.4e,f) do not show any remarkable difference between CNTR and EXP. This is probably due to the high precipitation occurred during these months: as explained before, ice and liquid water do not contribute to the ZTD, therefore, when it rains, the water vapour availability in atmosphere is reduced and it mostly exists as a cloud liquid water and raining drops. In Spring 2004 April and May had respectively 28 and 23 rainy days.

In Figure 5 the RMS for December shows a reduction of the maximum (purple, Fig.5a) for EXP (Fig.5b) on the left side of the domain and on the right side (from magenta to red), but an increase of the error (light green) on the top right corner). As for the Mean error, EXP of January (Fig.5d) reduces the error on the top left of the domain, but no remarkable changes are found between CNTR and EXP for February (Fig.5e,f).

March (Fig.6a,b) confirms the large improvement of EXP (Fig.6b) respect to CNTR (Fig.6a) removing the maximum on the bottom left corner of the domain. April (Fig.6c,d) and May (Fig.6e,f) still do not show any improvement of the ZTD assimilation.



Fig.3

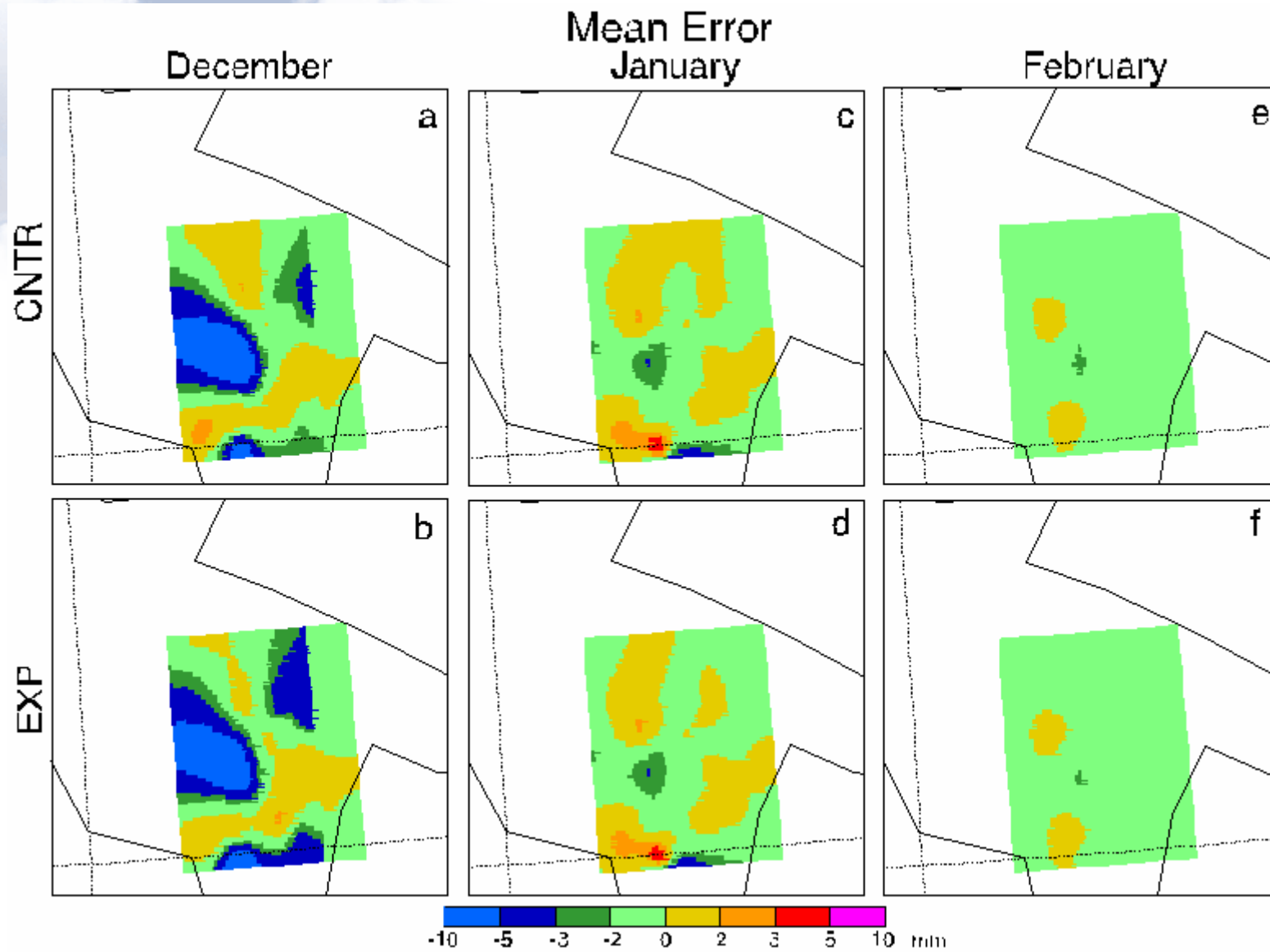


Fig.4

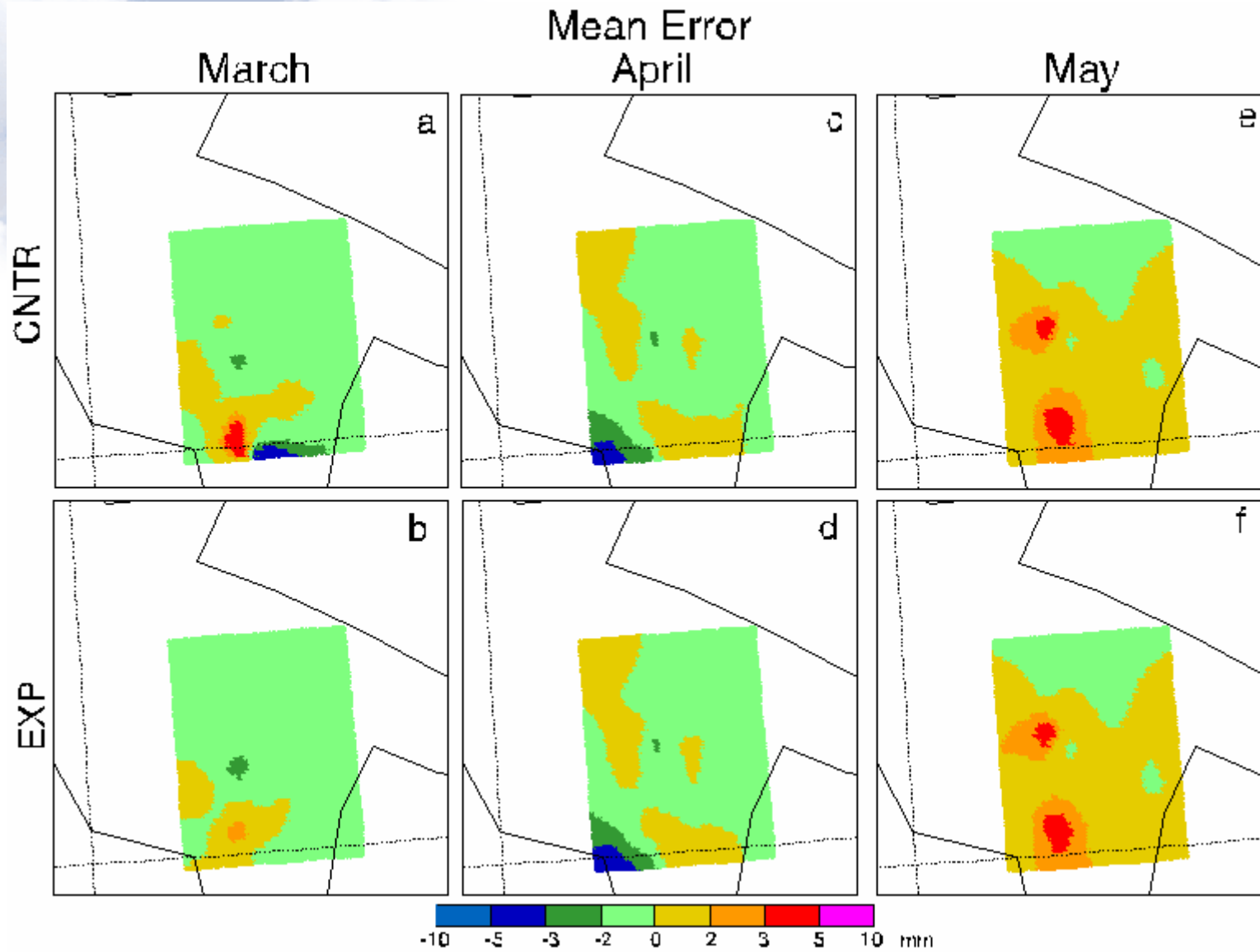


Fig.5

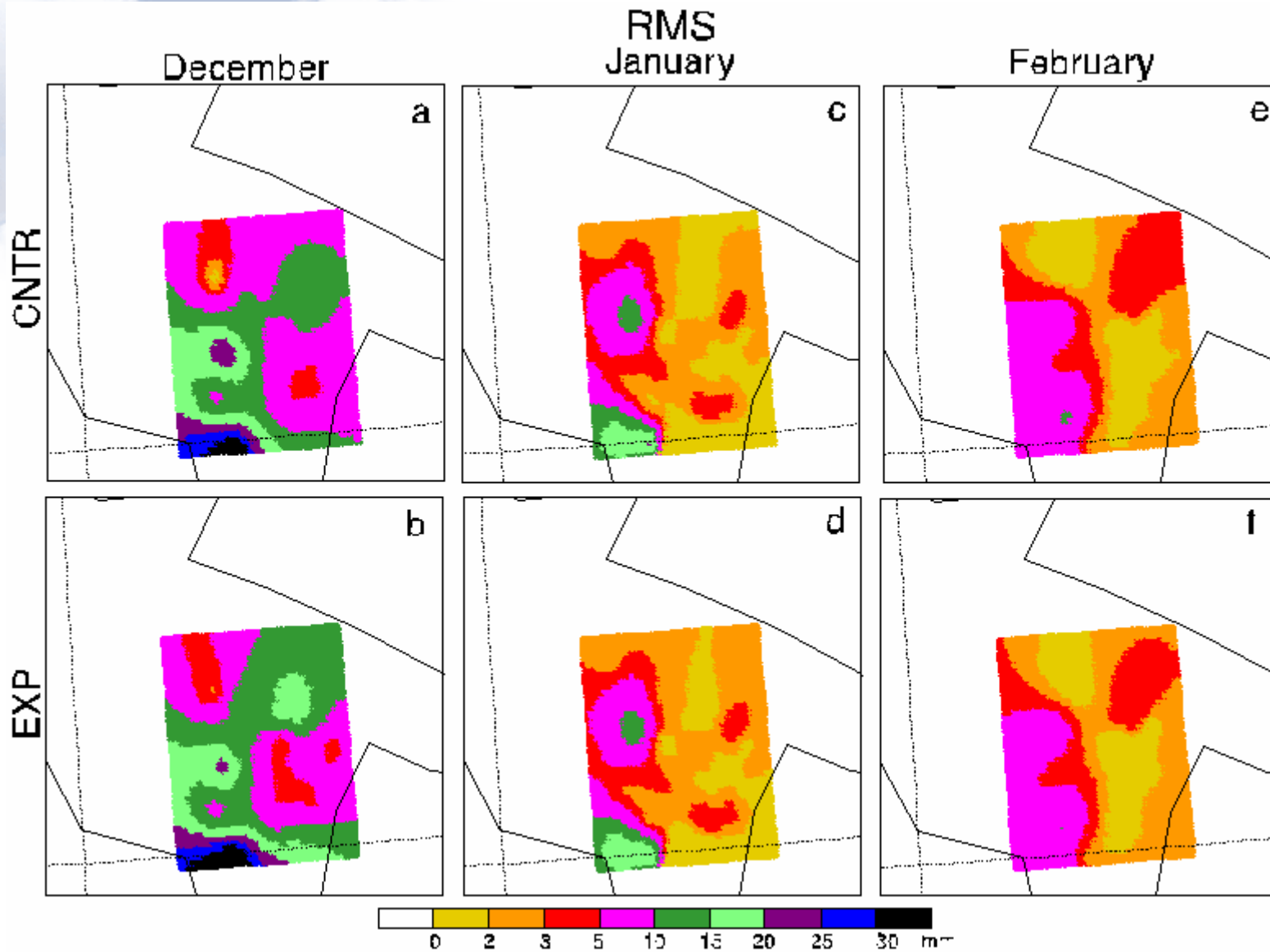
