Ultra-Rapid Orbits at ESOC, Supporting Real-Time Analysis

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Ultra-Rapid POD

- UltraRapid development started in Oct 1999 and regular submissions on March 2000 (wk 1051).
- Most of the IGS ACs have also started submissions around the same time.
- Combinations and Comparisons by AC Coordinator, started wk 1052.

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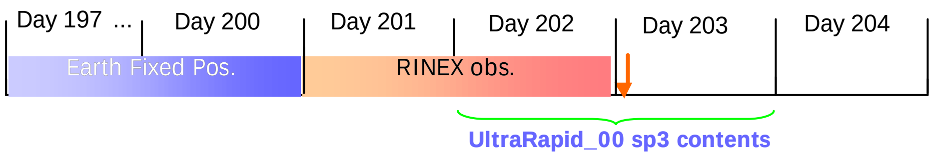
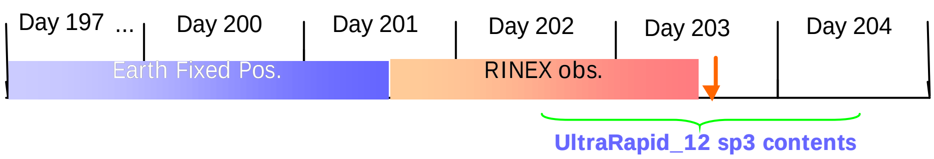
Processing Arc and Data Types

For the UltraRapid_00 processing:



For the UltraRapid_12 processing:



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Overall Status

- Ultra-Rapid processing at ESOC results in more than 11 of 14 successful submissions a week.
- Ultra-Rapid processing is stable and robust.
- Unfortunately *bad* satellites have had to been excluded: PRN 02, 15, 17, 21, 23, ...
- Station data delivery to IGS Data Centers is very good so that 30+ stations are always available.

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Ultra-Rapid Clock Biases

- For Real-Time use the product needed clock biases so that an external user could *fix* the GPS satellite quantities to analyse observations.
- UltraRapid clock development started Jan 2001 and regular submissions in March 2001 (wk 1107).
- Clocks are included in the sp3 file at the 15 minute epochs.
- Currently there are 3/4 AC contributing with clocks, but not always for the entire 48hr arc.

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Clock Bias Method

1. Clock bias estimation for satellites and stations is done from undifferenced observation processing together with all the other estimated quantities.
2. A fit is found for each satellite clock bias time series using a function to predict values into the future.
3. If the fit is successful < 10 ns RMS then the clock bias values for the entire 48 hours are included in the results file (estimated + predicted).
3. If the fit is not successful no values are published for the entire arc since it probably means the estimated values are faulty (discontinuities, gaps, etc)

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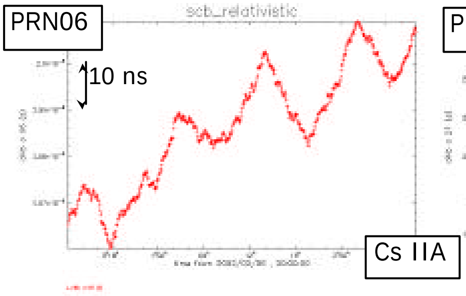
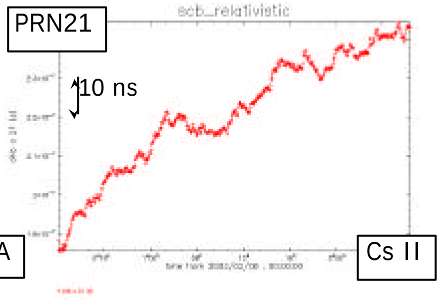
Clock Propagation Method (I/V)

Clock biases for each satellite have distinct characters, but they all have an offset and drift. Some periodic behaviour can sometimes also be observed. The propagation/prediction function chosen is:

$$y_{PRN} = A_0 + A_1 t + A_2 Sin(A_4 t + A_5)$$





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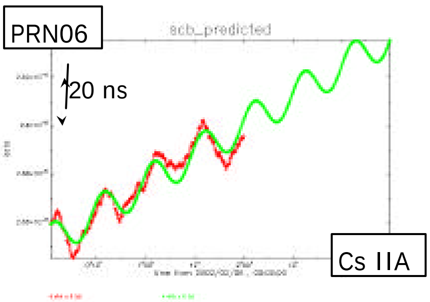
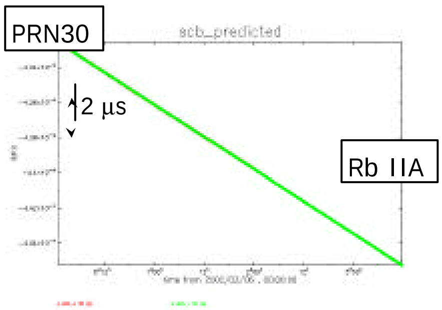
Clock Propagation Method (II/V)

Using the estimated (**RED**) values the function is fitted using LSQ iterative method to produce the best fit (**GREEN**) curve.

An error analysis then decides if the RMS of differences over the common part is < 10 ns for inclusion in the solution.





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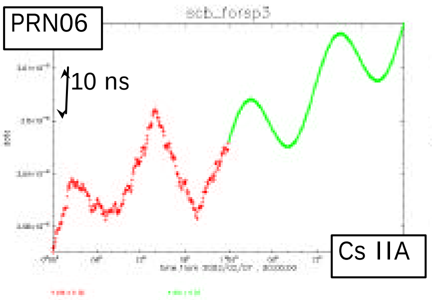
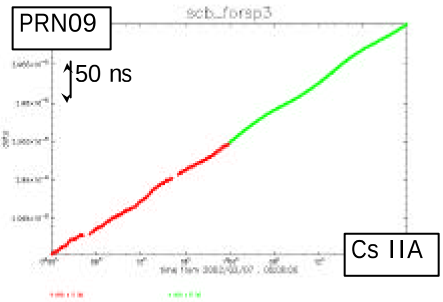
Clock Propagation Method (III/V)

The actual submitted values in the ESA UltraRapid product have the estimated (**RED**) values and the propagated (**GREEN**) values, moved at the transition point to avoid a jump in the clock bias sequence.





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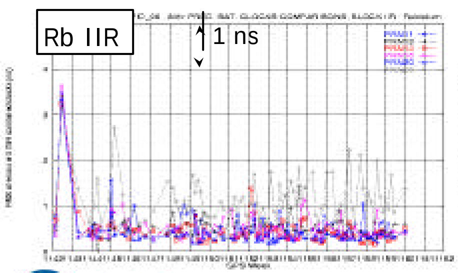
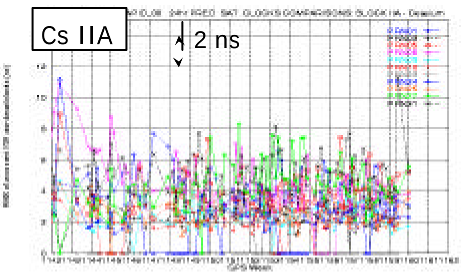
Clock Propagation Method (IV/V)

Clock Combination and Comparison results have been produced by the AC Coordinator showing agreements between ACs and to the IGR in the 2 to 6 nanosecond level.

Satellite by Satellite Comparisons show different agreements according to the clock and satellite type (correcting time series independently). http://nng.esoc.esa.de/gps/igs_ana.html





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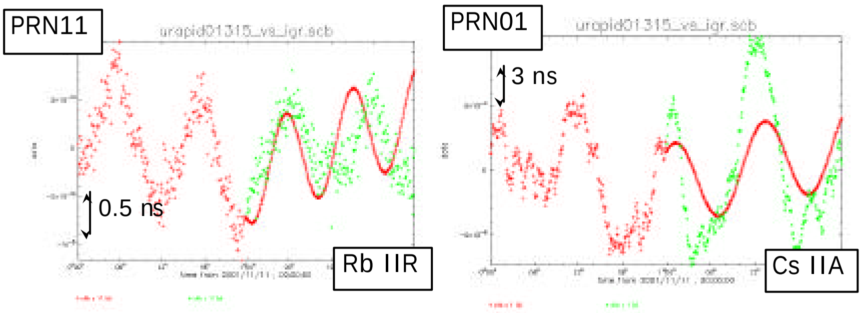
Clock Propagation Method (V/V)

The submitted (**RED**) clock bias values (estimated + propagated) shown against the estimated ESA Rapid Clock solution (**GREEN**).

(all values in the plots corrected for bias and drift for plotting purposes)

Basically each clock's inherent stability defines the level of error in the propagation.



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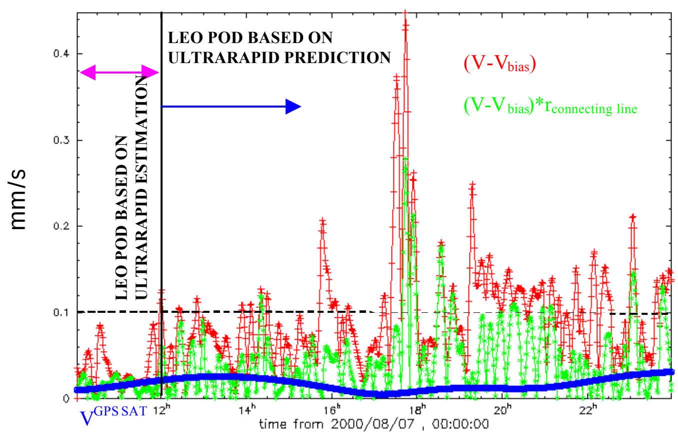
Using the ESA UltraRapid Orbits



ESA-UltraRapid vs. ESA-Final
velocity differences (mm/s) for Champ

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Key Issues

- UltraRapid clocks have now been delivered for over a year with a 3 to 6 ns RMS level. (Orbits for over two years with 15 to 25 cm)
- Variable arc and data selection and mixing (RINEX and positions) increases robustness and product quality.
- Using a batch processing strategy it will be difficult to increase stations used much more.

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Conclusions / Next Steps

- Since clocks degrade quickly, a higher frequency of update for the UltraRapids may be needed.

  (Do we need more epochs in the sp3 or a RNX clock file?)
- Some way of identifying clock predictions in the sp3 is needed, plus clarifying clock combination statistics in the ACC report.
- ESA has established an experimental ***HighRate*** hourly product which runs every hour and estimates clock biases (sta & sat) and troposphere values, using fixed UltraRapid Orbits.

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The Italian Near-Real Time GPS Fiducial Network for Meteorological Applications

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Outlook of the talk

- The Italian GPS Fiducial Network:

  operational & archiving activities.

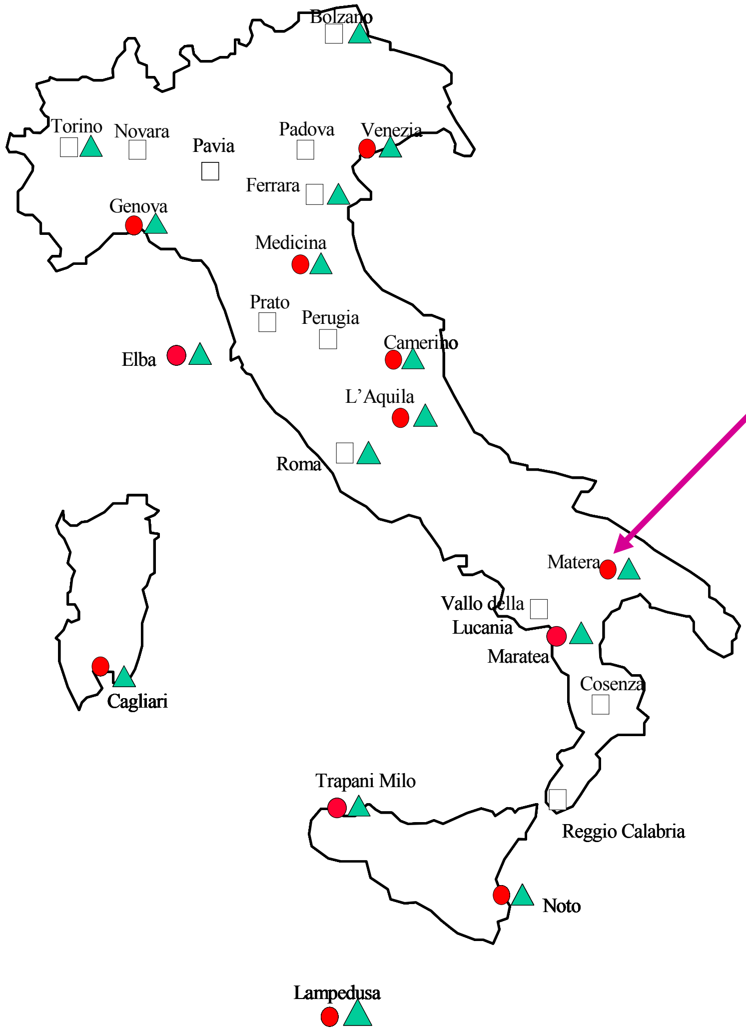
- Near-Real Time application for tropospheric monitoring:

  -GPS data processing: description & performance,

  -Post-Processed versus NRT ZTD estimates,

  -Comparisons of different NRT ZTD estimates within COST-716.

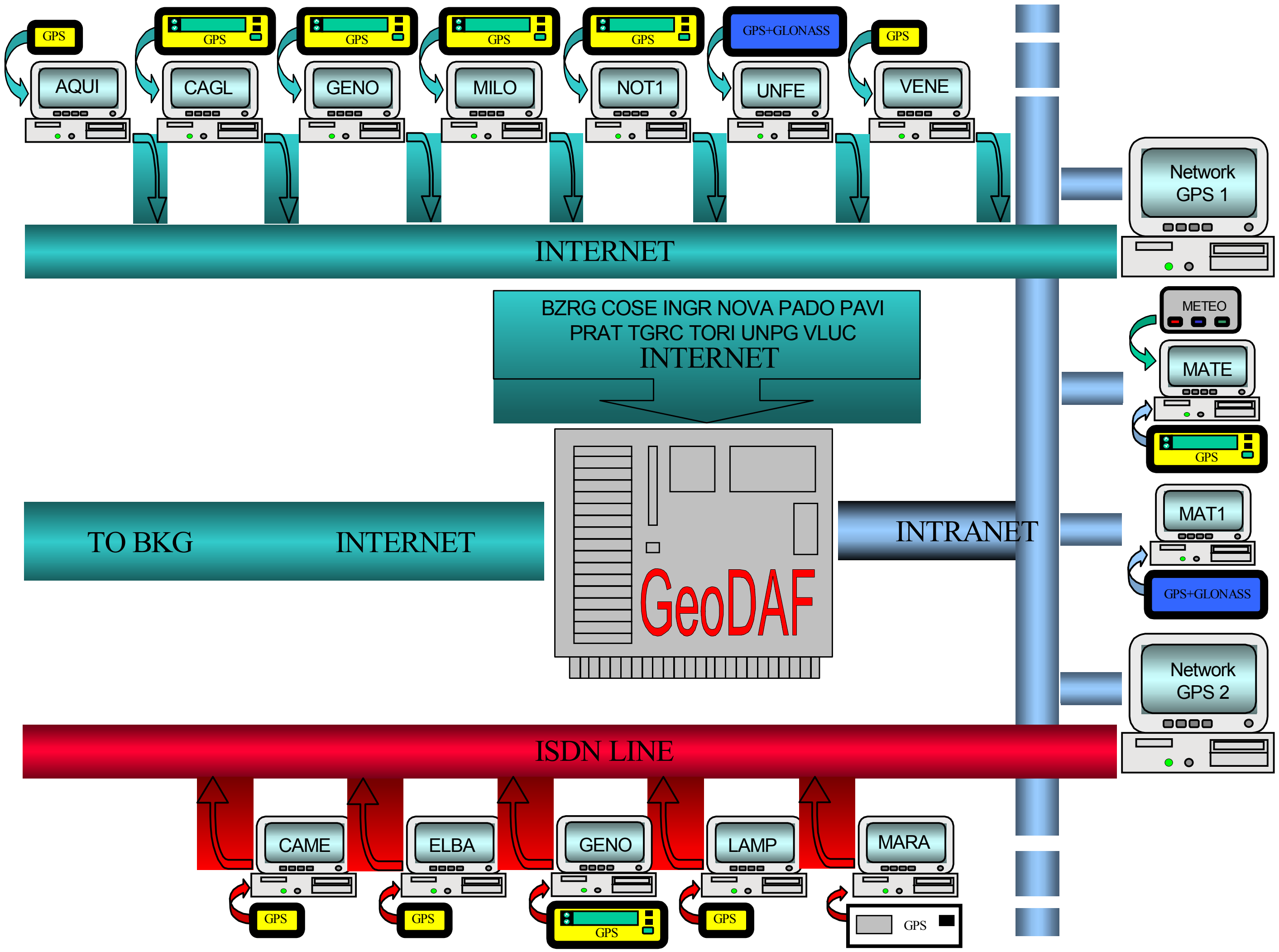
Italian GPS Fiducial Network



Matera ASI-CGS

- ● 12 ASI SITES
- □ 12 OTHER INSTITUTION SITES
- △ 16 HOURLY SITES

Operational & Archiving Activities



ftp://geodaf.mt.asi.it

http://geodaf.mt.asi.it

hourly data on line for 1 week

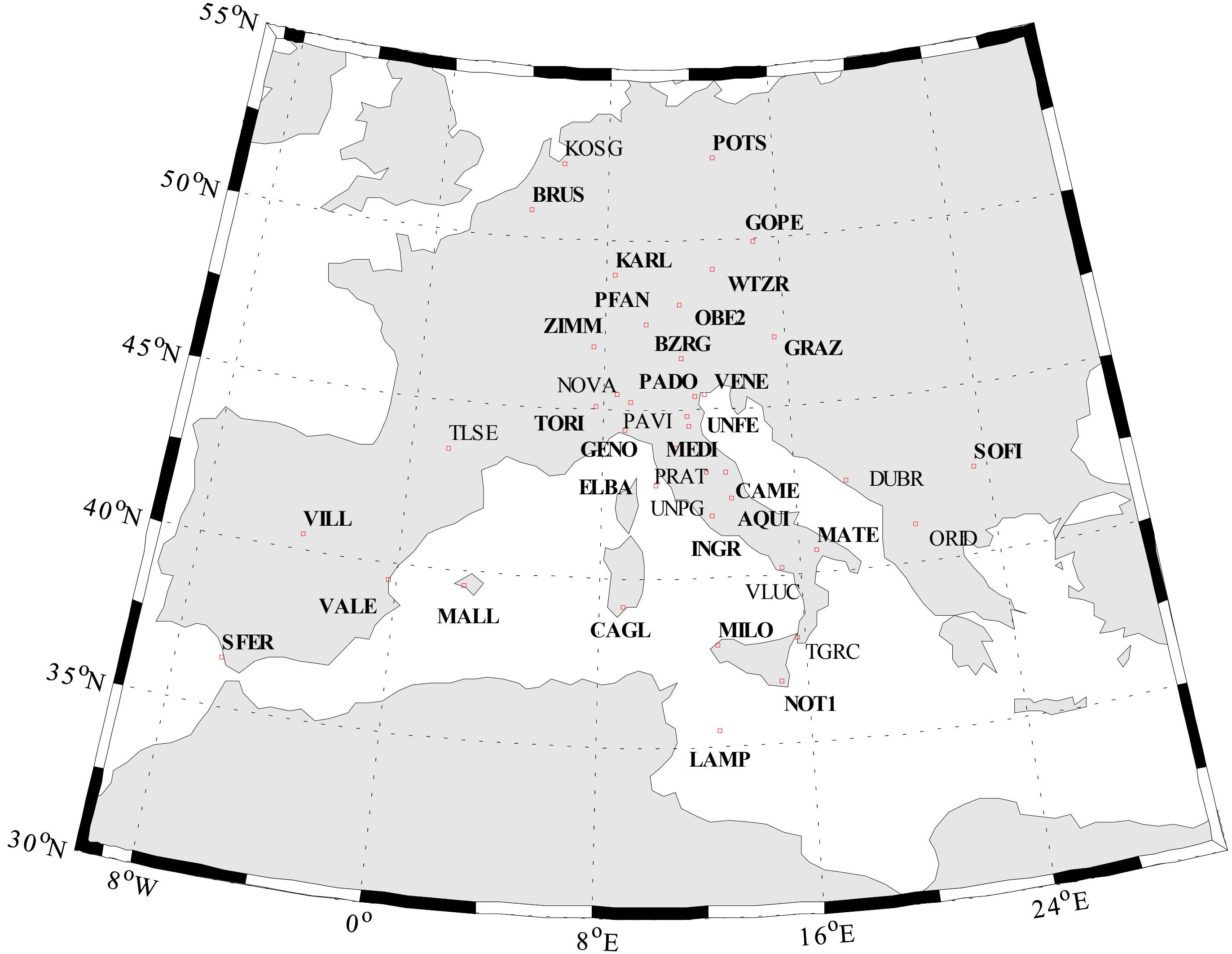
/GEOD/GPSD/NRTDATA/yyyy/doy

Nominal latency 3-12min

MATE high rata data available on line

/GEOD/GPSD/SHRDATA/yyyy/doy

ASI Analyzed GPS Ground Network



40 stations in Post-Processing Mode

30 stations in Near-Real Time Mode

Towards Real Time

Network, Data and Analysis Center Workshop 2002

Near-Real Time GPS Data Processing for Zenith Total Delay Estimation

Software	GIPSY-OASIS II, based on Square Root Information Filter
Strategy	Network Solution
Data Sampling Rate	5min
Cut-off angle	10deg
Sites	30 European Stations, Italy primary region
Data handling	24h sliding window
GPS satellite orbits	Fixed to IGU orbits
'Bad' satellite detection	Sp3 accuracy code
	Automatic detection & removal based on post fit phase observation residuals
'Bad' station detection	Automatic detection & removal based on post fit phase observation residuals
Station coordinates	Heavily constrained to 1 month of post-processed solution aligned to IGS-00
Earth Rotation Parameters	IGU
Ocean Loading	Applied (values provided by H.G.Scherneck)
Mapping function	Niell
ZWD constraint	20mm/sqrt(h)
Estimated Parameters	Satellite & station clocks w.r.t. a reference one
	Phase ambiguities (float)
	ZWD with time resolution of 5 minutes

Near-Real Time Processing Schedule

The NRT processing starts every hour at hh:18

1. GPS hourly files are retrieved from GeoDAF, IFAG & CDDIS;
2. at 03:20 & 15:20 UTC IGU products are fetched from IGSCB;
3. RINEX hourly files are merged into a single file with the previous 23 hours & pre-processed;
4. Parameter estimation & ZTD delivered to U.K. Met Office in COST716 V1.0 format.

