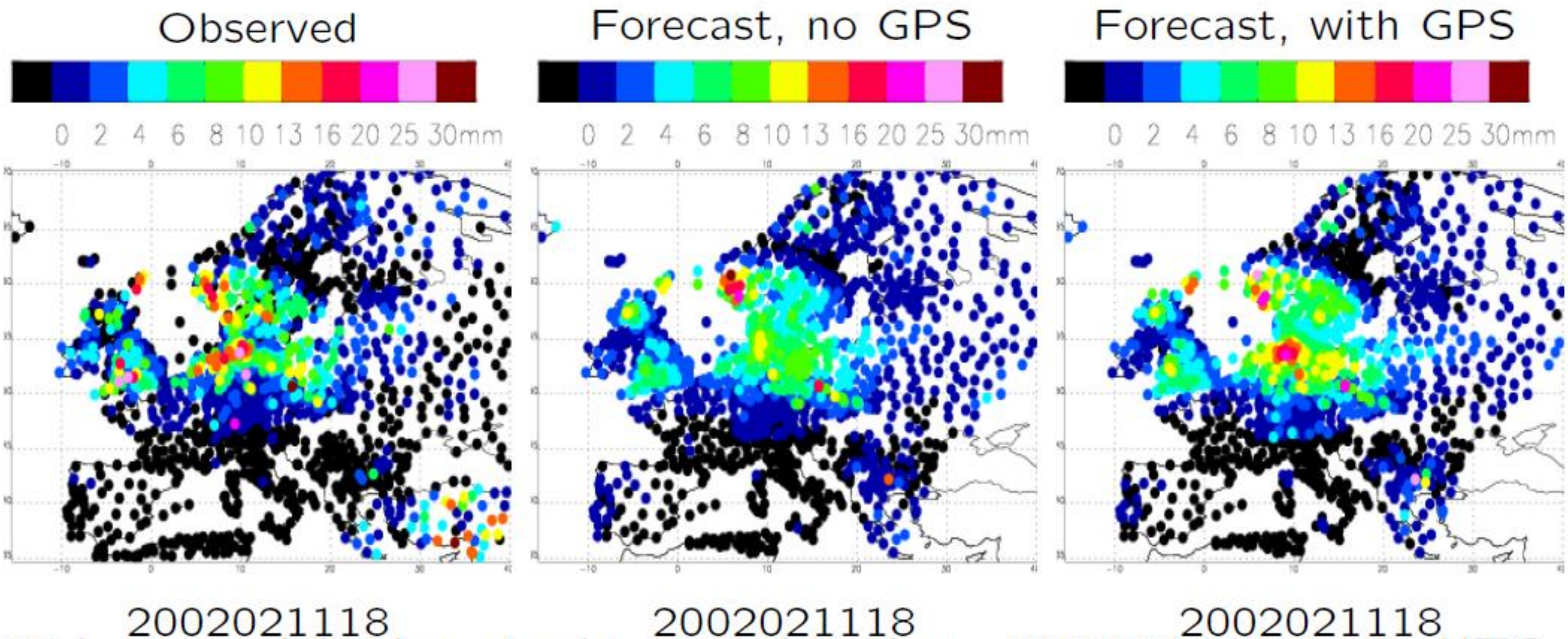
EIG EUMETNET GNSS Water Vapour Programme

E-GVAP

On the impact of ground-based GNSS data in European Meteorology

Henrik Vedel, hev@dmi.dk, DMI and E-GVAP team
Siebren de Haan, siebren.de.haan@knmi.nl KNMI and E-GVAP team
Jonathan Jones, jonathan.jones@metoffice.gov.uk,
Dave Offiler, Dave.offiler@metoffice.gov.uk, and
Gemma Bennitt, gemma.bennit@metoffice.gov.uk, UKMO and E-GVAP team



12 hour precipitation at rain gauge locations, 20020211 06 to 18 UTC.

G model

12 h precipitation

Observed | No GPS | GPS

2002021306

2002021318

2002021118

2002022006

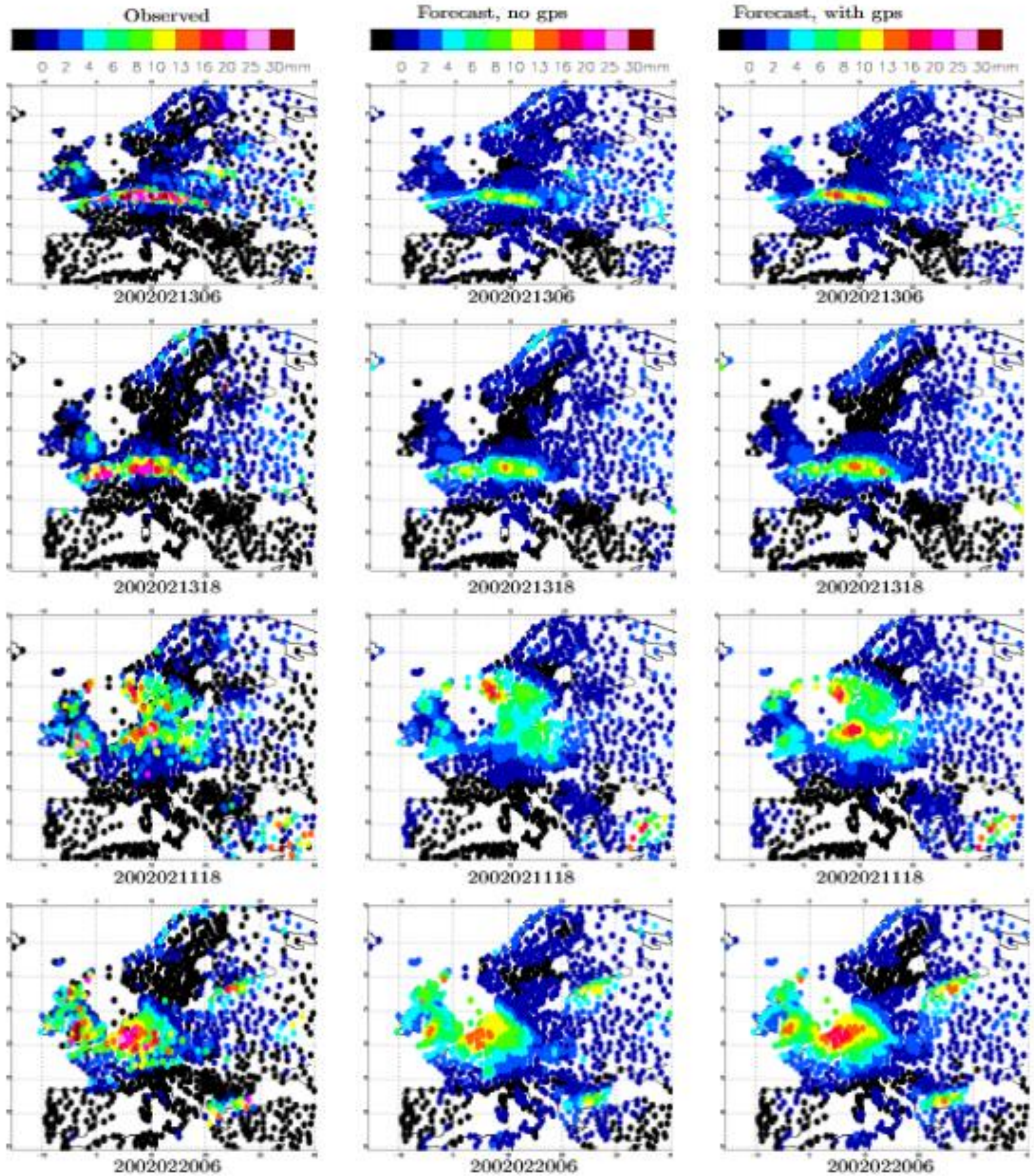
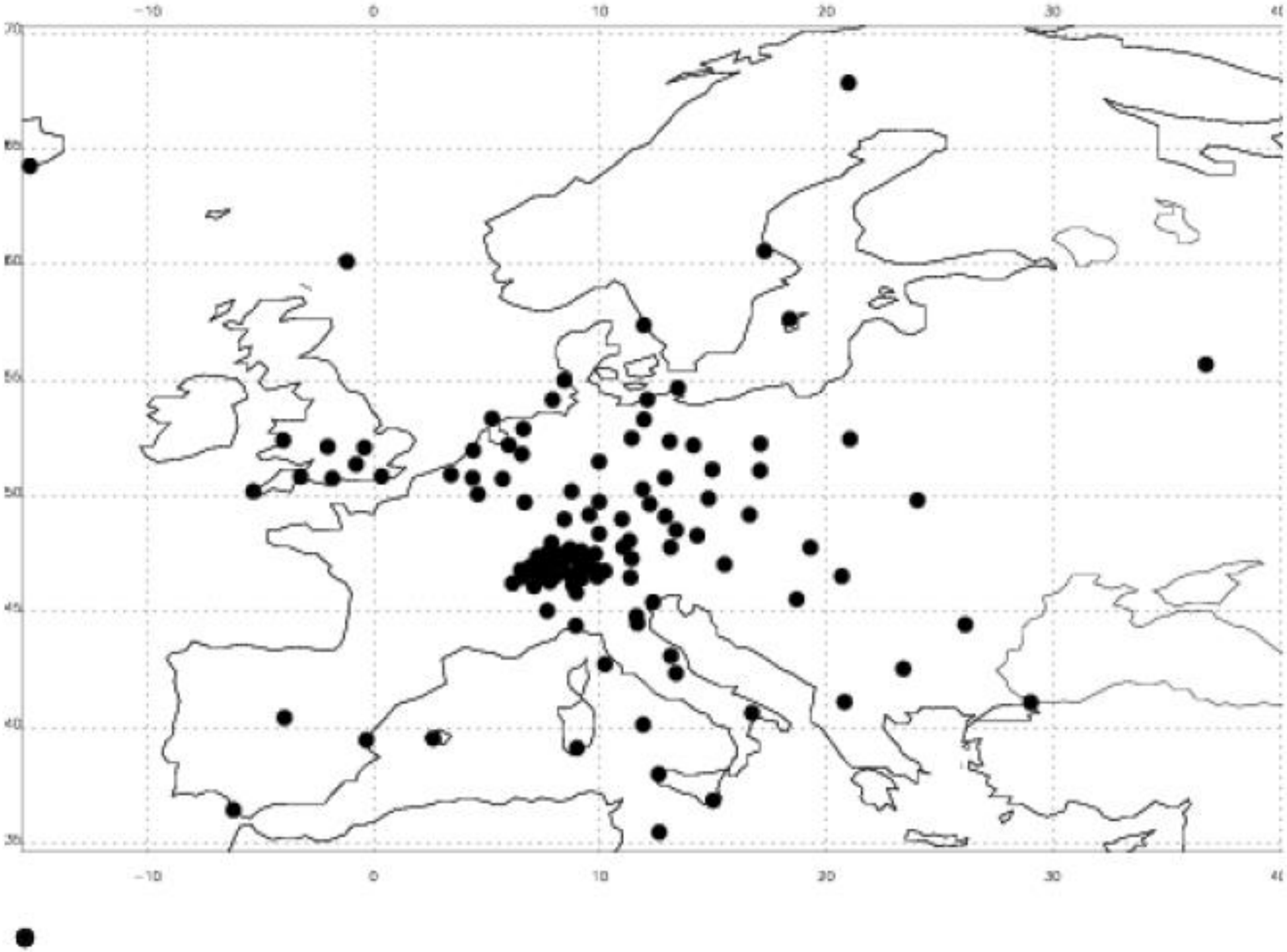
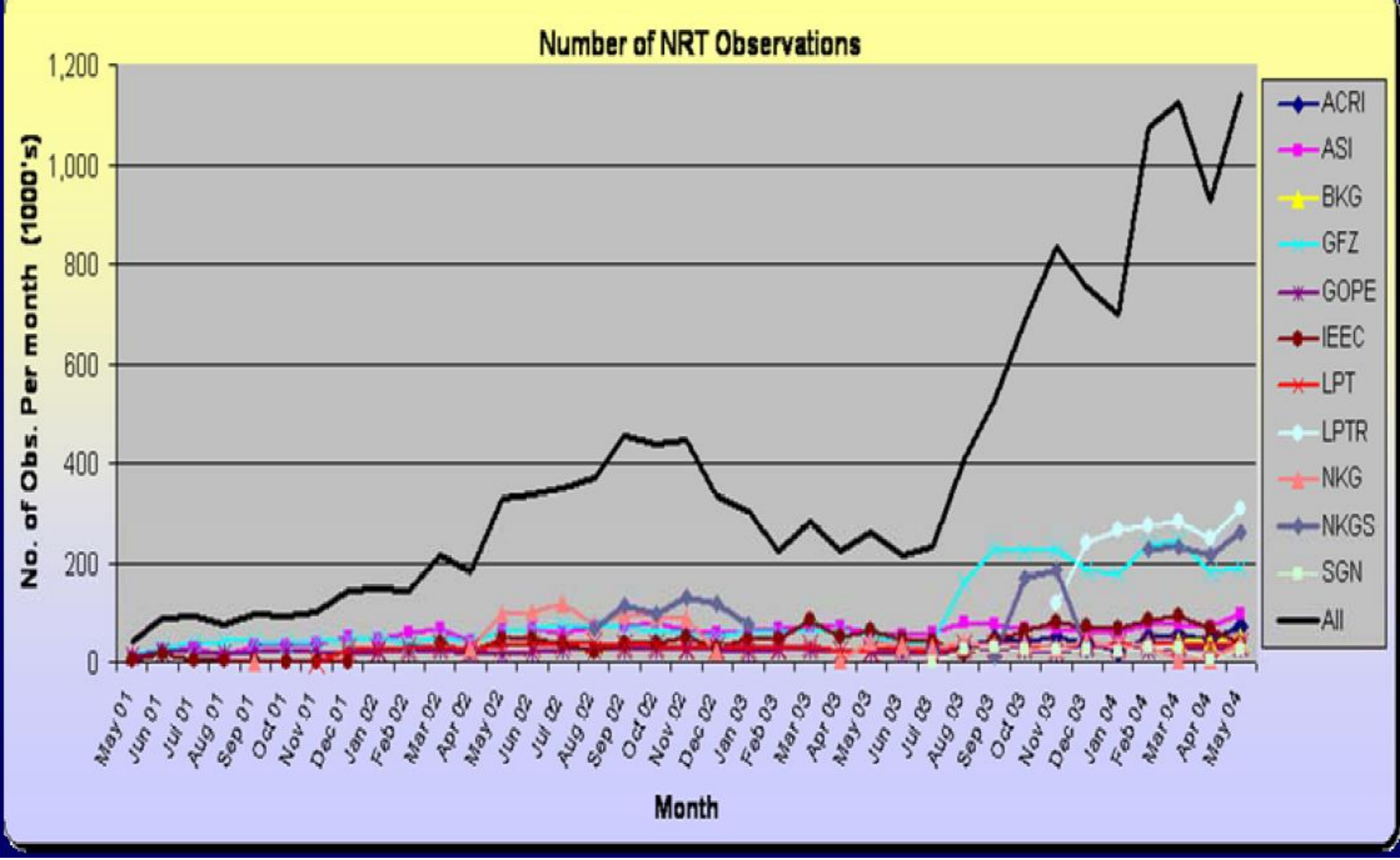
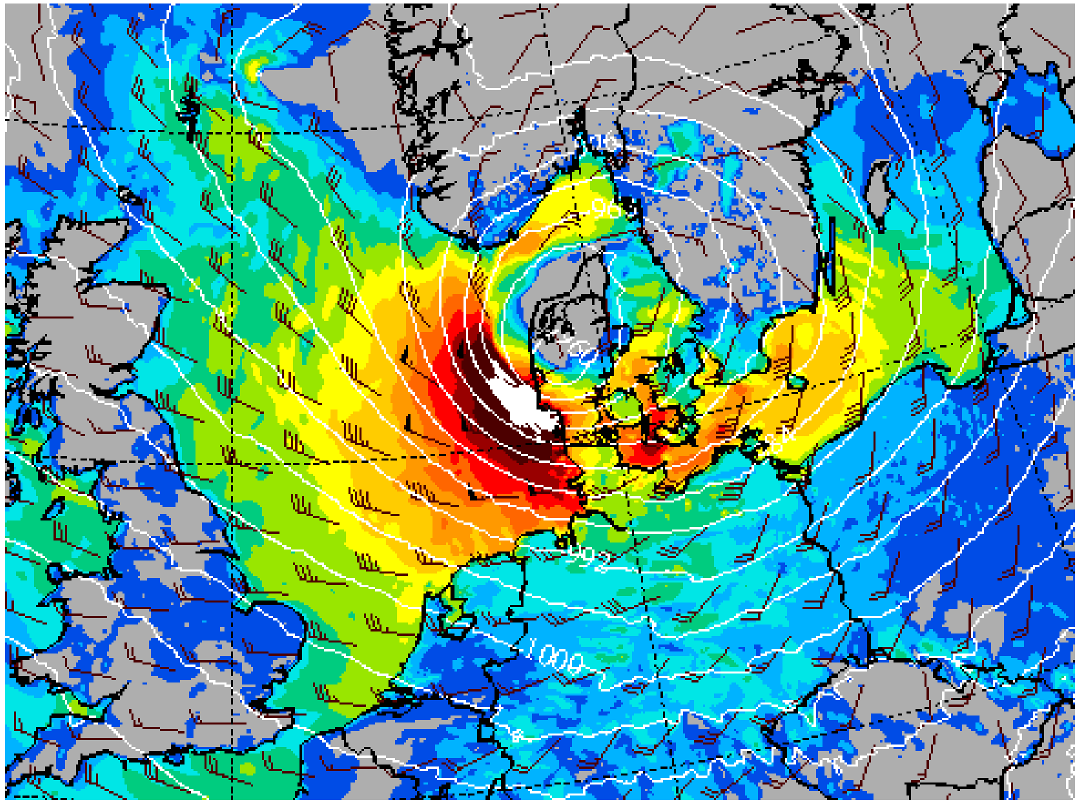


Figure 1. Comparisons of observed and predicted G-model 12 hour precipitation



Location of GPS sites providing ZTD data.

