ECMWF's forecast system developments

Erik Andersson

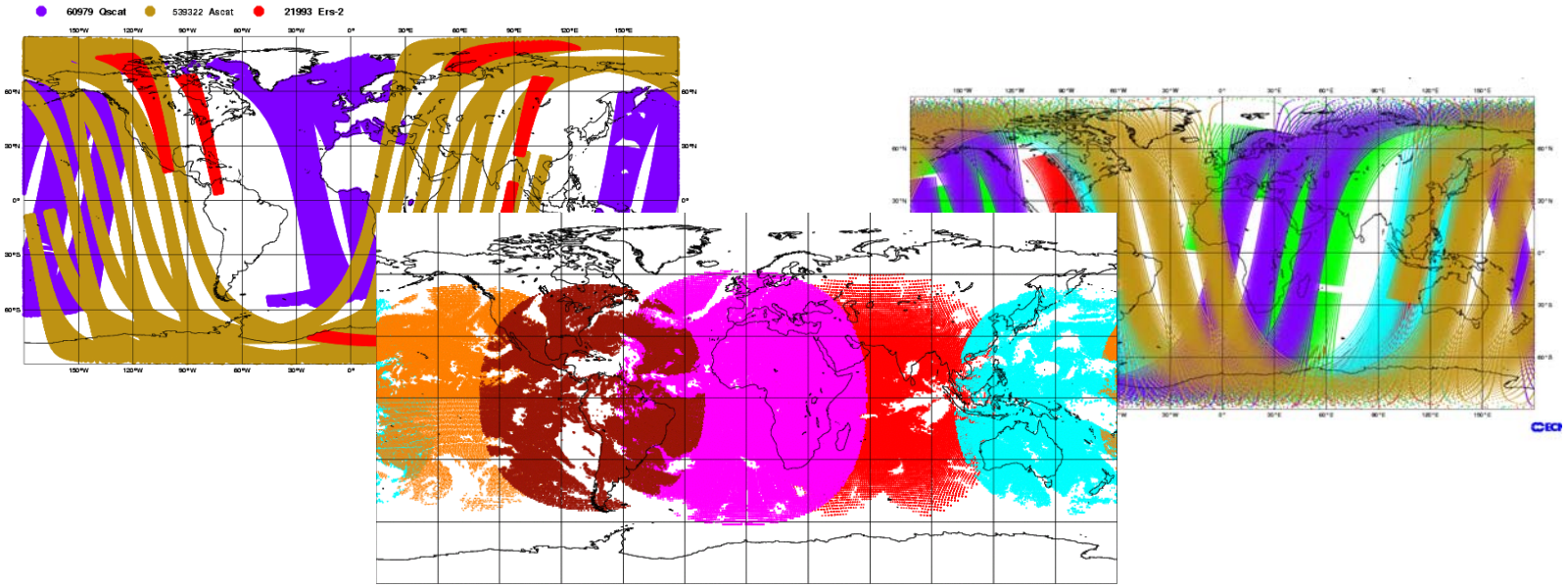
Workshop on
Meteorological Operational Systems,
Reading, 2-6 November 2009

Acknowledgement:
Colleagues in RD and OD,
Peter Bauer, Carla Cardinali and Lars Isaksen

ECMWF

Outline

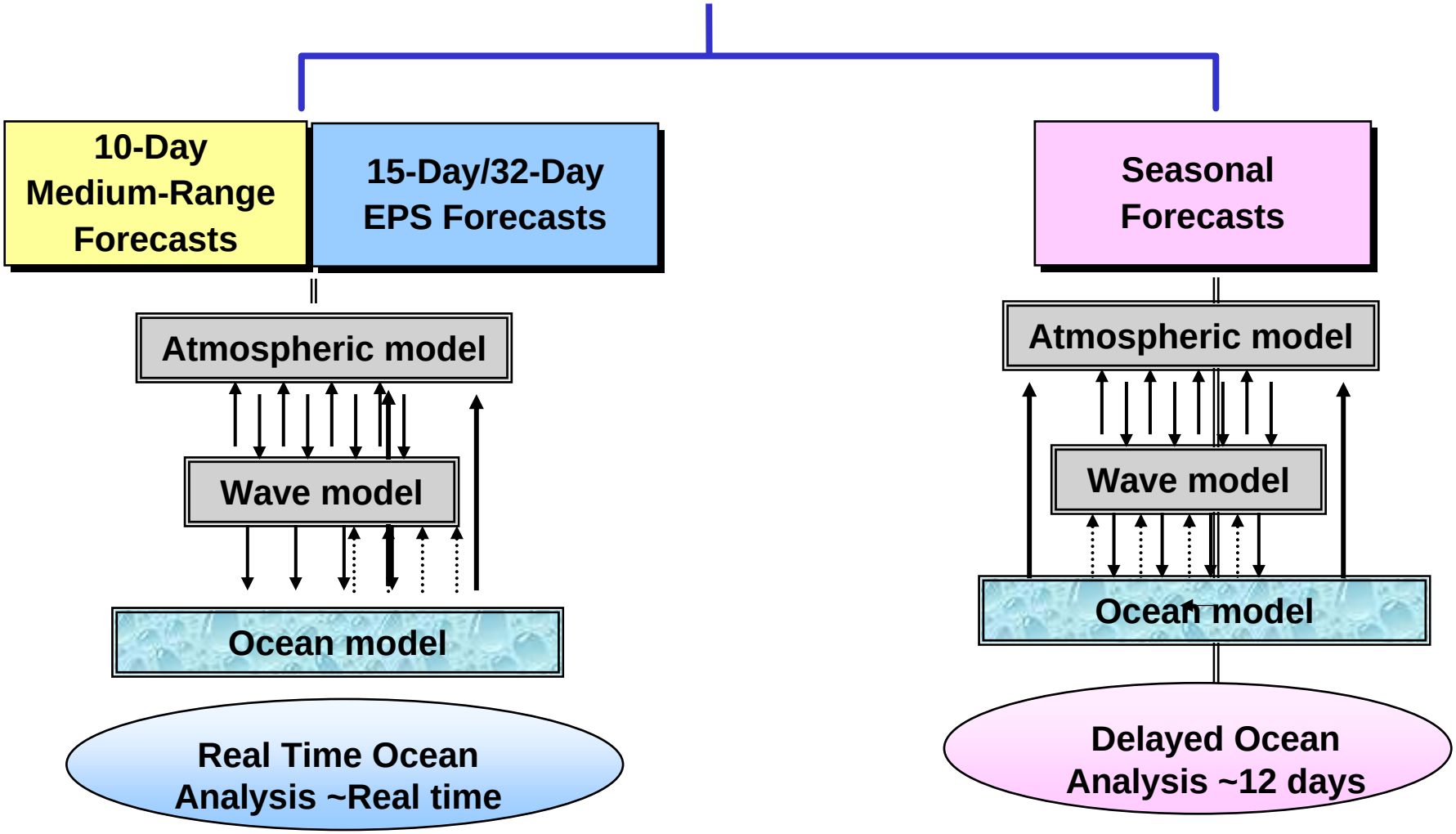
- **The operational forecast system**
- **Performance of ECMWF forecasts**
- **Increased horizontal resolution (16 km)**
- **Observation handling**
- **Workshop “focus on observations”**



The operational forecast system

- **High resolution deterministic forecast:** **twice per day**
  25 km 91-level, to 10 days ahead
- **Ensemble forecast (EPS):** **twice daily**
  51 members, 50/80 km 62-level, to 15 days ahead
- **Ocean waves:** **twice daily**
  - **Global: 10 days ahead at 40 km**
  - **European Waters: 5 days ahead at 25 km**
  - **Ensemble: 15 days ahead at 100 km**
- **Monthly forecast:** **once a week**
  51-members, 50/80 km 62 levels
- **Seasonal forecast:** **once a month**
  41-members, 125 km 62 levels, to 7 months ahead

ECMWF: Dynamical forecasts from days to seasons



ECMWF

Changes to the forecast system (1)

06 Nov 2007	**Cy32r3**	**IFS cycle implementation**
20 Jan 2008		**Revised production schedule: Products available 10 to 15 minutes earlier**
11 Mar 2008		**Integration of monthly forecast system with the medium-range EPS**
20 May 2008		**Assimilation of Metop/GRAS bending angles (radio occultation data)**

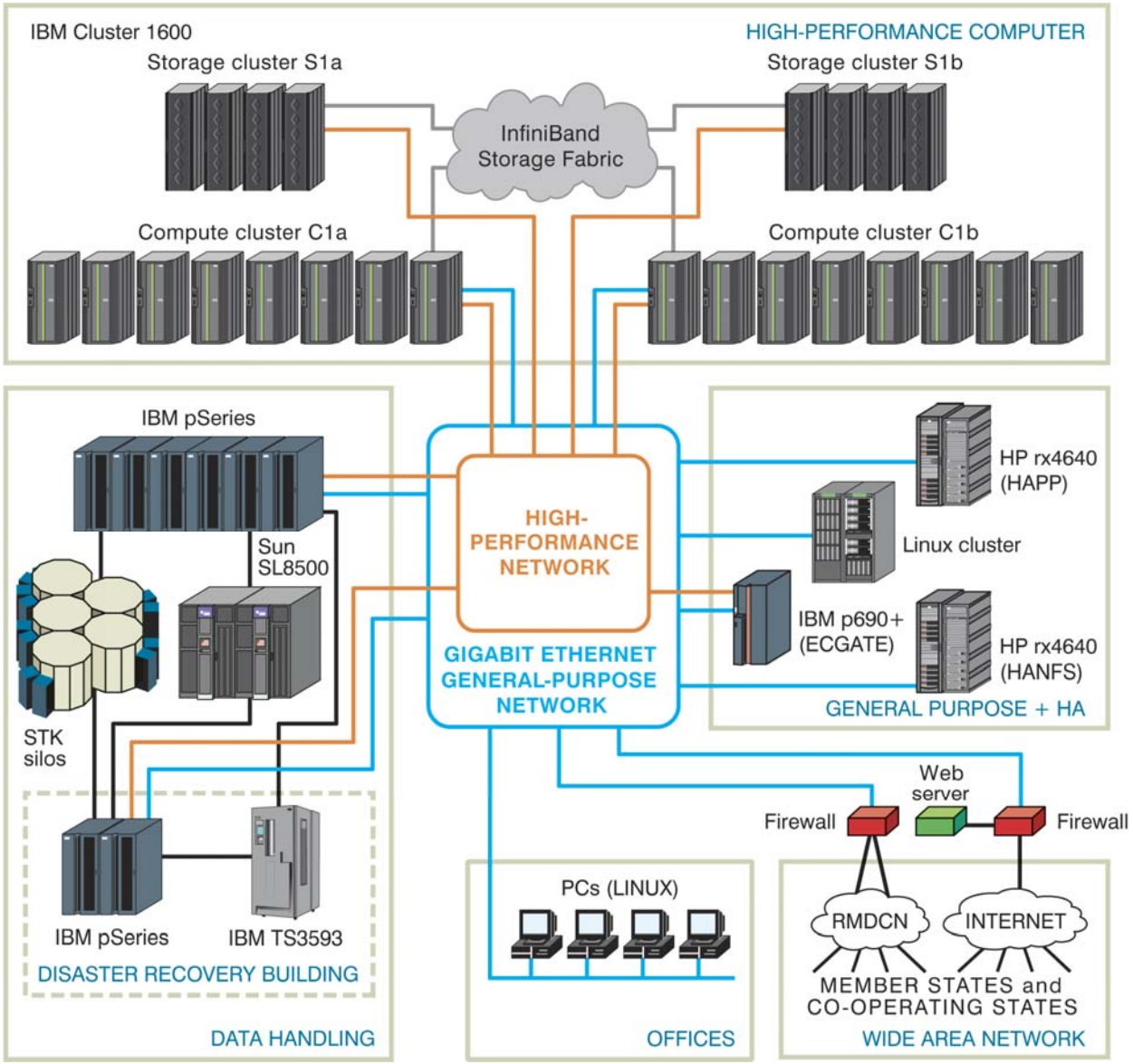
Changes to the forecasting system (2)