The total computing time is about 40min for 30 stations on a workstation HP VISUALIZE C3600.

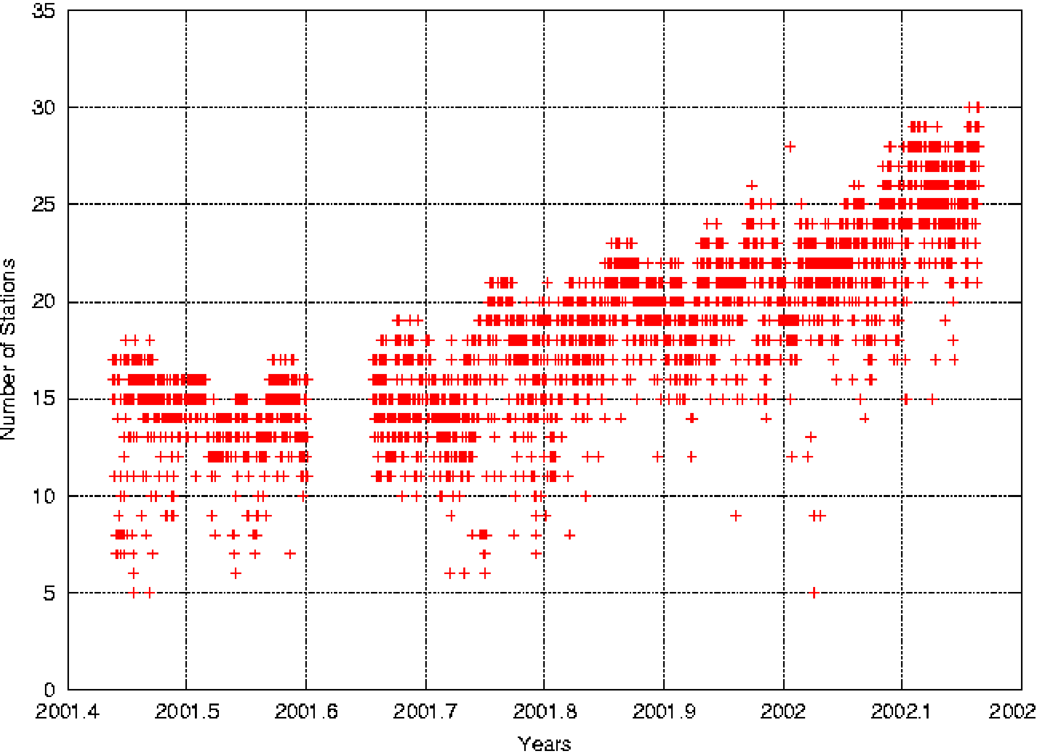
Step 1 to 3 take about 10min, step 4 takes about 30min.

The processing lasts more than the nominal CPU time if a 'bad' satellite or a 'bad' station is detected and removed based on post fit phase observation residuals, in this case step 4 has to be re-run causing an overlap of more batches.

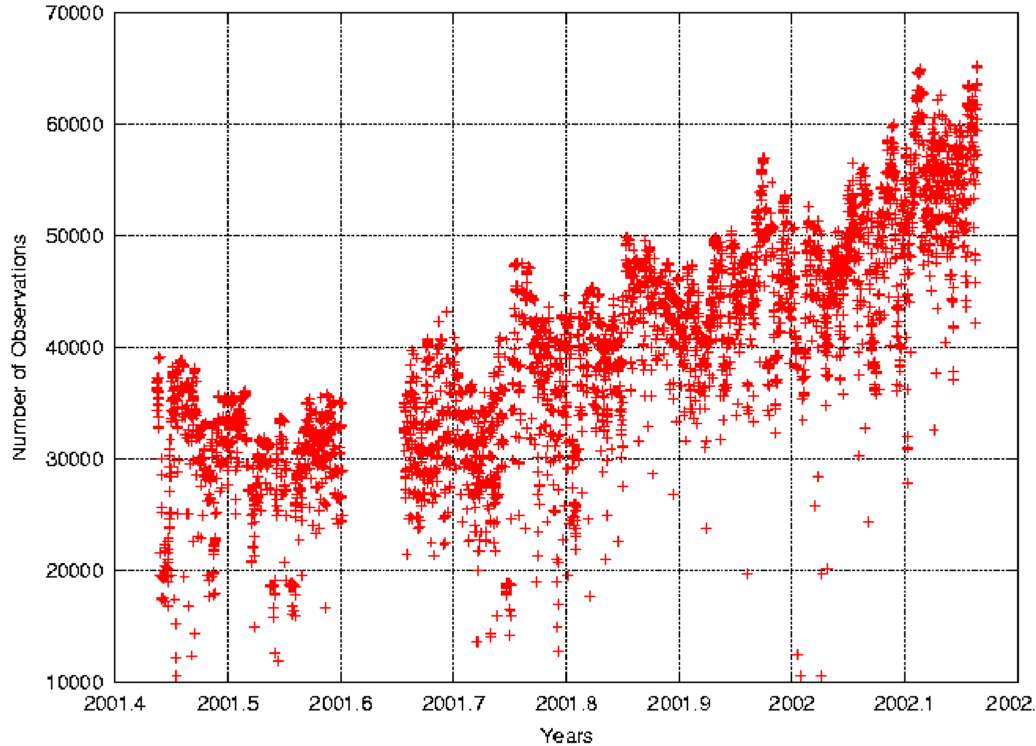
Processing Statistics

June 2001-February 2002

Number of analyzed stations versus time.



Number of observations versus time.



Timeliness and Accuracy requirements for Operational Weather Forecast

Timeliness

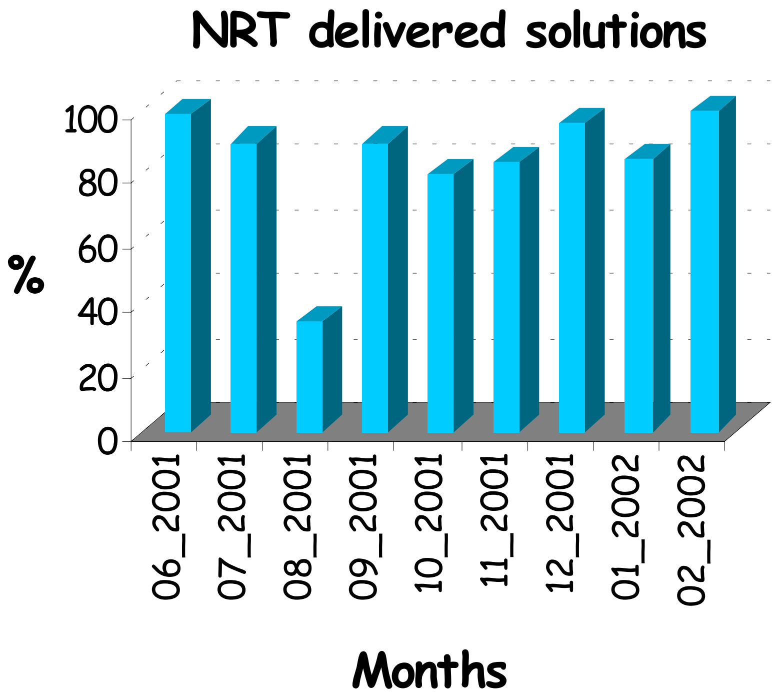
- 75% of observations must arrive within 1h45'
- Use of predicted GPS orbits
  - "Bad" orbits happen
- Fast and reliable data flow (GPS and ZTD)

Accuracy

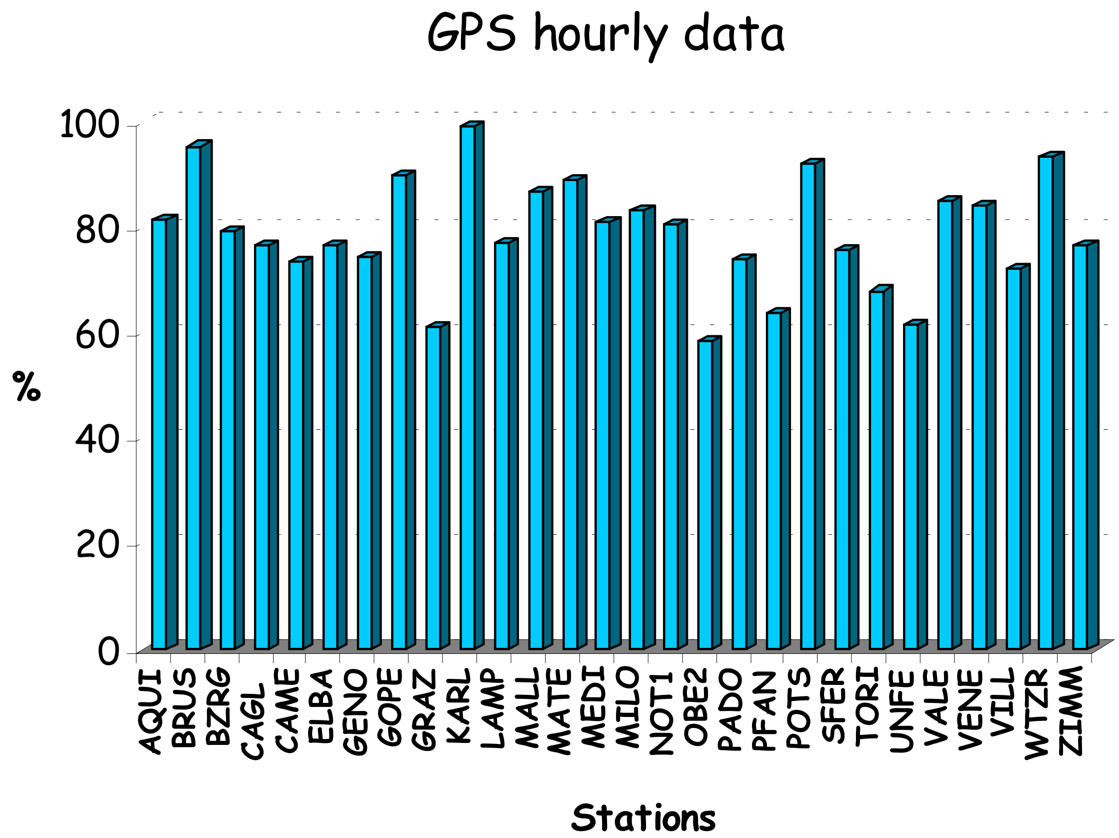
- Use of predicted orbits with minimum degradation of ZTD products w.r.t Post-Processed (NRT STD 3-10mm)
- ZTD retrieved from end of processing window

Near Real Time System Performances

June 2001-February 2002



An average of 80% of NRT solutions are delivered each month.

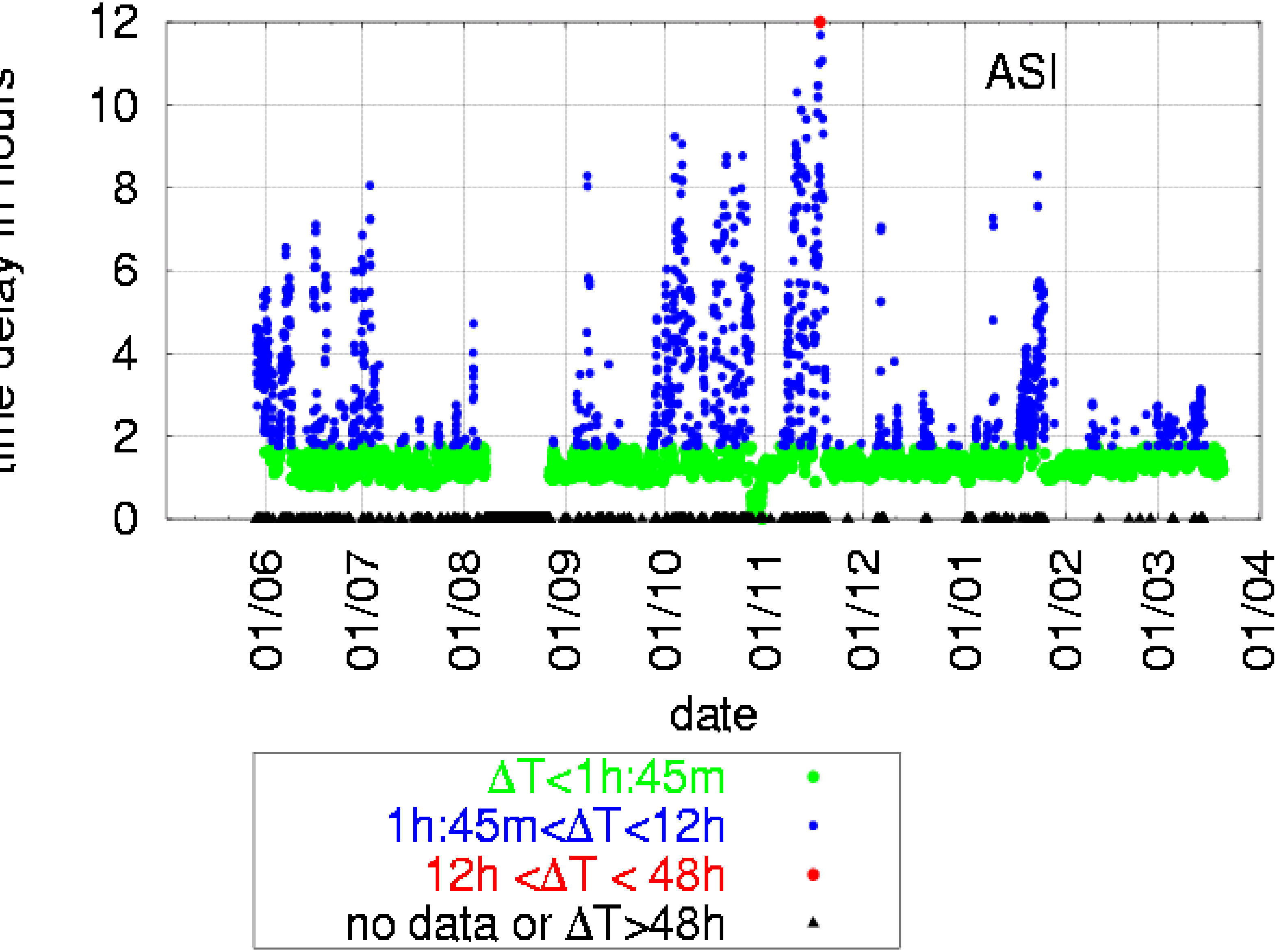


An average of 80% of hourly files are available to be processed in NRT mode. 20% of data arrive too late or are lost.

Near Real Time System Performances

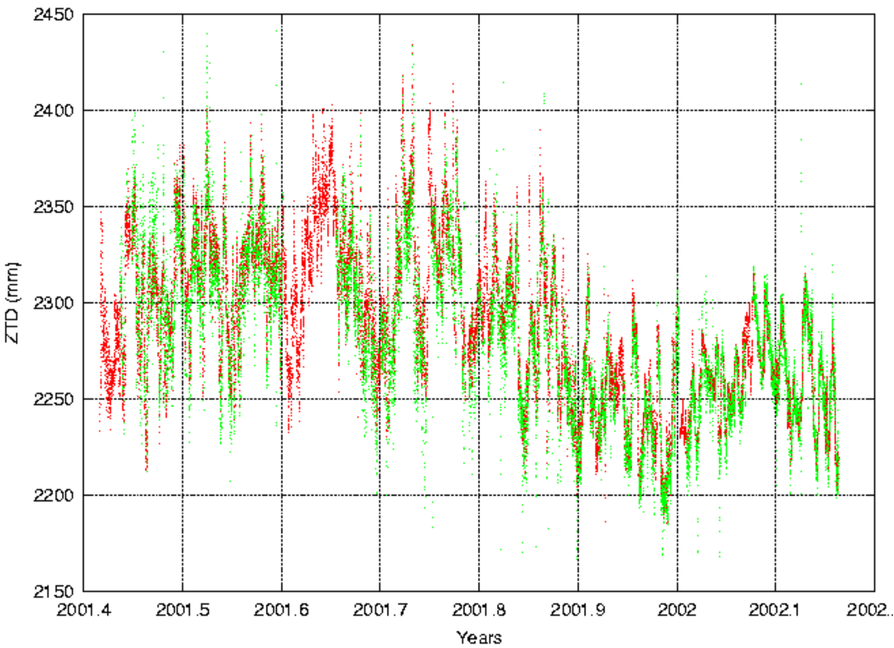
June 2001-February 2002

http://www.knmi.nl/samenw/cost716/stat/latencyASI.html



The green solutions reach the met agencies within 1h45', the blue ones occur when a bad satellite and/or station is detected and removed.

Post-Processed versus NRT ZTD



ZTD time series for Matera.