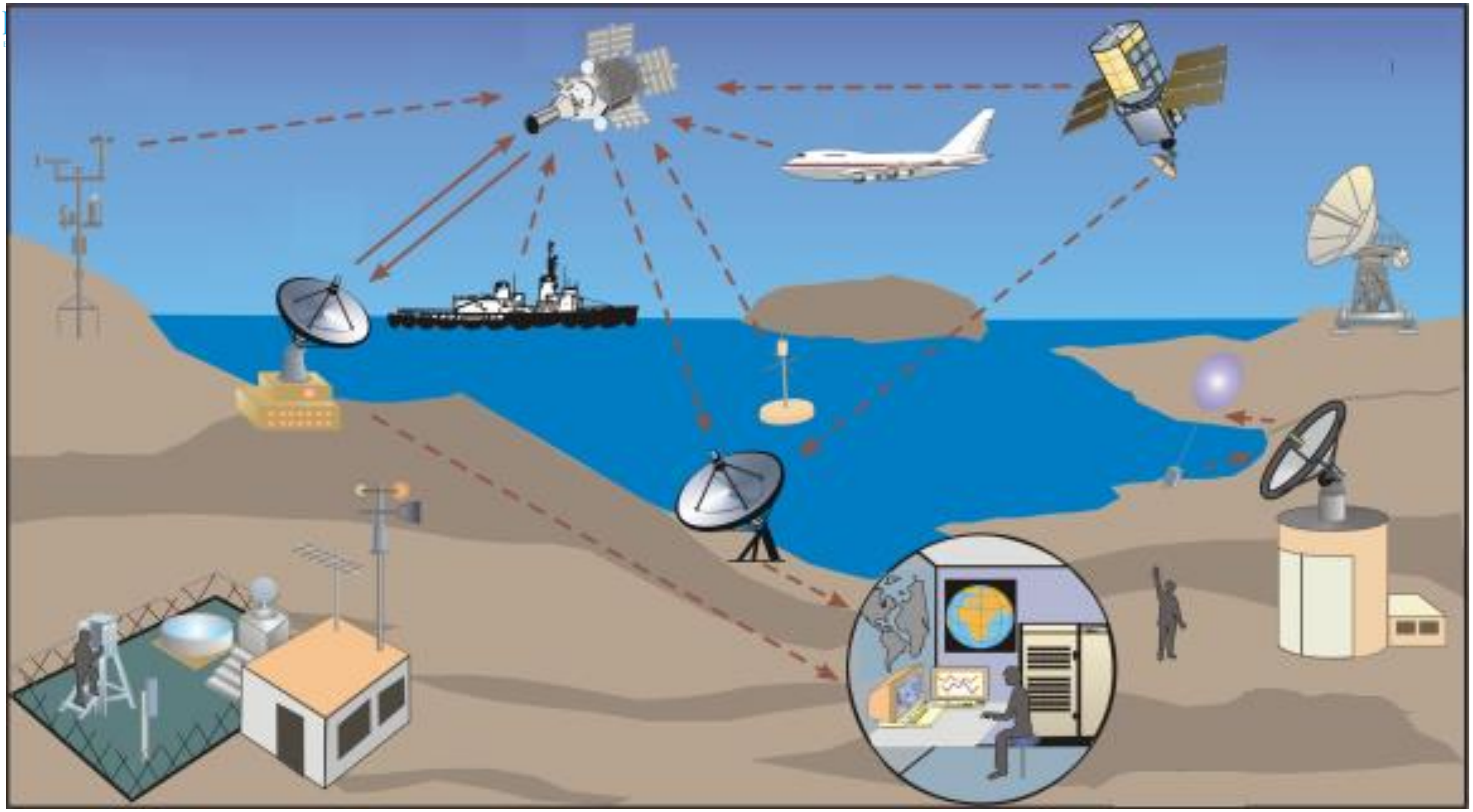

Number of NRT Observations
No. of Obs. Per month (1000's)
1,200
1,000
800
600
400
200
0
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02
Apr 02
May 02
Jun 02
Jul 02
Aug 02
Sep 02
Oct 02
Nov 02
Dec 02
Jan 03
Feb 03
Mar 03
Apr 03
May 03
Jun 03
Jul 03
Aug 03
Sep 03
Oct 03
Nov 03
Dec 03
Jan 04
Feb 04
Mar 04
Apr 04
May 04
Month
ACRI
ASI
BKG
GFZ
GOPE
IEEC
LPT
LPTR
NKG
NKGS
SGN
All


1000

Lewis Fry Richardson, Cambridge University Press, 1922

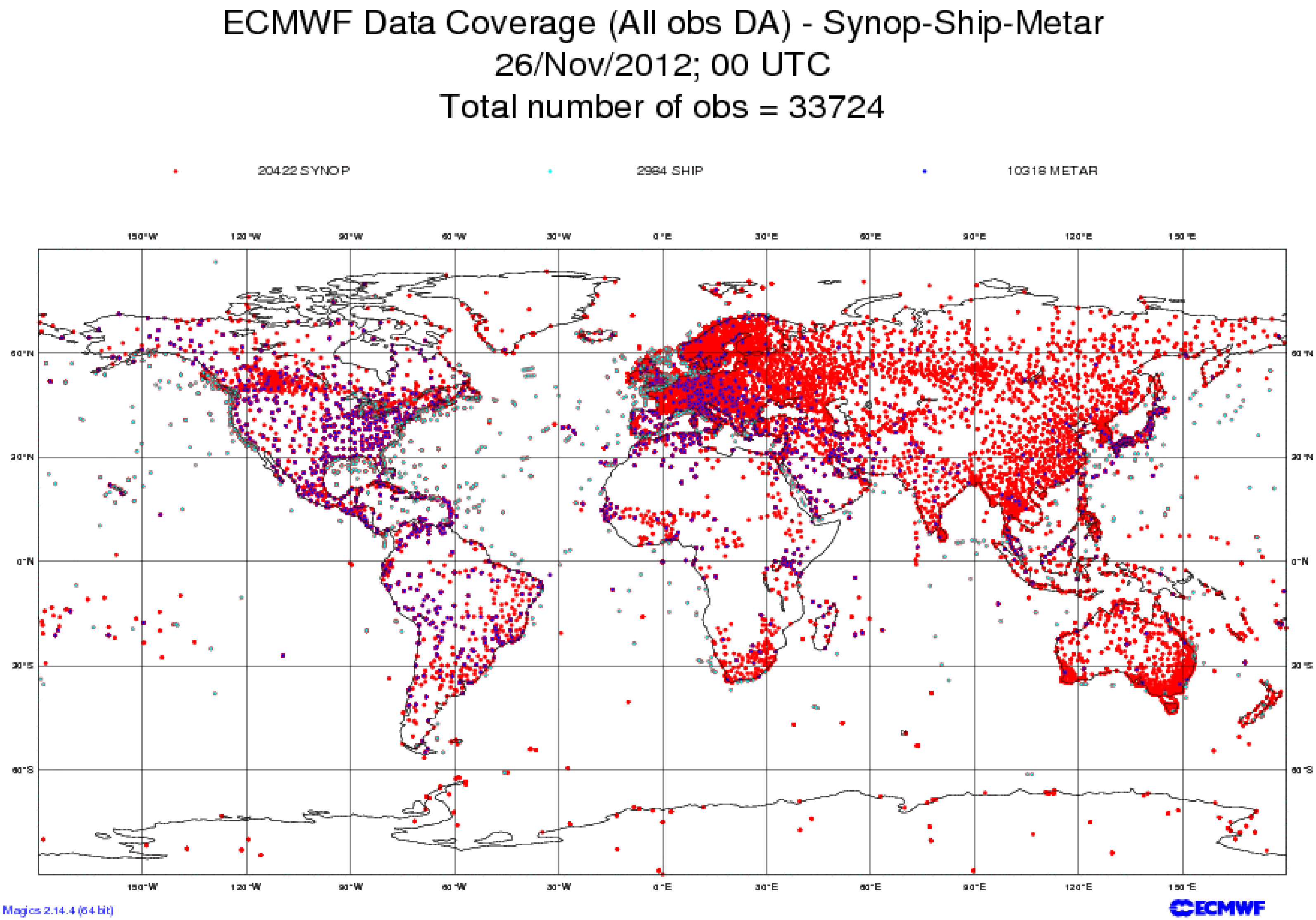
Weather Prediction by Numerical Process

- Fundamental equations
  - Newton's second law
  - Conservation of mass
  - Equation of state for ideal gases
  - Conservation of energy
  - Conservation of water mass
- Effects of radiation, condensation, turbulence, surface friction, lower boundary conditions, etc.
- Discretization and solution by finite differences

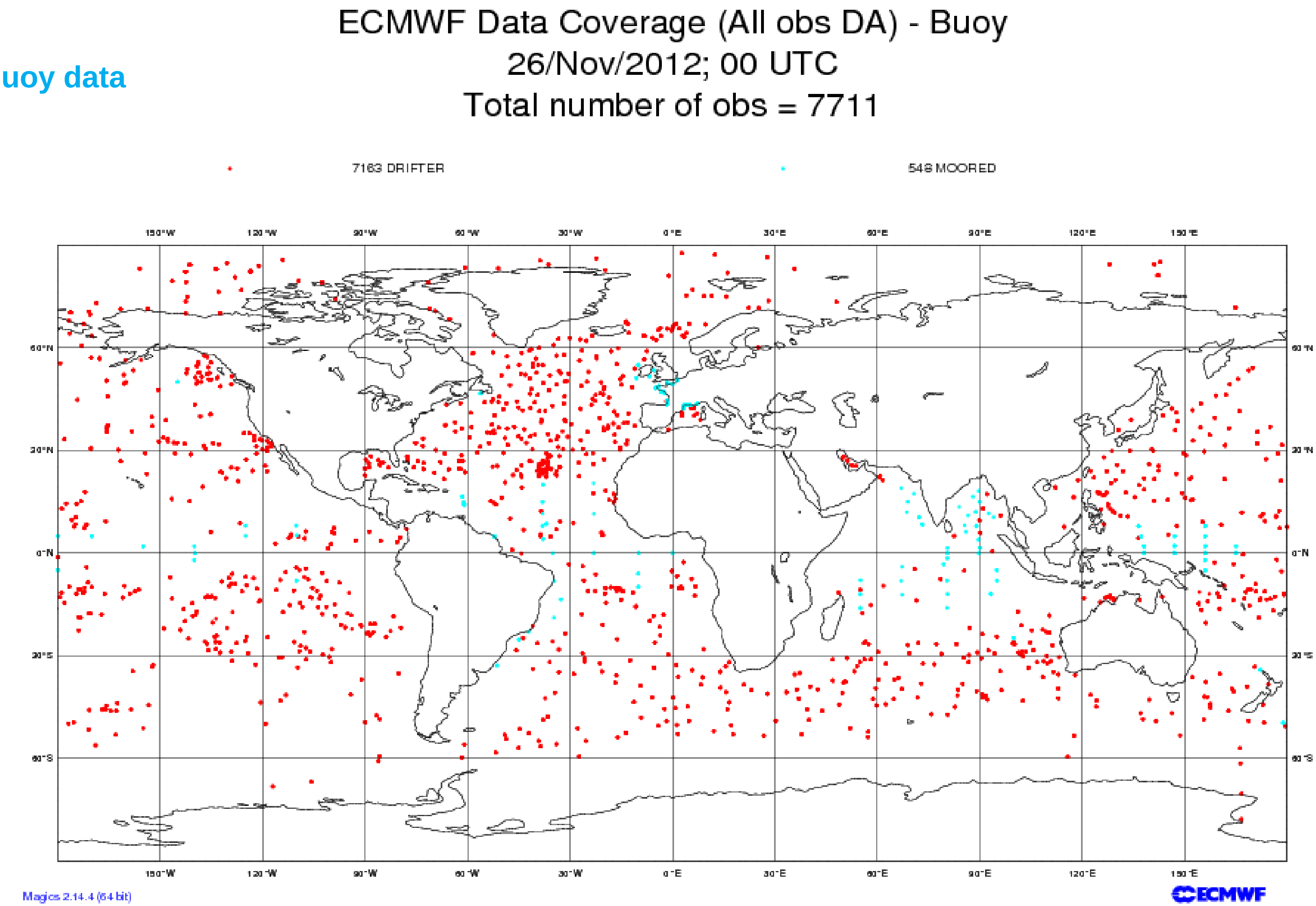


Some of the obserations used in making the analysis: Surface pressure, radiosonde data, aircraft data, satellite radiances, satellite clouds, satellite cloud motion vectors, wind profiler observations, buoy data, radar data, etc.

Pressure observations from ground (land and ships)



Buoy data

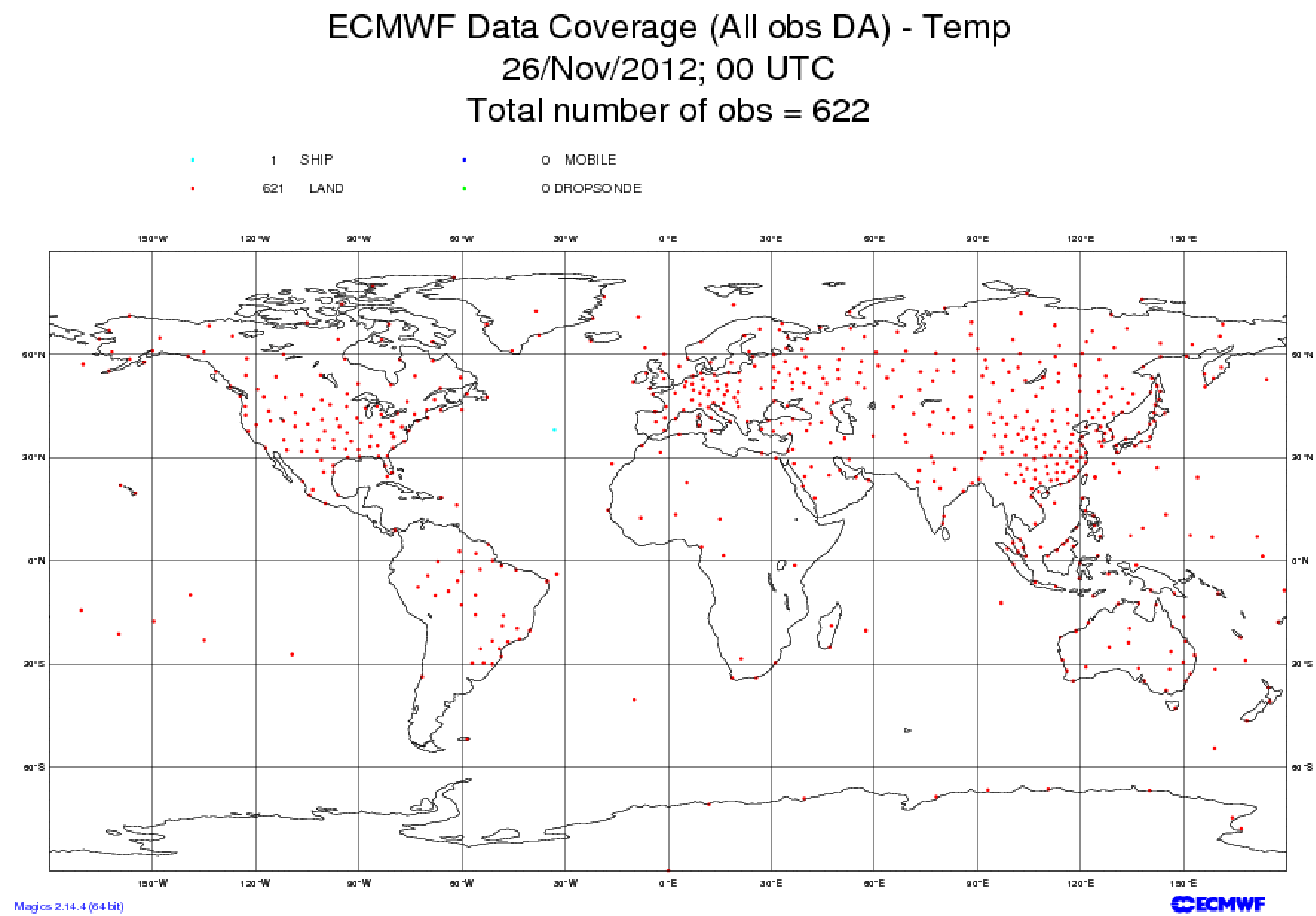


ECMWF Data Coverage (All obs DA) - Buoy
26/Nov/2012; 00 UTC
Total number of obs = 7711
7163 DRIFTER
548 MOORED
150°W
120°W
90°W
60°W
30°W
0°E
30°E
60°E
90°E
120°E
150°E
60°N
30°N
0°N
30°S
60°S
Magics 2.14.4 (64 bit)
ECMWF