03 Jun 2008	**Cy33r1**	**Improved moist physics for 4D-Var** **Assimilation of additional satellite data** **Extended coverage and increased resolution for the limited-area wave model**
30 Sep 2008	**Cy35r1**	**Better handling of the melting of falling snow** **New SST (high-resolution product from the UK Met Office)** **Sea ice analysis from the EUMETSAT Ocean and Sea Ice SAF**

Changes to the forecast system (3)

10 March 2009	**Cy35r2**	**Revised snow scheme** **Direct all-sky 4D-Var assimilation of microwave imagers** **RTTOV-9 (developed by NWP-SAF)** **Use of ERA-interim analyses for the re-forecasts for EFI and monthly forecasts**
12 May 2009		**Operational assimilation of temperatures from 5 Indian radiosondes**
8 Sep 2009	**Cy35r3**	**Weak constraint 4D-Var (stratosphere)** **Non-orographic gravity wave scheme** **Assimilation of cloud-affected radiances for infra-red instruments**

Current computer configuration



2 POWER-6 clusters, each with 272 p6-575 nodes

32-core nodes at 4.7 GHz, in-order execution

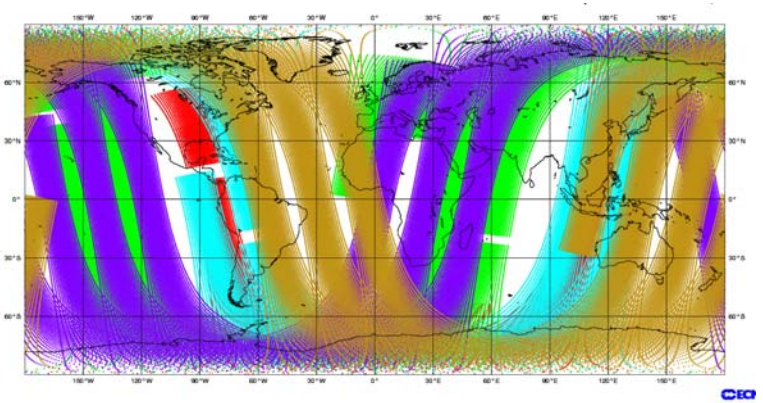
ECMWF

Data Handling System

- **Stores over 10 petabytes**
- **Sun Microsystems was selected**
  - **SL8500 tape libraries**
  - **T10000B tape drives**
  - **1-terabyte cartridges**
- **Acceptance testing ongoing**
- **Migration during 2010**

Software development projects

- **GRIB edition 2**
  - Required for vertical resolution upgrade in 2010
  - Software and test data now available
- **Metview/Magics**
  - New interactive features
- **Web re-engineering**
  - Highly available
  - Interactive
- **Observation handling**
  - Archiving
  - Monitoring
  - Graphics



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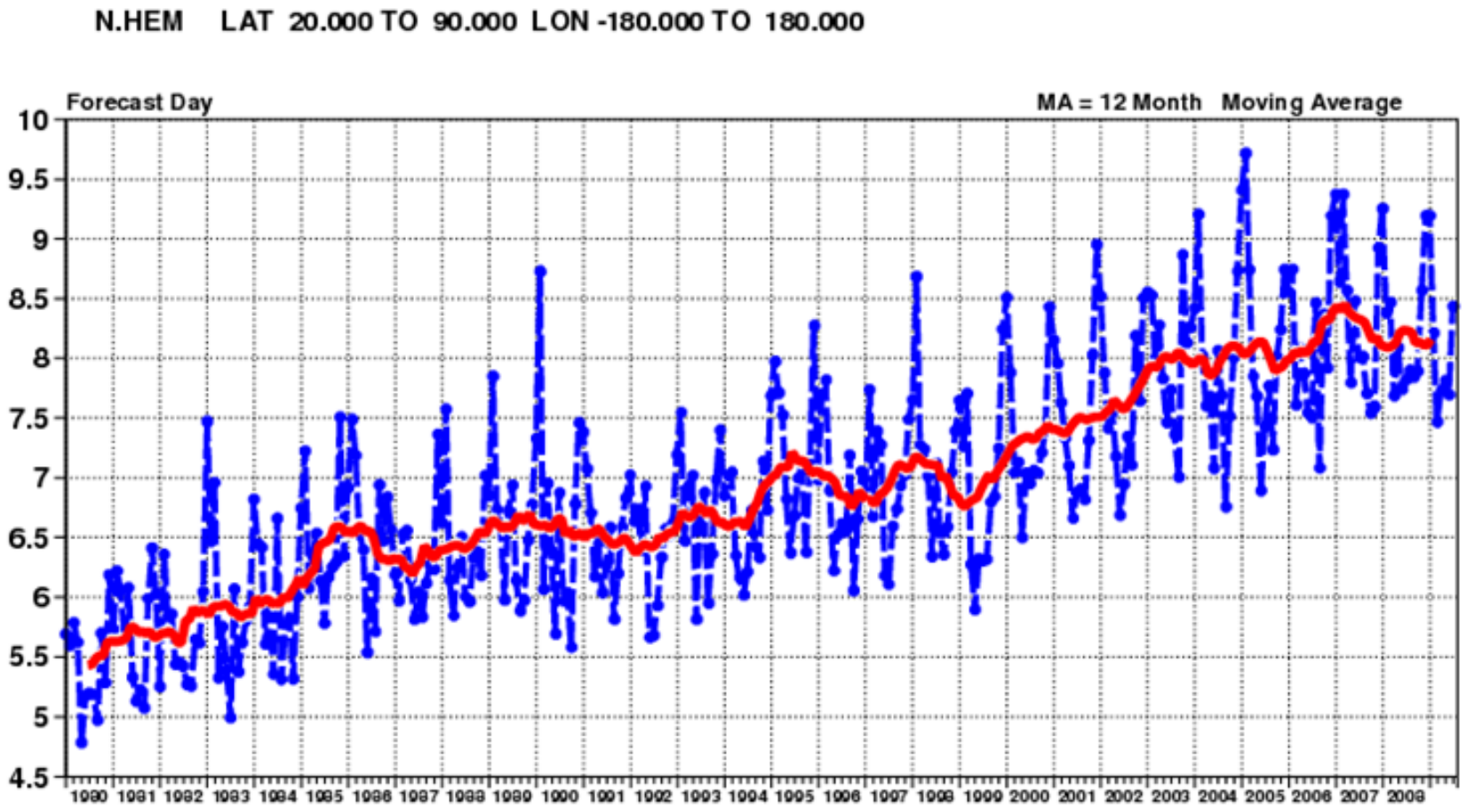
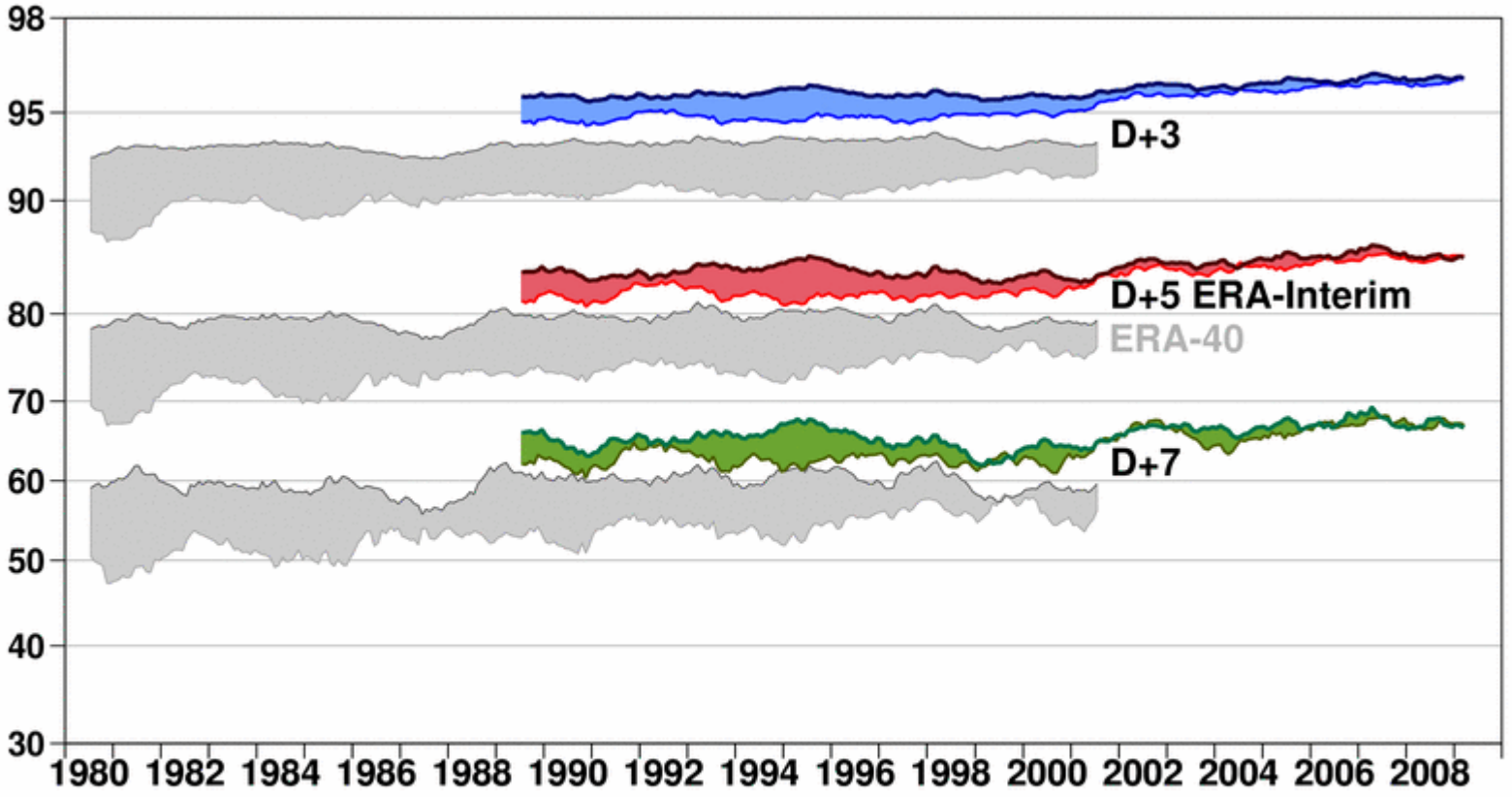
Z500, Time series of ACC=0.6 N.Hem