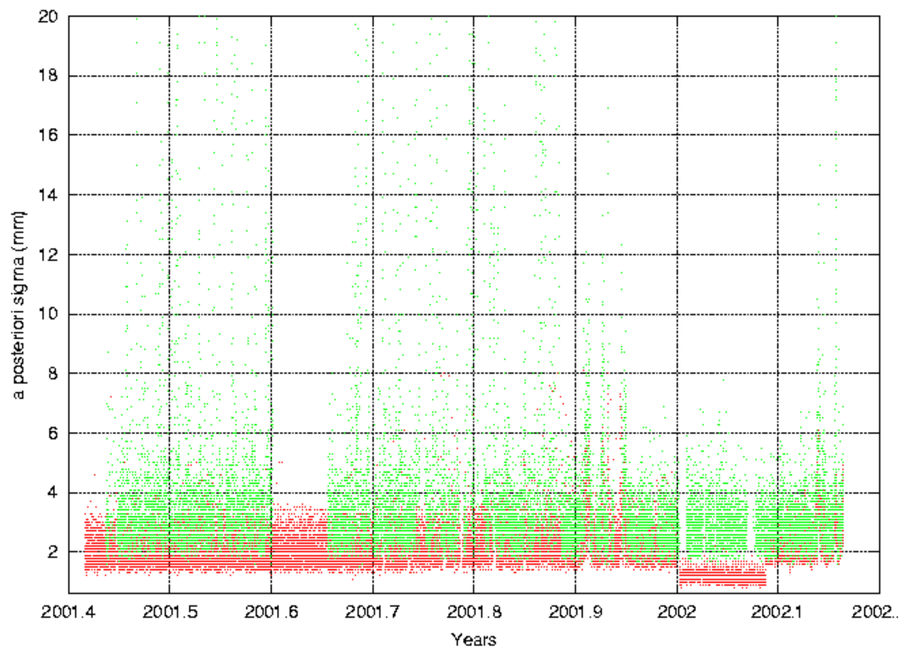
Red= Post-Processed

Green=Near-Real Time

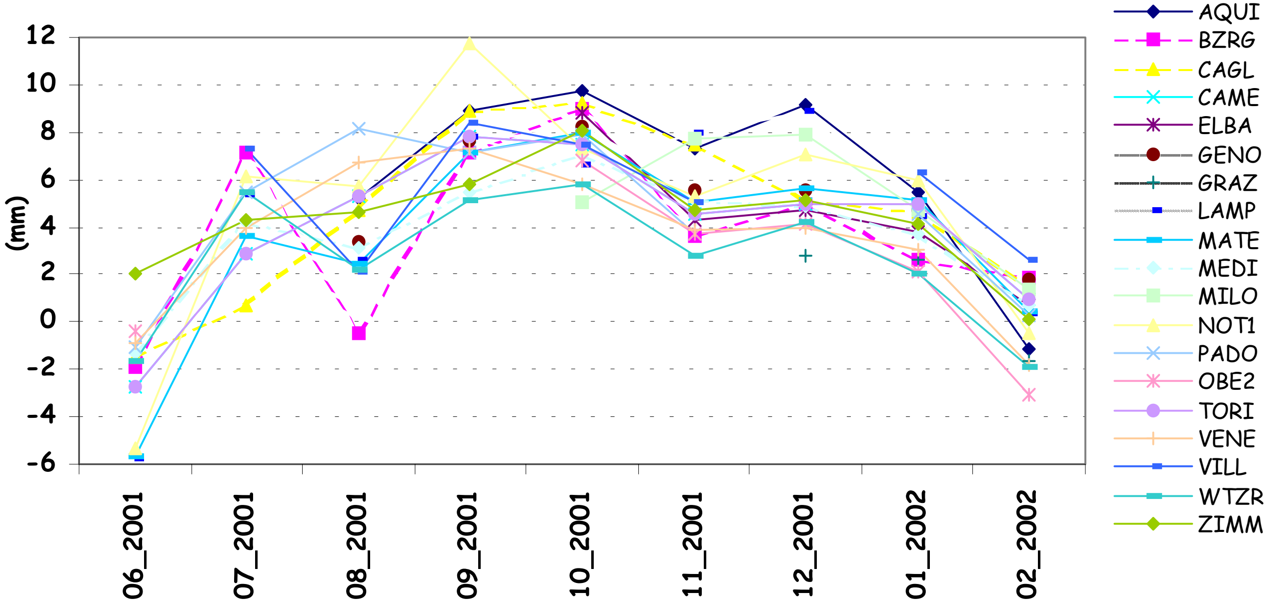
A posteriori σ_{ZTD} for Matera.

≈1,3 mm for Post-Processed

≈1.5, 10mm for NRT

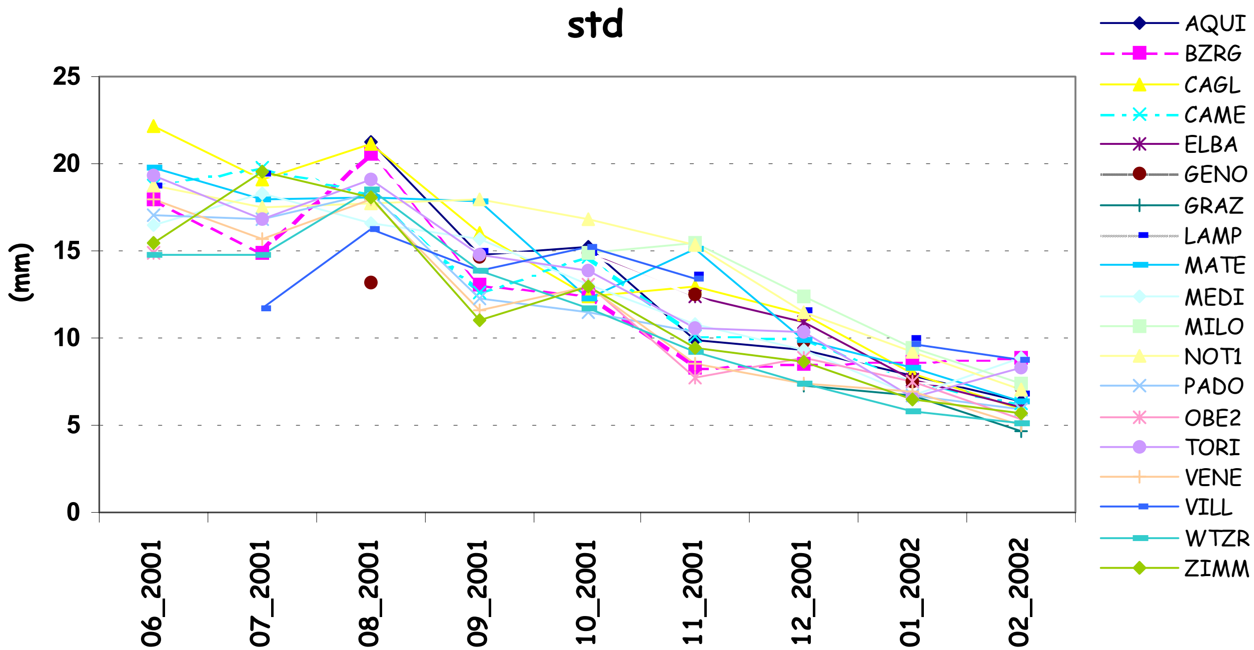


Montly variation in Post-Processed versus NRT ZTD
bias



Bias: -6mm to 10mm

Montlhy variation in Post-Processed versus NRT ZTD
std



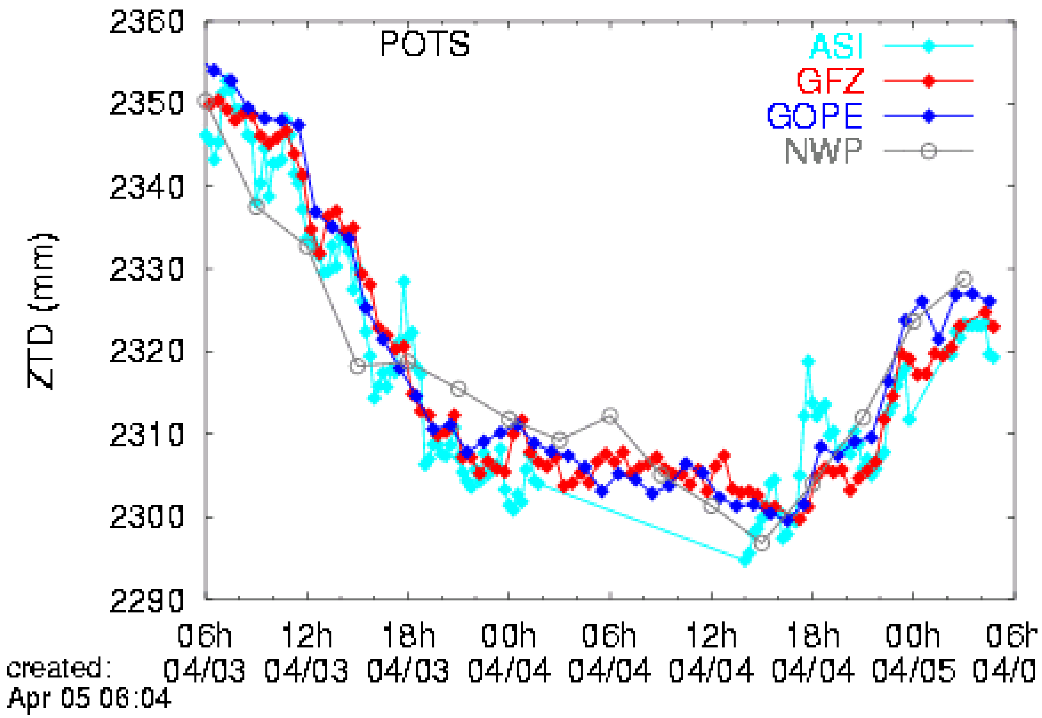
STD: 20mm to 5mm

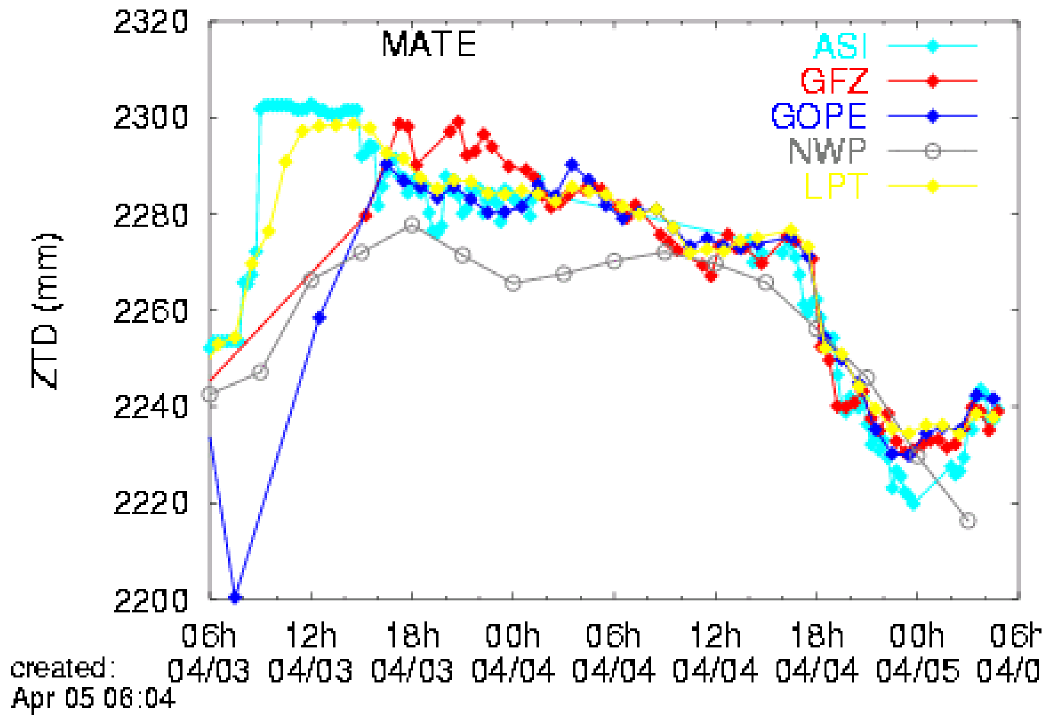
[1 kg/m^2 PWV = 6mm ZTD]

COST-716 NRT ZTD and IWV

http://www.knmi.nl/samenw/cost716/ztd_iwv.html

About 130 sites in Europe continuously monitored in NRT mode, processing distributed among 6 AC.





Comparisons with independent NRT ZTD estimates

BRUS

ASI-GFZ

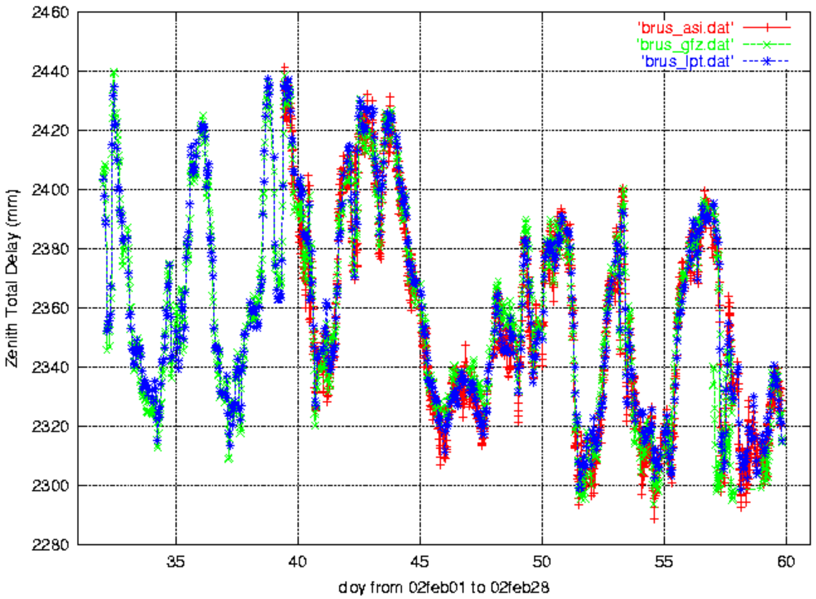
Bias=-1.36mm

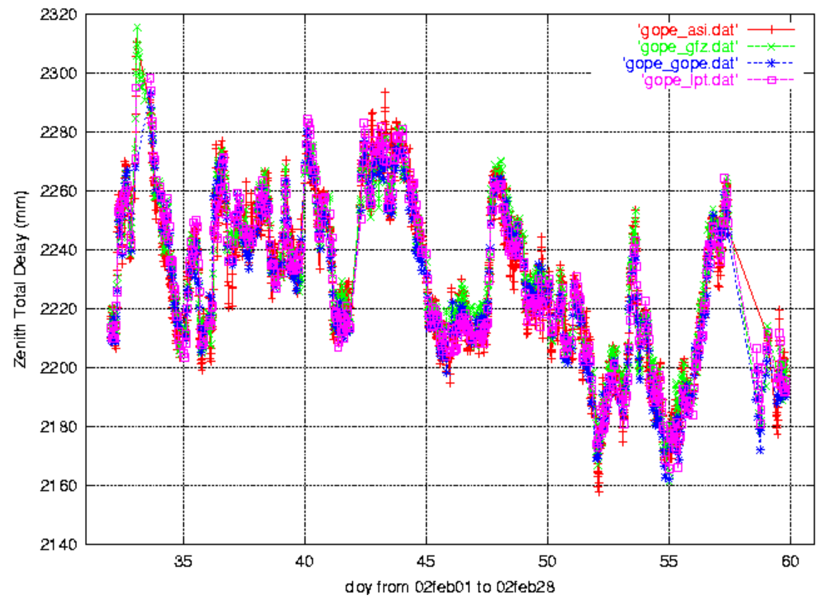
Std=7.12mm

ASI-LPT

Bias=-2.31mm

Std=6.02mm





GOPE

ASI-GFZ

Bias=-1.92mm

Std=5.88mm

ASI-LPT

Bias=-0.20mm

Std=6.19mm

ASI-GOPE

Bias=0.80mm

Std=6.13mm

CAGL

ASI-GOPE

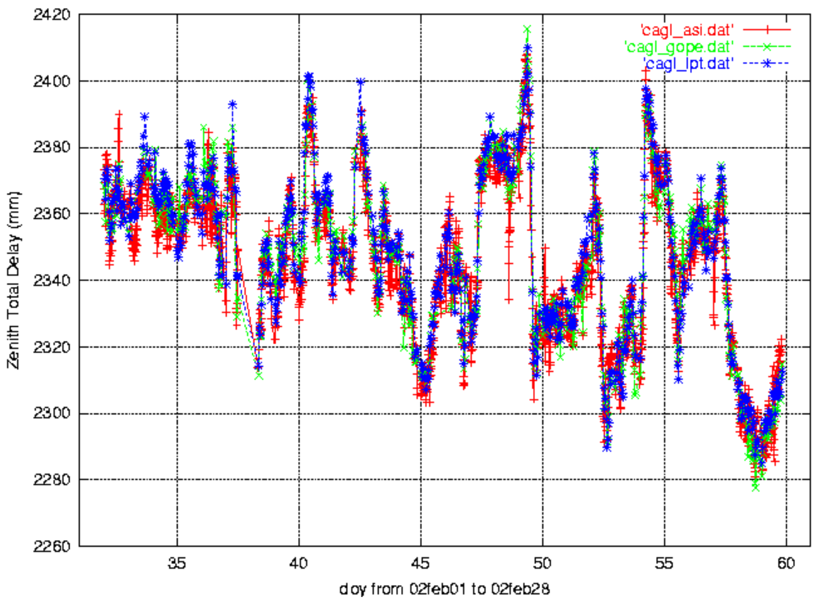
Bias=-2.38mm

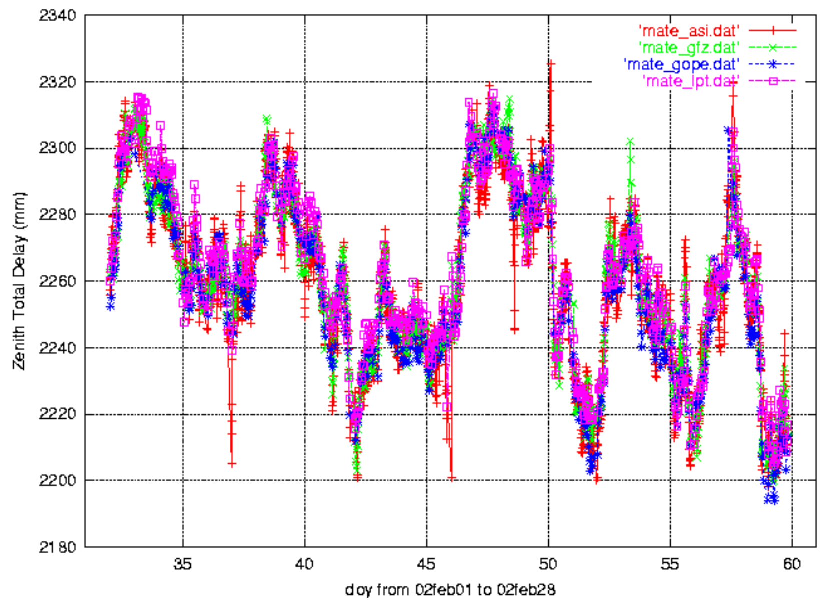
Std=7.04mm

ASI-LPT

Bias=-3.09mm

Std=6.33mm





MATE

ASI-GFZ

Bias=-0.71mm

Std=6.71mm

ASI-LPT

Bias=-3.23mm

Std=7.18mm

ASI-GOPE

Bias=1.46mm

Std=7.70mm

Comparisons with independent NRT ZTD estimates

agenzia spaziale italiana

telespazio s.p.a.