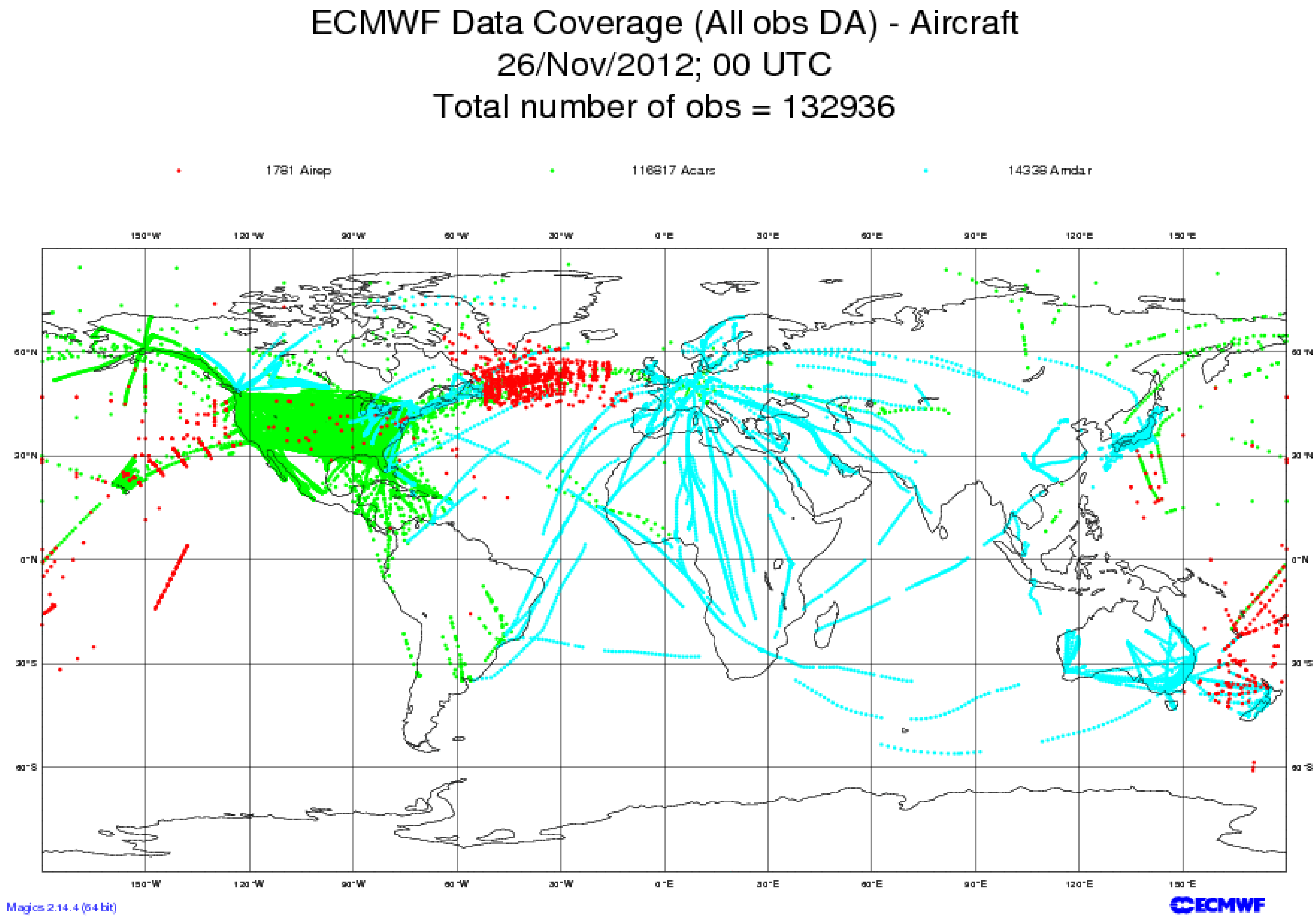
EUMETNET

European Meteorological Services Network

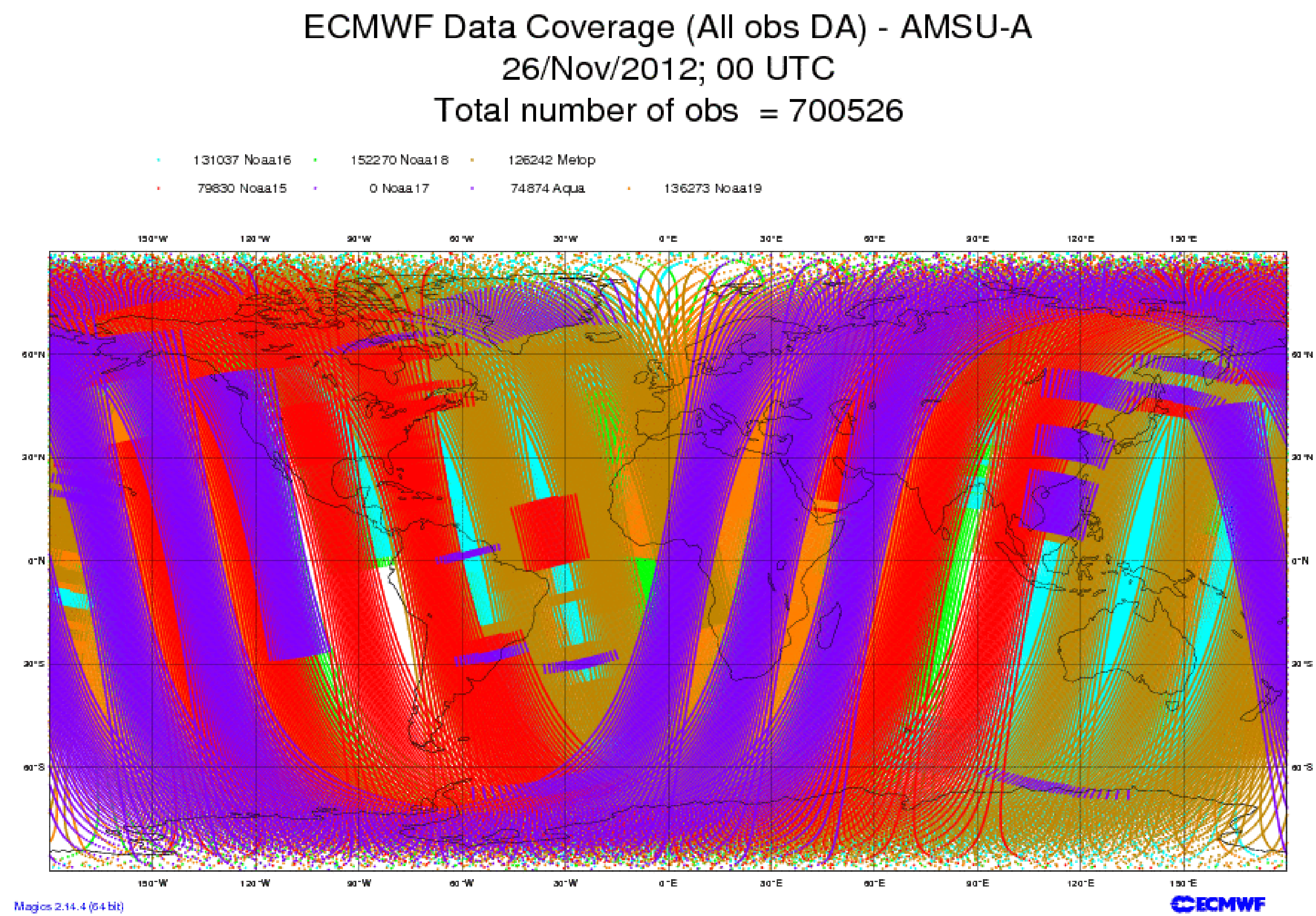
Ra



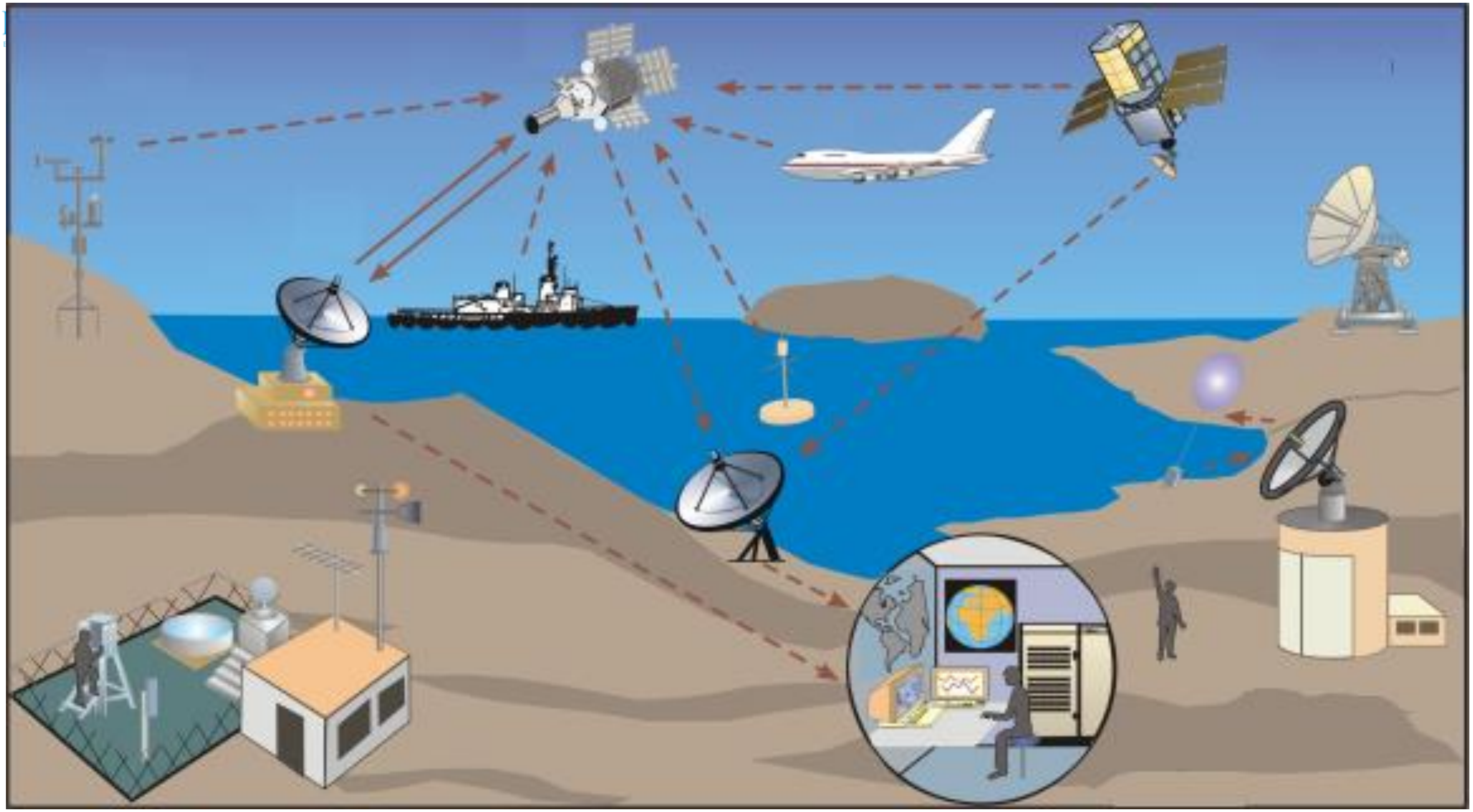
Aircraft data
(starting, landing, and cruising obs. of temperature and wind)



Ra



ECMWF Data Coverage (All obs DA) - AMSU-A
26/Nov/2012; 00 UTC
Total number of obs = 700526
131037 Noaa16
152270 Noaa18
126242 Metop
79830 Noaa15
0 Noaa17
74874 Aqua
136273 Noaa19
150°W
120°W
90°W
60°W
30°W
0°E
30°E
60°E
90°E
120°E
150°E
60°N
30°N
0°N
30°S
60°S
Magics 2.14.4 (64 bit)
ECMWF

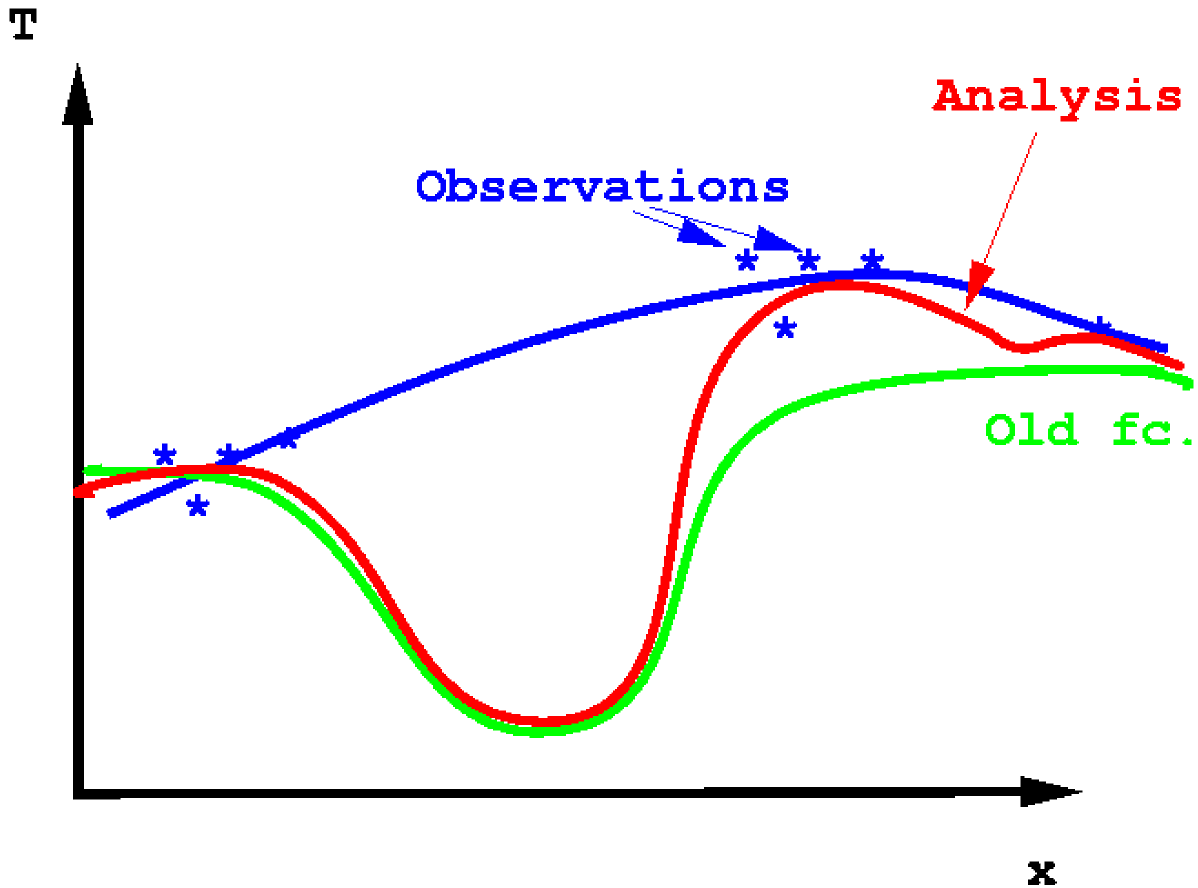


Surface pressure, radiosondes, aircraft, satellite radiances, satellite clouds, satellite cloud motion vectors, radar observations, wind profiler observations, buoy data, etc.

+ Ground based GNNS data and GNSS RO data

 # Model variables – order 100 to 1000 million

 # Observations – order 0.01 to 1 million


T
Analysis
Observations
Old fc.
x

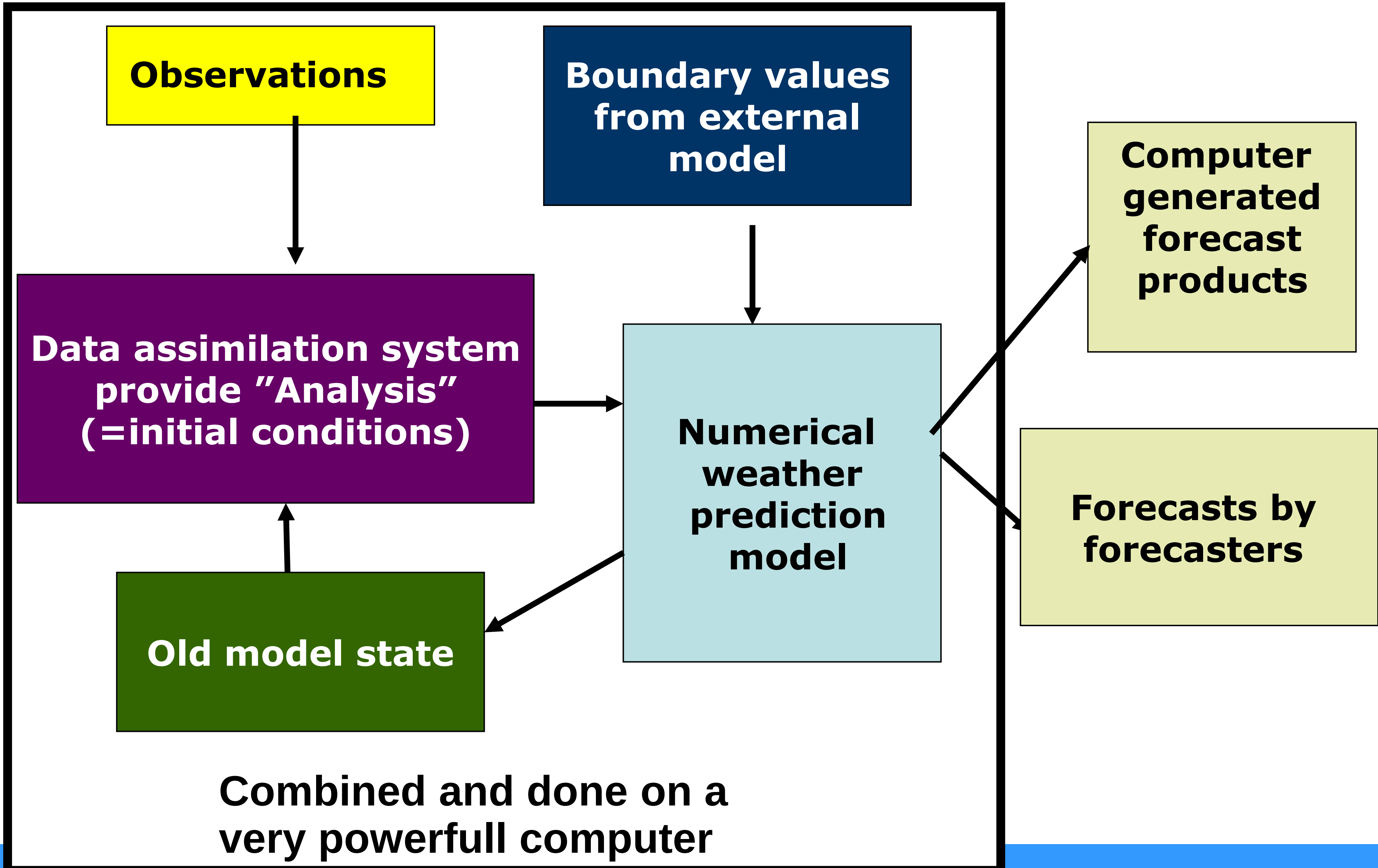
$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}_b - \mathbf{x})^{\mathrm{T}}(\mathbf{P}_b)^{-1}(\mathbf{x}_b - \mathbf{x}) + \frac{1}{2}(\mathbf{y} - \mathcal{H}(\mathbf{x}))^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{y} - \mathcal{H}(\mathbf{x}))$$

x = NWP model state, x_b = first guess model state.
y = observations.
H(x) = observation operator, determines NWP model estimate of y given x.
P_b = Matrix containing the errors and error correlations for the NWP
R = Matrix containing the errors and error correlations for the observations
Error correlations of observations normally assumed zero.

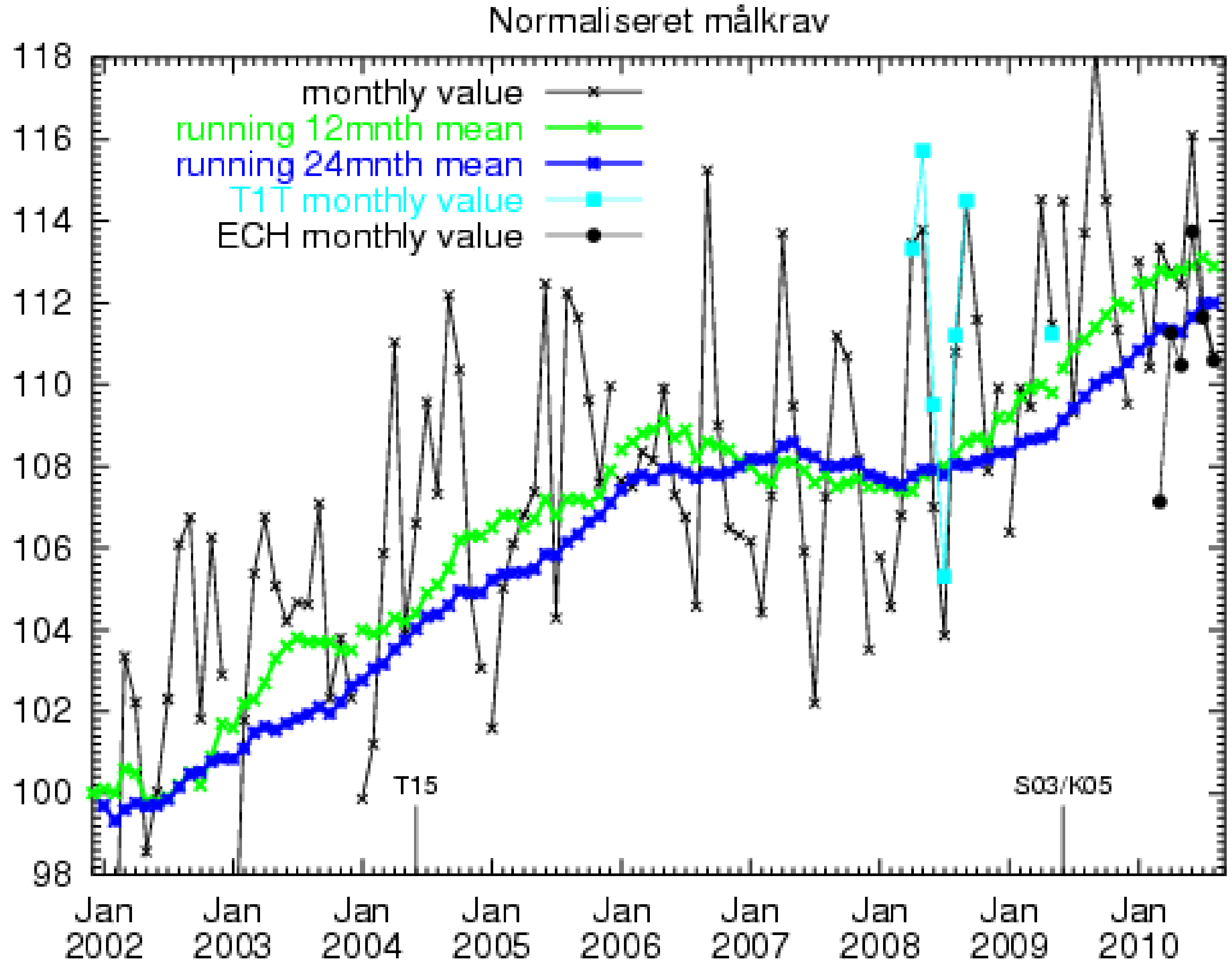
In J each piece of information is weighted statistically, according to its uncertainty. The error correlations in P, results in each observation having an impact on different model variables in the neighborhood of the observation location.