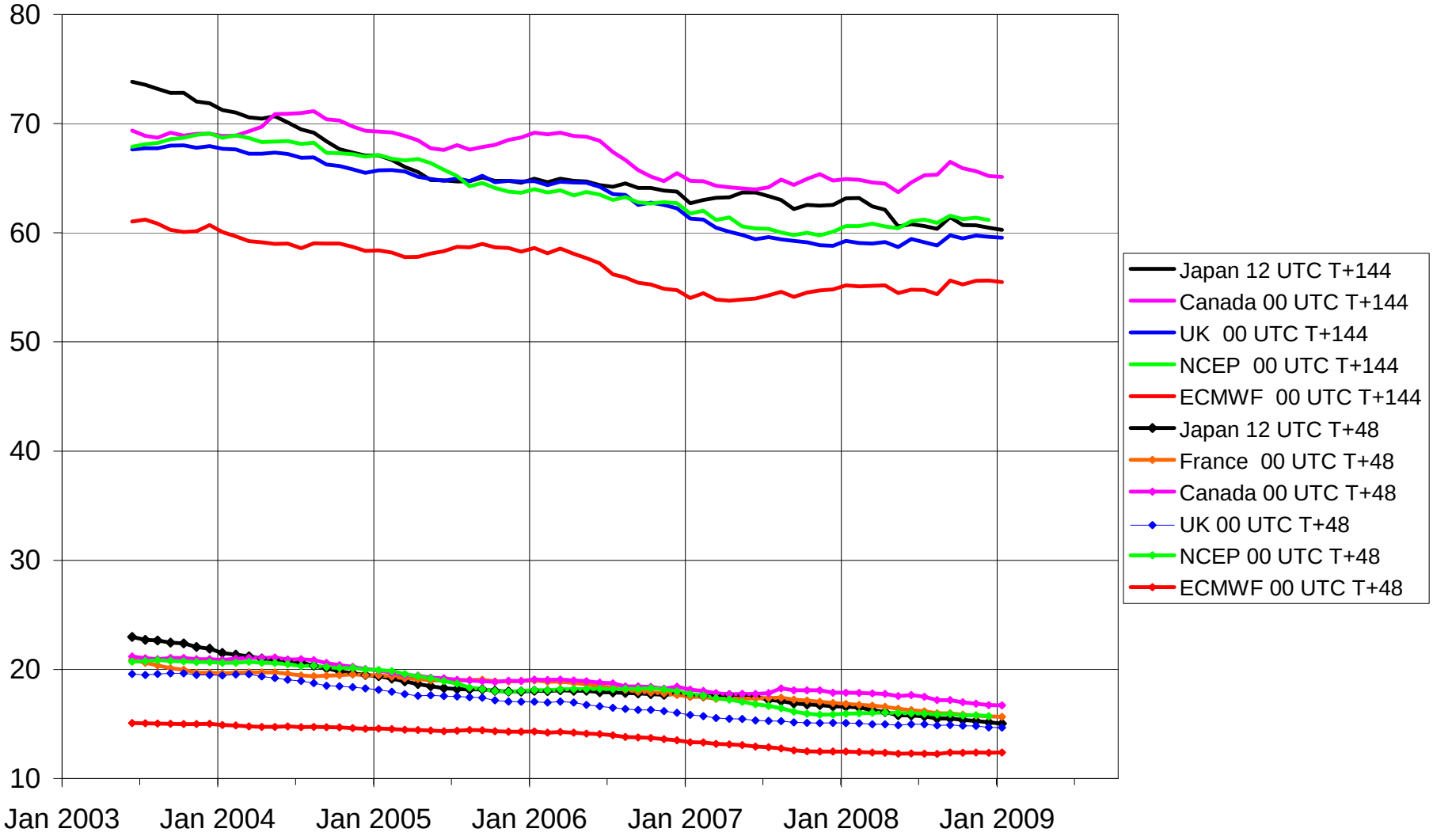


Forecast range at which anomaly correlation equals 60%

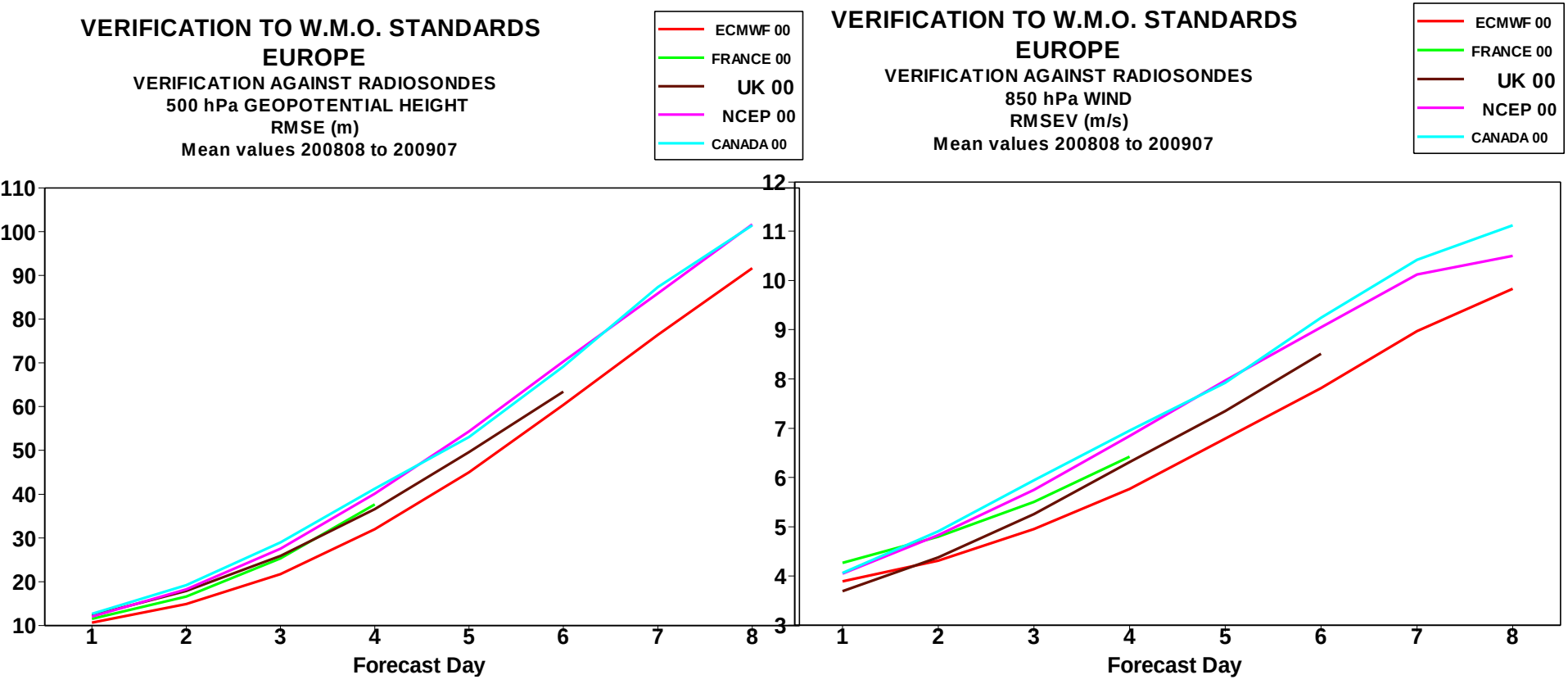
ERA-Interim, ACC for Z500



Z500 RMS, N.Hem., WMO standard scores



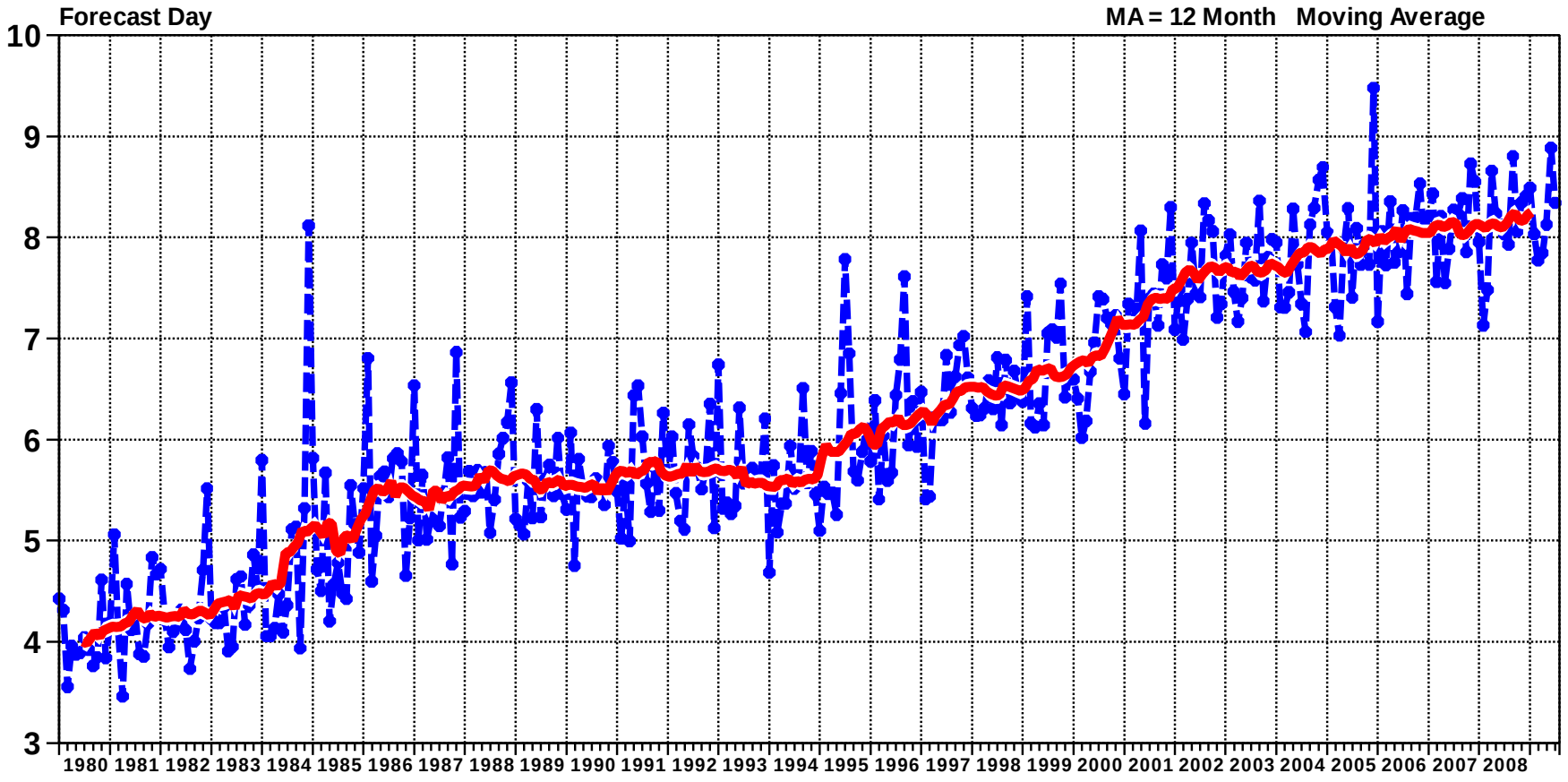
Comparison with other centres, Europe



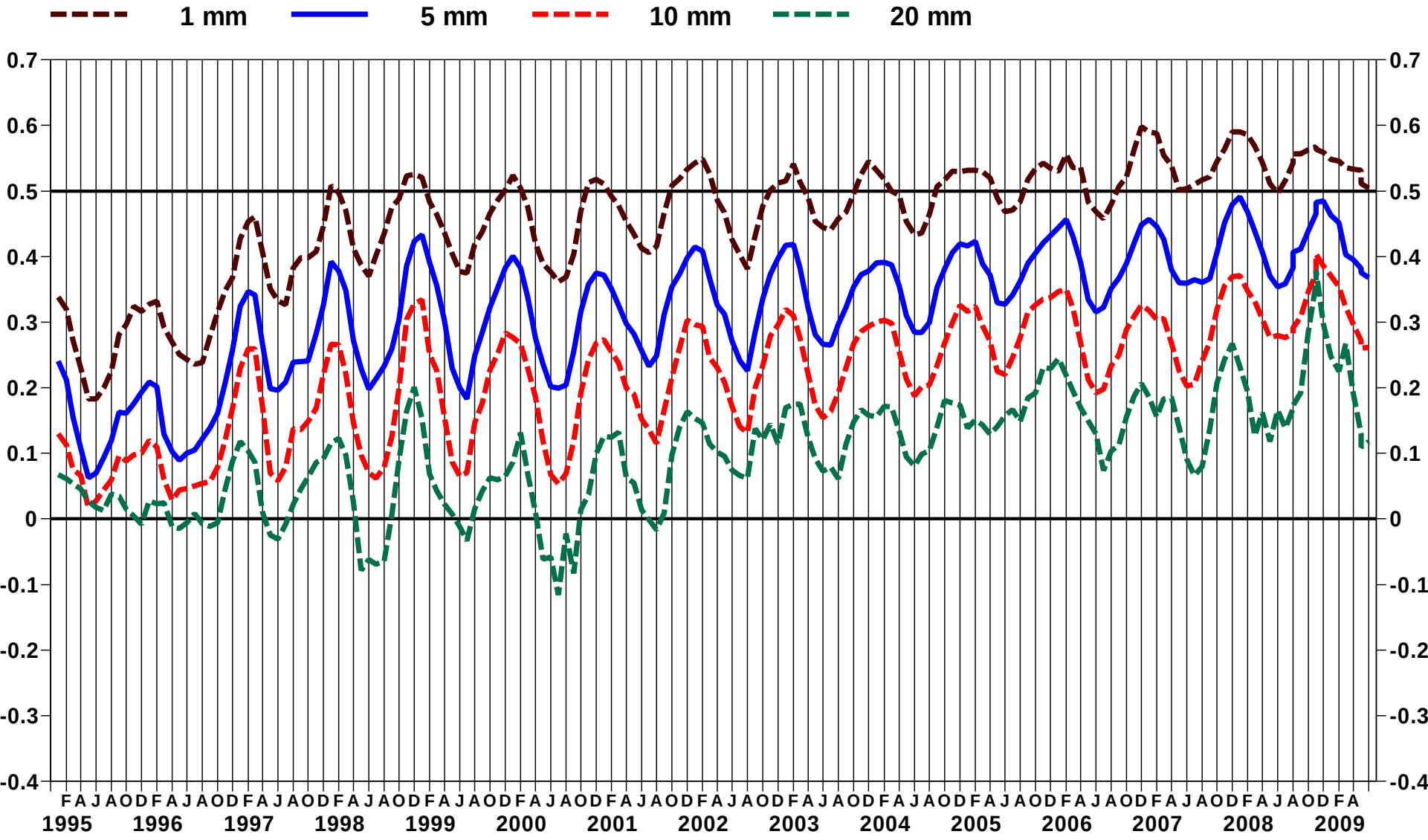
WMO/CBS exchanged scores using radiosondes

Z500 and wind850 RMS error over Europe (annual mean).

Z500, Time series of ACC=0.6, S.Hem



EPS precipitation skill, Day-4, Europe