PFAN

ASI-GFZ

Bias=-2.89mm

Std=5.41mm

ASI-LPT

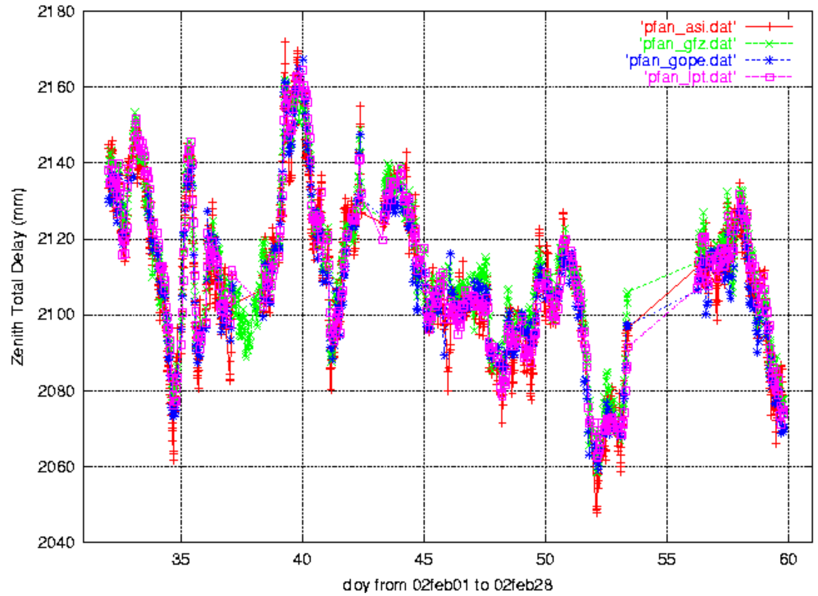
Bias=-1.52mm

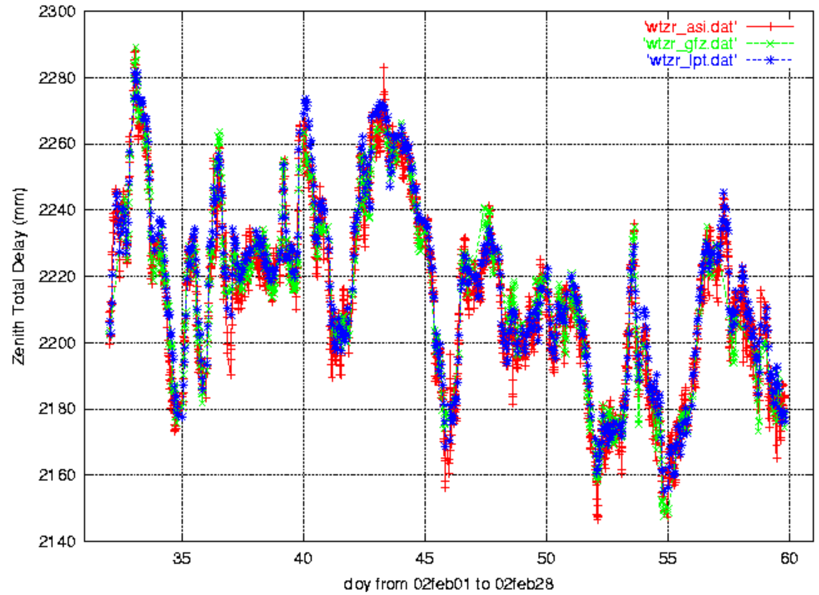
Std=5.92mm

ASI-GOPE

Bias=0.39mm

Std=6.23mm





WTZR

ASI-GFZ

Bias=-0.92mm

Std=6.12mm

ASI-LPT

Bias=-2.75mm

Std=5.52mm

POTS

ASI-GFZ

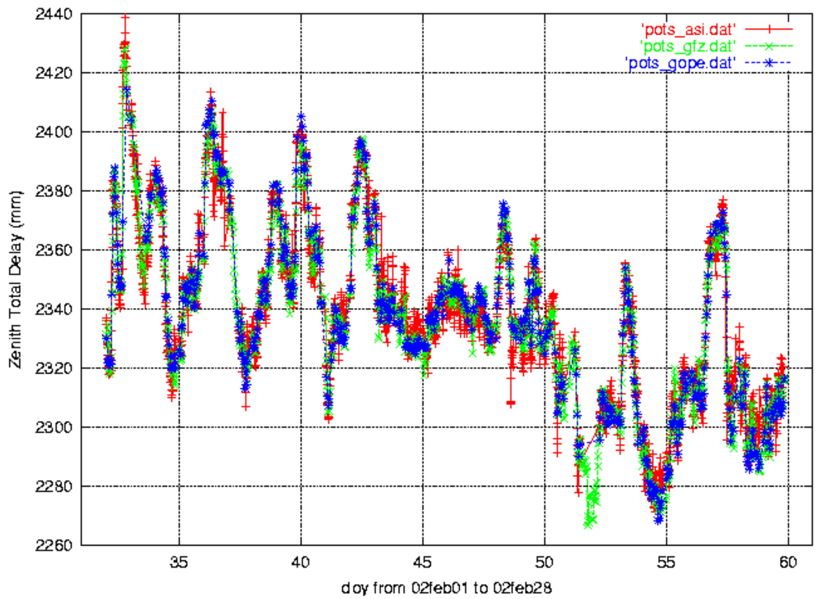
Bias=0.91mm

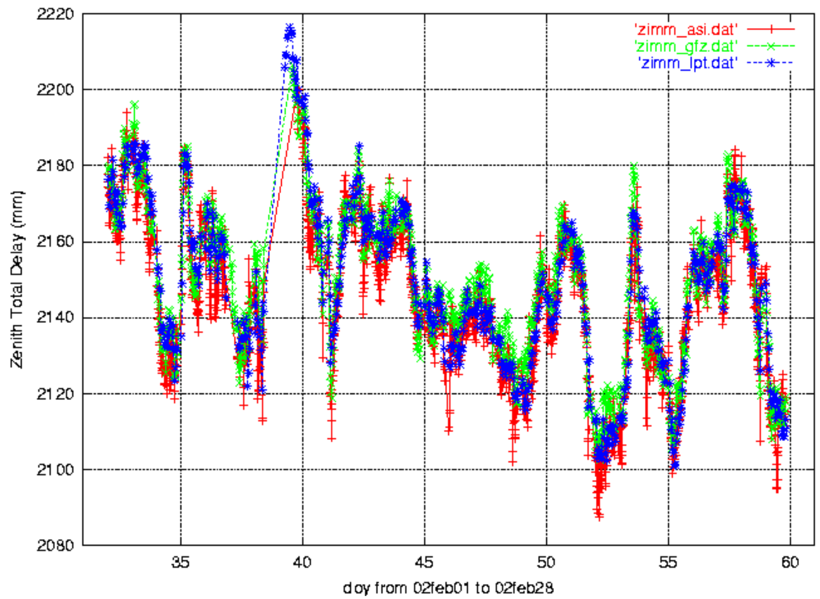
Std=6.14mm

ASI-GOPE

Bias=0.36mm

Std=6.00mm





ZIMM

ASI-GFZ

Bias=-4.54mm

Std=5.98mm

ASI-LPT

Bias=-2.61mm

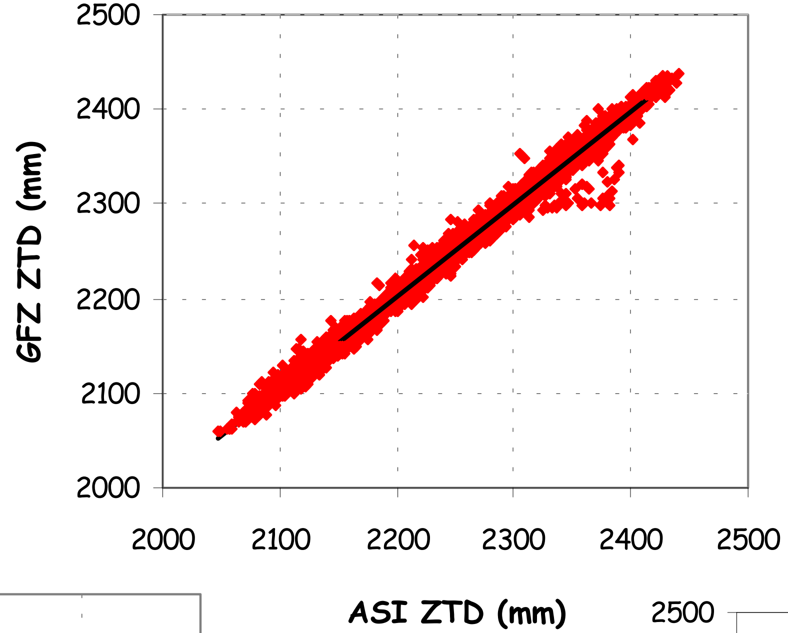
Std=5.95mm

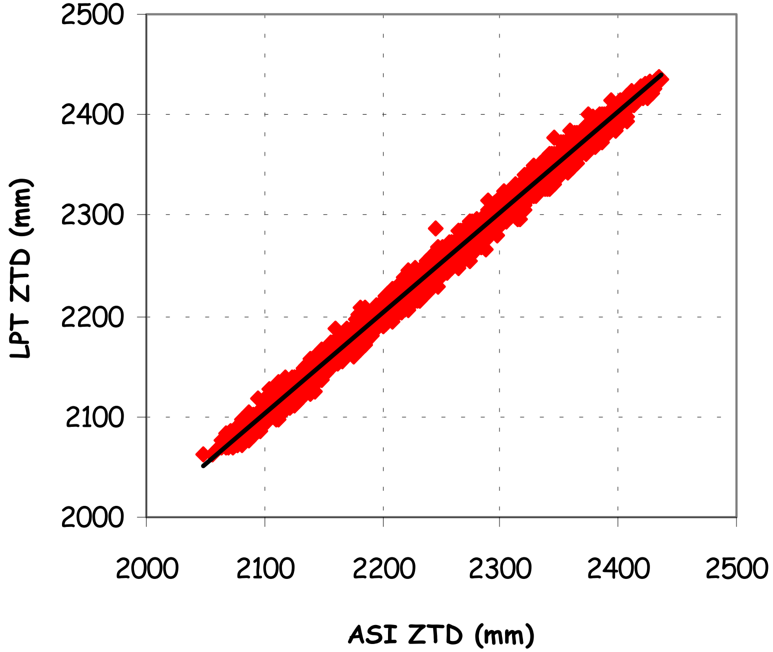
IGS

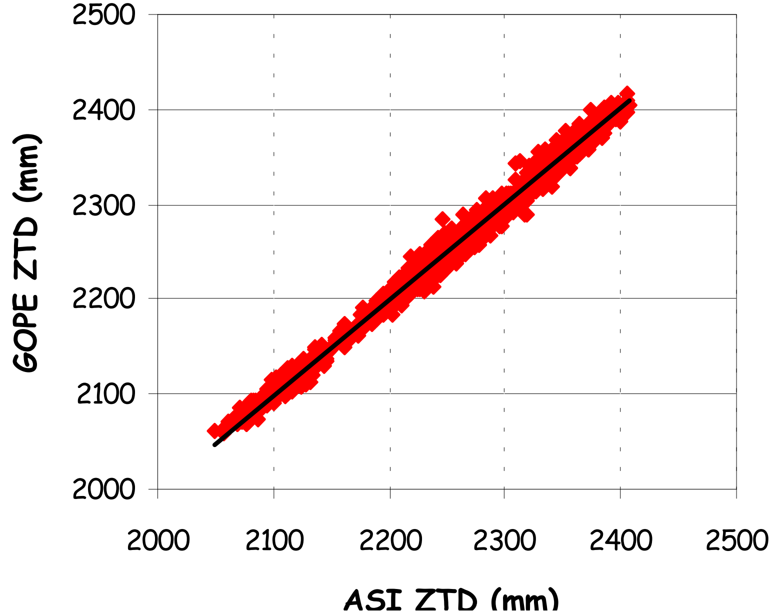
Comparisons with independent NRT ZTD estimates

February 2002

Correlation Coefficient ≈ 1







Conclusions

•A NRT GPS network and a system for ZTD monitoring have been developed in Italy and is in routine operation since June 2001.
  - Post-Processed vs NRT ZTD bias: -6-10mm; std: 20-5mm.
    The std decreases due to processing tuning.
  - Good agreement w.r.t other NRT ZTD solutions (few mm bias; 5-7mm std).

•Operational Weather Forecast Requirement
  - 75% of observations within 1h45' almost reached.

•Critical aspects: hourly data reliability, predicted orbits quality

What IGS can do

AC: IGU orbits are good enough, better are welcome.

Tracking Stations: collect hourly data on a regular and continuous basis to avoid data gaps, and to set-up a fast, efficient and 'machine readable' Quality Check on hourly files to detect 'bad' ones.

IGS workshop “Towards Real Time”, Ottawa, 8 April 2002

What about using GPS for Weather Forecasting?

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E-mail: H.vanderMarel@geo.tudelft.nl

Ground-based GPS for Meteorology

Proof of concept has already been given by many (inter)national studies and projects.

Two (main) types of applications:

	Latency:
1. Operational meteorology	
a. Numerical Weather Prediction (NWP)	< 1h45m (near real-time)
b. Forecasting and nowcasting applications	< 1h (real-time)
2. Climate research and monitoring	Post processing

Need Zenith Total Delay (ZTD) or Integrated Water Vapour (IWV)

Operational potential is the topic of COST Action 716:

Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications for Europe

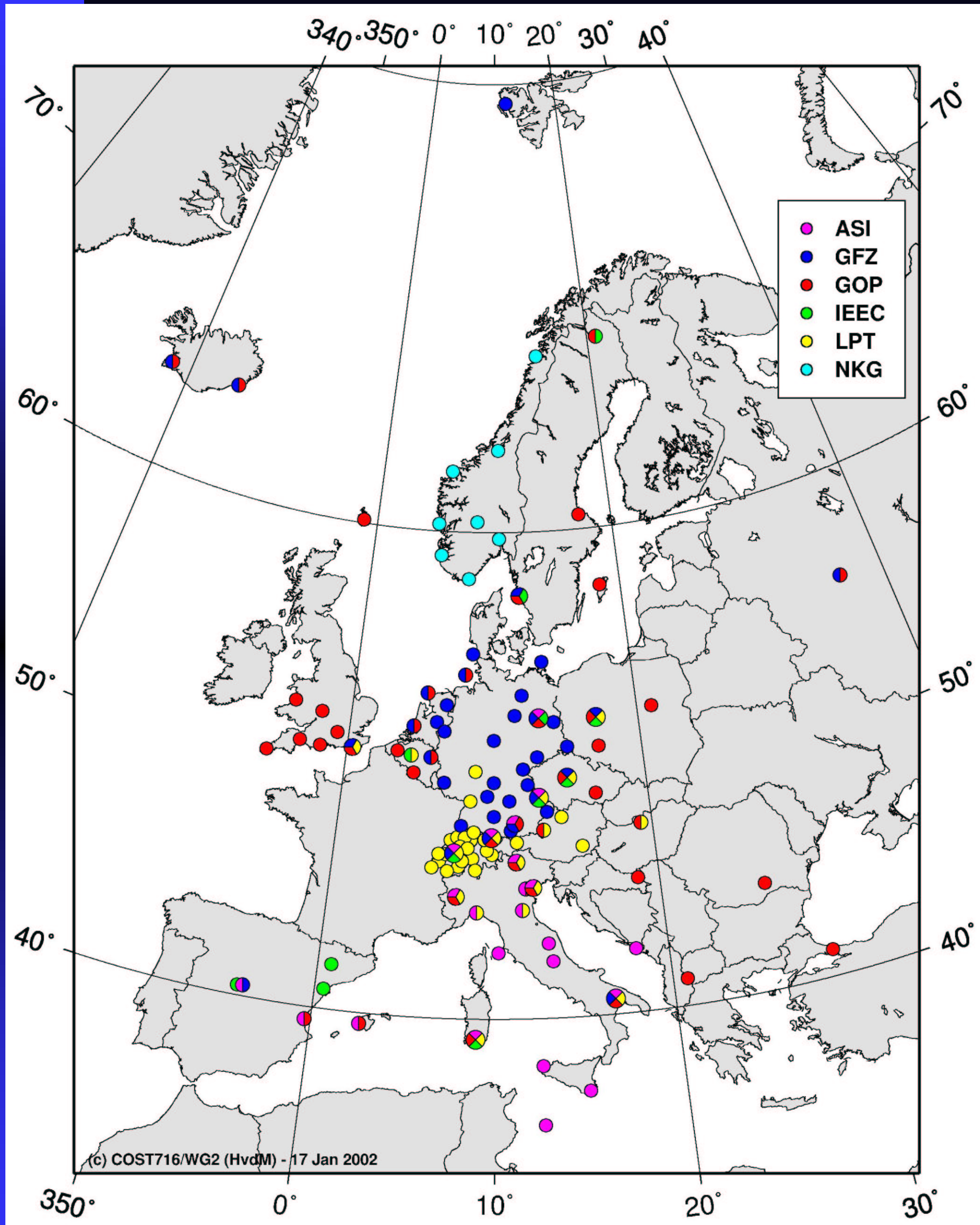
COST-716 Action

Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications for Europe

- Action in force September 1998 (duration 5 years).
- Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and UK.
- Promotes co-operation within Europe by funding workshops and working group meetings
  - 1st Workshop 10-12 July, 2000, Oslo, Norway
  - 2nd Workshop 28-29 January, 2002, Potsdam, Germany
  - Final Workshop planned for 2003
- Brought together geodesists and meteorologists
- 4 working groups

COST-716 Working Groups

1. State of the art and production requirement
2. Demonstration project
   a) Benchmark dataset
      - To test and validate algorithms, dataflow, etc. for NRT
      - 9-23 June, 2000, 44 stations by 7 analysis centers
   b) Near real time network demonstration (NRT)
      - Started March 2001, over 100 GPS stations, 6 analysis centers
   c) Post-processed network for Climate applications
      - based on EUREF troposphere combination
3. Assimilation into NWP and assessment of impact
4. Planning for the operational phase



NRT demonstration trial

Started March 2001

Operational A/C's:

GFZ, GOP, IEEC, ASI, LPT, NKG

>100 stations

Expected soon:

CNRS/ACRI, others?

http://www.knmi.nl/samenw/cost716.html

COST716 NRT demonstration trial (1)

- Organised around several near real-time networks
- GPS data collection and processing handled by analysis centers
  - uses IGS and EPN data centers, completed with several local data centers, resulting in a dense network
  - analysis independent from EPN and IGS
- Analysis centers are relatively “free” to organise the processing as they like, as long as they
  - compute properly validated Zenith Total Delays (ZTD),
  - with a well defined quality indicator,
  - in an agreed format (COST v1.0 format),
  - within <u>1 hour 45 minutes</u>
- ZTD will <u>not</u> be combined (would only delay results)

COST716 NRT demonstration trial (2)

- ZTD within 1h45m to UKMO in the COST format (ftp)
  - Acts as a gateway to participating meteorological institutes
  - Converted into BUFR format (used on the GTS)
- Ftp-mirror at TUD/Delft (holds the full archive)
- The ZTD is converted to IWV at KNMI using
  - Measured pressure and temperature at GPS site
  - Pressure and temperature interpolated from nearby synoptic sites

  Displayed on the WWW; IWV data available by ftp

  http://www.knmi.nl/samenw/cost716.html
- The ZTD are used for NWP assimilation trials by WG/3

COST format v1.0 for ZTD/IWV

- The proposed exchange format is the COST v1.0 format (based on CLIMAP) or BUFR format
- The COST v1.0 is an ASCII format that can be converted into BUFR
- BUFR is the standard format used on the GTS network

- COST format has been adapted to include slant delays, processing statistics, q/c information
- Includes also surface meteo data and IWV
- COST files can contain data for more than one station (virtual files)

NRT analysis centers

GPS analysis centers which contribute to the NRT trial are:

ASI_ Agenzia Spaziale Italiana, Matera, Italy
GOP_ Geodetic Observatory, Pecny, Czech Republic
GFZ_ GeoForschungsZentrum, Potsdam, Germany
IEEC IEEC, Barcelona, Spain
LPT_ Federal Office of Topography, Wabern, Switzerland
NKG_ Nordic Geodetic Commission (Statens Kartverk, Norway)

Expected (soon?):
NKG_ Nordic Geodetic Commission (Onsala Space Obs. Sweden)
ACRI Valbonne, France (will take over from CNRS)
Others…?

Different processing strategies and software are used

NRT analysis strategy (1)

	software	#stations	#global	strategy
ASI	GIPSY	24		Sliding window
GFZ	EPOS	41(115)	25	Global + PPP
GOP	Bernese	46	0	NEQ stacking
IEEC	GIPSY	12		Sliding window
LPT	Bernese	43	8	NEQ stacking
NKG	GIPSY	20	35	Global + PPP

> 110 stations at least one of 6 analysis centers

~ 22 stations observed by 2 analysis centers

~ 8 stations observed by 3 analysis centers

~ 10 stations observed by 4 analysis centers

NRT analysis strategy (2)

	software	elev. cut-off	data window	ZTD Samples	Data Samples
ASI	GIPSY	10	24 h	15 min *)	300 sec
GFZ	EPOS	15	12 h	30 min	2.5 min
GOP	Bernese	10	12 h	1 h	30 sec
IEEC	GIPSY			15 min	
LPT	Bernese	10	7 h	1 h	30 sec
NKG	GIPSY	10	24 h	15 min?	?