Finding the x that minimizes J, corresponds to finding the maximum likelihood estimate of the atmospheric state in terms of the model variables.

Ingredients of a non global numerical weather prediction system



Example of forecast skill evolution



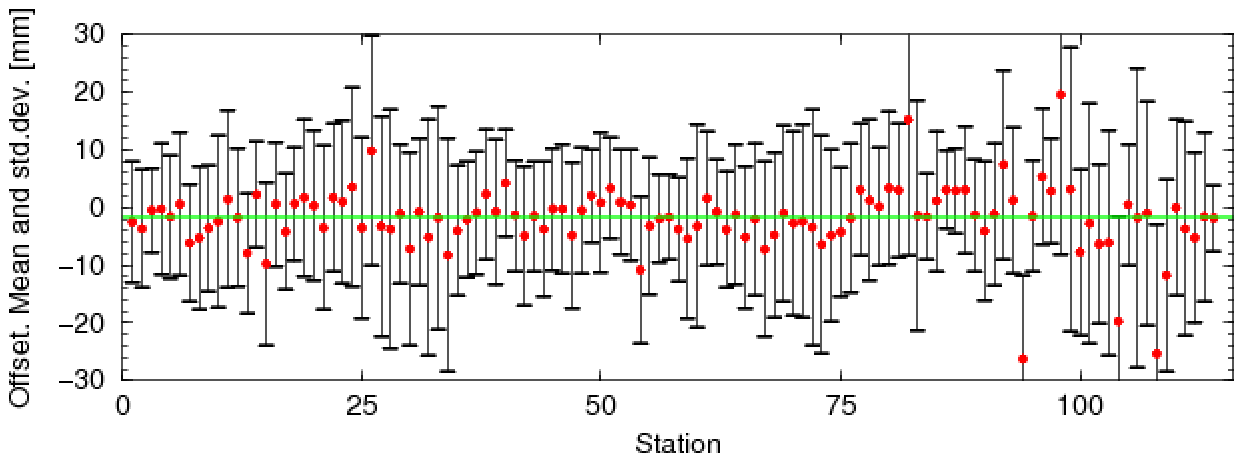
Better data assimilation systems (3 and 4DVar), more and new types of observations, and NWP model improvement are the cause for improvement

Foto: Bax Lindhardt/Scanpix 2011

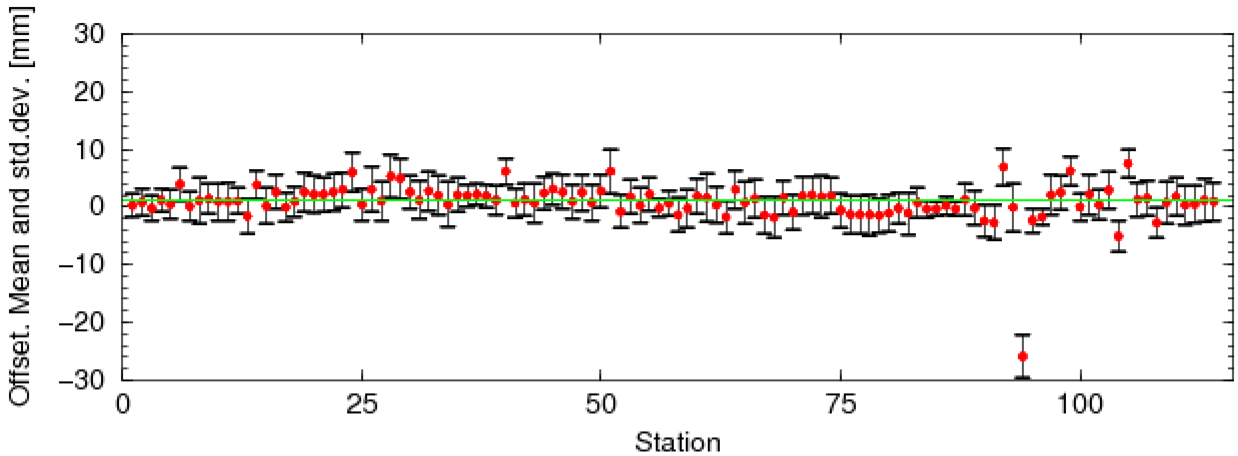
Yet, still unforeseen events..

In particular related to heavy, local precipitation, A phenomena expected to increase, due to global warming.

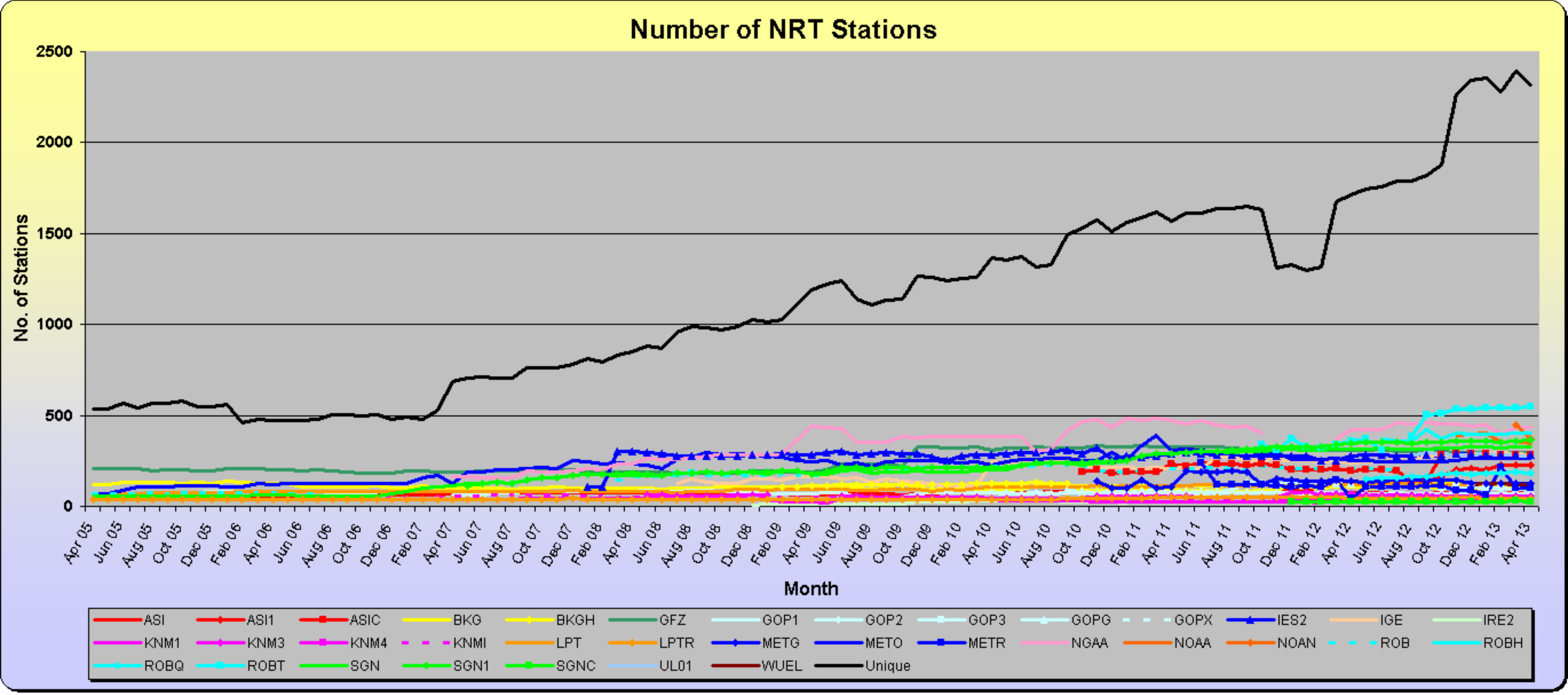
ZTD offsets between radiosonde and NWP



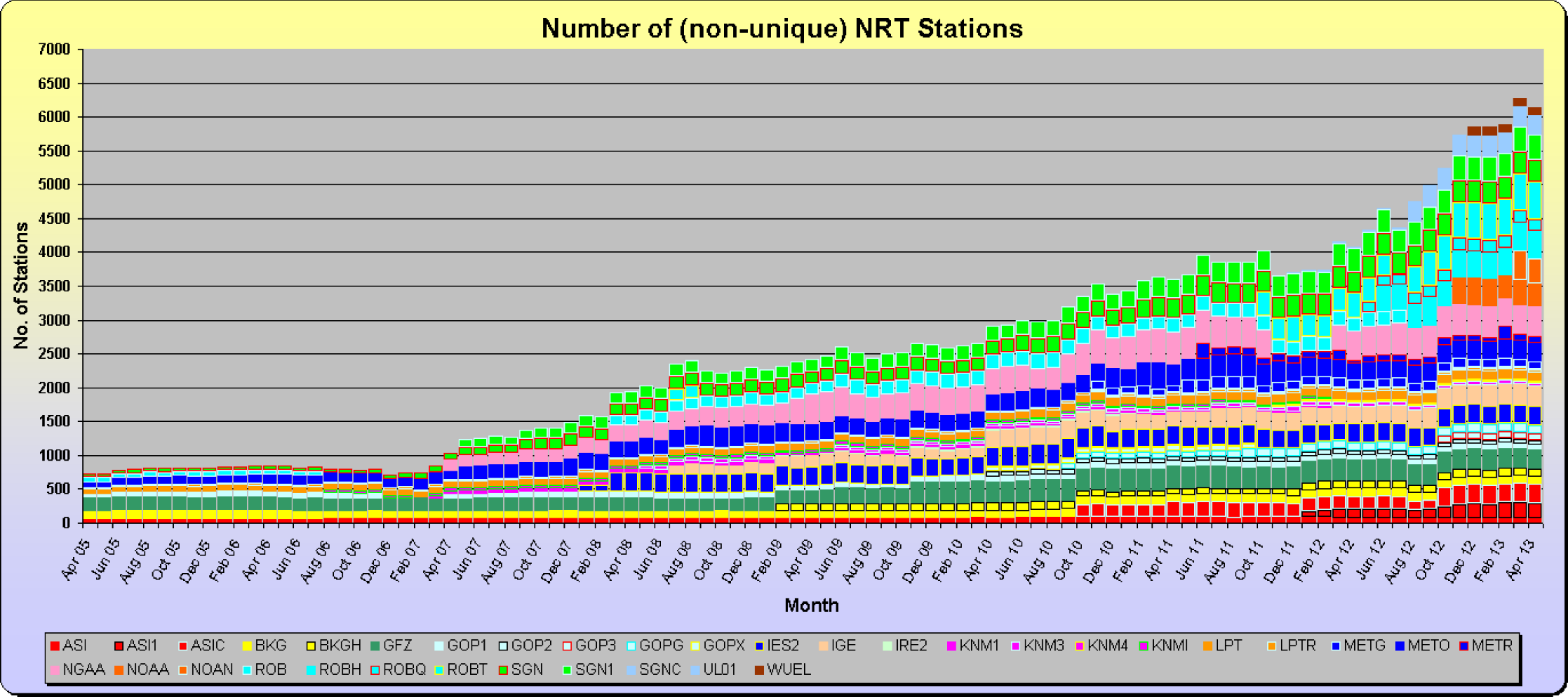
ZHD offsets between radiosonde and NWP



- Because NWP is better in estimating ZHD than ZTD, the ZTD provides in reality information about water vapour, when assimilating ZTD.
- Use NWP surface pressure (proportional to ZHD) in GNSS data processing instead of climatology?



Number of GNSS sites in E-GVAP data distribution versus time. Today about 2400 sites.

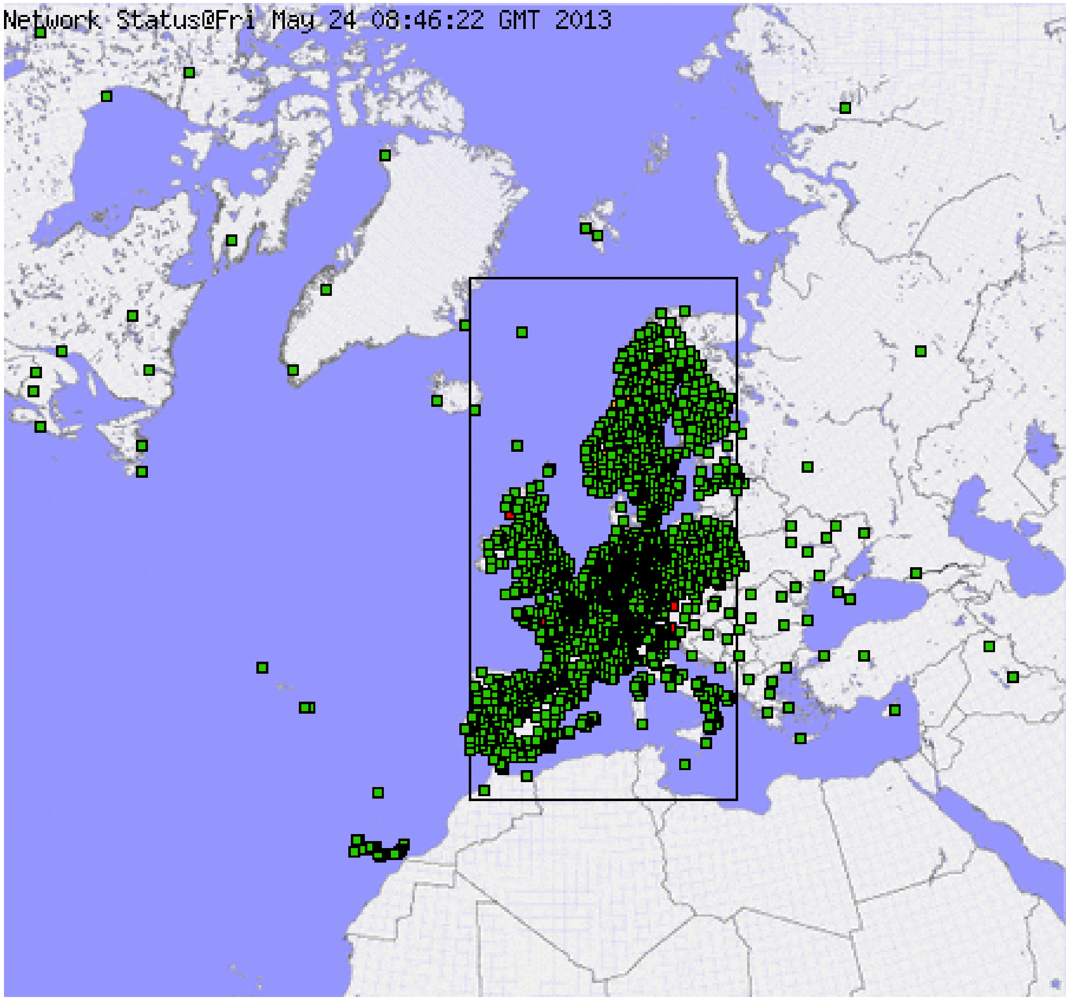


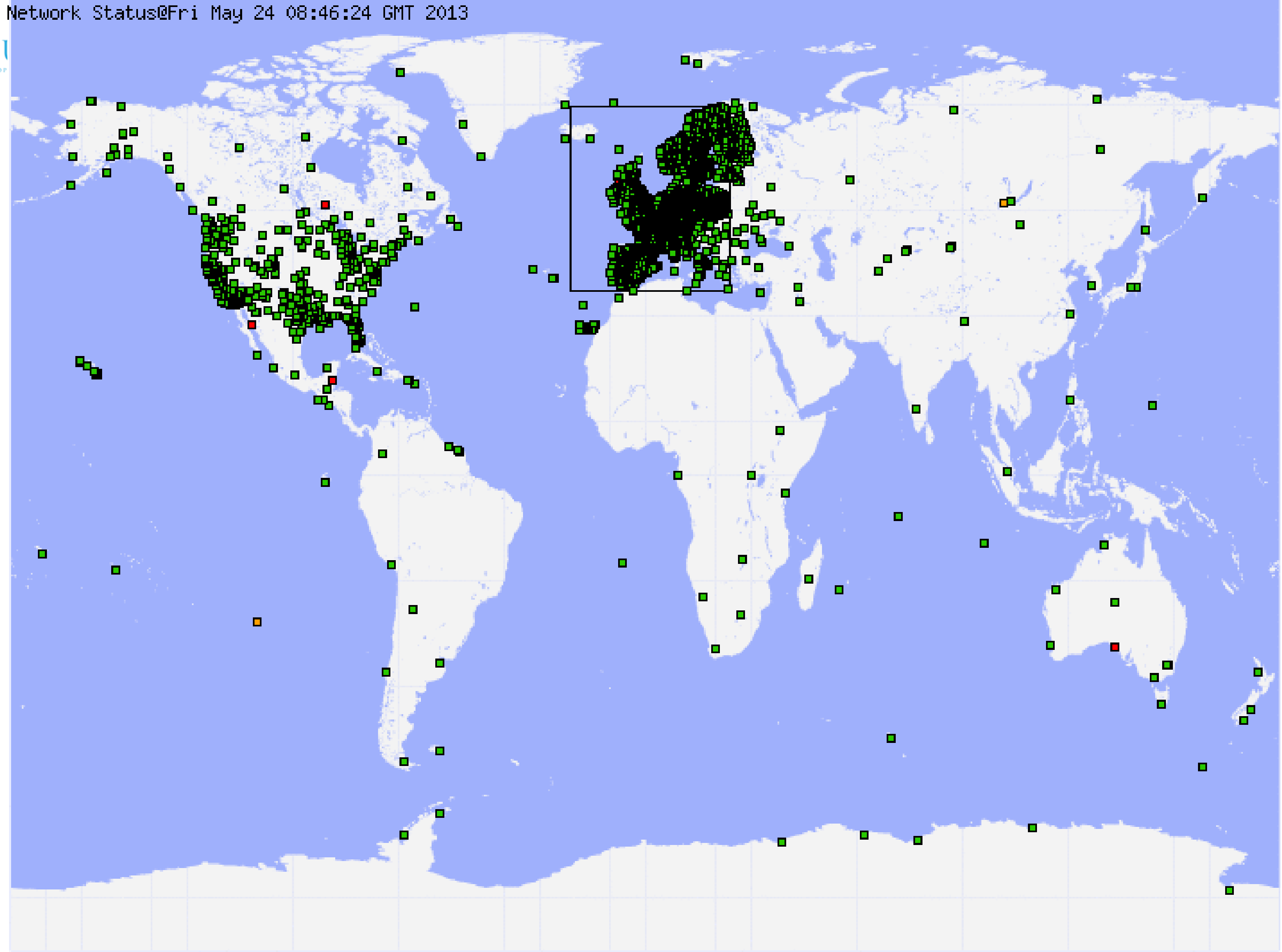
Number of AC-GNSS site combos versus time.

The significant overlap in site processing is in part for each AC to get a network of sufficient spatial extent.
It enables E-GVAP to do inter-comparison of ZTDs from many more sites than just supersites, which is good for quality control.