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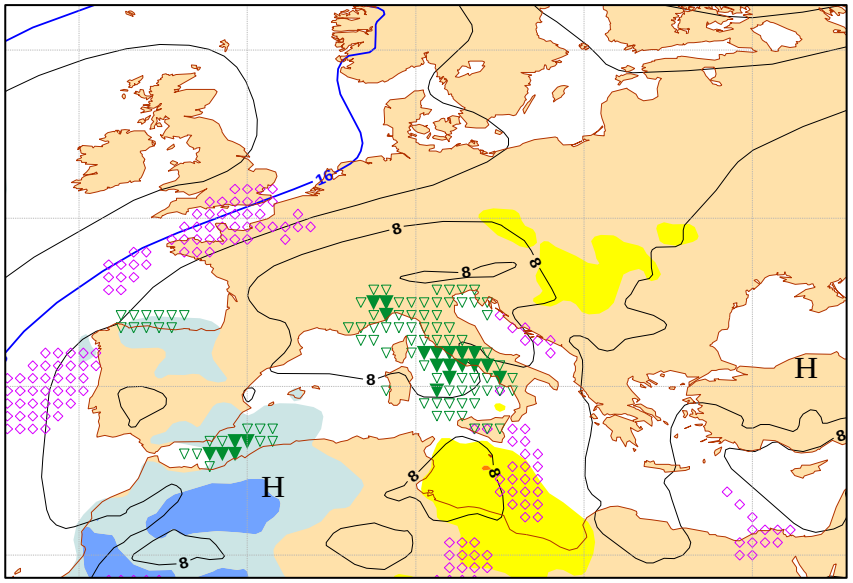
The Extreme Forecast Index

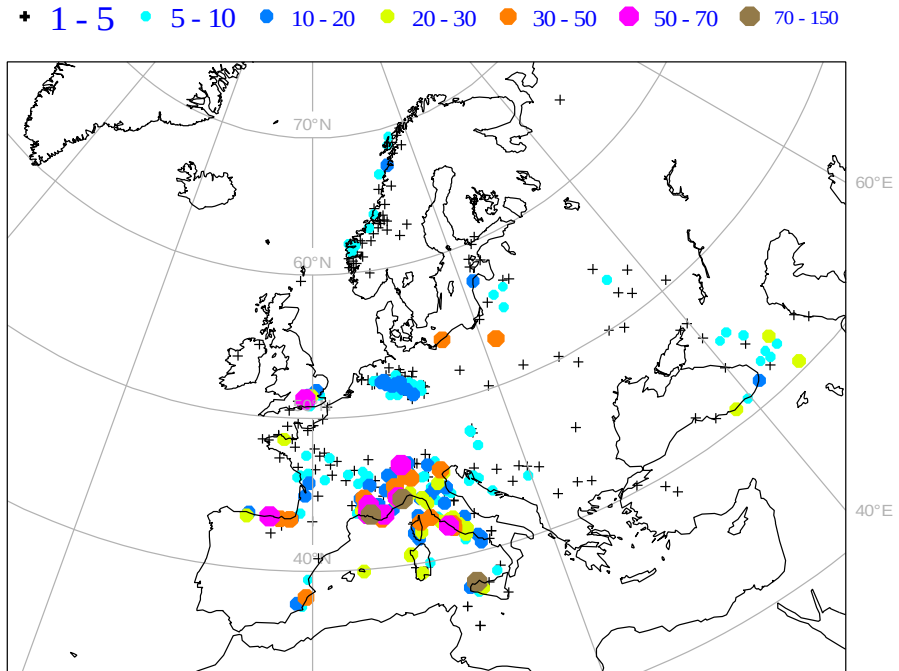
Deterministic model gave good forecast for Italy

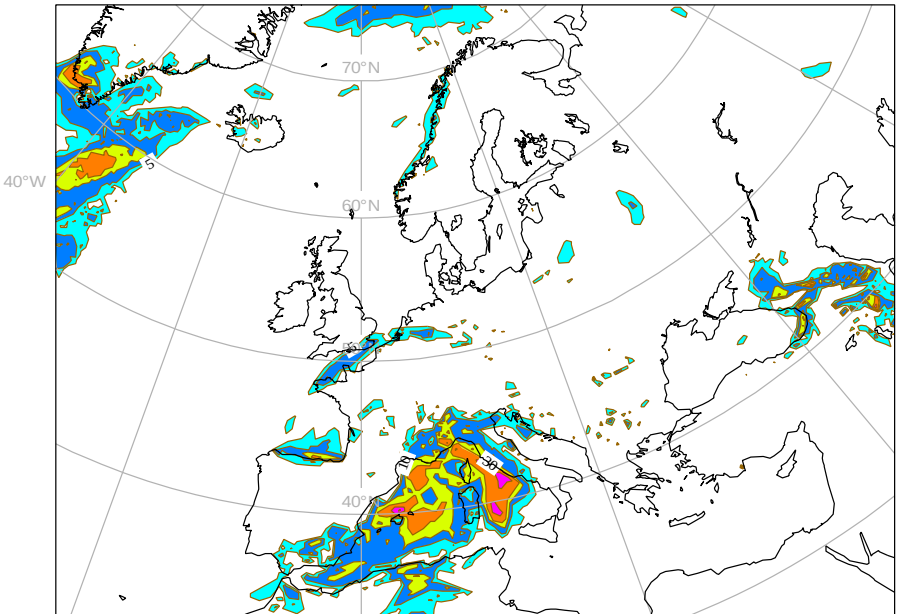
EFI gives good indication 3 days ahead for heavy precipitation in Italy and SE France



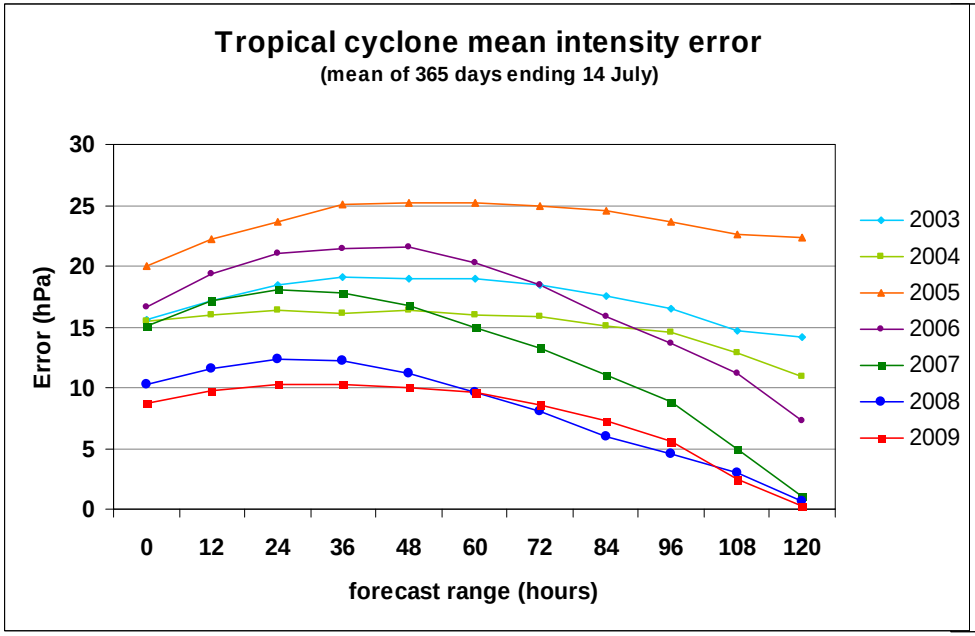
T799 forecast basedate: 20090914 0UTC
VT: 20090915 6UTC to 20090916 6UTC

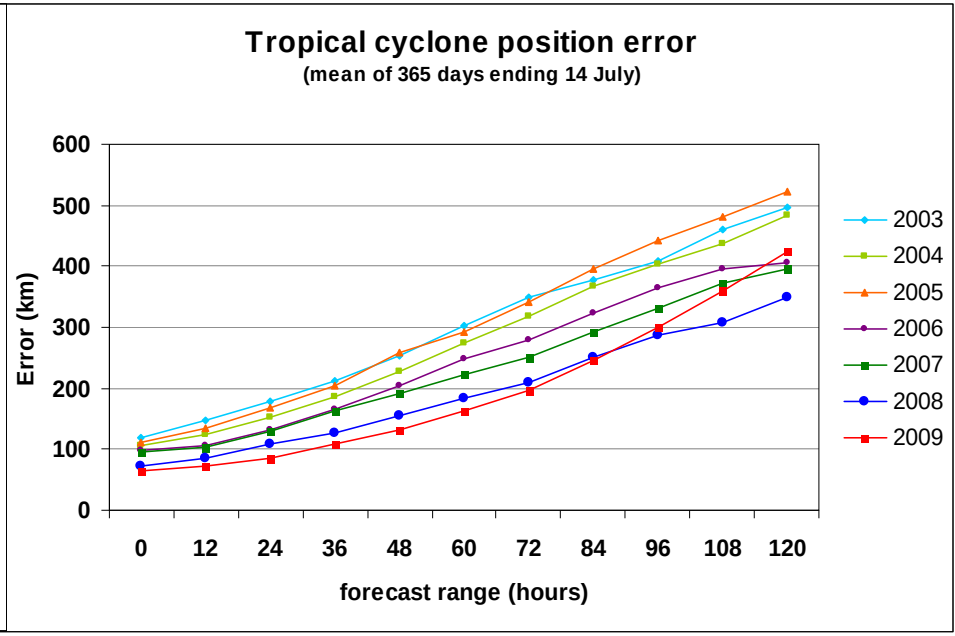
Observed acc precip
VT: 20090915 6UTC to 20090916 6UTC