*) averaged from 5 minute ZTD estimates

NRT analysis strategy (3)

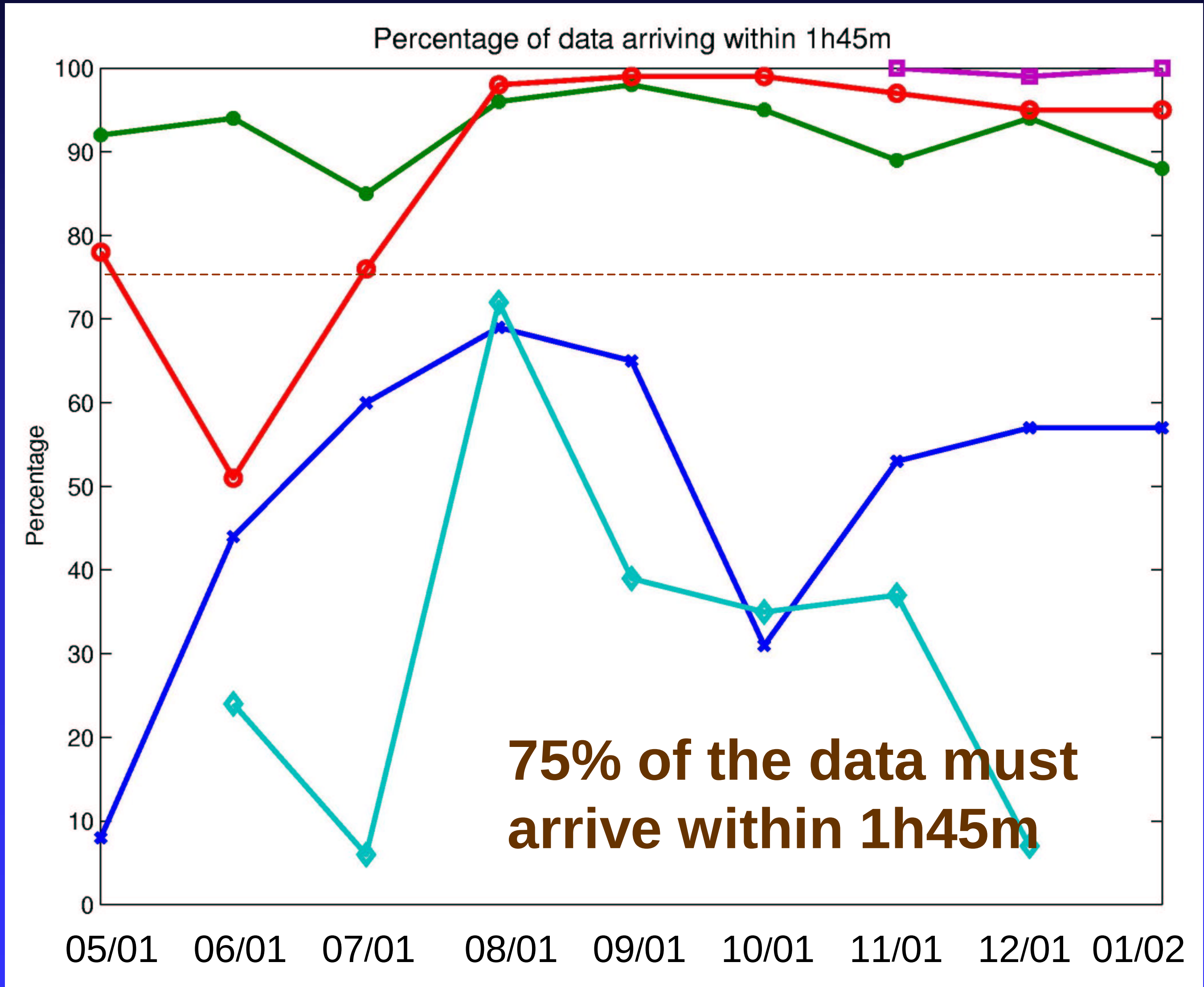
	software	orbits	Orbit relax.	Coordi-nates	Ocean loading
ASI	GIPSY	IGS Ultra	No	Free	Scherneck
GFZ	EPOS	GFZ Ultra	Est 2)	Fixed GFZ	Patiatakis
GOP	Bernese	IGS Ultra	No 1)	IGS-00 3)	Scherneck
IEEC	GIPSY				
LPT	Bernese	IGS Ultra	No	ITRF2000 3)	Scherneck
NKG	GIPSY	IGS Ultra ?	Est 2)	ITRF2000	?

1) satellites can be excluded in 2 iterative steps

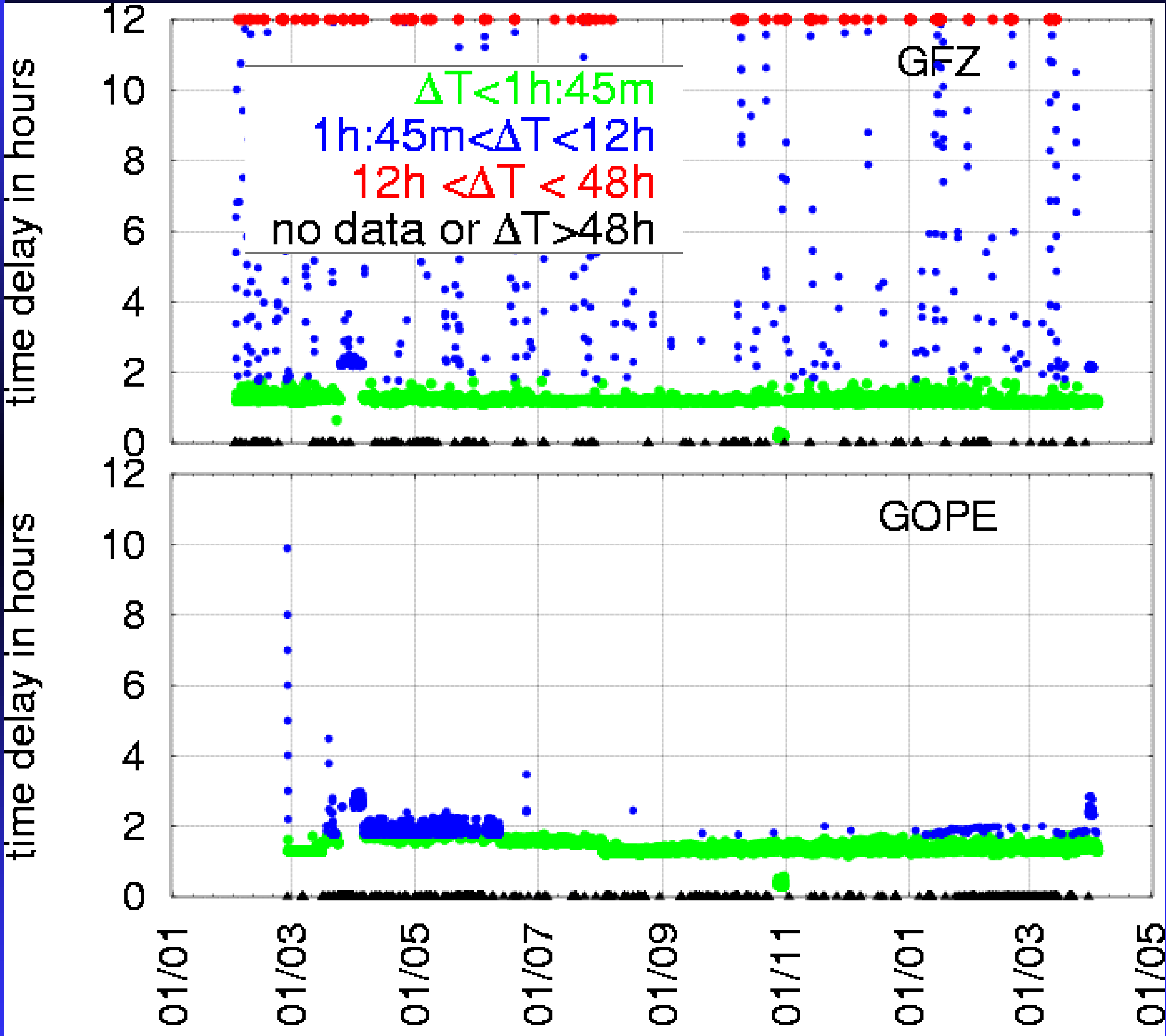
2) satellite orbits and clocks estimated from global network

3) coordinates updated monthly

Percentage of NRT data within 1h45m



Display of time delay on the WWW



http://www.knmi.nl/samenw/cost716.html

Accuracy of results

Comparison with combined post-processed solution for the special benchmark campaign (9-23 June 2000, NW Europe) :

		NRT			Post processed		
Center	#sites	Stdev	Bias	Scatter of bias	Stdev	Bias	Scatter of bias
ASI	43	4.14	-0.69	+-1.75			
CNRS	41	5.34	-1.51	+-1.26	3.2	-2.2	+-1.3
GFZ	41	4.84	-5.04	+-1.44	2.9	-3.9	+-1.3
GOP	42	6.41	1.19	+-1.69	2.8	1.4	+-1.0
IEEC	23	5.11	-1.12	+-1.76			
LPT	43	5.14	2.35	+-1.05	3.3	4.8	+-1.3
NKG	39	4.45	0.83	+-0.99			

Units in mm ZTD

Radiosonde	GPS	Distance
Cam/UK	CAMB	2.8 km
	NEWL	20.4 km
Ded/D	WSRT	66.5 km
Dlg/D	LDBG	1.2 km
	POTS	73.8 km
Hem/UK	HEMS	1.7 km
	LOWE	25.4 km
Her/UK *)	HERS	4.4 km
Ler/UK	LERW	4.4 km
Ndb/NL	KOSG	43.8 km
	DELF	55.7 km
Pay/CH	ZIMM	81.3 km
	EXWI	84.5 km
Sel/SWE *)	ONSA	37.9 km
Jbg/DK	ONSA	184.4 km
Wat/UK	NOTT	9.8 km

Comparison with Radiosondes

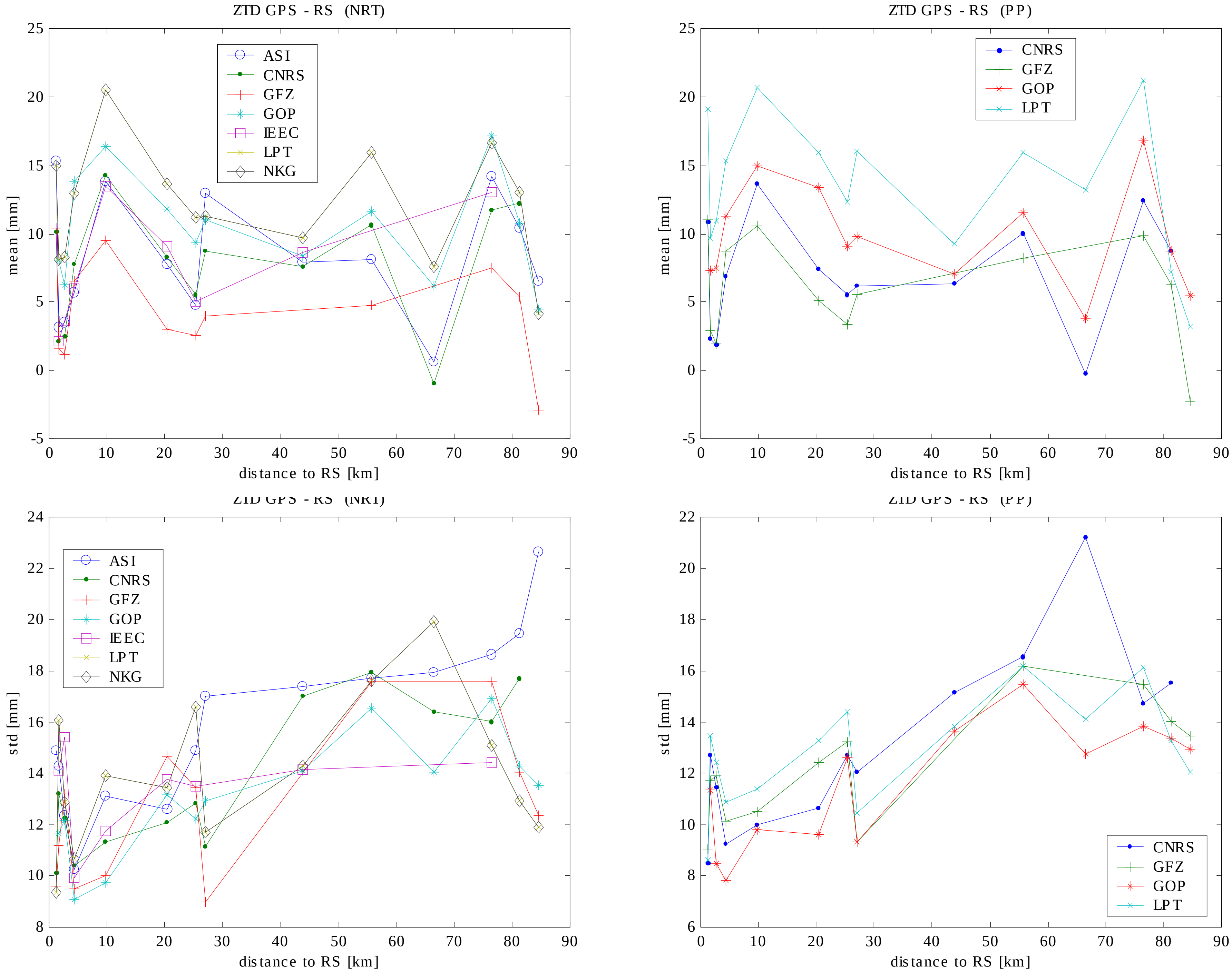
ZHD from surface pressure and Saastamoinen

ZWD and IWV from integration of radiosonde profile

RS data from Her/UK and Sel/SWE not yet processed

Benchmark dataset

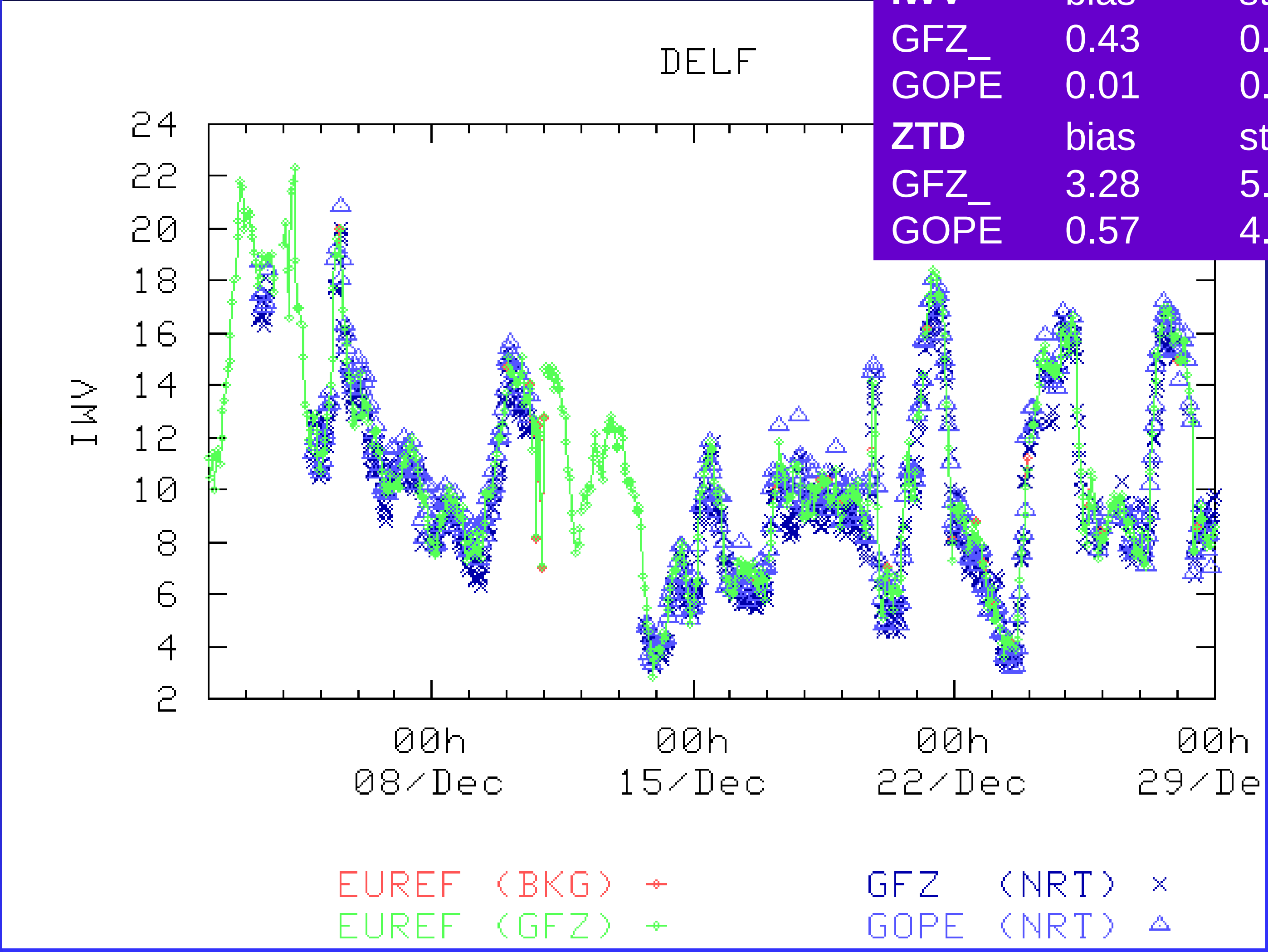
RS data processing courtesy Siebren de Haan, KNMI



ZTD GPS - RS (NRT)
ASI
CNRS
GFZ
GOP
IEEC
LPT
NKG
mean [mm]
distance to RS [km]
ZTD GPS - RS (PP)
CNRS
GFZ
GOP
LPT
mean [mm]
distance to RS [km]
ASI
CNRS
GFZ
GOP
IEEC
LPT
NKG
std [mm]
distance to RS [km]
CNRS
GFZ
GOP
LPT
std [mm]
distance to RS [km]

Comparison with EUREF combination

IWV	bias	st.dev.	
GFZ_	0.43	0.84	mm
GOPE	0.01	0.65	mm
ZTD	bias	st.dev.	
GFZ_	3.28	5.56	mm
GOPE	0.57	4.21	mm



Numerical Weather Prediction (NWP)

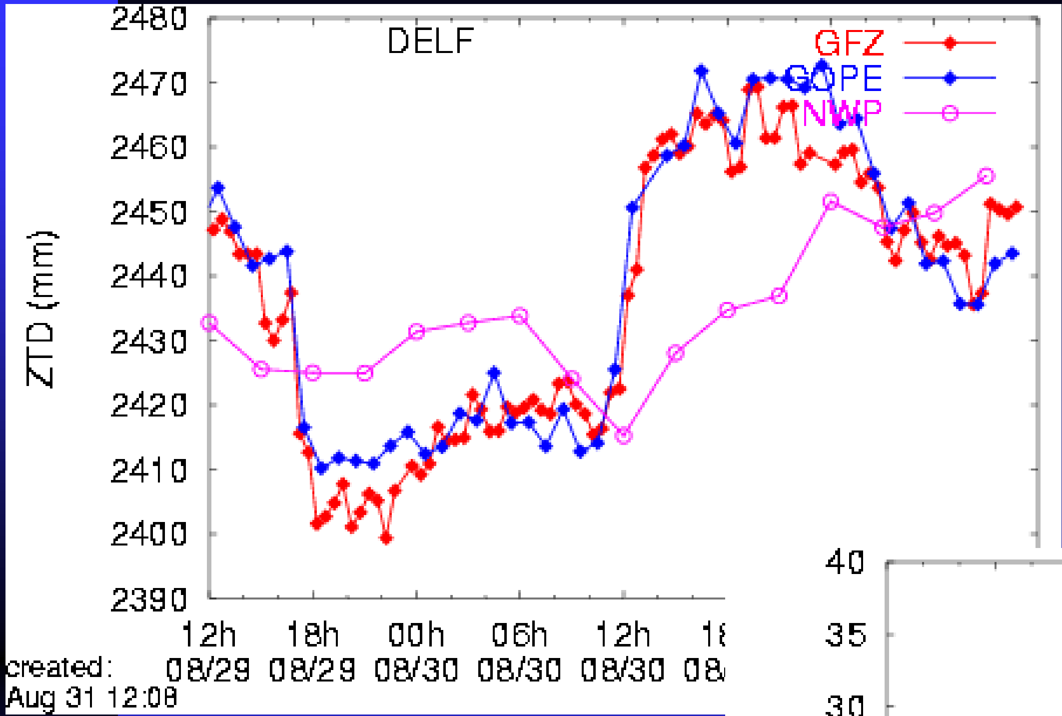
- Assimilation of observations
  - Optimal Interpolation (nudging techniques)
    - assimilate at grid points and regular intervals
    - based on profiles: GPS --> pseudo profiles (risky)
  - 3D-VAR (assimilate at location of observation)
  - 4D-VAR (assimilate at location and time of observation)