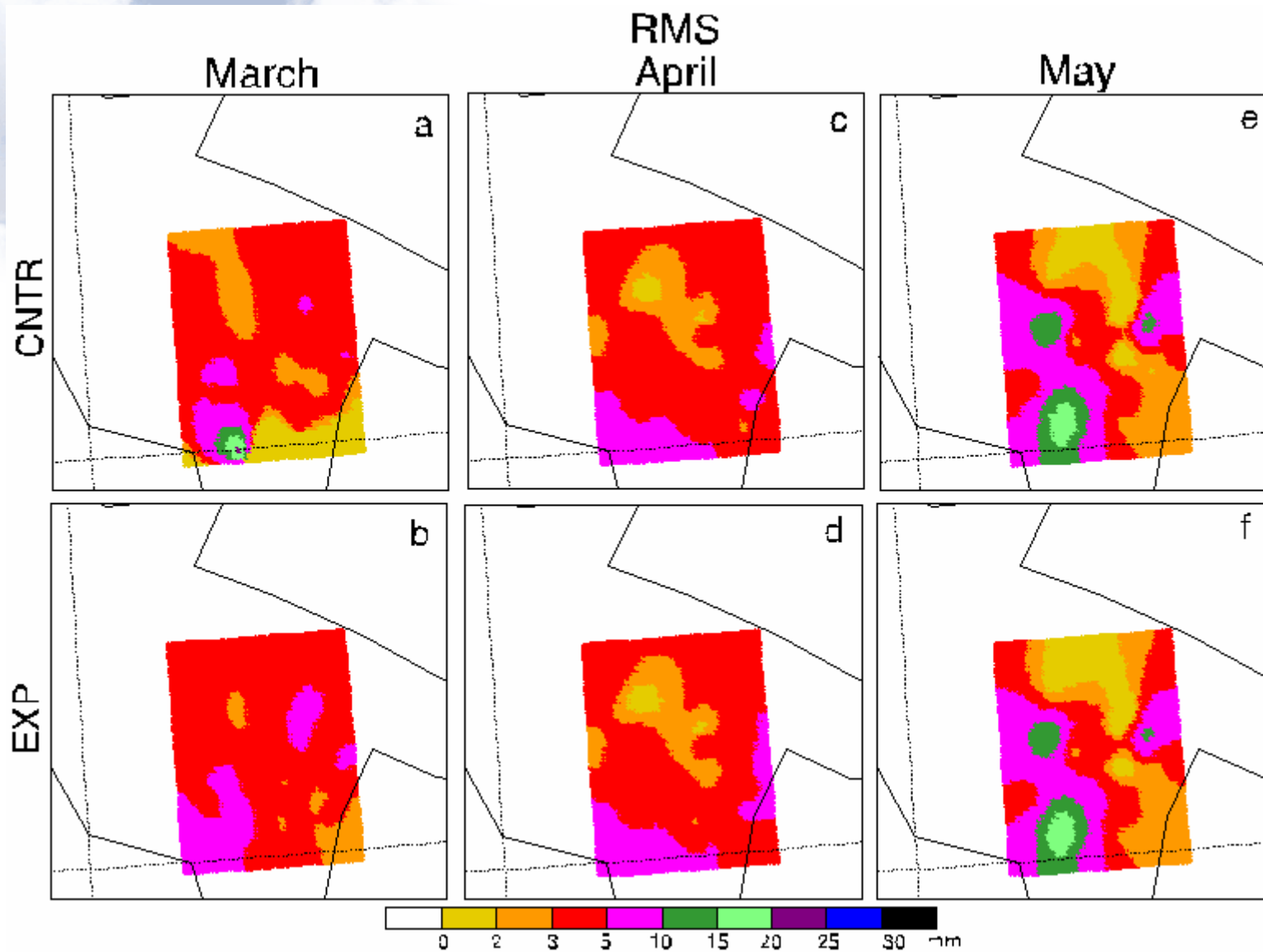


Fig.6



REMARKS

- The assimilation of the GPS ZTD has been performed operationally since December 2003, using the data produced by the high density ground-based receivers on the south of Italy.
- The distribution of the antennas has been decided to cover those areas of complex orography and the down slope of the Apennines.
- Two daily experiments are performed; the first one, CNTR, is used as reference and no data assimilation is performed. The second one, EXP, uses the Initial Conditions improved by the assimilation of GPS ZTD.
- Results show that the assimilation of ZTD, that provides information on the atmospheric water vapour content, improve the forecast during the transition between winter and spring, when the release of the water vapour increases. Because of liquid water and ice do not give any contribution to ZTD, the raining months such as April and May 2004, do not show any remarkable changes between the corresponding CNTR and EXP.
- *It has to be pointed out that this study has been performed using a low resolution of the model domains, i.e. 9km. Usually, this resolution is considered to be too low to produce a valuable improvement on the forecast.*

Thanks for you
attention.