Tropical cyclones



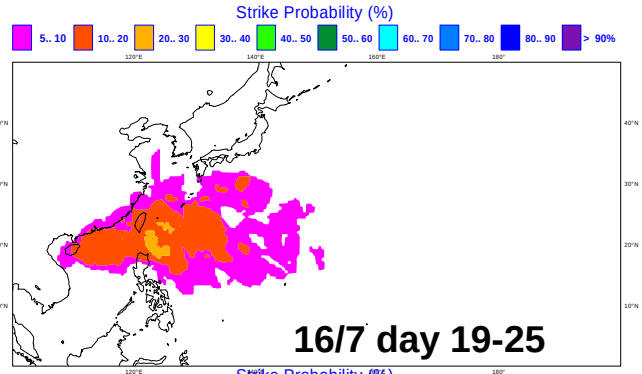


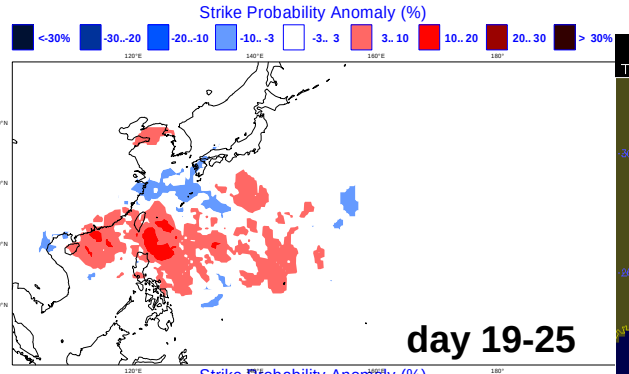
Verification of TC predictions from the operational deterministic forecast for 12-month periods ending on 14 July.

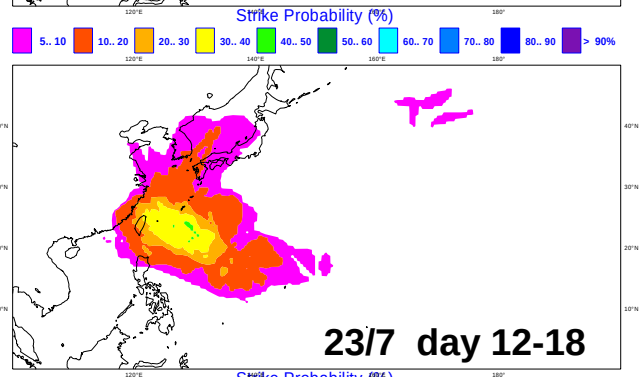
Typhoon Morakot (Taiwan) 3-9 August 2009

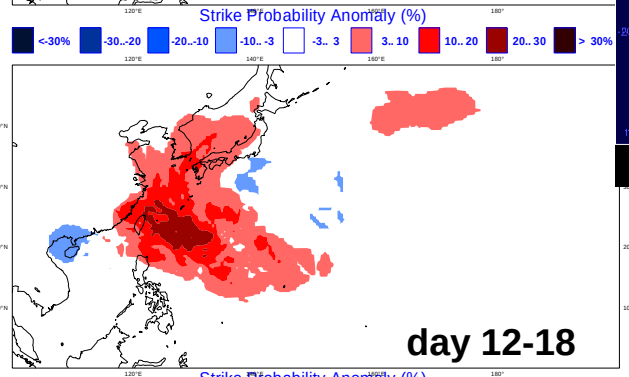
Strike probability that TC will pass within 300 km for days 5-11, 12-18, 19-25

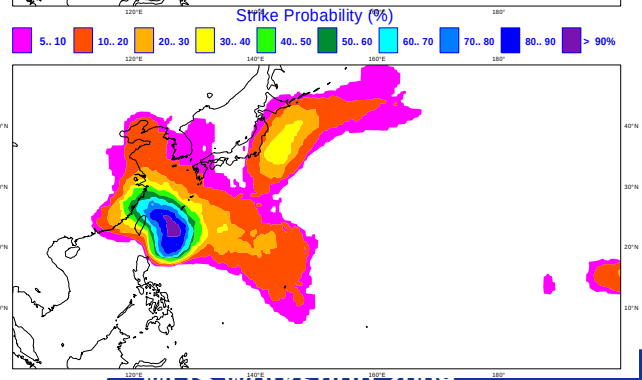
probability anomaly (%)= difference between forecast probability and climate probability
valid for 3-08-09 to 9-08-09

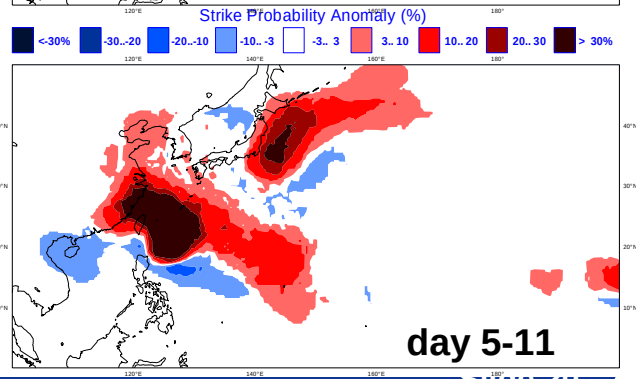


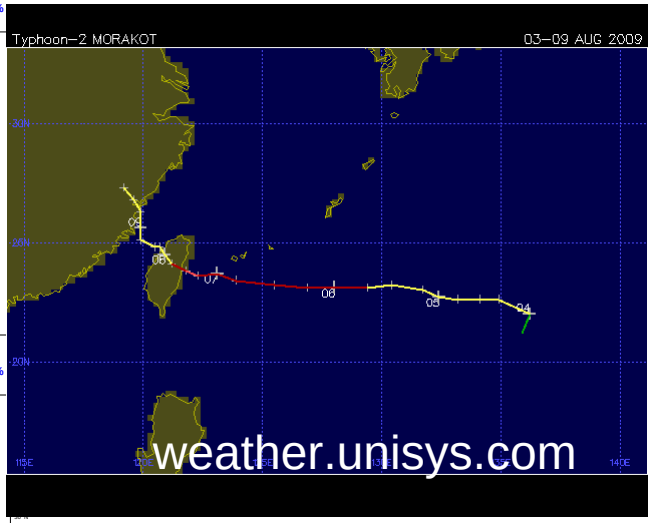












Strike probability anomaly for the monthly forecast increased as the lead time becomes shorter

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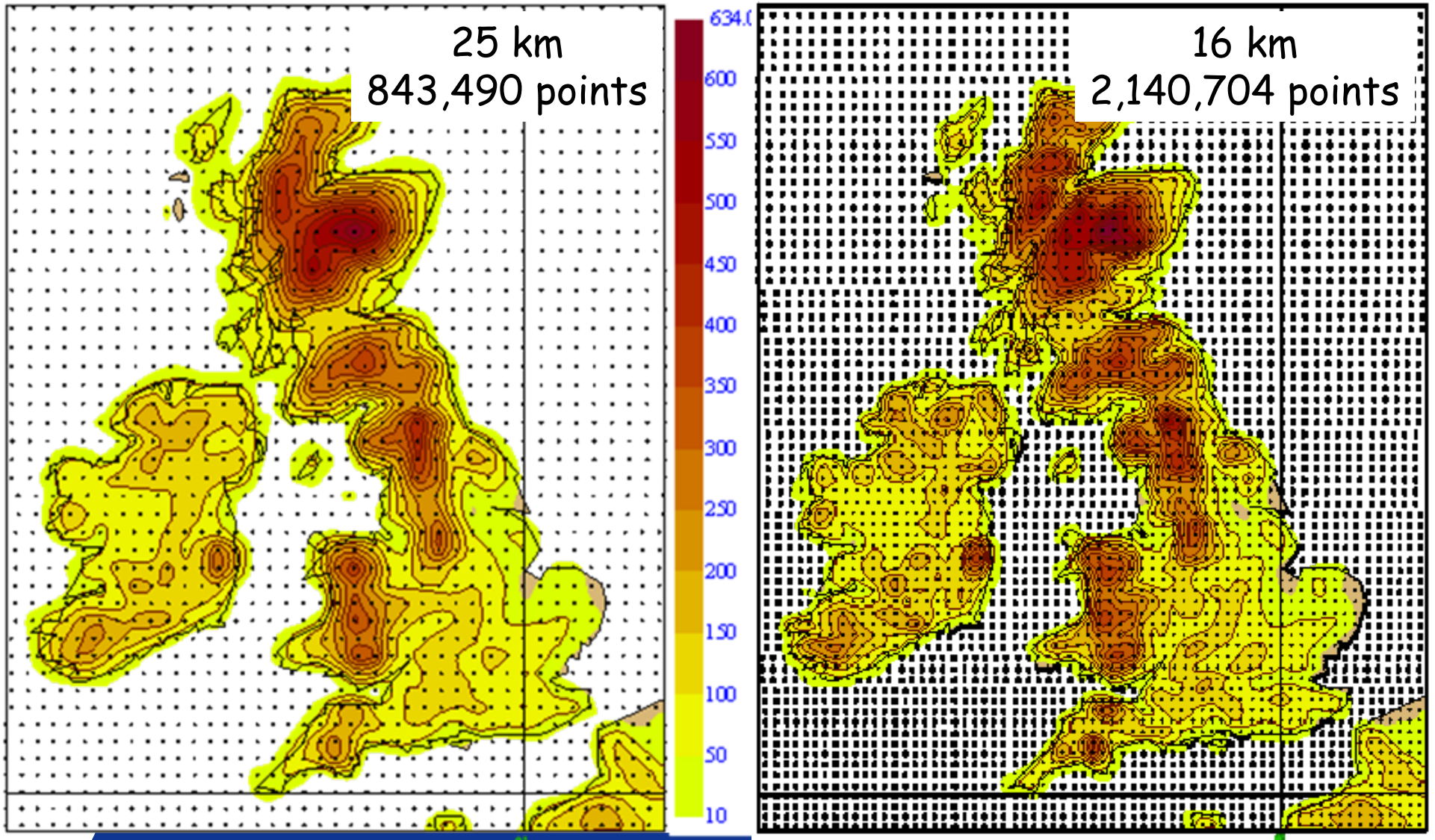
Next: Increased horizontal resolution

- **Deterministic from T799 to T1279 (16 km)**
- **EPS from T399 to T639 (32 km)**
- **Wave model increases from 0.36 to 0.25 degrees**