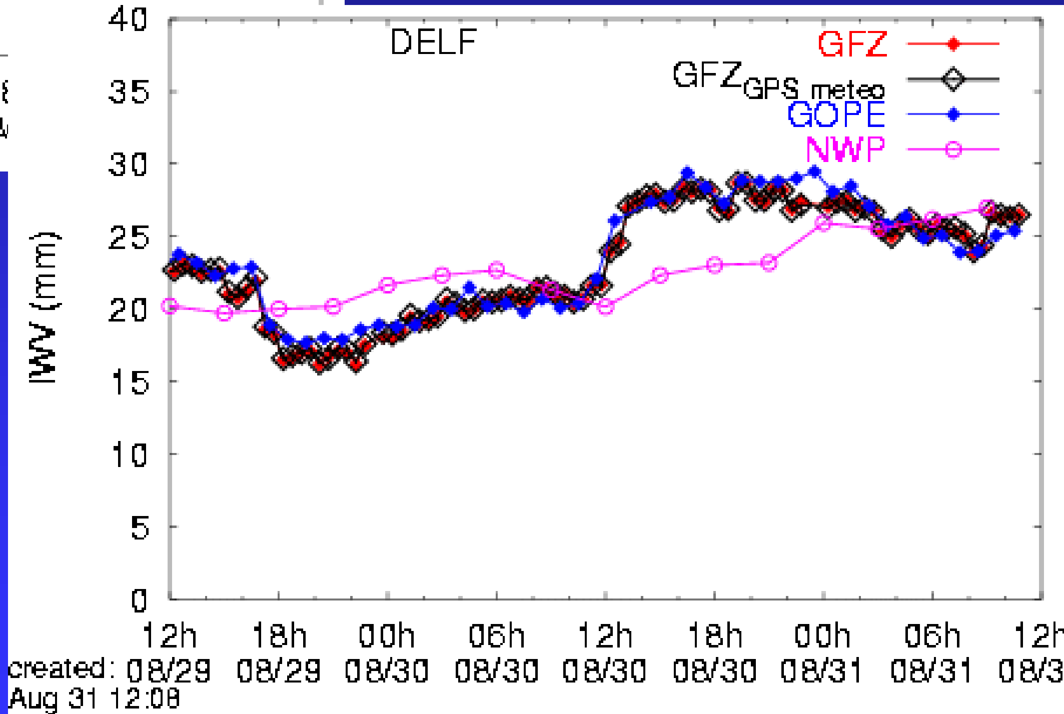
  Assimilation and forecast period are typically 3 and 6 h
- Spatial domain and horizontal resolution
  - Range from regional to high resolution local/mesoscale models
  - Highest resolutions are now typically 12 km
  - Resolution and domain are tradeoffs with computer power
- Number of vertical levels (typically about 30)
- Background model (ECMWF)

Numerical Weather Prediction (NWP)

- No operational assimilation in Europe yet
- Results from assimilation trials show
  - that GPS data does not make the forecast worse
  - in some cases a slight improvement in the forecast of precipitation
- Why is the impact of GPS presently only marginal?
  - radiosondes and other data tend to dominate the models and models are tuned for these observations
  - (high resolution) 4D-VAR models would be better at utilizing GPS data
  - takes time to get new types of data accepted into the existing operational models
- Comparisons against HIRLAM were extremely useful and often highlighted major discrepancies with the GPS observations, which would be useful for forecasting if available in time

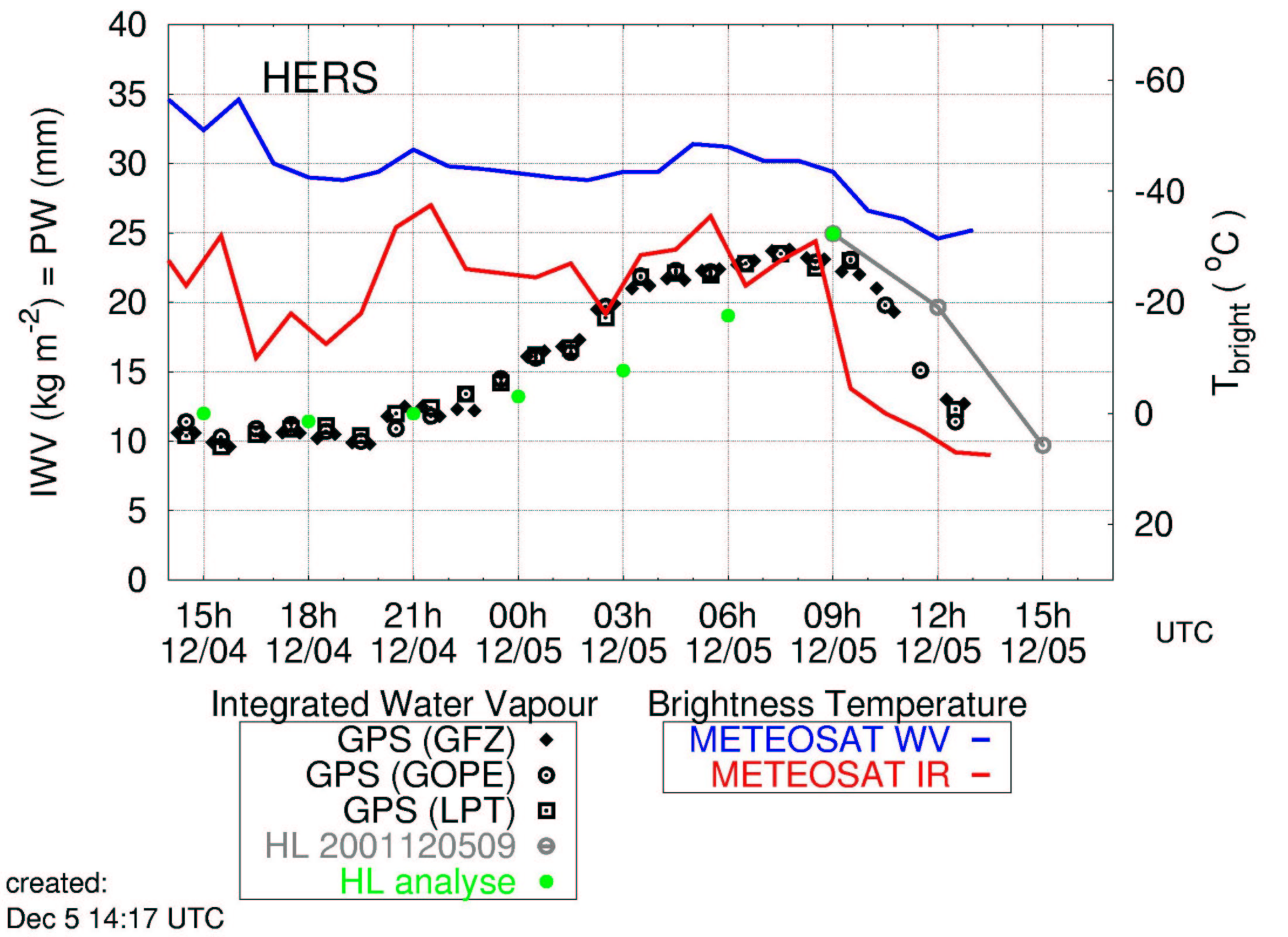
Comparison of ZTD and IWV with HIRLAM





http://www.knmi.nl/samenw/cost716.html

Example of forecasting application (1)

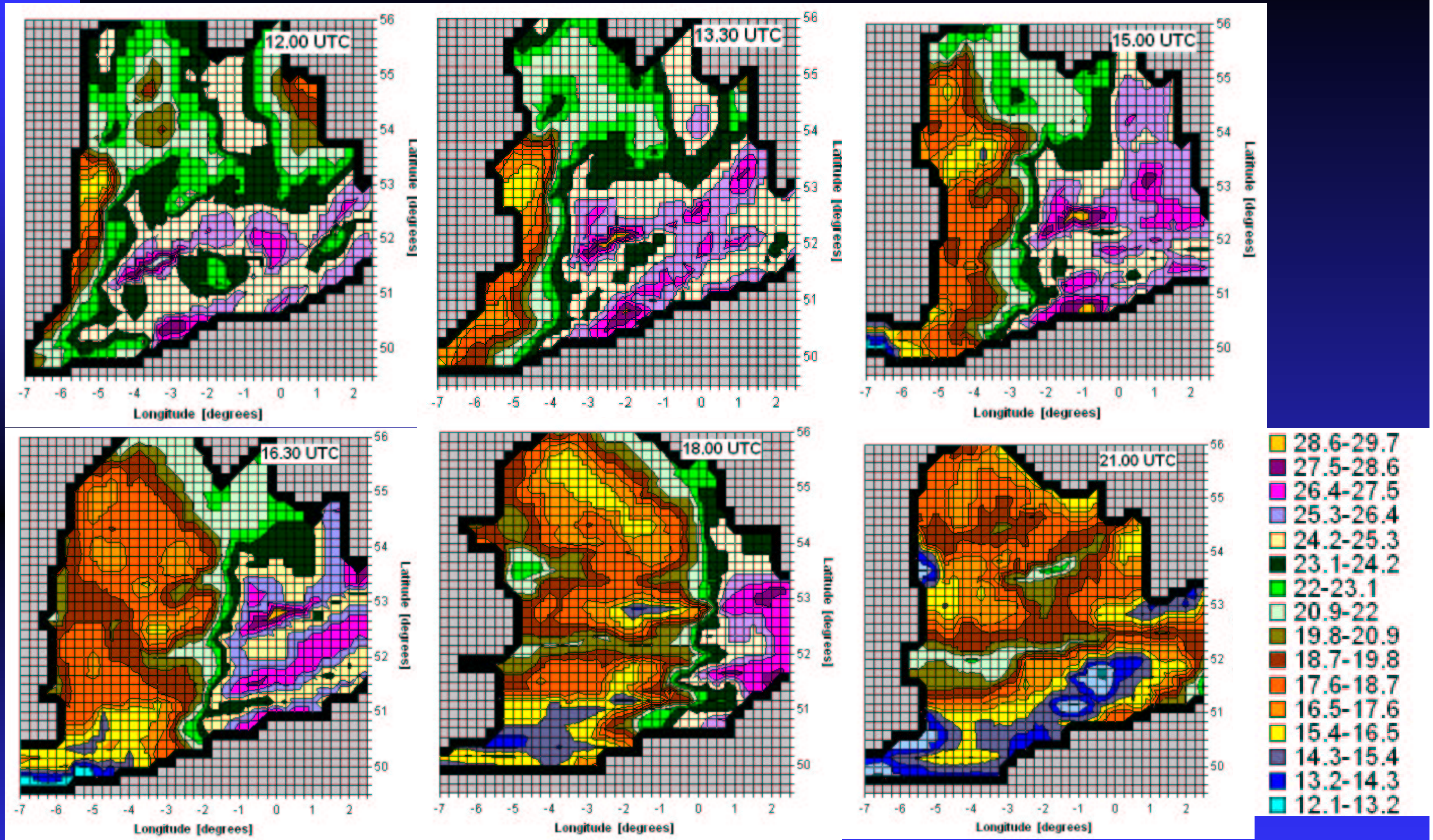


Courtesy Siebren de Haan, KNMI, The Netherlands

Example of forecasting application (2)

- Using archived data at IESSG, Nottingham
- 30 station network, station separation of 70 km
- 15 minutes temporal resolution
- Winds at 3km used to advect IWV values at times other than nominal (within 2 hours) to enable more detailed contours to be drawn

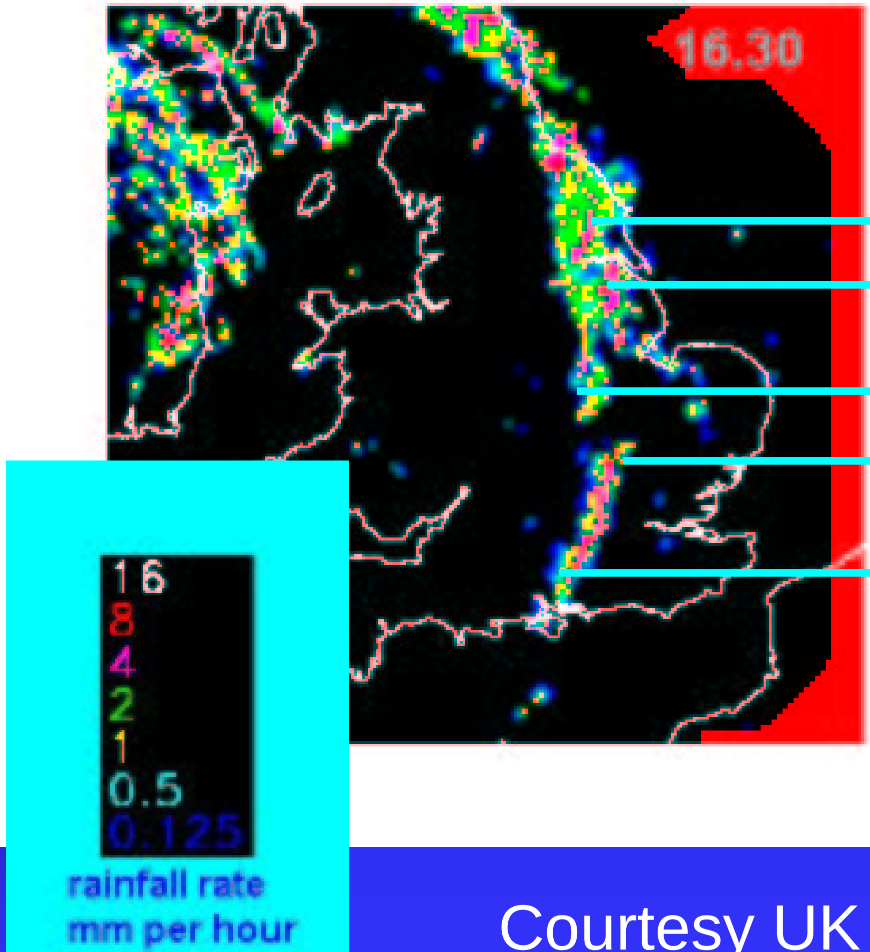
- Data for 10 July 2001
- Speed of advection between 5-20 m/s
- Equivalent spatial resolution of 20 km

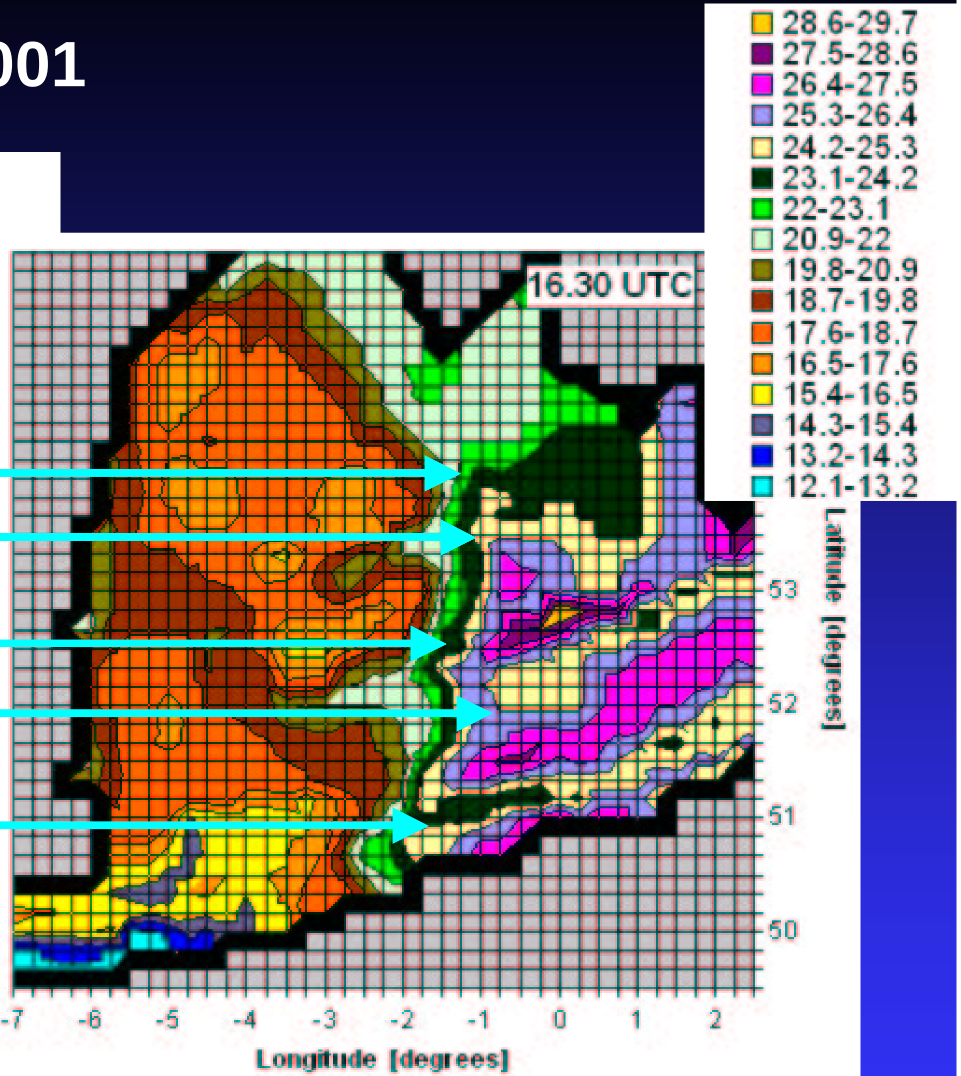


IWV in mm for 10 July 2001

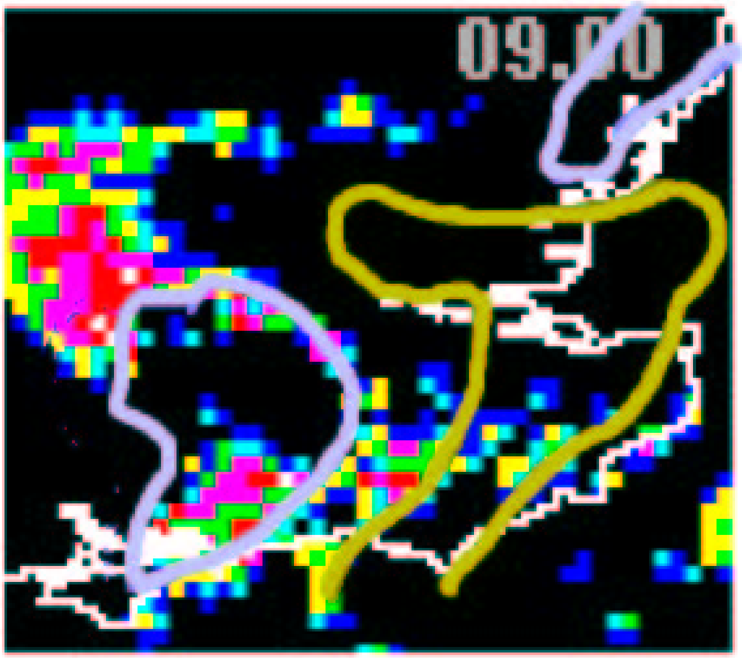
Courtesy UK Met Office, IESSG

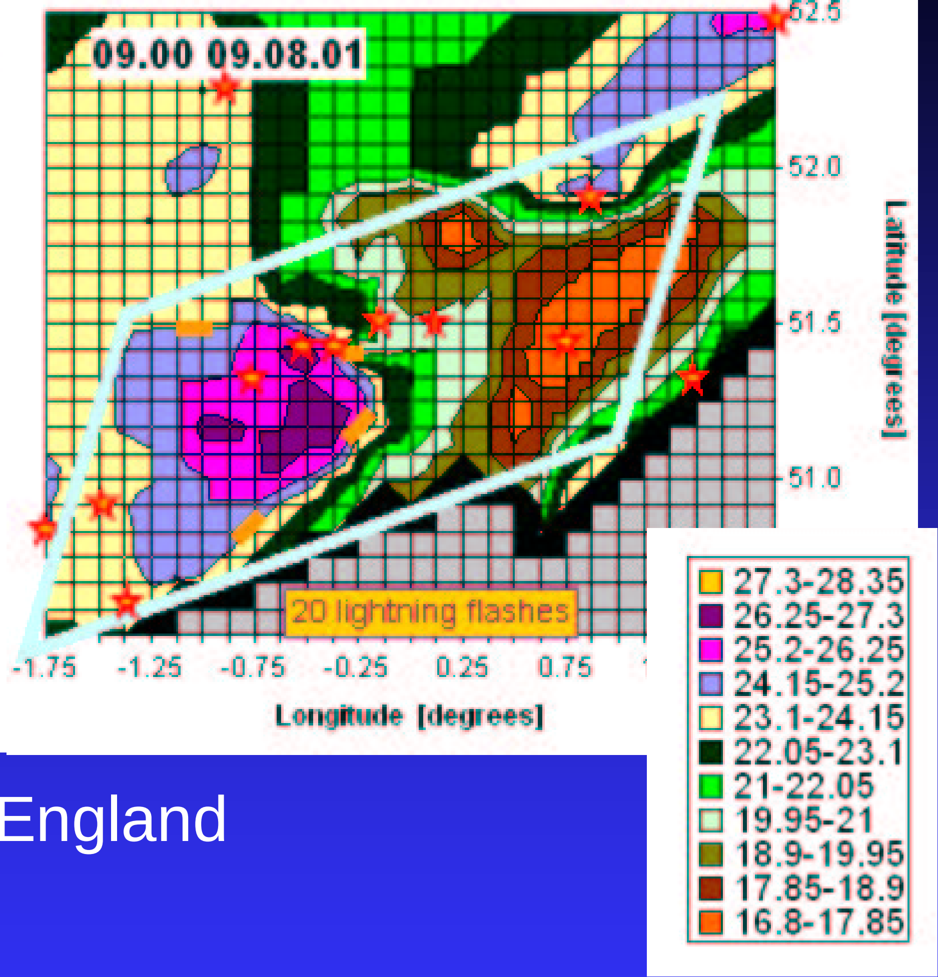
IWV in mm for 10 July 2001





Courtesy UK Met Office, IESSG





Thunderstorms in South East England

9 August 2001

Estimated at 9 km spatial resolution / 12 stations

Courtesy UK Met Office, IESSG

Assessment of optimal density

- Must be determined from trials and impact studies
- Initial studies indicate that for forecasting applications a spacing of 50-70 km is required (in a few areas even a higher density)
- But don't wait with using GPS
  - Use what is available now at whatever spacing (the additional investment is not very large anyhow)
  - There are enough GPS sensors deployed now to demonstrate capability, even if the network is not ideal
- Many countries have or are in the process of setting up (commercial) networks for Real Time Kinematic (RTK)
- Should try to form partnerships