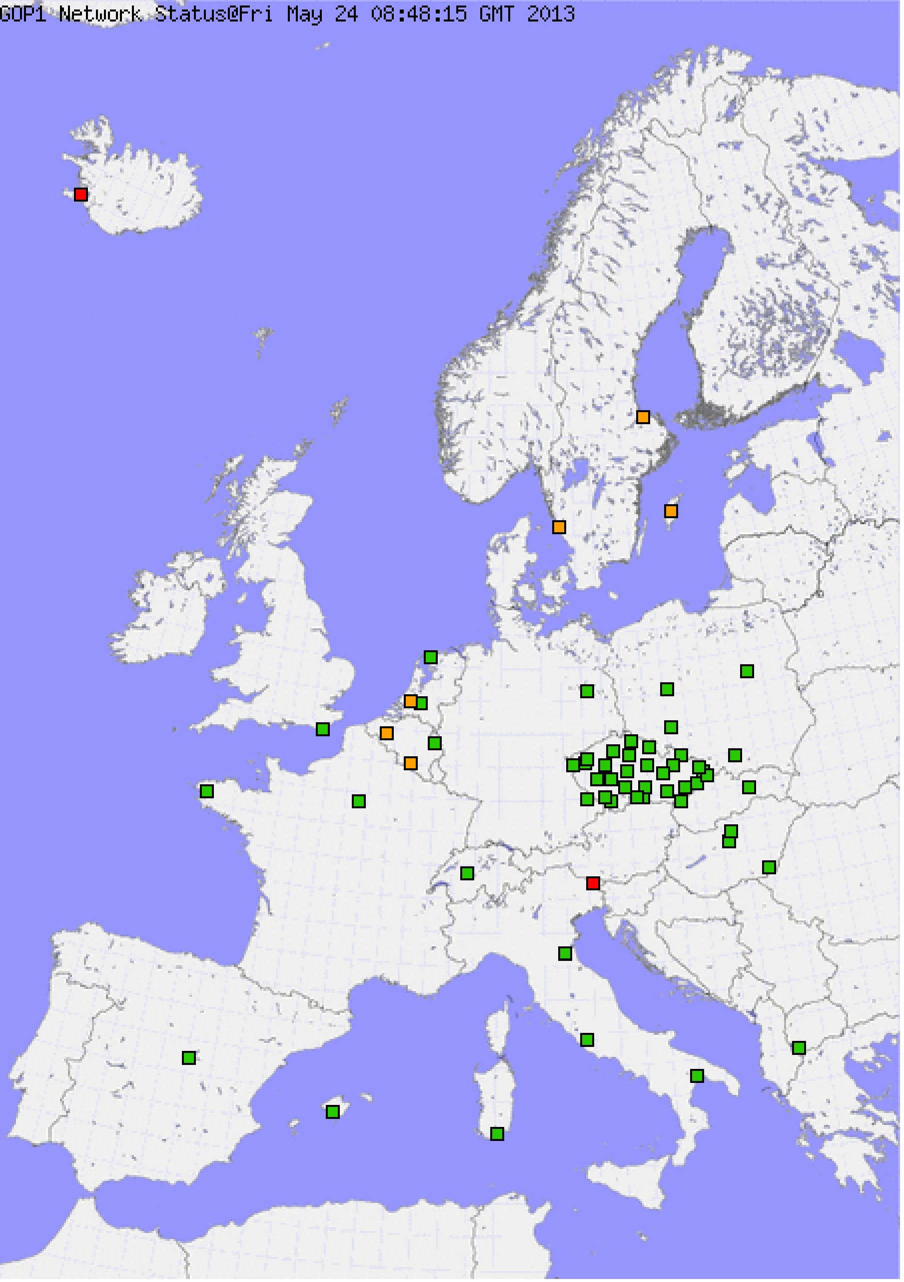
EUMETNET
European Meteorological Services Network

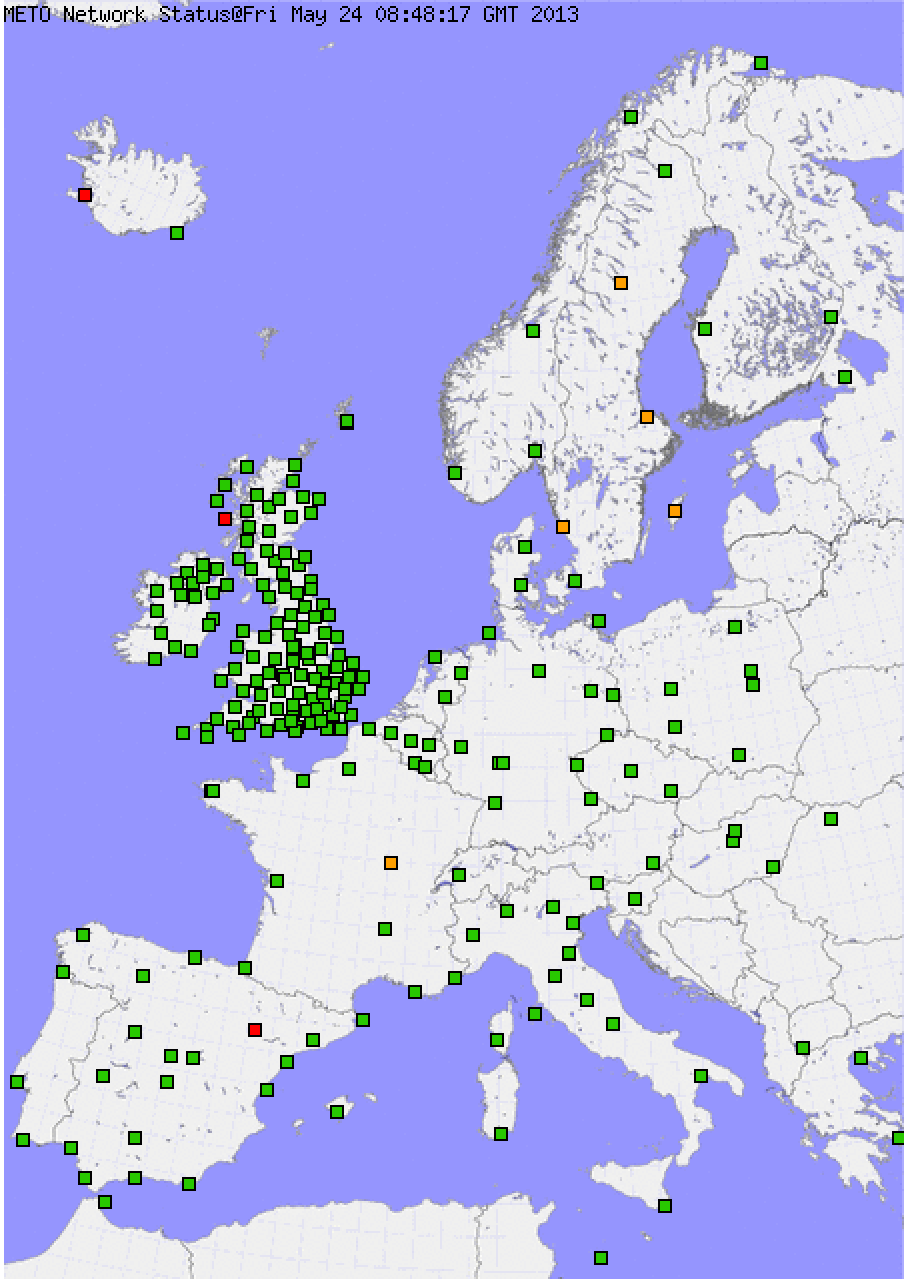
Data coverage

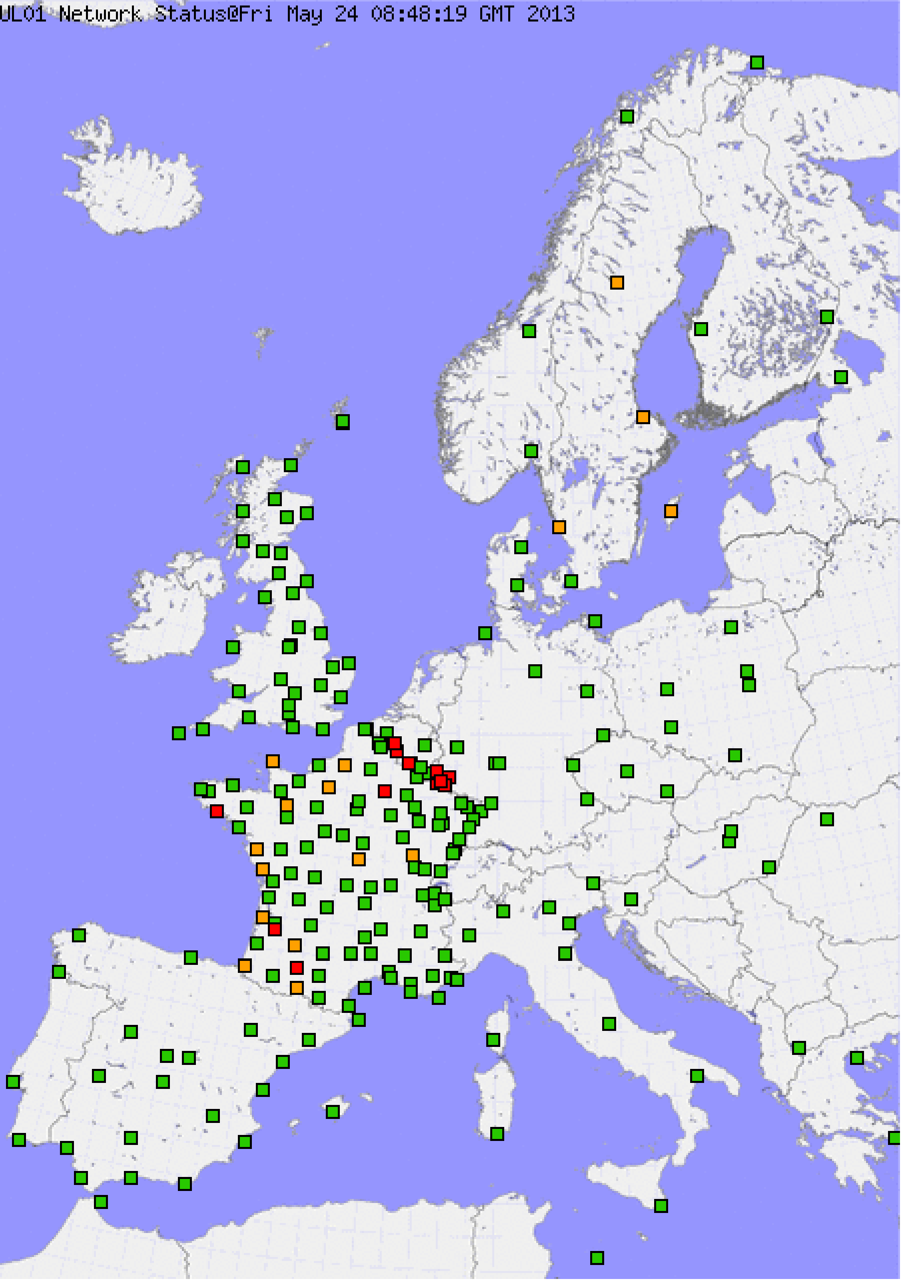


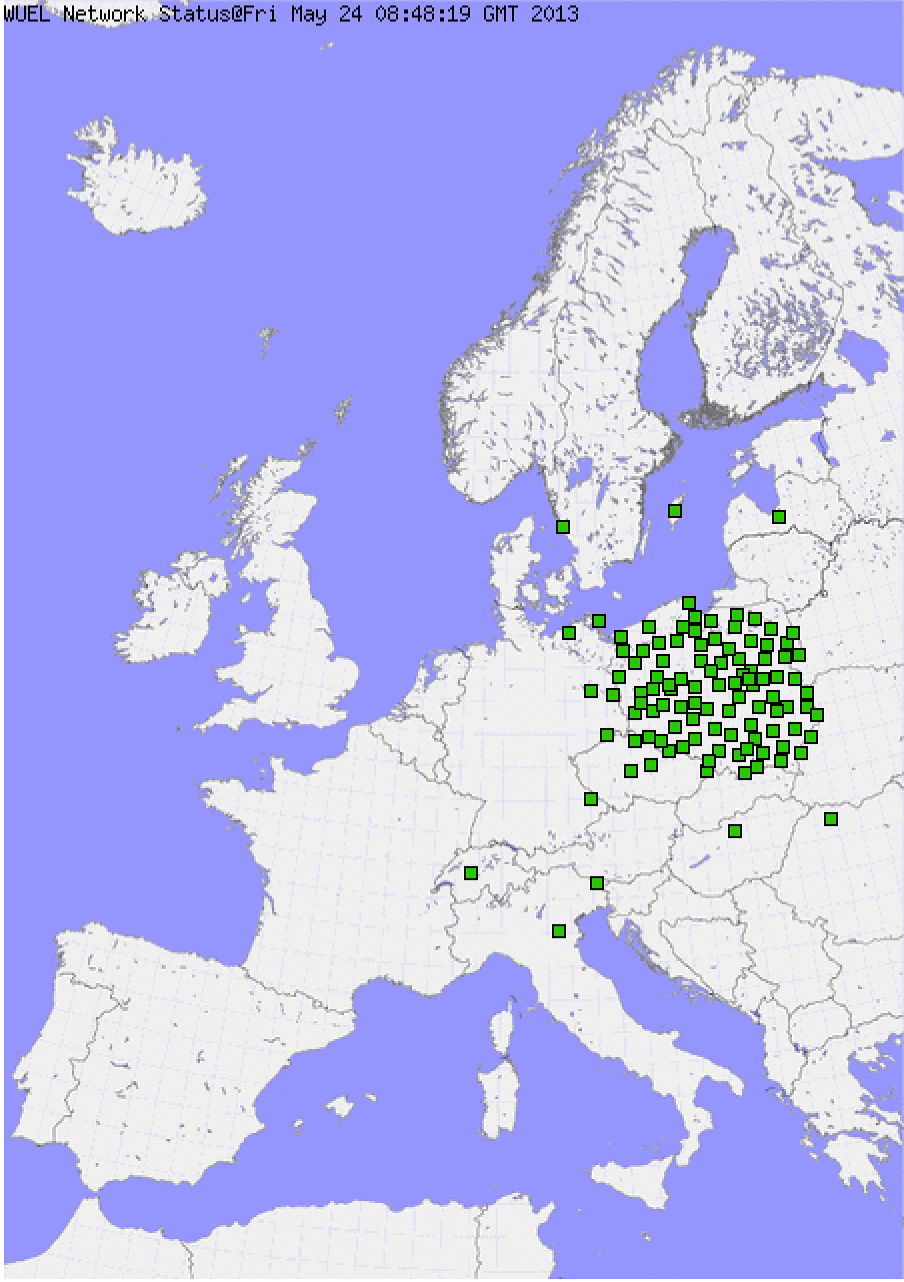


DATA COVERAGE


GOP1 Network Status@Fri May 24 08:48:15 GMT 2013


METO Network Status@Fri May 24 08:48:17 GMT 2013


UL01 Network Status@Fri May 24 08:48:19 GMT 2013


WUEL Network Status@Fri May 24 08:48:19 GMT 2013

EUMETNET
The Network of European Meteorological Services

EUREF – The IAG Reference Frame
Sub-commission for Europe

MEMORANDUM OF UNDERSTANDING

between

A: EUREF, the Reference Frame Sub-Commission for Europe of the International Association of Geodesy (IAG)

and

B: EUMETNET, the Network of European Meteorological Services.

MoU between EUREF and EUMETNET since 2007

MoU now made between EUPOS and EUMETNET

Operational status regarding European use in NWP

- **Four institutes, assimilate E-GVAP data in their operational models.**
  - **Météo France in Arpege (global), Aladin (regional) and Arome (meso scale, at 2.5 km).**
  - **UK Metoffice in NAE (regional), UK4 (meso scale), and in global model**
  - **KNMI (Netherlands)**
  - **DMI (Denmark)**
- **Many met institutes close to start operational usage.**

- **Data distributed by E-GVAP used also by national met offices in the US and Canada in operational forecasting.**