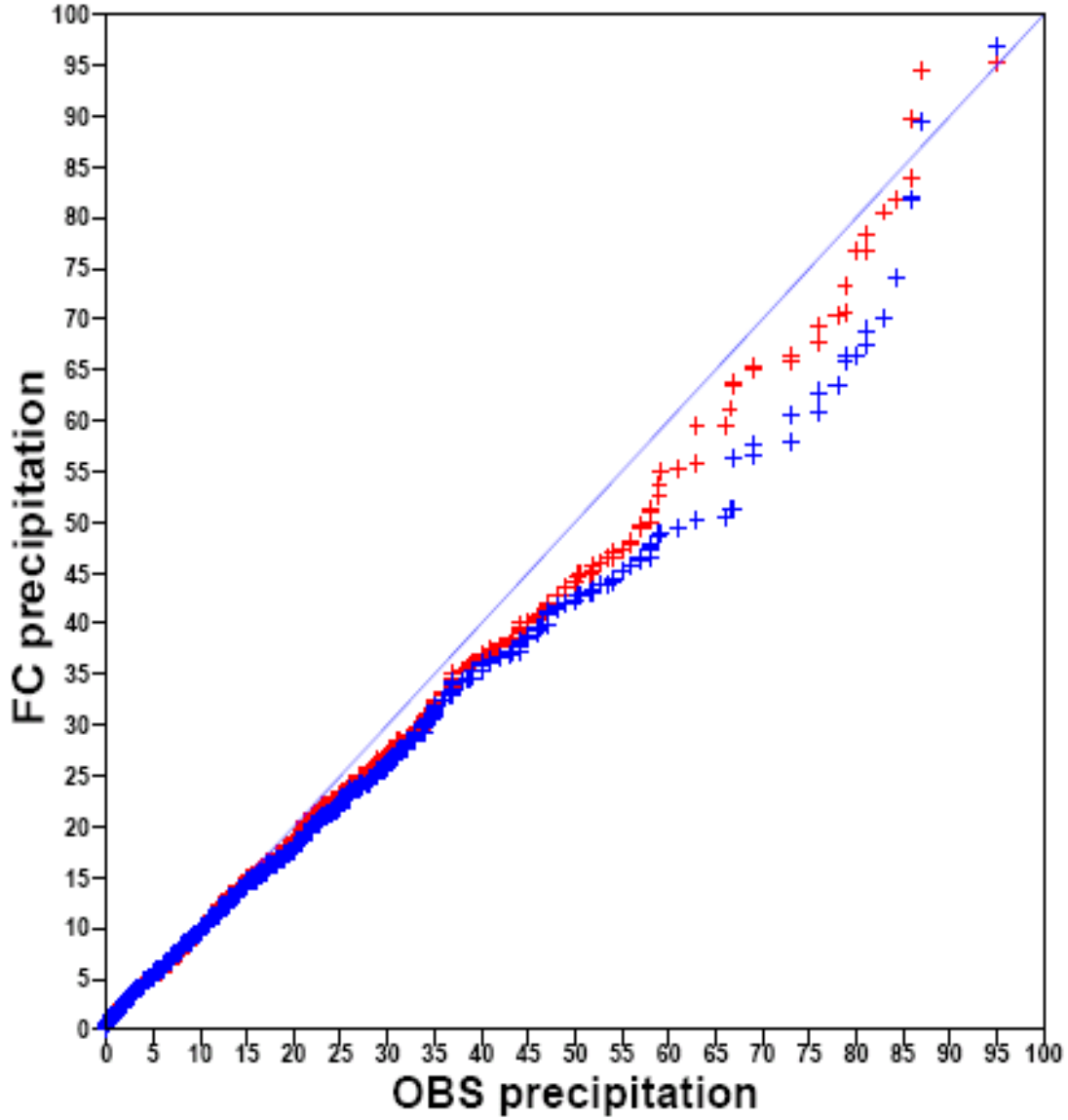
- **E-suite is currently running**
- **Implementation planned for January**
- **Required improvements to the technical infrastructure**
  - **Visualization**
  - **EMOSLIB**
  - **MARS**
- **Information web pages for users and test data**

http://www.ecmwf.int/products/changes/horizontal_resolution_2009/

Model grids for T799 and T1279



T1279 & T799 versus Obs precipitation, Europe



T1279

T799

Showing 36 hour forecasts in winter

Higher resolution improves on high precipitation amounts

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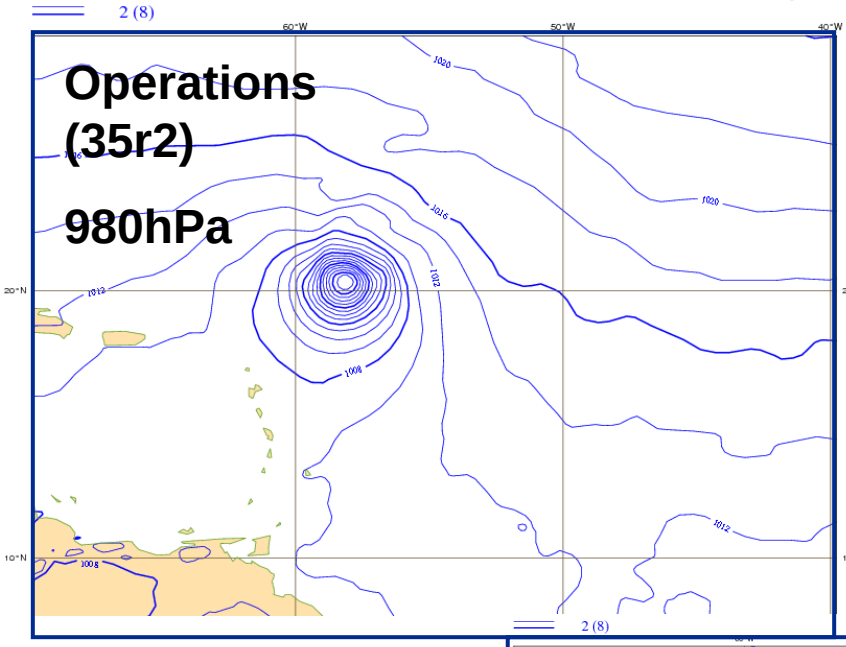
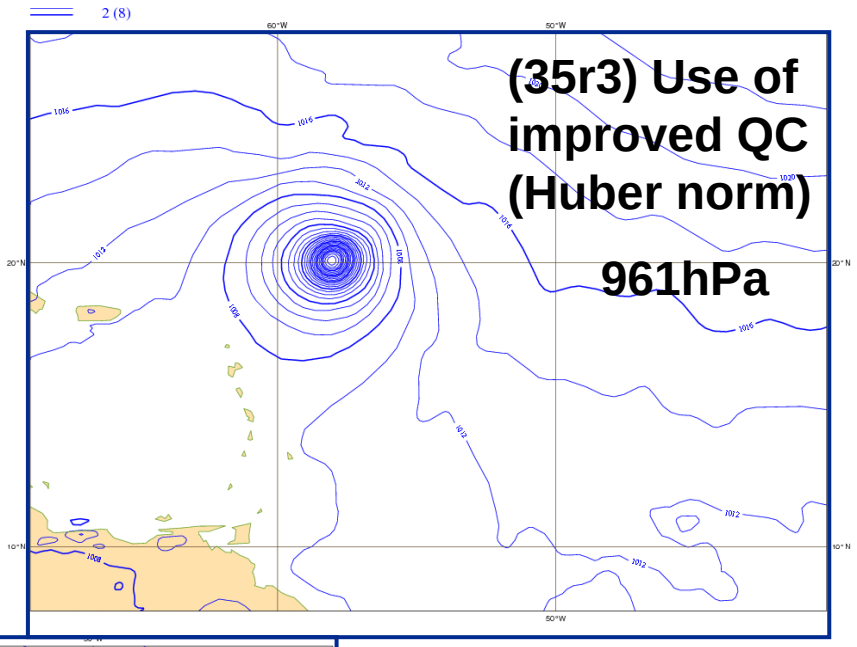
T1279 Tropical cyclone analysis