Post-processing network for climate

- The requirements for climate research and climatology are basically the same as for the NRT network, but
  - more precise, smaller biases (absolute accuracy 1 kg/m^2) and long term stability (< 0-2 g/m^2 decade) demanded
  - less strict on timeliness (1-2 months)
  - use time- and spaced-averaged water vapour columns
    - horizontal sampling 1° x 1° to 0.5° x 0.5°
    - time resolution 1-5 days or hours for special projects
  - no direct interest in zenith delays
  - time domain >> 10 years (source WG/3)
- Starting point: EUREF combined troposphere product
  - conversion to IWV
  - comparisons with NRT

Conclusion (1/2)

- COST-716 has shown it is possible to compute ZTD for NWP within 1h45m using existing GPS networks
- The accuracy is sufficient for NWP and forecasting
- GPS data does not make the forecast worse, or at best GPS has a slight positive impact on the forecast of precipitation
- NWP is not expected to benefit fully from GPS data until 4D-VAR is operational
- Comparisons against NWP are extremely useful and often highlight major discrepancies with the GPS observations
- Several nowcasting and forecasting applications emerged
  - data interval of 15 minutes (instead of 15-60 minutes)
  - timeliness of a real time service (latency < 1 hour)
  - spatial scale of the data can be regarded as sub-regional
  - horizontal spacing of better than 70-100 km

  Accuracy and reliability should be more or less the same as NWP

Conclusion (2/2)

- Weather forecasting needs primarily IGS Orbits and Clocks
  - computations of ZTD should be performed on computers managed by meteorological institutes in liaison with geodetic institutes
  - orbit improvement, or the processing of a global network, should not be necessary for the ZTD processing
  - real-time orbits and clocks could be needed for some applications
- Is (near) real-time ZTD from IGS needed?
  - maybe for constraining of stations common with IGS (could apply to double difference processing)?
  - maybe for comparison purposes?
- Operational weather prediction does not fall into a single category
  - Some aspects are scientific, some civil, some military (e.g. the UK Met Office is a Ministry of Defence agency), some commercial.
  - It is more of a problem for operations than in the development phases where the work can be treated as purely scientific

Acknowledgements...

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G. Weber, BKG, Frankfurt, Germany

plus all the anonymous station managers supplying hourly GPS data, IGS, EUREF and other data and analysis centers.

Real-Time Delivery of the Canadian Spatial Reference System - Strategy, Challenges and Applications

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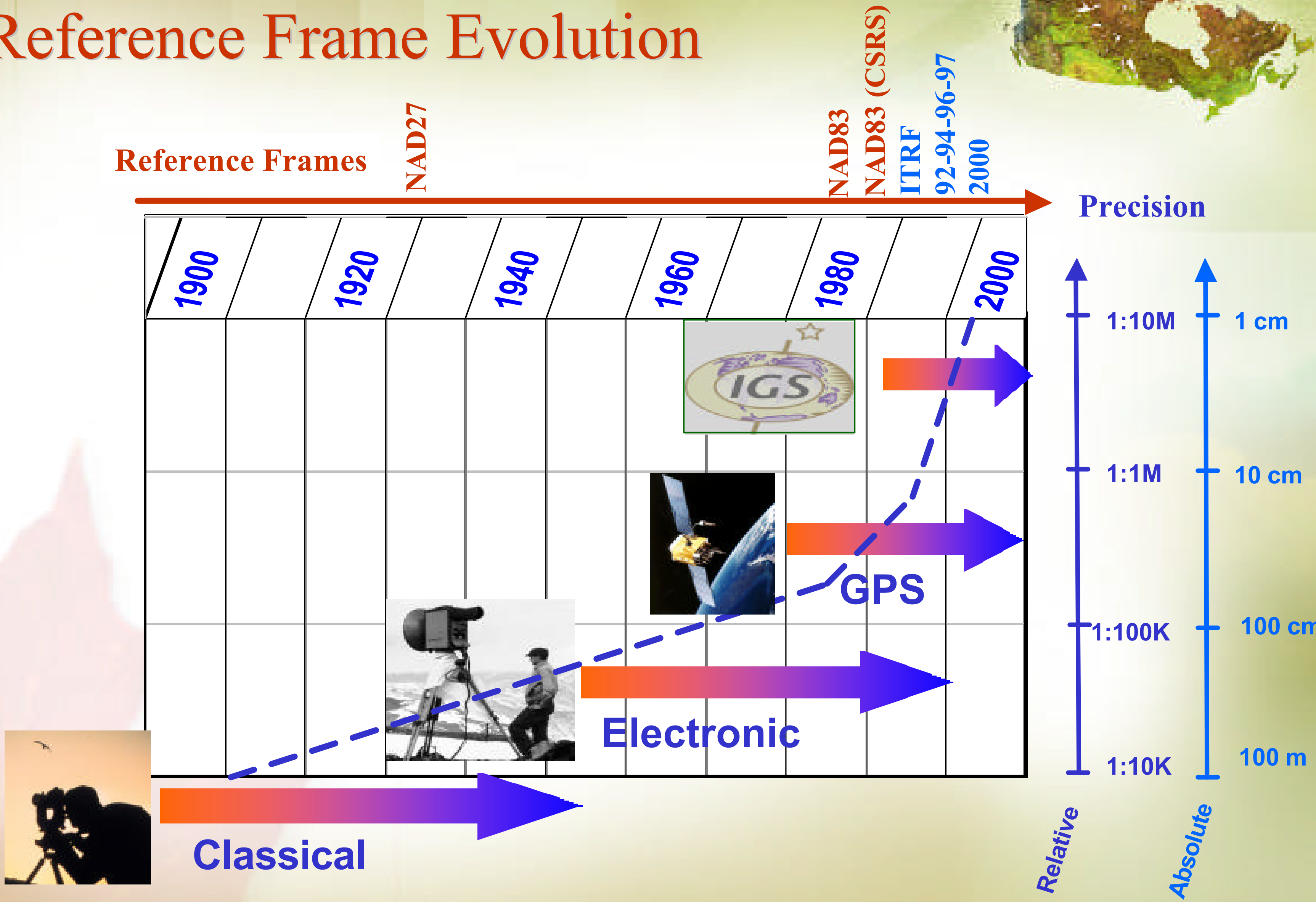
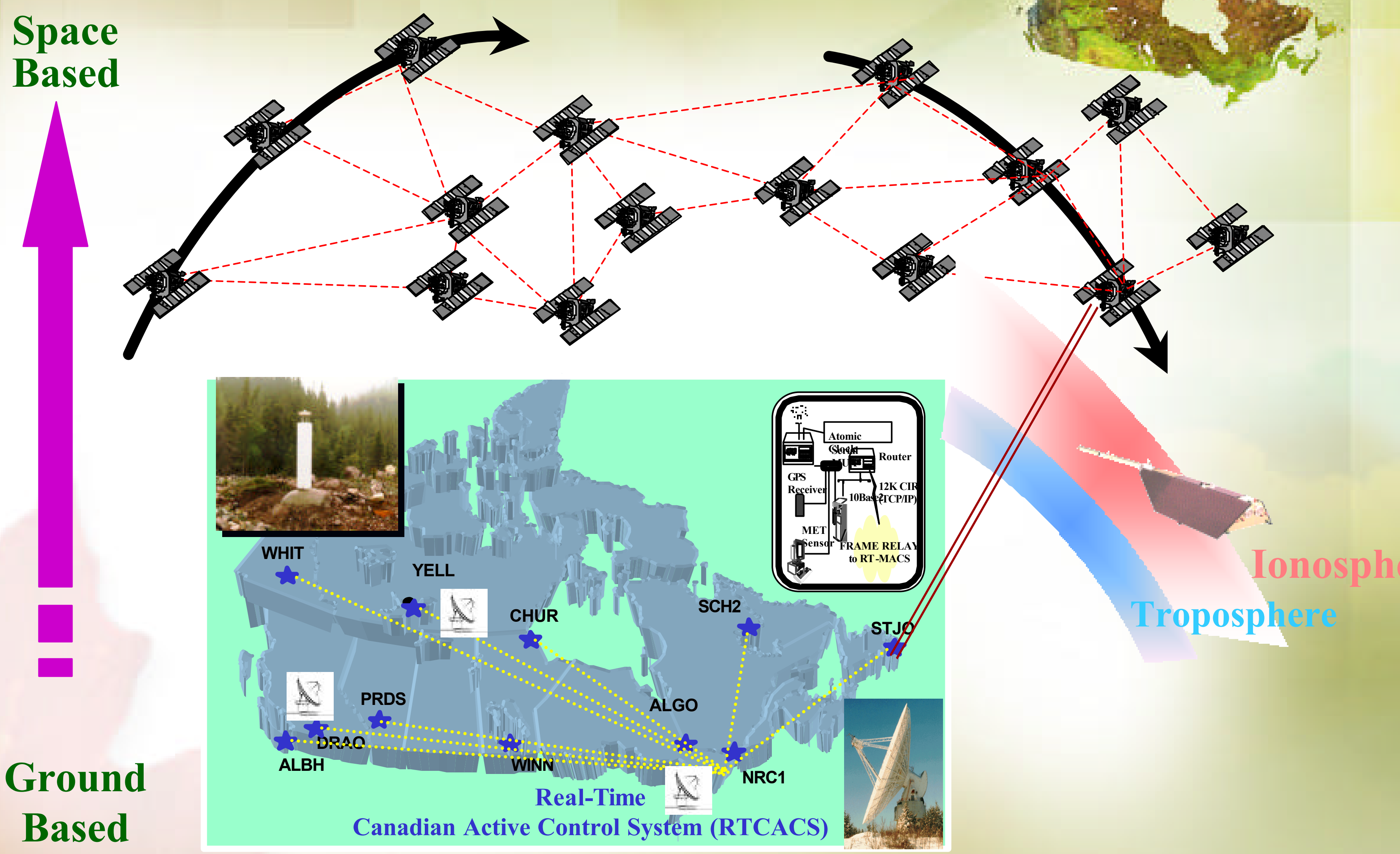
Outline

- **Technology, precision and geodetic reference frame evolution;**
- **Enabling products for near real time geodesy;**
- **Applications and operational challenges.**

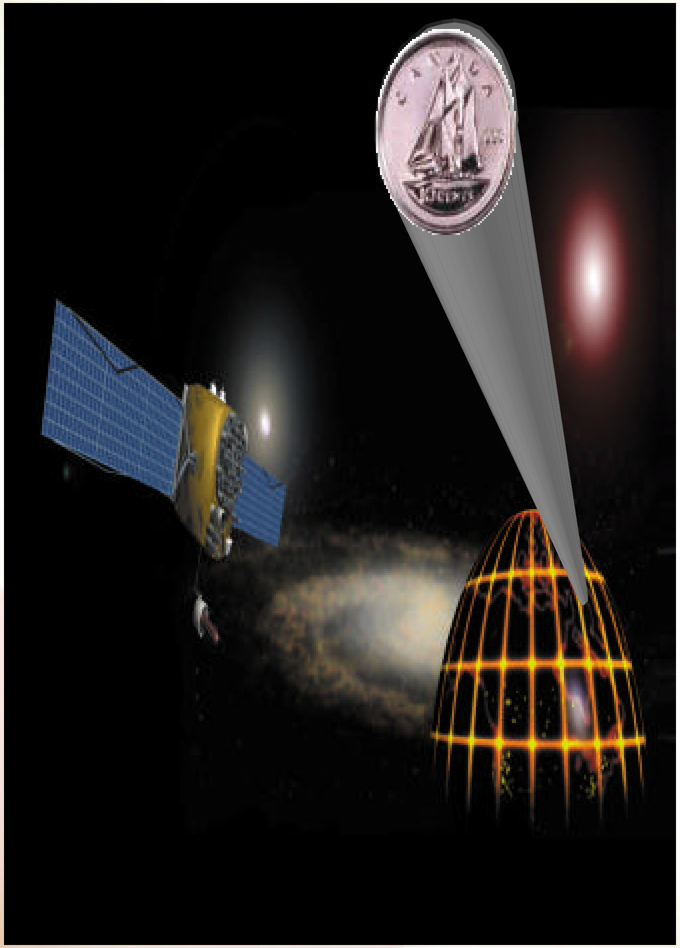
Technology, Precision and Reference Frame Evolution

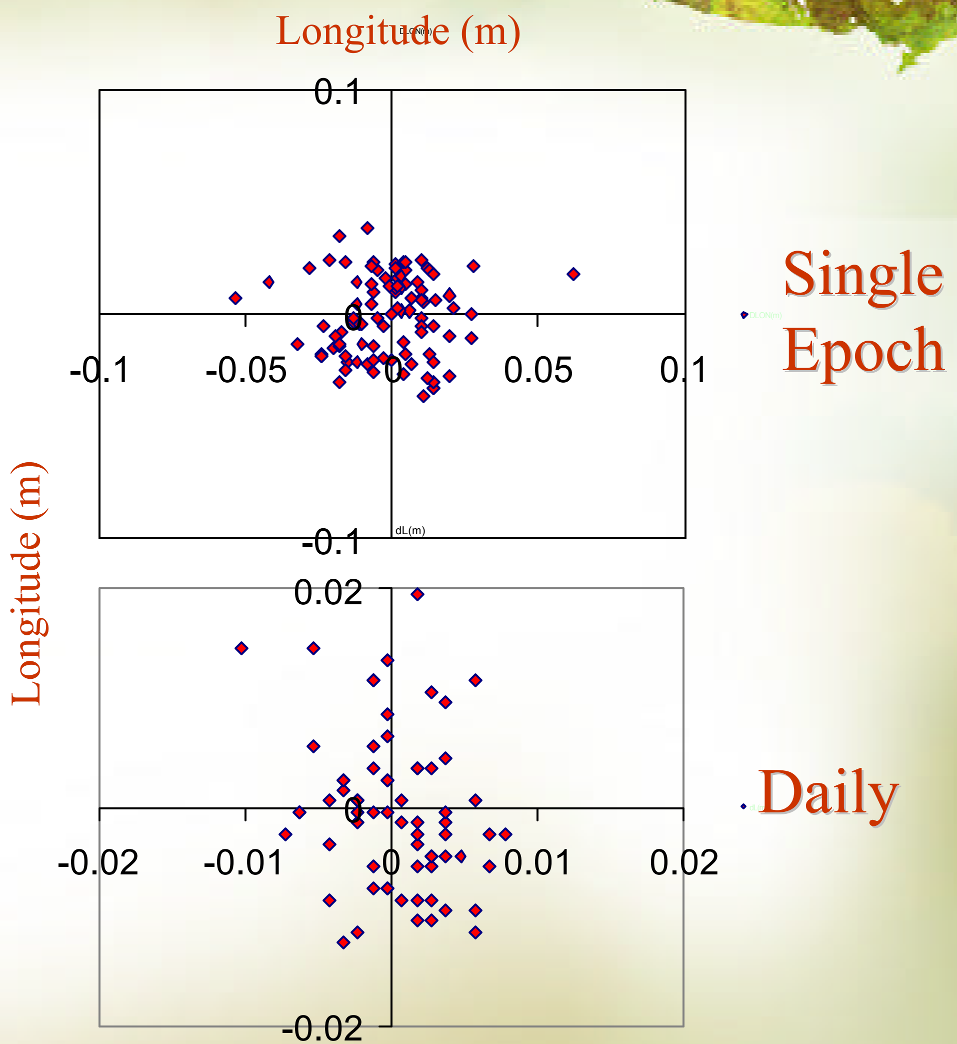


Reference Frame Delivery: The GPS/IGS Revolution



Performance of IGS Orbit Products





Enabling Near Real Time (NRT) Geodesy

- IGS ultra rapid orbits;
- NRT Access to wide-area/global GPS observations;
- Robust code/carrier network processing;
- High-resolution correction format;
- Multiple delivery mechanisms and channels;
- Single/dual frequency user applications.