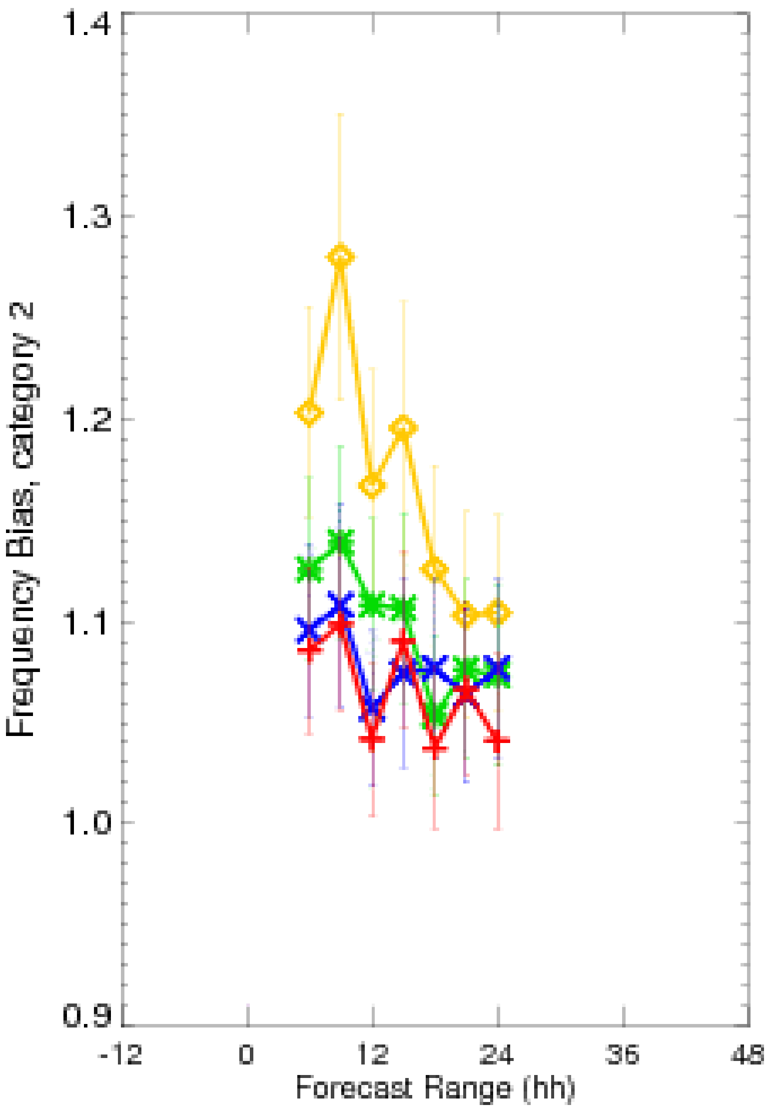
Latest impact trials at UK Metoffice

- 41 day trial – July 2011
- 4km 3D-VAR

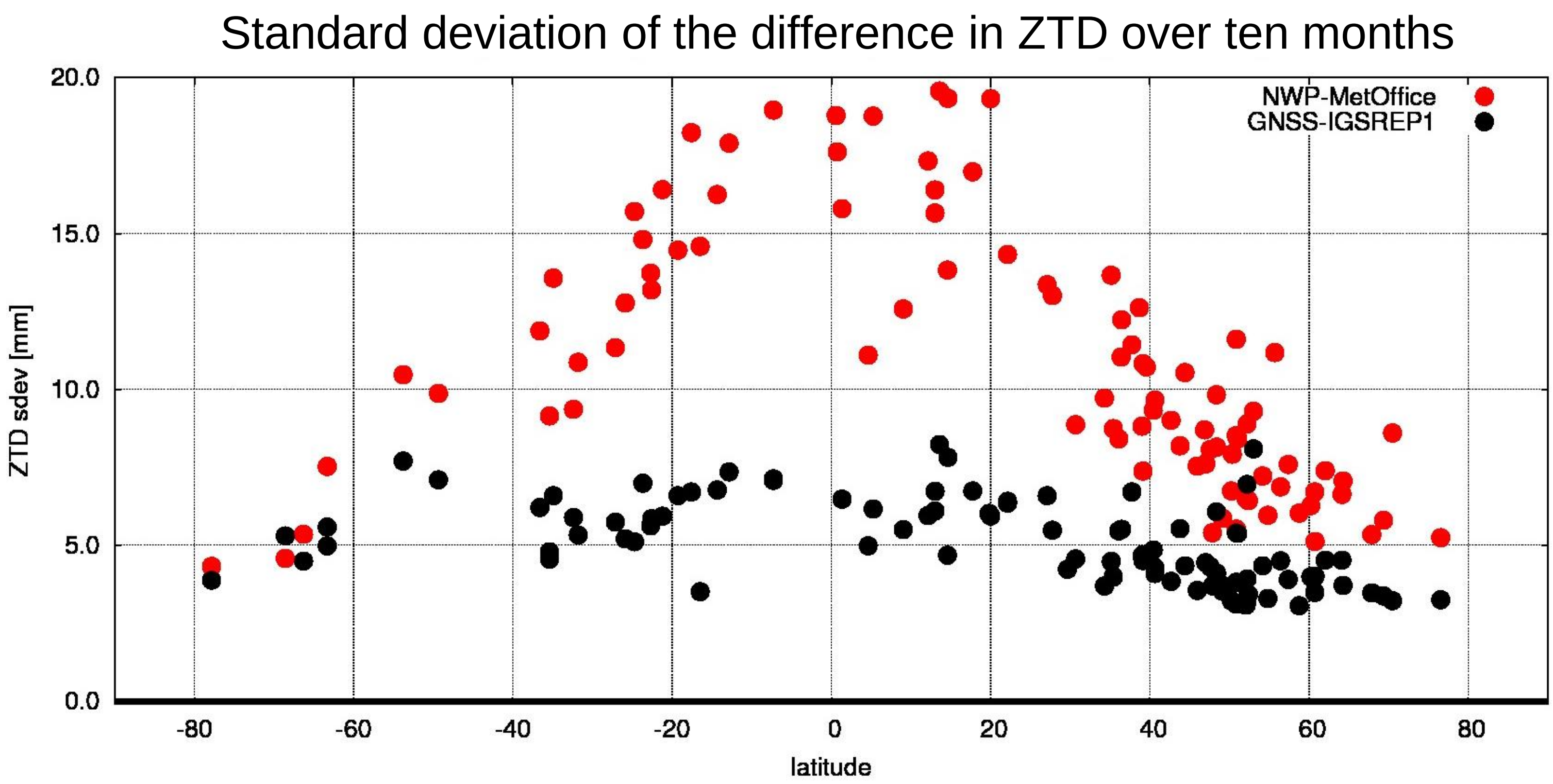
Control	Trial 3	Trial 1	Trial 2
Assimilation as normal for operational model (observation error = 6mm)	**ZTDs not assimilated**	**ZTD observation error = 9mm**	**ZTD observation error = 12mm**
	3.2% increase in $T_{surface}$ RMS error	**1.2% increase in $T_{surface}$ RMS error**	**1.5% increase in $T_{surface}$ RMS error**

6 hour precipitation accumulation

- Yellow = Trial 3
- Green = Trial 2
- Blue = Trial 1
- Red = Control



Global



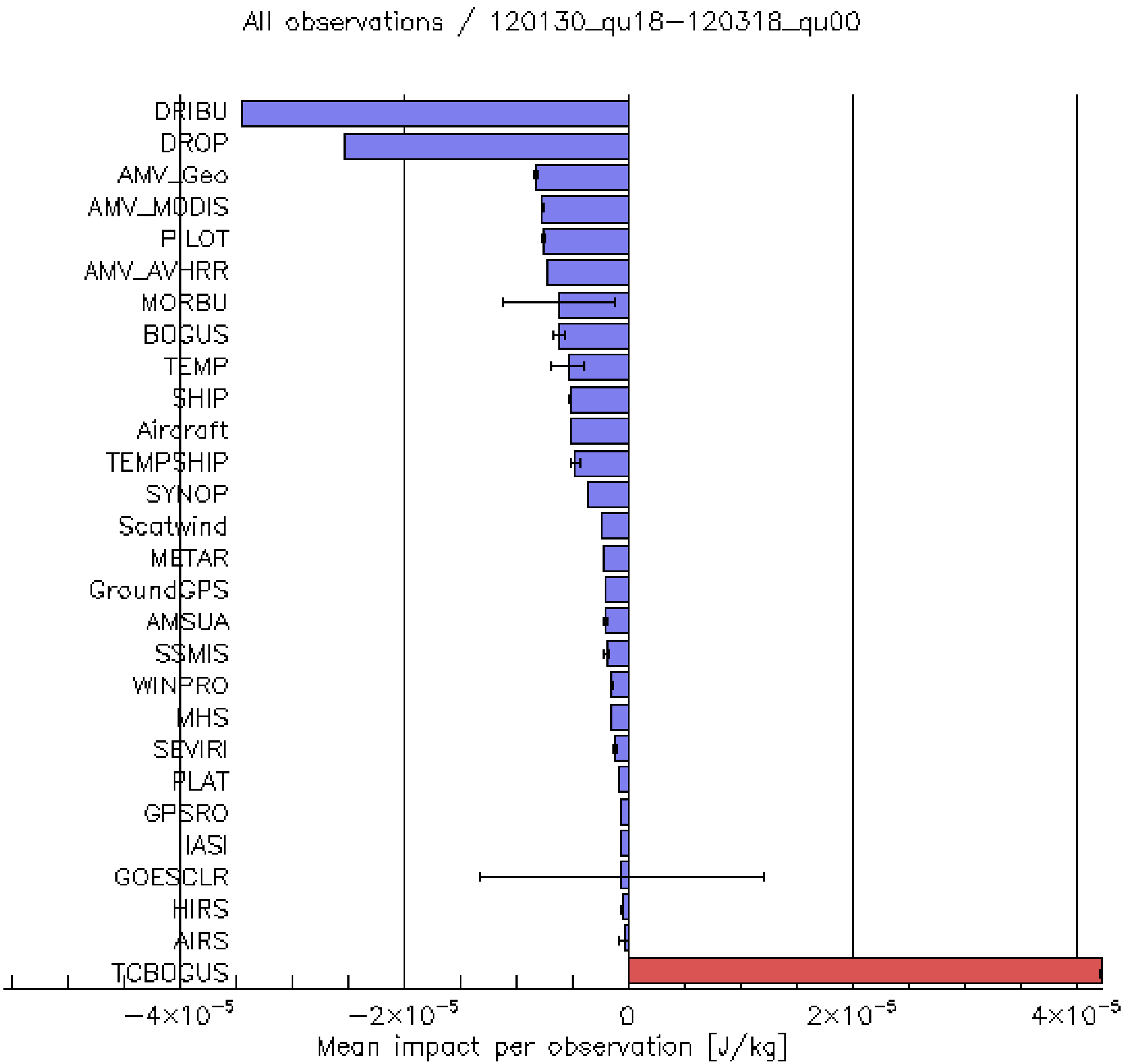
$\sigma_{\text{GOPG ZTD - NWP ZTD}}$ and $\sigma_{\text{GOPG ZTD - IGS REPRO ZTD}}$

Dousa and Bennitt 2012

Latest impact trials: Global

- 41 day Summer trial, 41 day Winter trial
- 40km horizontal resolution

Control	Trial 1: Winter 2012	Trial 2: Summer 2012
Assimilation as normal for operational model (observation error = 9mm)	Observation error = 15mm Observations from GOPG and METG added	Observation error = 15mm Observations from GOPG and METG added
	Zero impact on average	2% decrease in RMS errors across various parameters. Improvements seen almost entirely in southern hemisphere and tropics

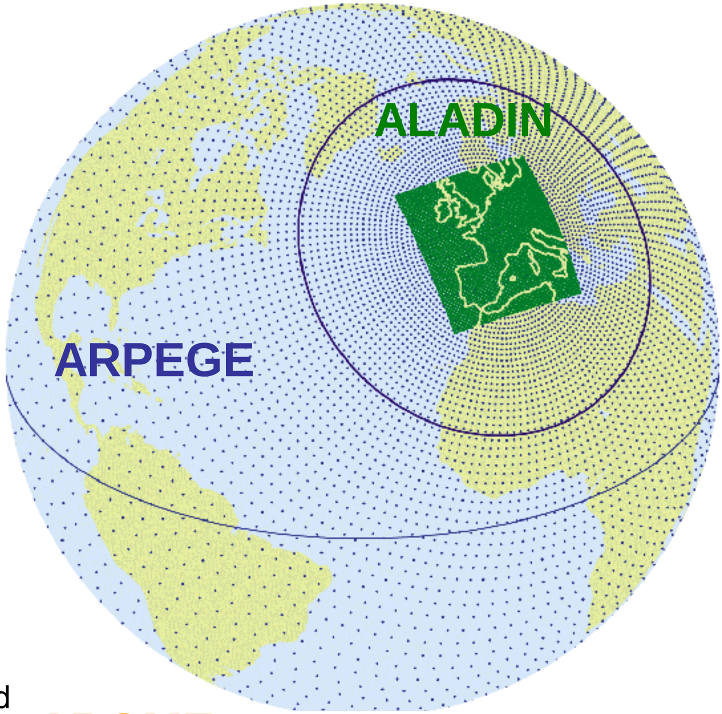


Courtesy of Richard Marriot

Meteo France slides by Patrick Moll.

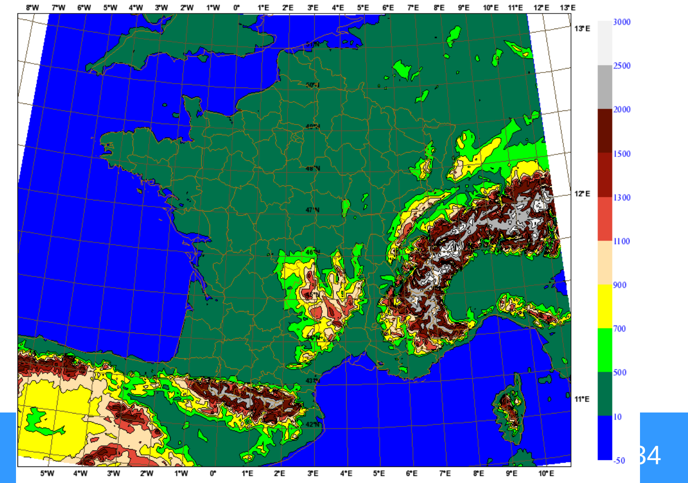
The operational assimilations at Météo-France

- **<u>Global model and 4DVAR assimilation system ARPEGE</u>**
  - Vertical: 60 levels, model top at 0.1 hPa (~65 km altitude)
  - Horizontal: T538, stretched model: highest horizontal resolution over France (~15 km)
  - 4DVAR assimilation (non-stretched) with two minimizations: T107 / T224
  - Analysis horizontal resolution is about 90 km (globally)
  - **Assimilates European GPS ZTD data since 19 September 2006**
  - Note: there are still operational runs of our non-stretched global model



- European limited-ared model and 3DVAR assimilation system **ALADIN**
  - Horizontal resolution 9.5 km, same vertical levels as ARPEGE
  - 3DVAR assimilation with 1 minimization at full resolution (6h period)
  - One version running over France
  - **Assimilates European GPS ZTD data since 19 September 2006**
  - Other versions running for La Réunion Island (Eastern Indian Ocean) and specific areas of interest : do not assimilate any GPS ZTD data

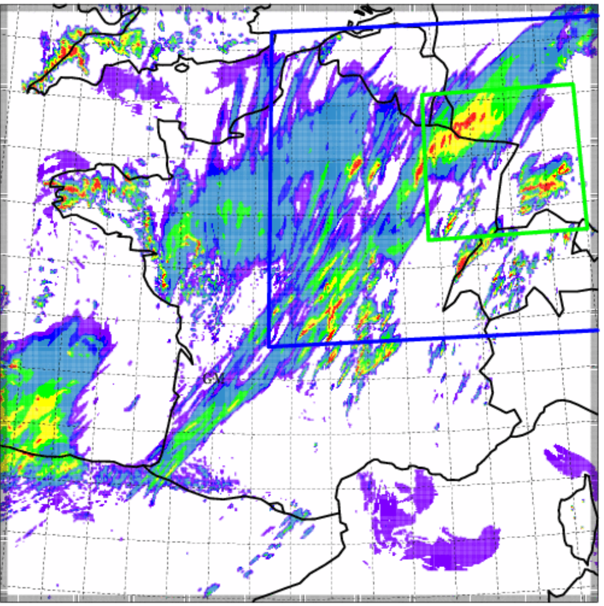
AROME



- High-resolution mesoscale non-hydrostatic model with a 3DVAR assimilation system **AROME** over France
  - Horizontal resolution 2.5 km, 41 levels
  - 3DVAR assimilation with 1 minimization at full resolution (3h period)
  - **Assimilates European GPS ZTD data over France since 22 April 2008**

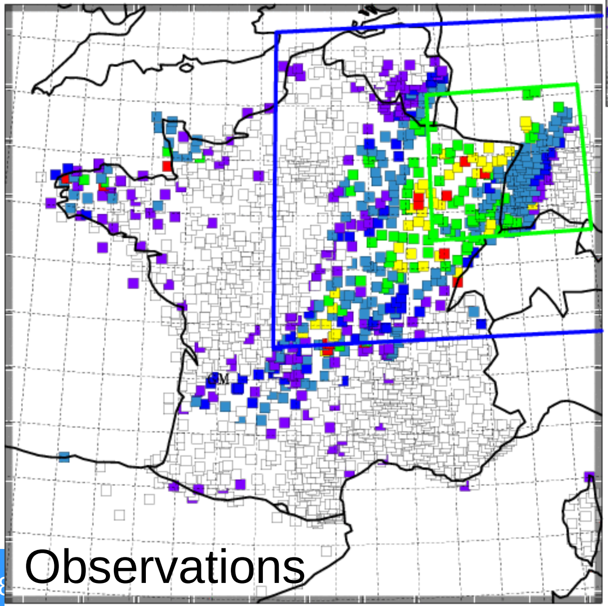
Impact on AROME forecast (OSE experiment)

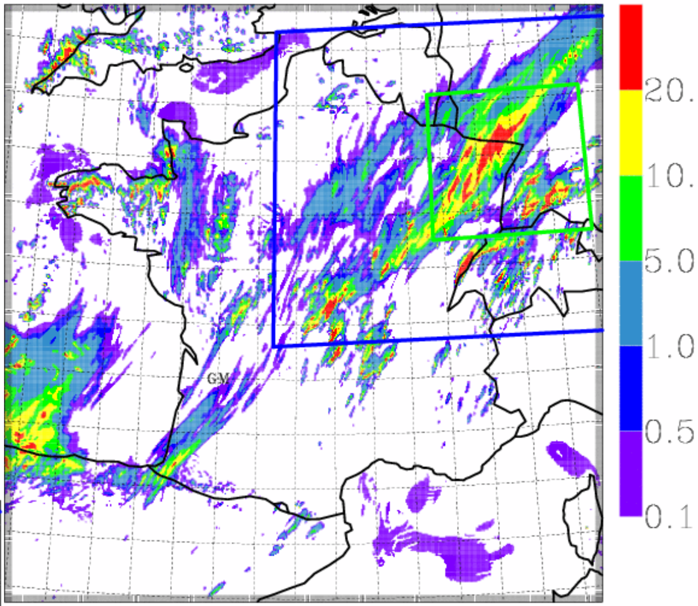
AROME, 15h forecast starting from the 00UTC analysis, 19 july 2008



WITHOUT ZTD data assimilation

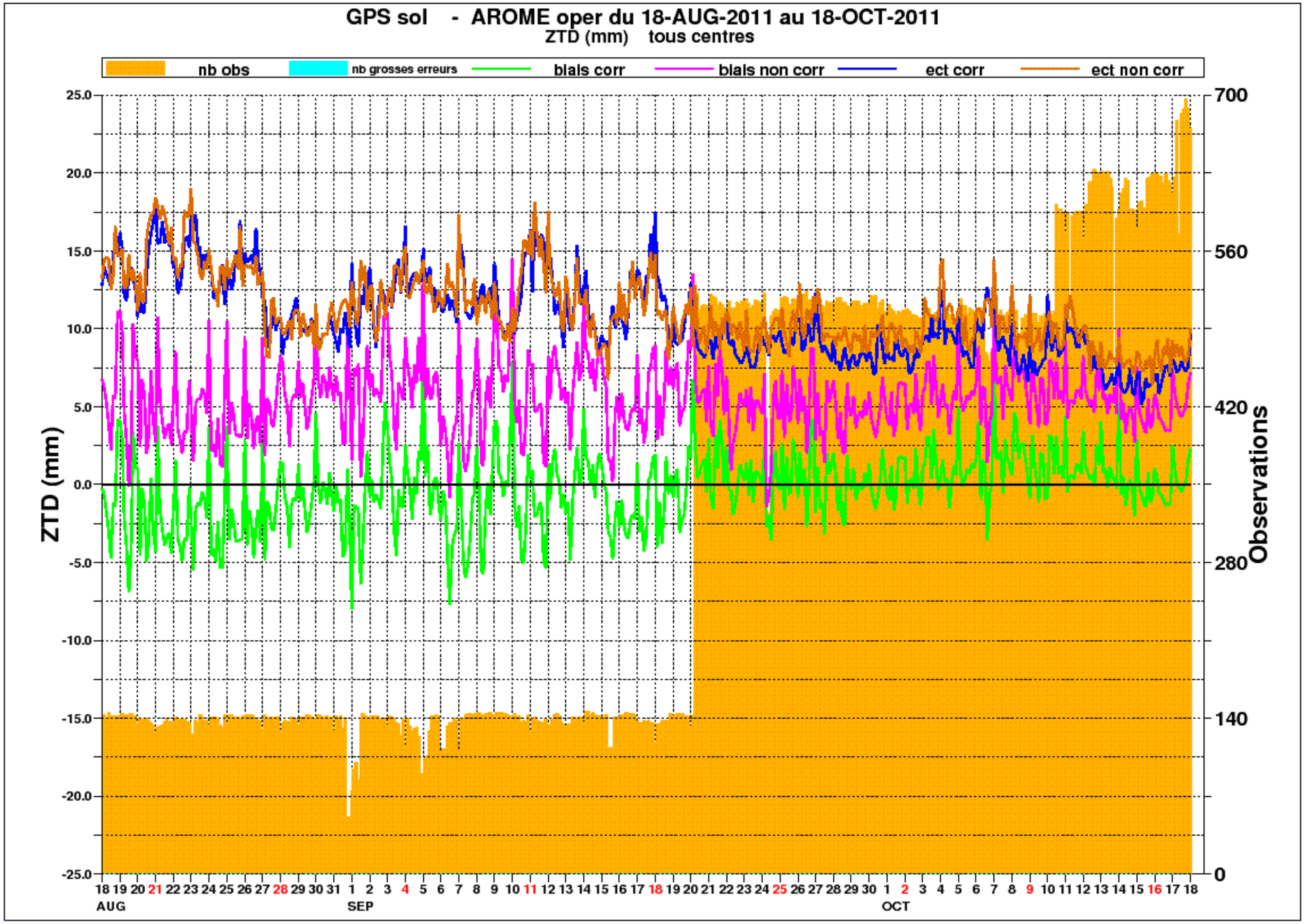
Cumulated rainfall between 03UTC and 15UTC, 19 july 2008