Huber norm QC also beneficial

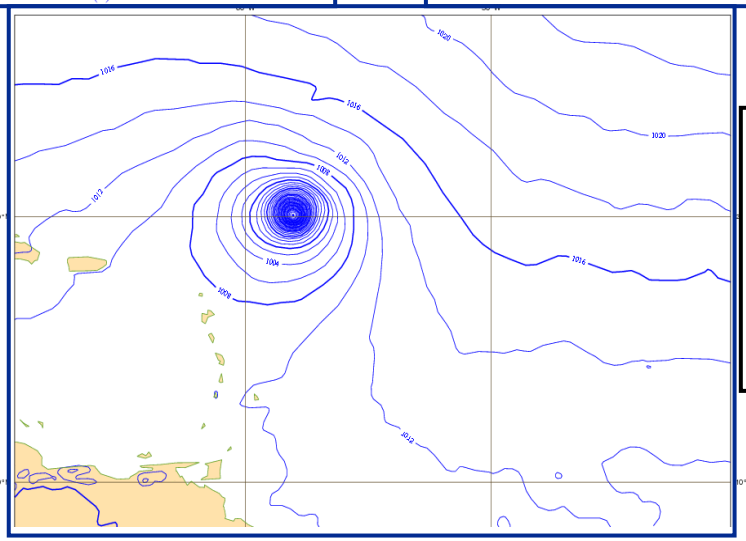




Hurricane Bill,

20 Aug. 2009

Observed MSL pressure~944hPa



(36r1) High-res system T1279 + T159/T255/T255

945hPa

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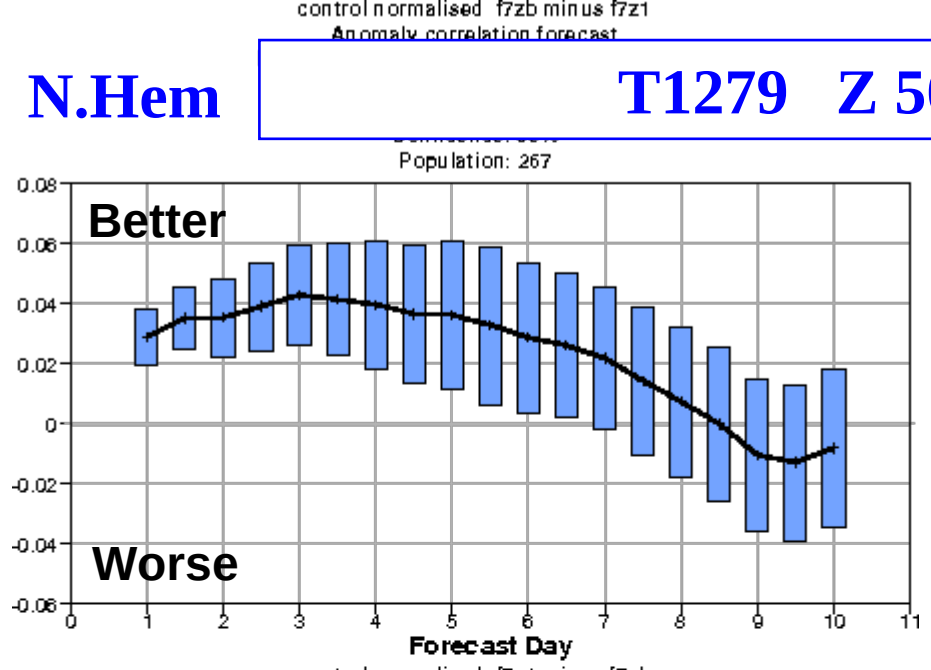
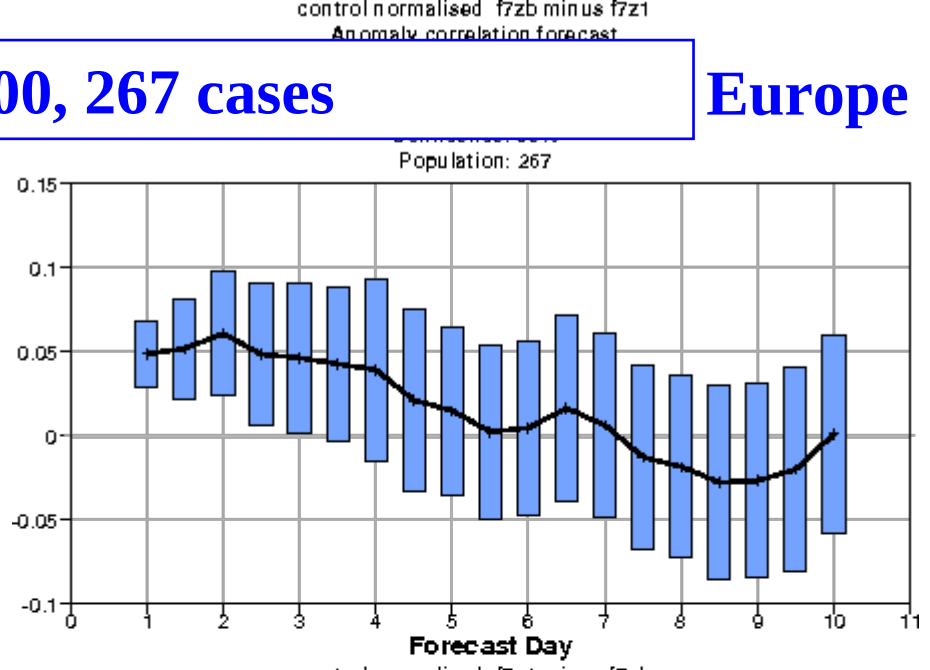
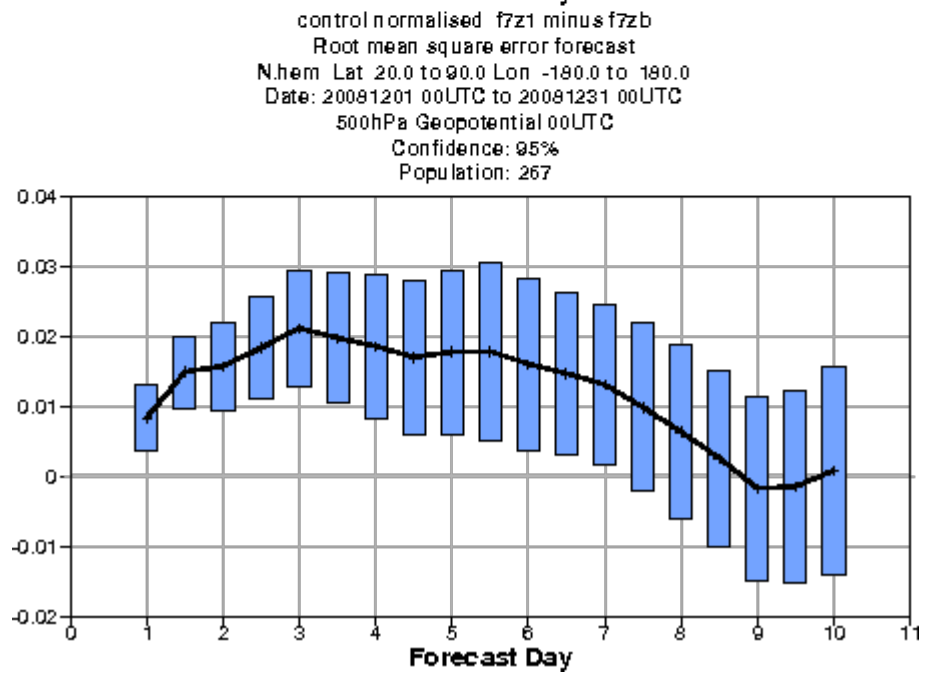
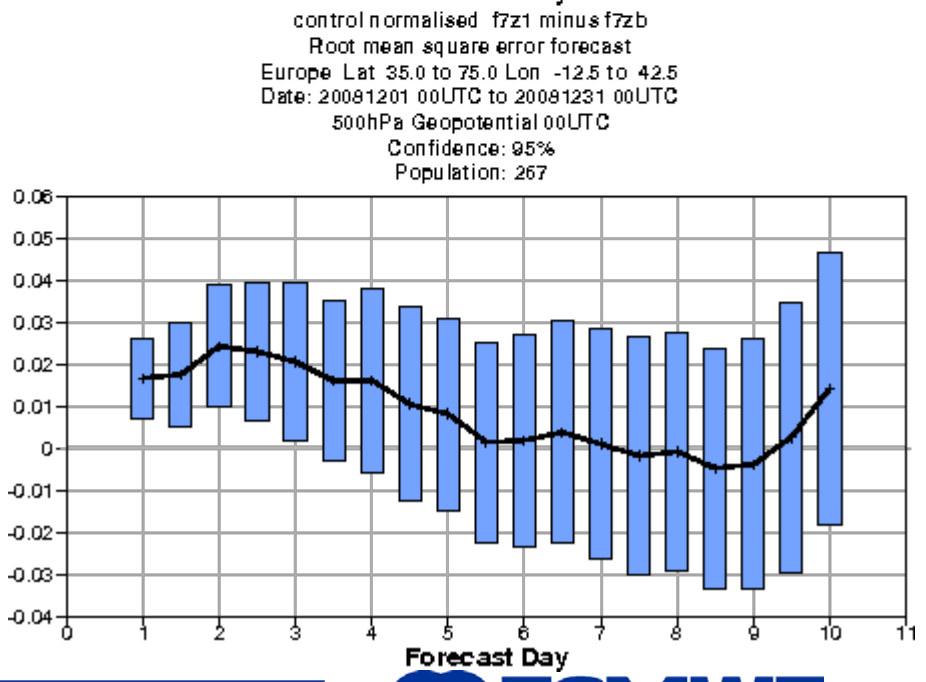
N.Hem T1279 Z 500, 267 cases Europe









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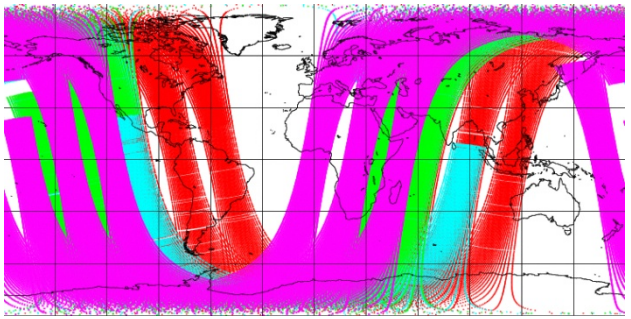
Data acquisition and pre-processing 2009

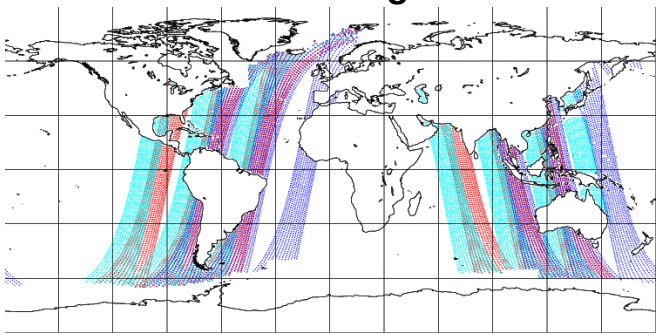
- **MSG All Sky Radiances**
- **ASCAT low resolution level 2 early delivery data from EUMS (Metop02)**
- **ASCAT low resolution level 2 soil moisture data from EUMS (Metop02)**
- **NOAA-19 ATOV data**
- **MSG-2 atmospheric Motion Vectors**
- **AVHRR winds produced from CIMSS/UW-Madison (NOAA15,16,17,18)**
- **SBUV/2 data version 8 NOAA19 ozone profiles**
- **Coriolis/SDR data (passively monitored)**
- **Additional weather radar wind profiles from Poland and Slovenia**
- **ATOV data from Asia Pacific (RARS - NOAA15,16,17,18)**
- **Cloud motion winds from Sat Id-513(CMA FY-2)**
- **Modis winds produced from CIMSS/UW-Madison (AQUA - TERRA)**
- **JASON-2 Operational Geophysical Data Record (OGDR) products in BUFR format**

Example of satellite data coverage

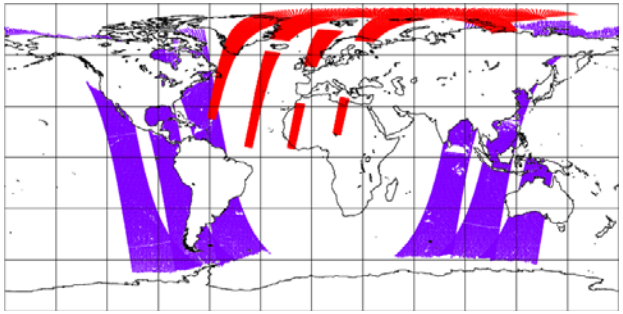
LEO Sounders



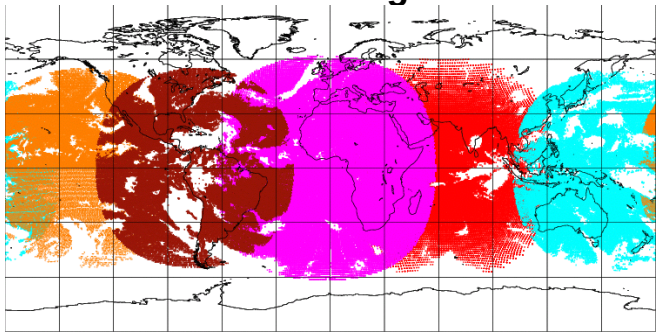
LEO Imagers



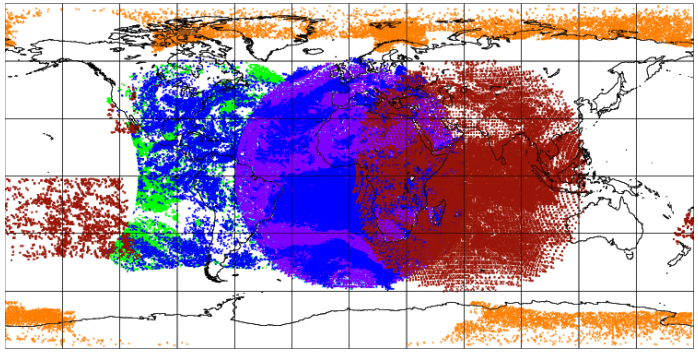
Scatterometers



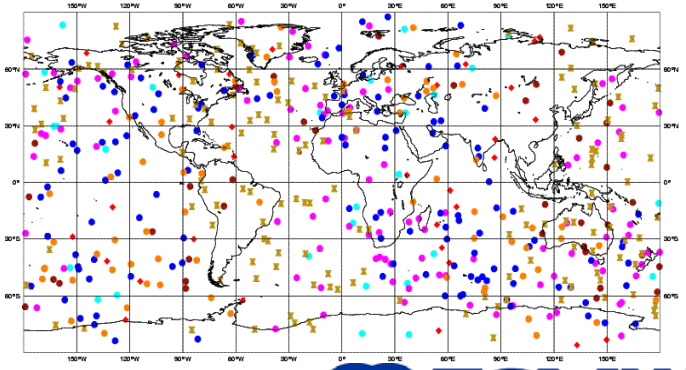
GEO imagers



Satellite Winds (AMVs)