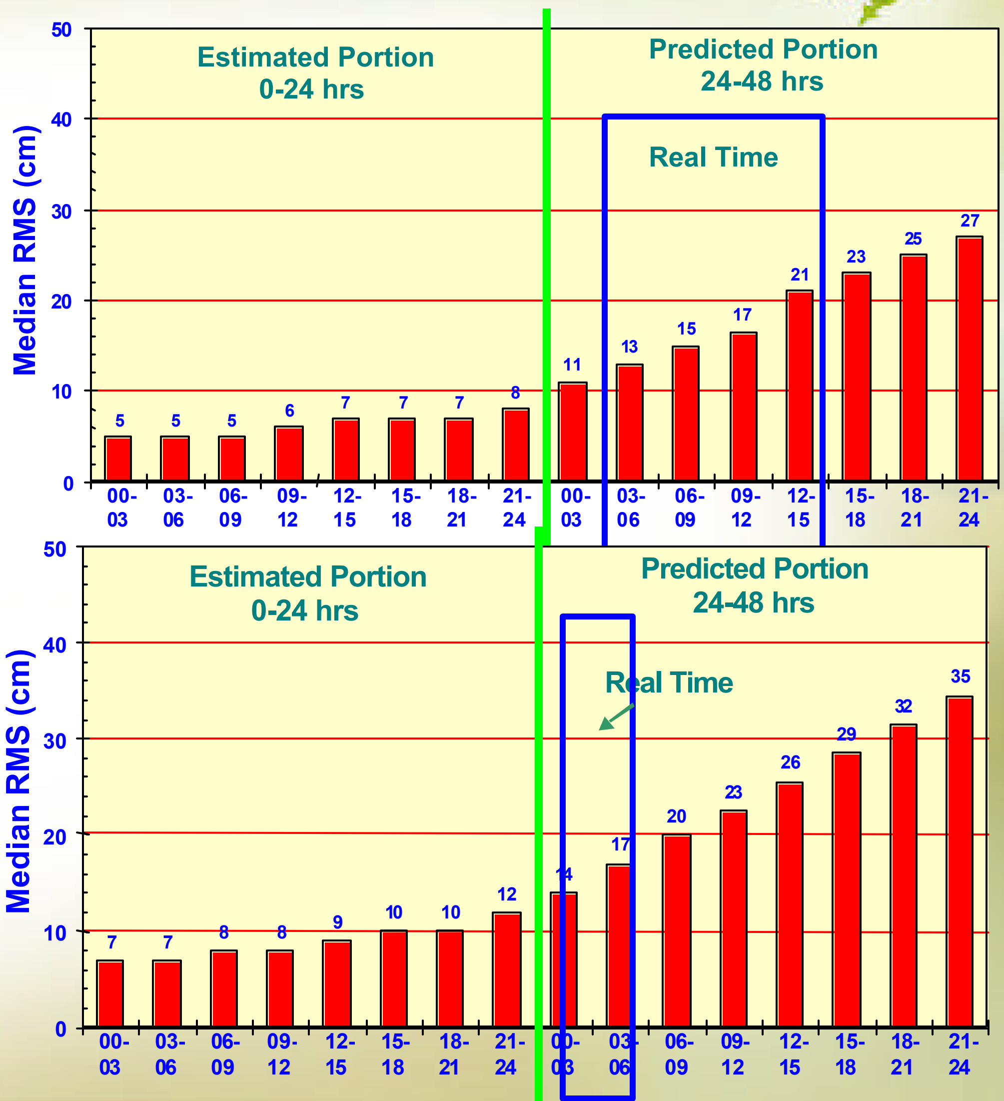
Ultra-Rapid GPS Orbits

Orbit Median RMS
January 1-March 20 2002

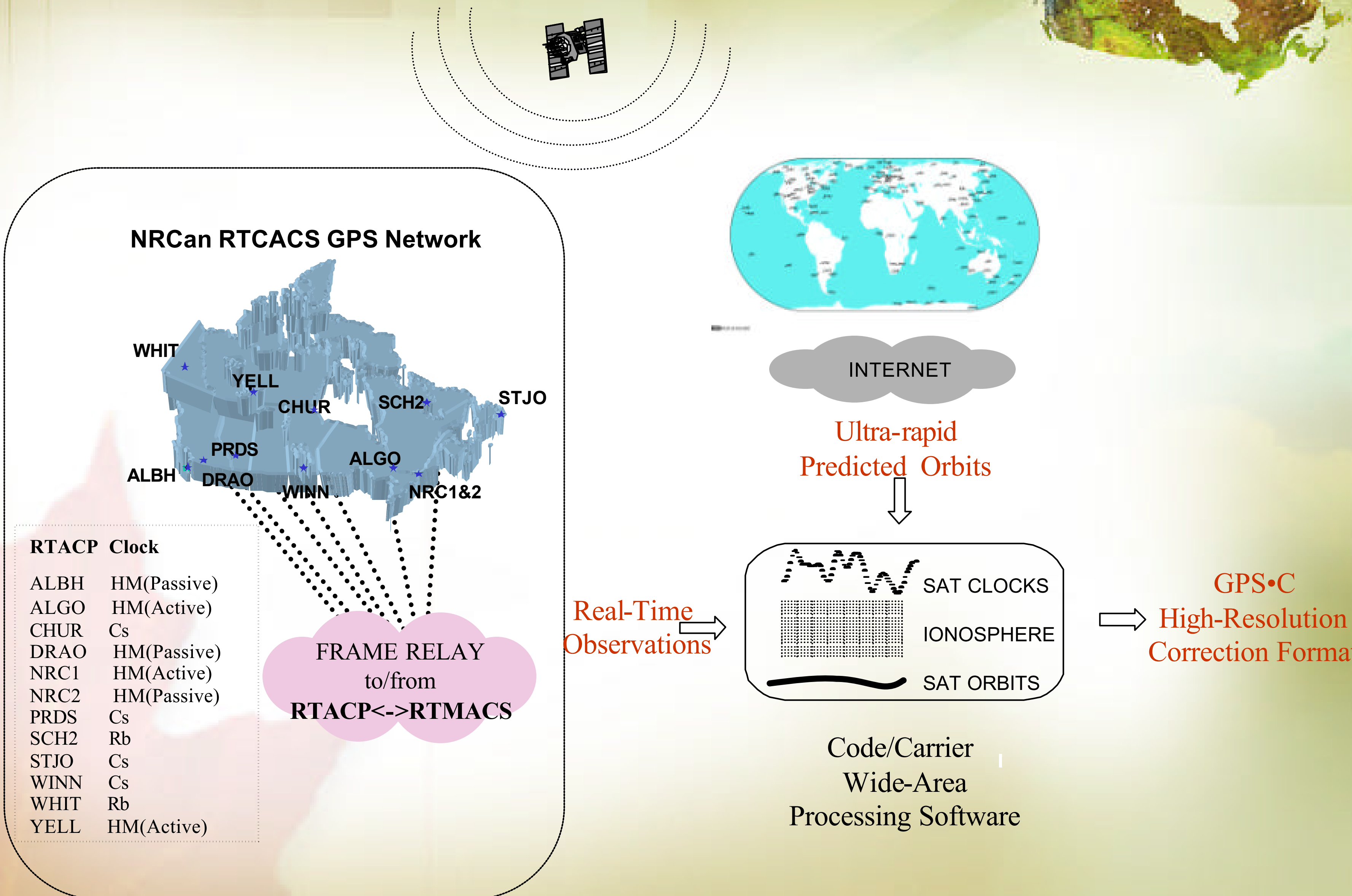
Bernese v4.2 (HP-UX 11.0 / Class A500)
Hourly RINEX data for 80 IGS stations
accessed through CDDIS, SIO, BKG and AUSLIG Data Centers

Apriori orbits: NRCan Ultra Rapid, IGU and/or or BRD

Apriori ERP: IERS Bulletin A

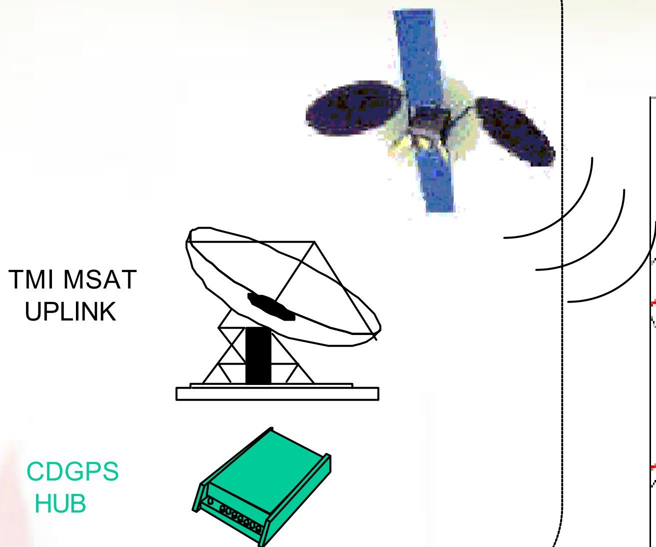


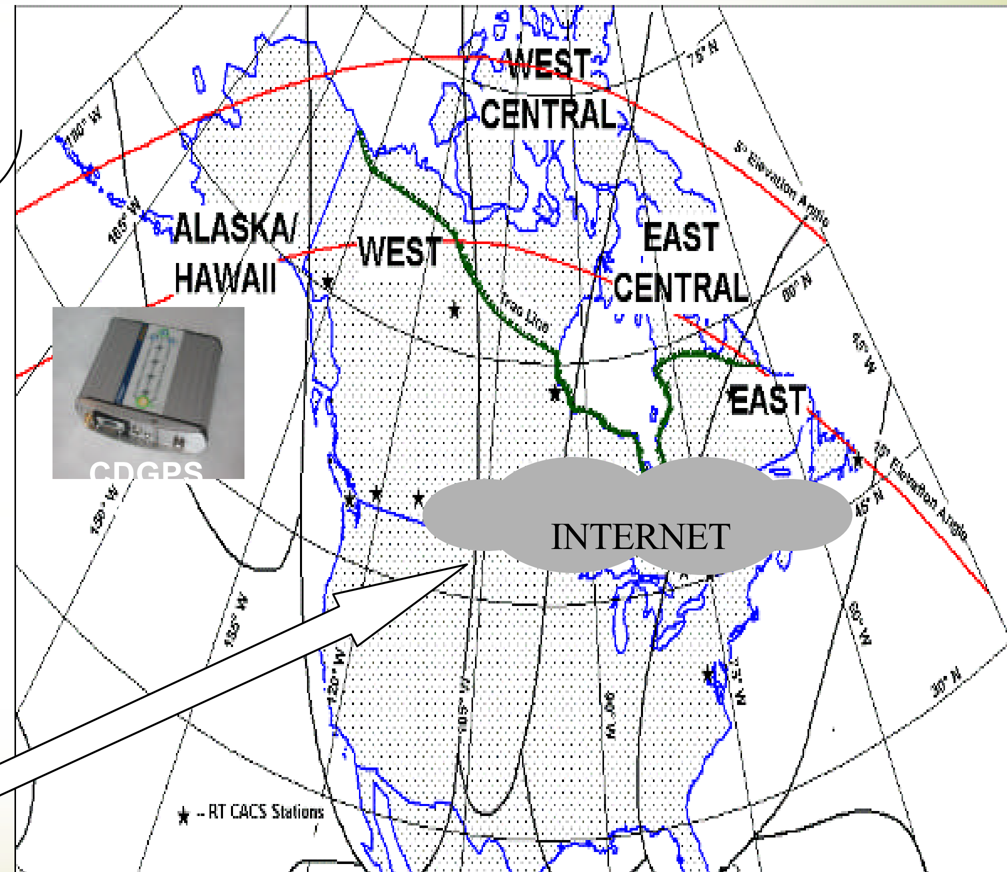
Real-Time Precise Satellite Clocks



Multiple Delivery Channels

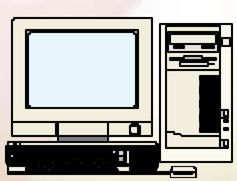
CDGPS
Canada-wide Differential GPS Program



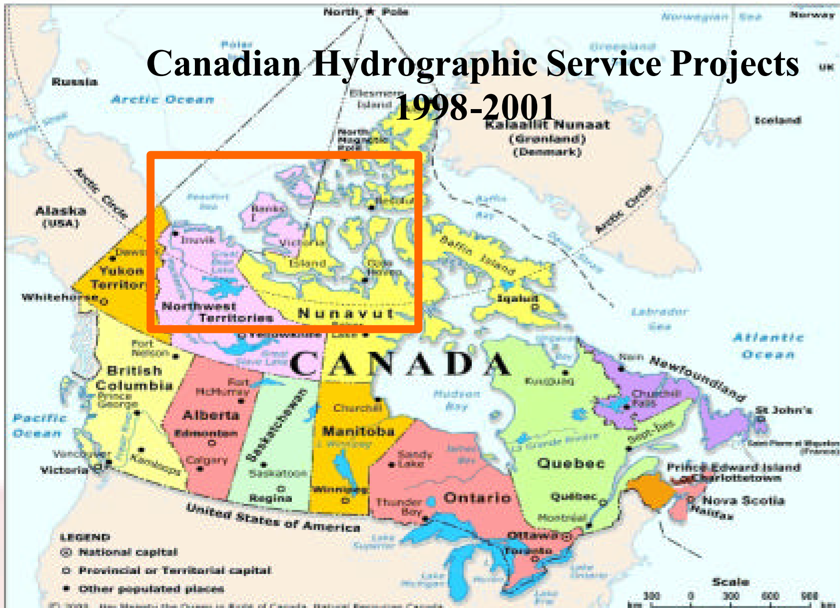


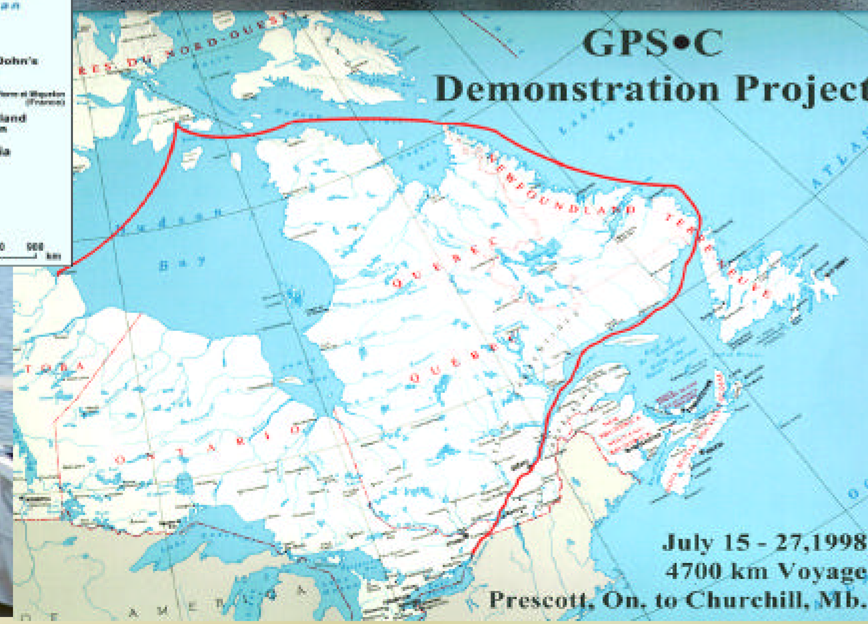
GPS•C High-Resolution Correction Format

Internet GPS Data Relay



NRT Geodesy - Applications

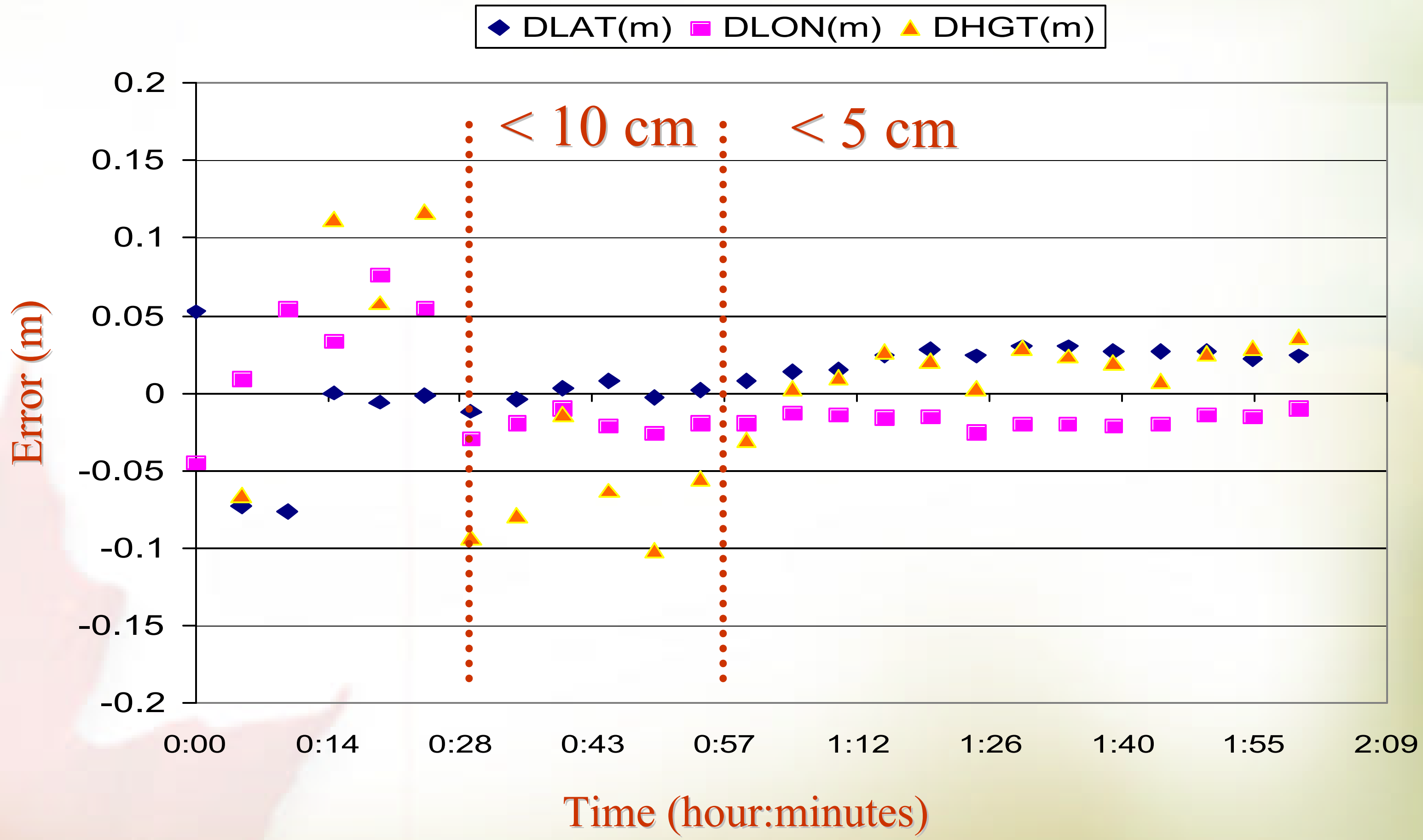




NRT Geodesy - Challenges

- **Standard High-Resolution Real-Time Wide-Area/Global Correction Format**
- **Fast Ambiguity Resolution Algorithms for Static/Kinematic Applications**
- **Enhanced Modeling for Improved Single Epoch User Solution**
- **Reliable Delivery and GPS User Adoption**

Faster Ambiguity Resolution Algorithms



Enhance Modeling for Single Epoch Solution

Geophysical

Earth Tide Displacement

Satellite->Receiver Phase Wind-up

Ocean Tide Loading

Sub-Daily ERP

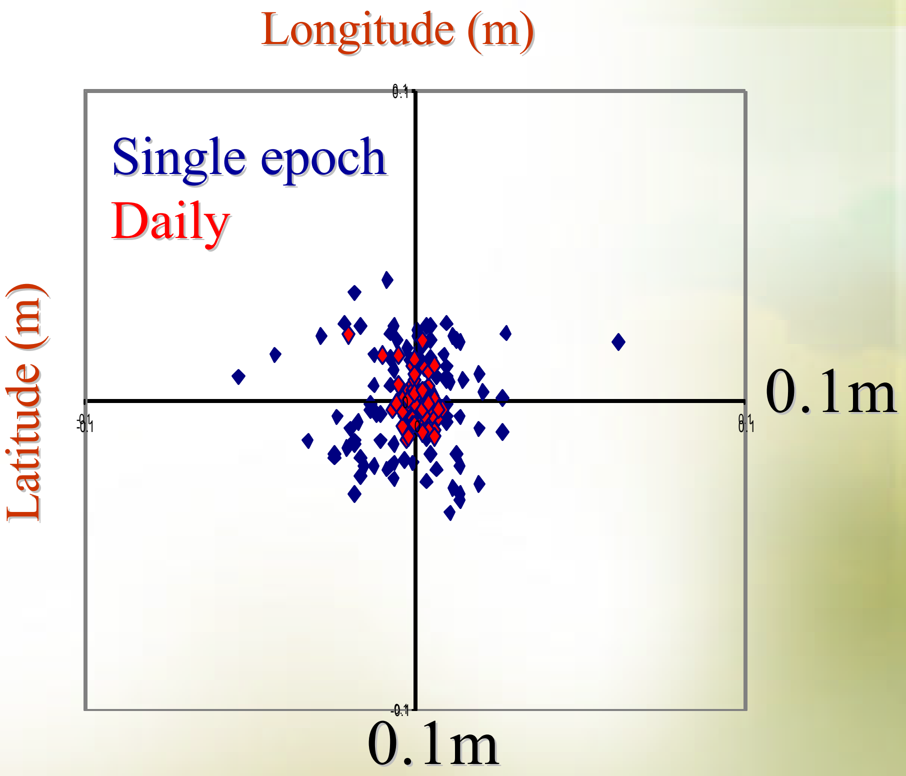
Physical

Receiver/Satellite Antenna Phase Centre

Multipath

Atmospheric

Geometric



Conclusion

- GPS Technology and IGS Products are changing the way the Canadian Spatial Reference System is delivered;
- Development of GPS products that enable Near Real Time Geodesy is well under way;
- Realizing the highest possible positioning accuracy within relatively short time frames will remain a challenge.