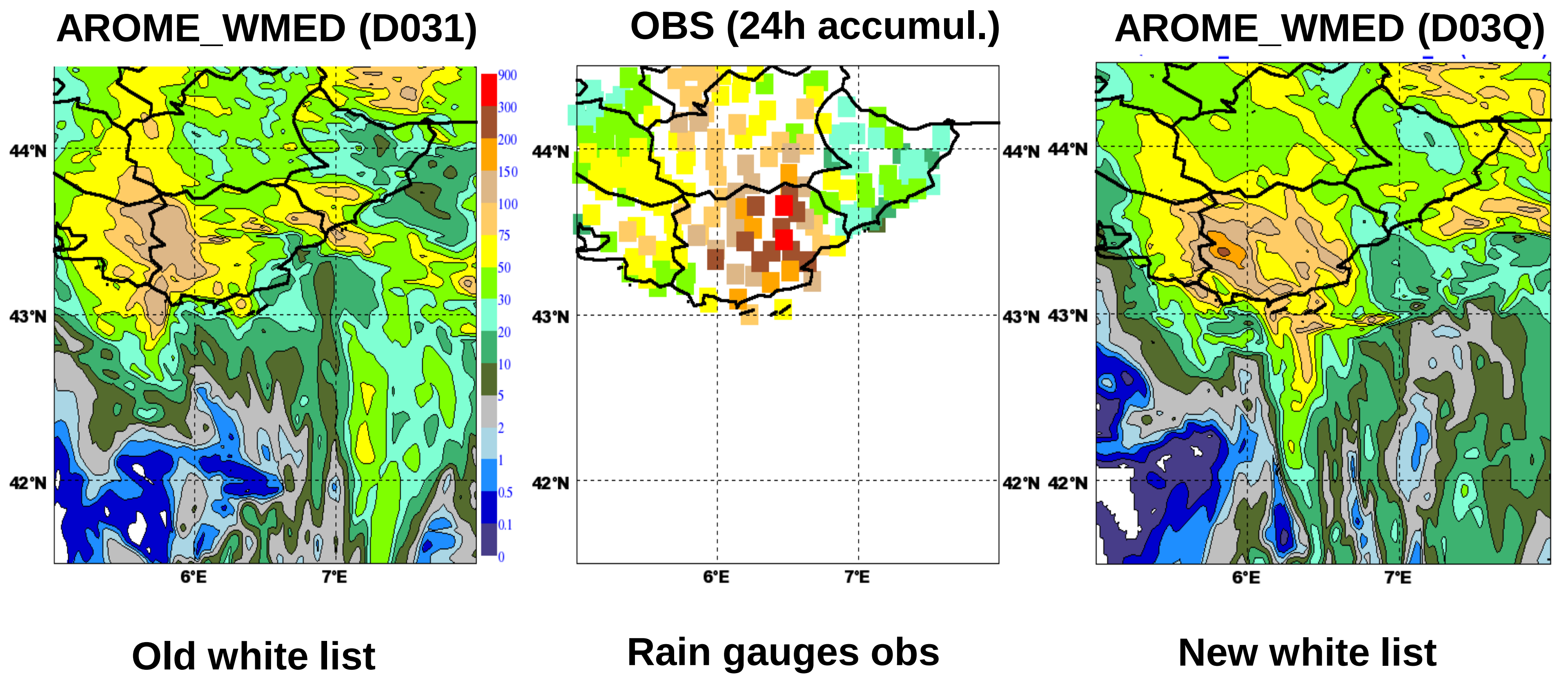
WITH ZTD data assimilation

Monitoring example (time-series)



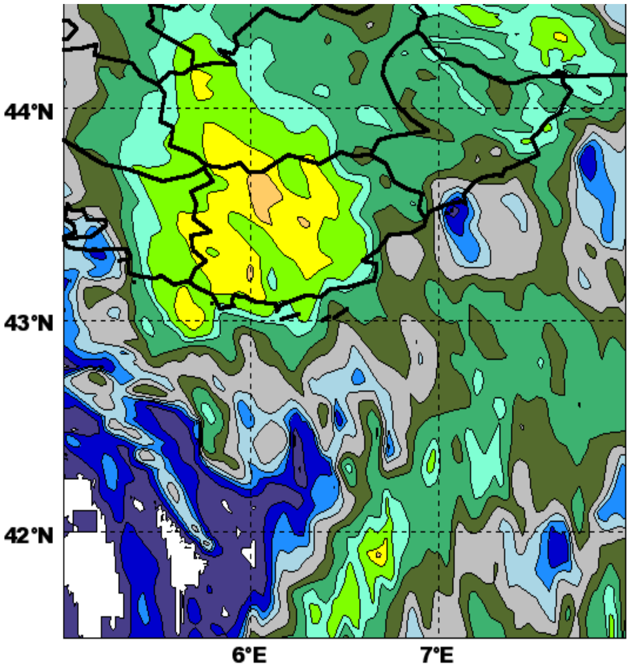
DPREVI/COMPAS

15/06/2010 – 06UTC



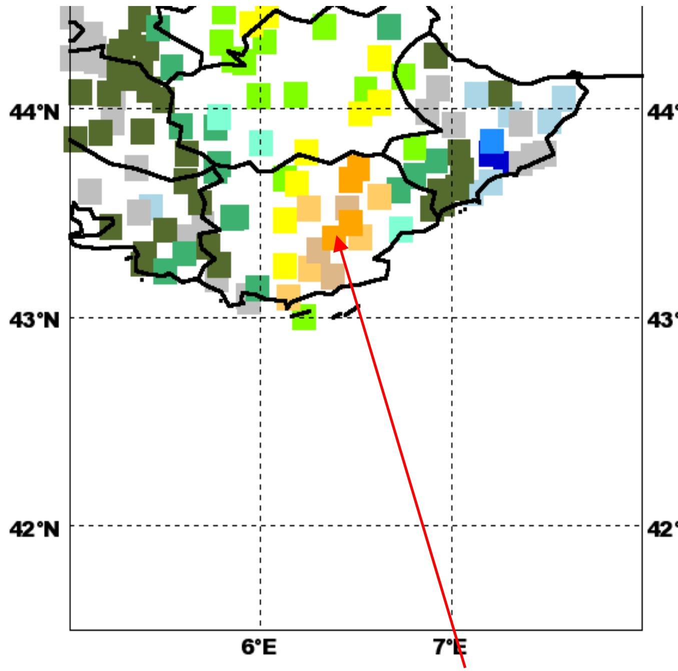
15/06/2010 – 09UTC

AROME_WMED (D031)



Old white list

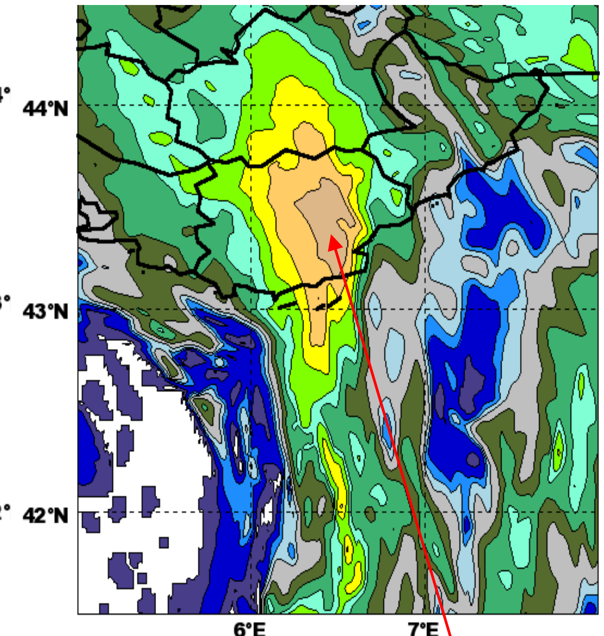
OBS (6h Accumul.)



195mm/6hr

Rain gauges obs

AROME_WMED (D03Q)



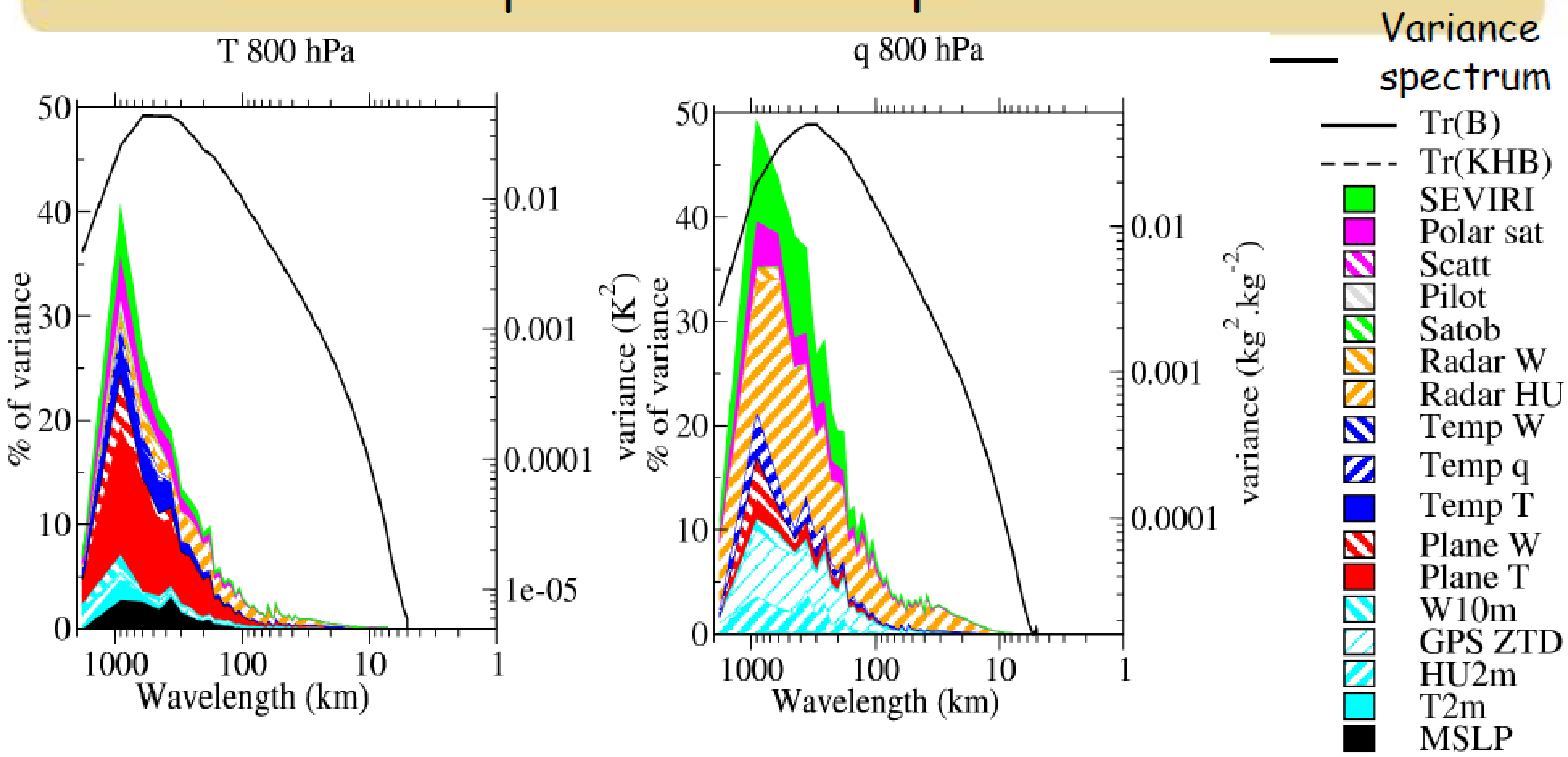
130mm/6hr

New white list

Conclusion:

More GNSS data (denser network) improves the Arome forecasts

Spectral decomposition



- Higher reduction of variance error for wavelengths corresponding to the higher values of variance spectra
- For wavelengths shorter than :
  - 200 km, only radar and plane measurements for temperature (GPS for specific humidity) contribute to the variance reduction
  - 100 km, the variance reduction reach only 5% of the error variance and it is only provided by radar observations

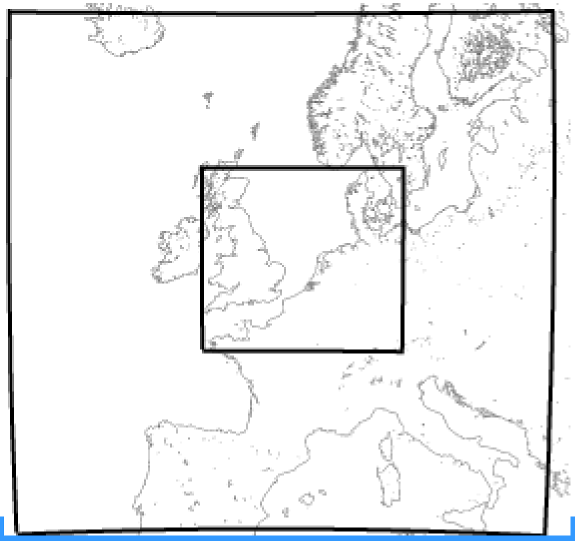
Slide from Pierre Brousseau, Météo France

KNMI slides by Siebren de Haan

Case study with hourly assimilation (model U) of only
- ModeS aircraft data (wind, temperature)
- Surface pressure data
- extra with gb GNSS data added
- extra with GNSS and radar line of sight wind data added

Comparison to standard operational model (H), with and without GNSS data, running in a 6 h cycle, and assimilating all "standard" observations.

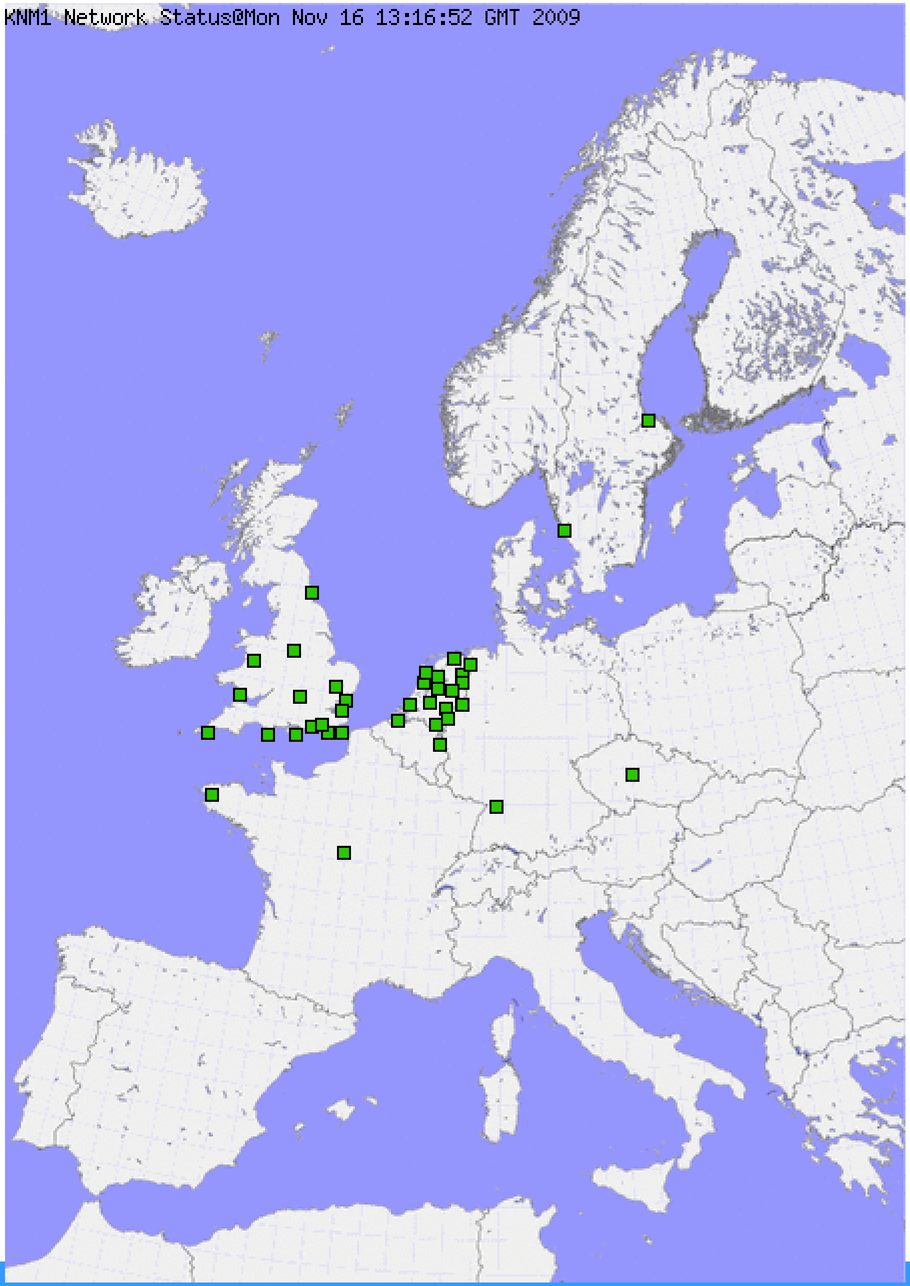
Model resolution 11 km for both U and H models.



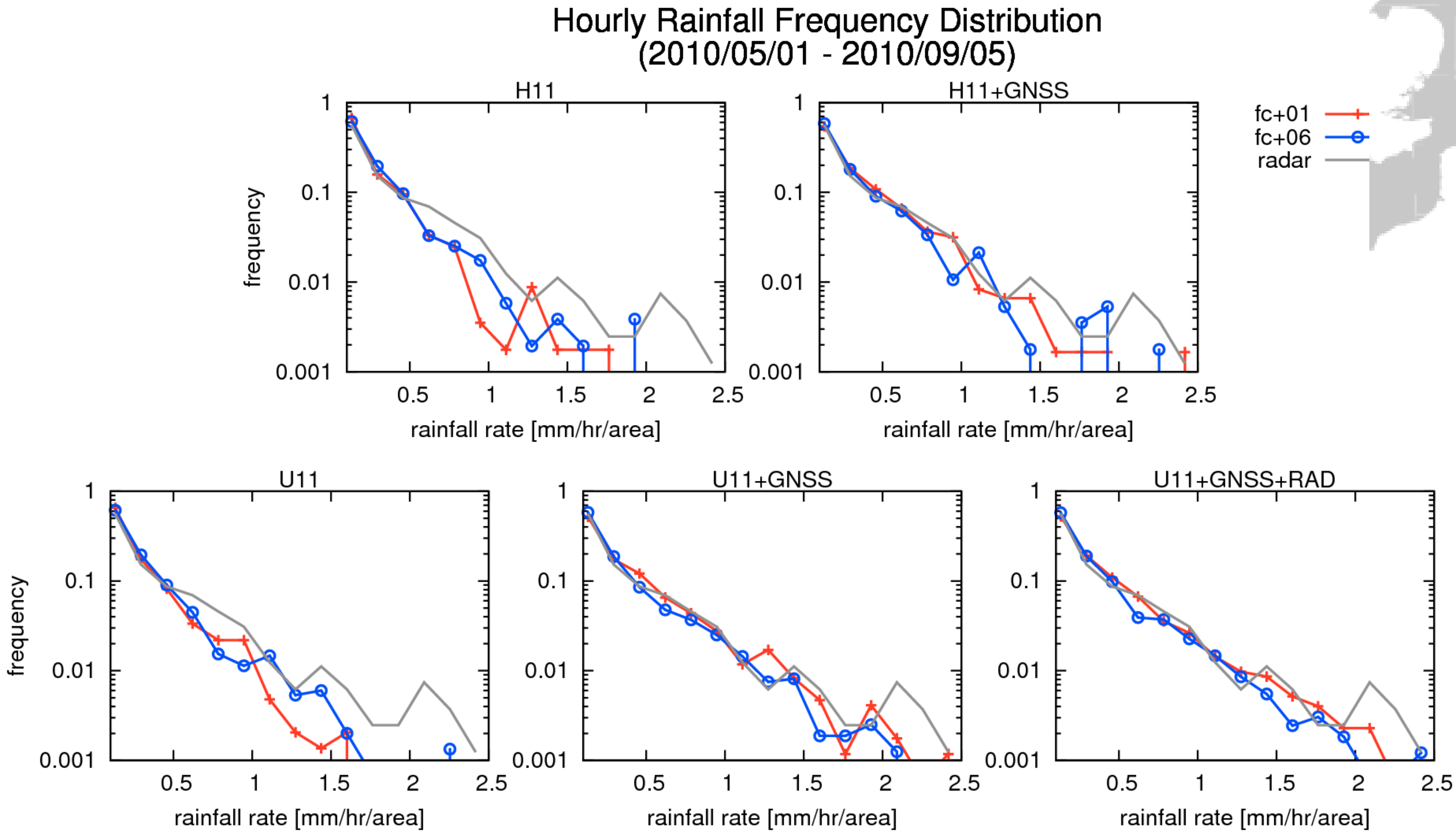
Subhourly ZTDs

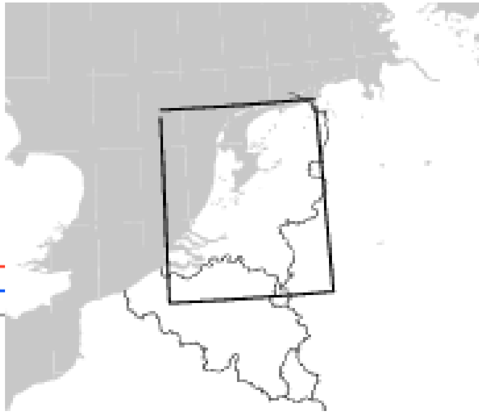
- Every 15 minutes
  - NL : Kadaster
  - GB : Ordnance Survey
- Available within 5 min.

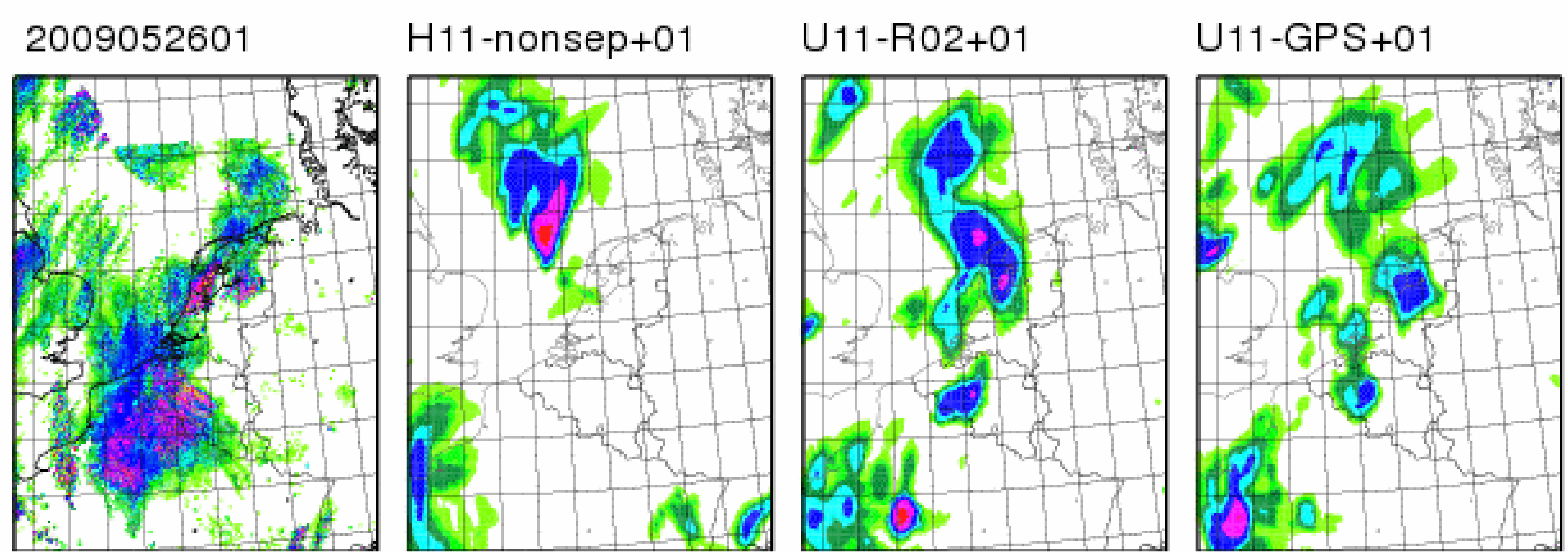
- Water Vapour Fields



Rainfall forecast verifcation







radar | ReRUN H11 | U11+ModeS | U11++GPS

Analysis time 2009/05/26 00UTC

- **U11+ModeS** en **U11+ModeS+GPS** heavy convection above Belgium
- Convection North-France less extreme **U11+ModeS+GPS**

Both hourly runs

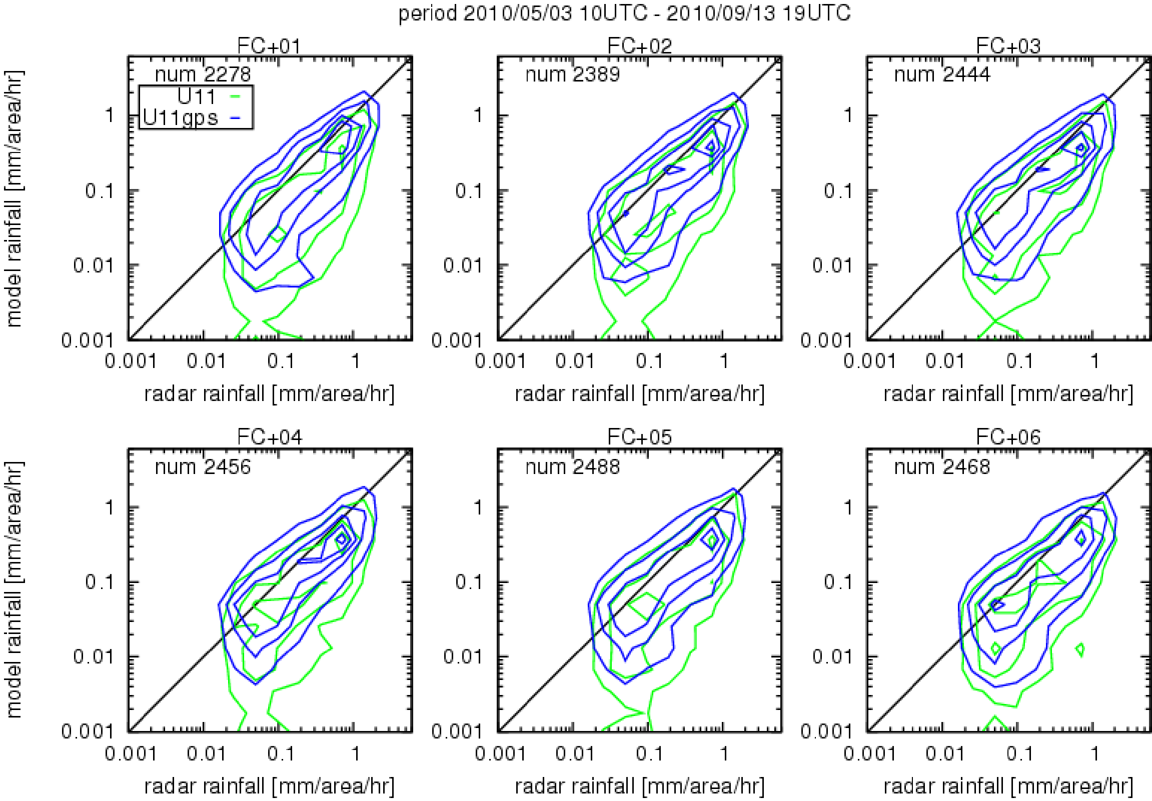
Observations U11

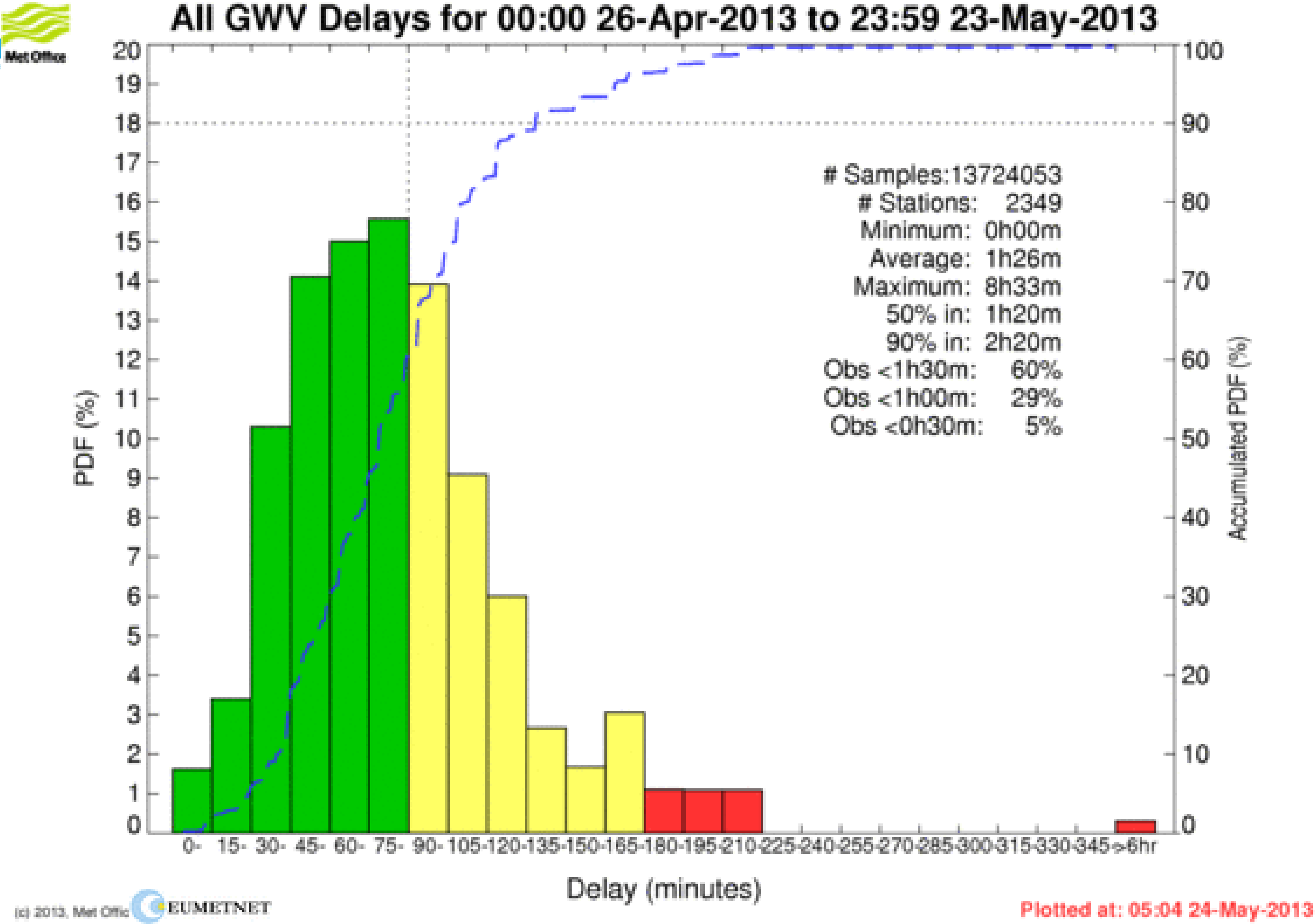
- Synop Pressure
- Aircraft (f,d,T)
- GPS (~q)

Conclusions:

- No Spinup signal
- Better match with radar RR when GPS is assimilated
- Static bias correction

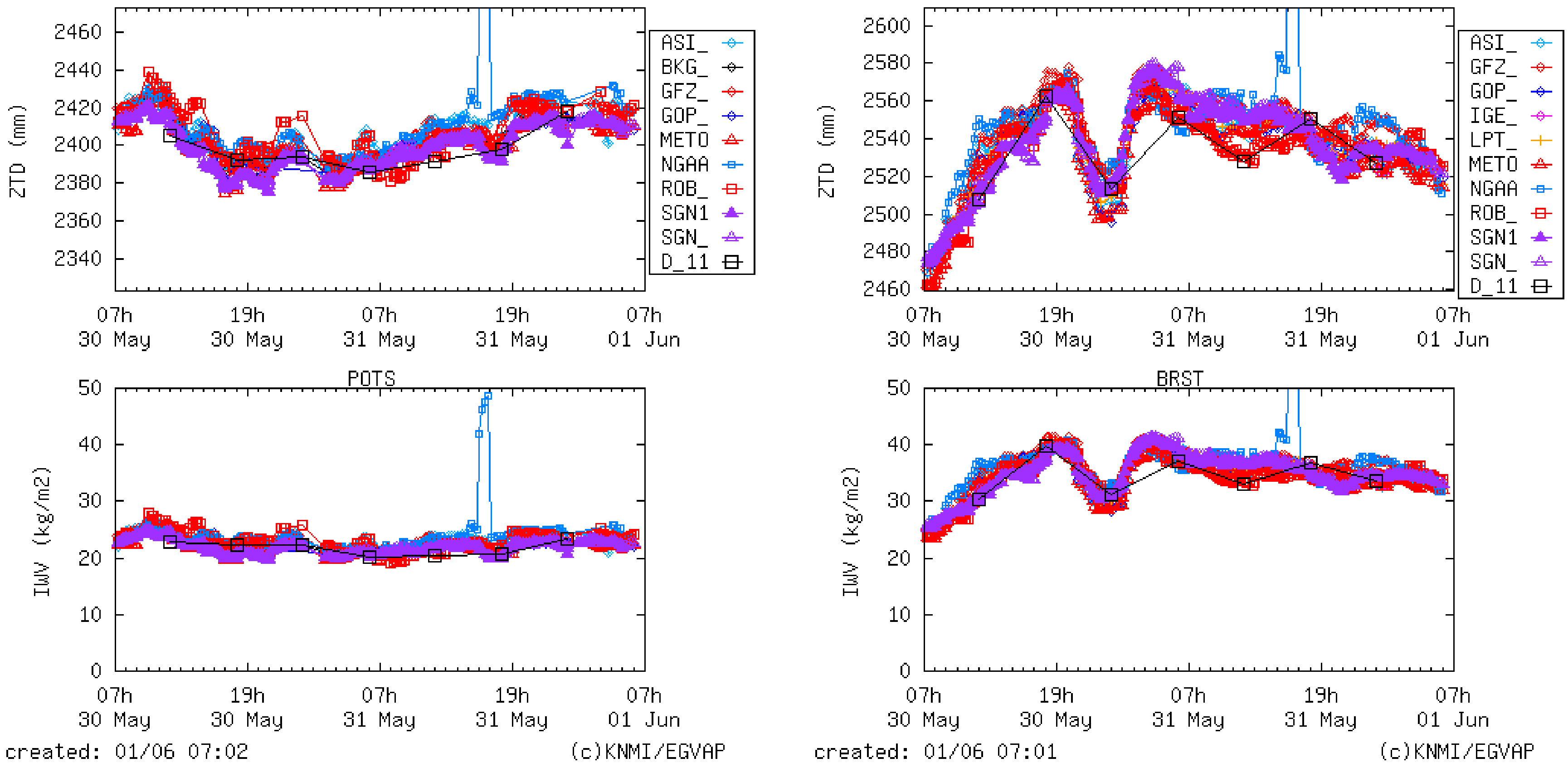
Todo: impact of other obs.





Timeliness: Age of observations when arriving in UKMO database, counted in 15 min bins.

Active quality control, AQC



Example highligting

1) General agreement between 9 ACs (and NWP) at two sites = good quality.
2) But: When one AC is wrong at one site it is **also** wrong at the other. This is very particular to GNSS ZTD estimation, and dangerous to NWP.

Conclusion regarding use of ZTD

- **It is demonstrated that the NRT GNSS ZTD estimates for European sites has a positive impact on NWP skill.**
- **The EPN sites constitute an important backbone of the system, being included to some degree by all ACs**

- **It is demonstrated that densifying the network improves forecast skill.**
- **Besides there are still parts of Europe where coverage is poor.**
- **It is demonstrated that faster cycling of NWP (hourly) with use of GNSS data improves forecast skill.**

- **Hence, ZTDs from additional sites and faster access will further increase benefit. IGS RTS can help achive that.**

- **There is scope for improving the data assimilation tools. E.g, regarding bias correction methods, estimation of observation errors, selection of AC-site combos for sites processed by multiple ACs, and active quality control.**

- **We are far from having exploited all potential benefits of ZTD estimates in NWP, and far from being saturated.**

The future

Great potential for improving ground-based GNSS meteorology.

- **Through production of new GNSS based atmospheric estimates, providing a higher information content per GNSS site. Such as GNSS gradients, GNSS slants/residuals and GNSS tomography.**
- **Through introduction of NWP nowcasting models, that makes better usage of the high timefrequency of GNSS observations and of local dense networks.**
- **Use of GNSS in climate monitoring.**

In addition there is a potential for improving GNSS positioning by using information about the current atmospheric state, from meteorological observations and/or NWP models.

This is some of the goals of a new EU COST action that kicked off earlier this month.

It´ll be presented in the next talk by Jonathan Jones. Don´t go away!

Contact Details

Henrik Vedel
E-GVAP programme manager
GIE/EIG EUMETNET

E-GVAP Programme Manager
Henrik Vedel, PhD, Senior scientist
Danish Meteorological Institute, FM
Lyngbyvej 100
DK 2100 Copenhagen
Denmark

Tel: + 45 3915 7445
Email: hev@dmi.dk
Web: egvap.dmi.dk

GIE EUMETNET Secretariat
c/o L'Institut Royal Météorologique de Belgique
Avenue Circulaire 3
1180 Bruxelles, Belgique

Tel: +32 (0)2 373 05 18
Fax: +32 (0)2 890 98 58
Email: info@eumetnet.eu
Web: www.eumetnet.eu