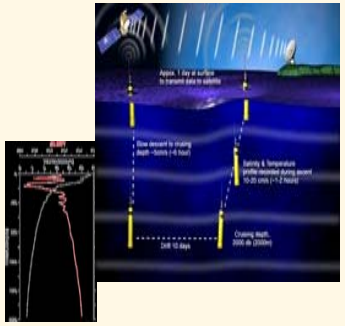


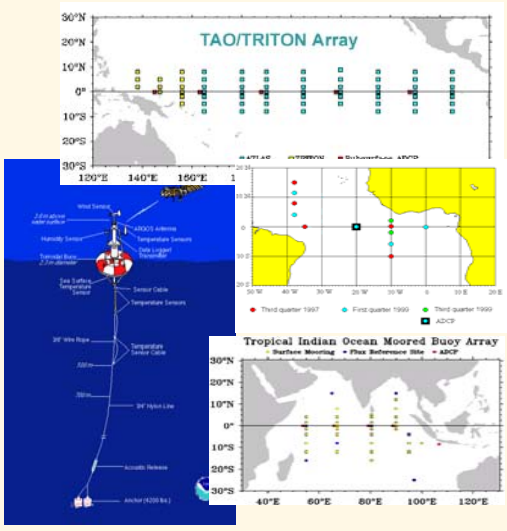
GPS Radio Occultation

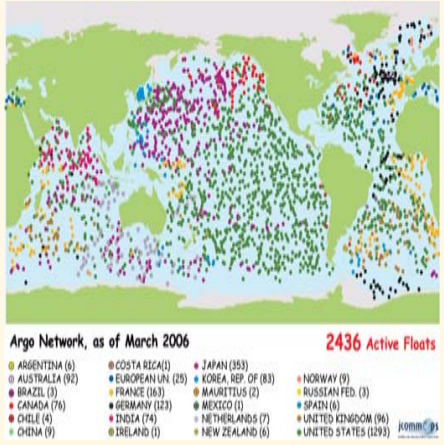


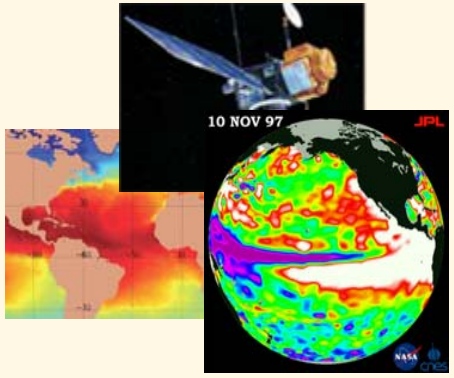
ECMWF

Observations used in ocean analysis

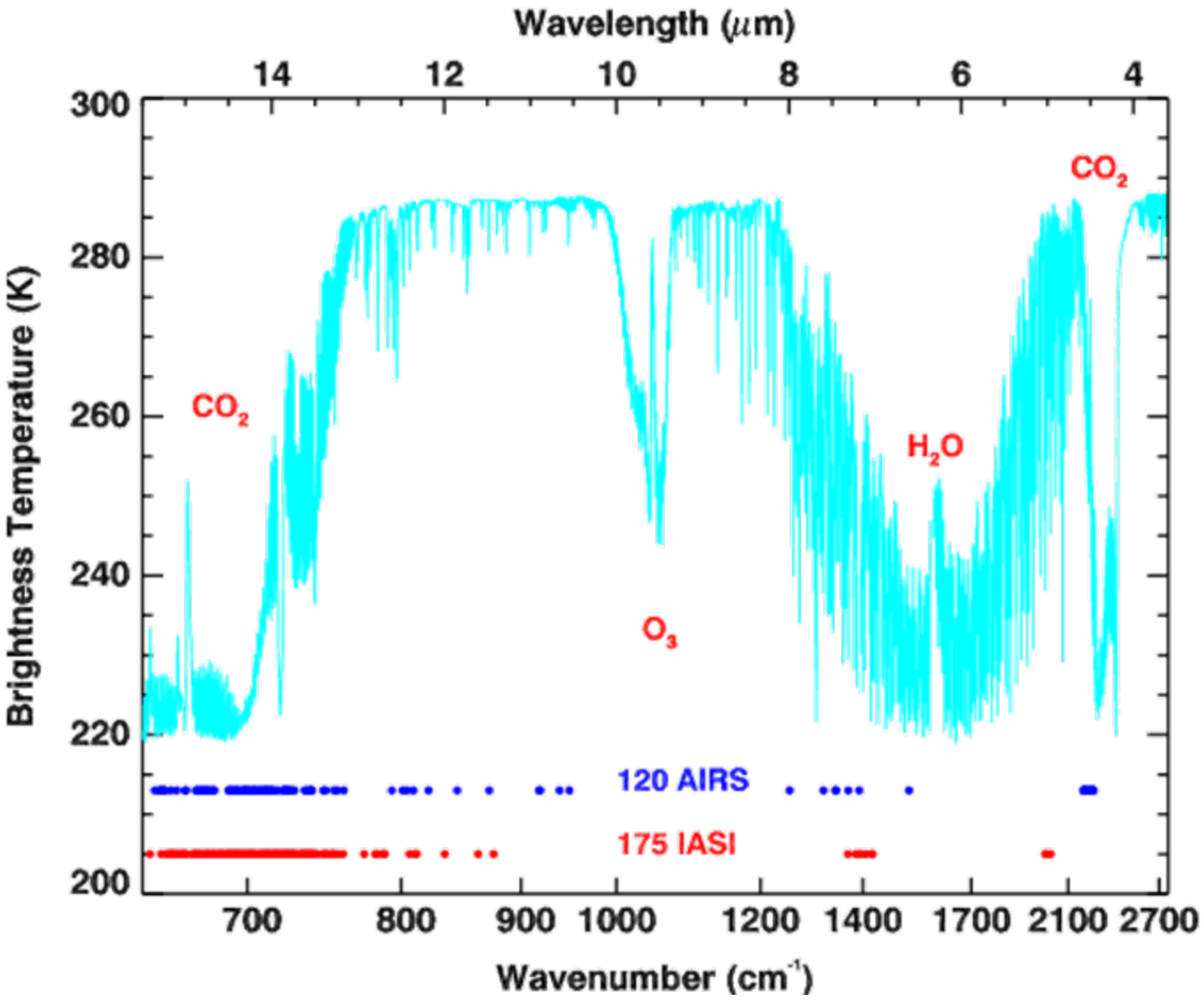








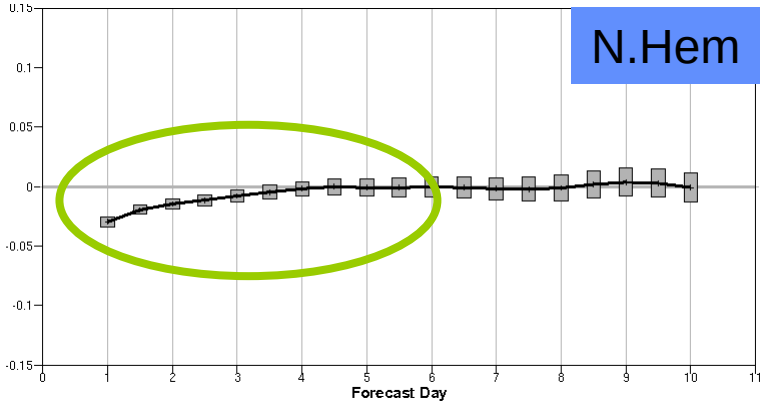
IASI and AIRS advanced sounders

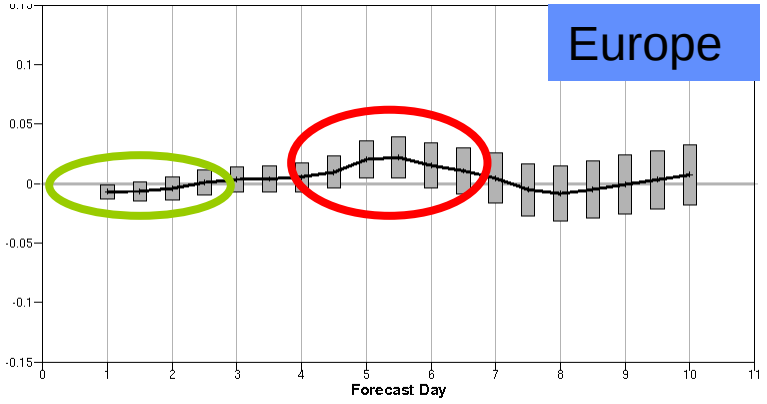


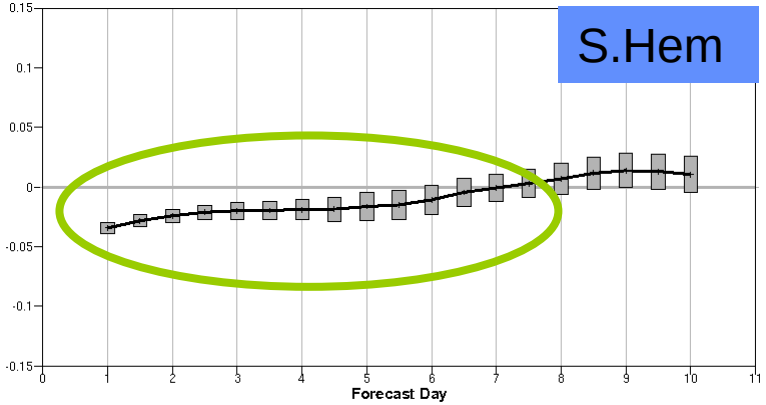
ECMWF

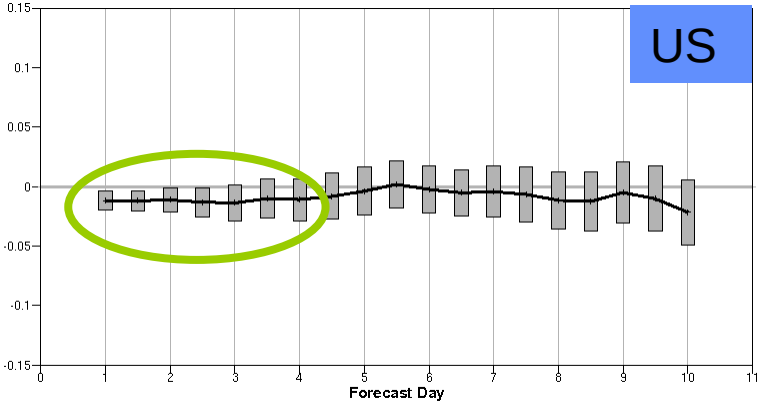
IASI Denial OSE Results

CYCLE 35R2 one year verified against OPS analyses (500 hPa geopotential)

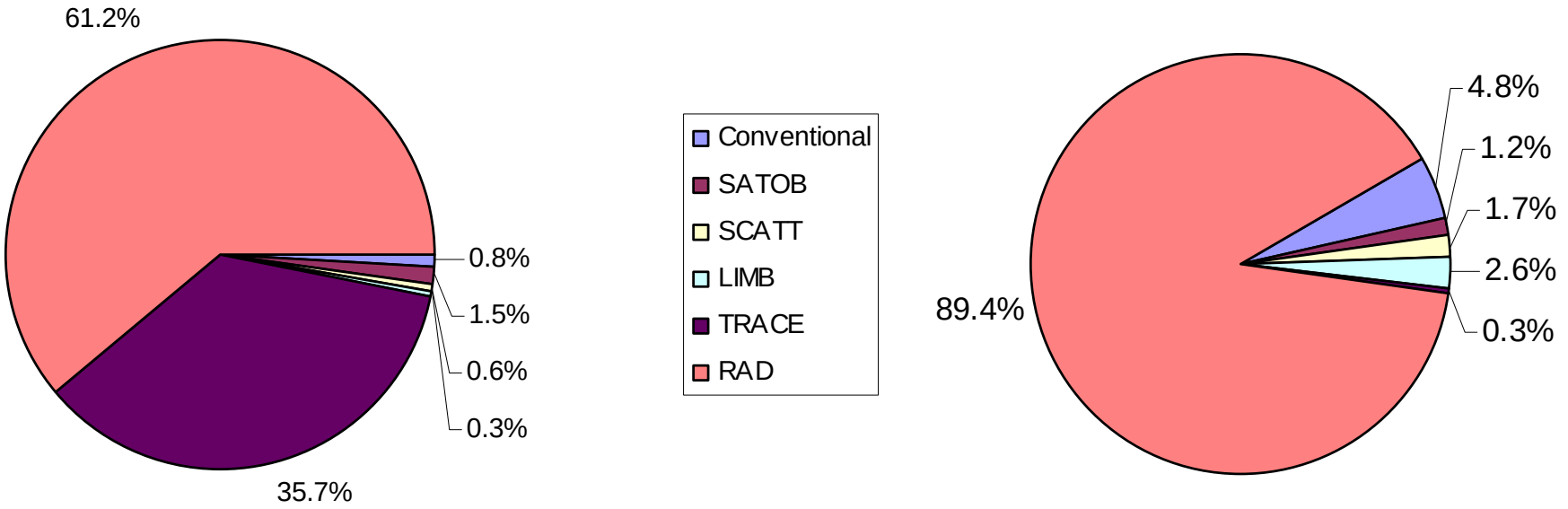








Screening → Assimilation (20080424)



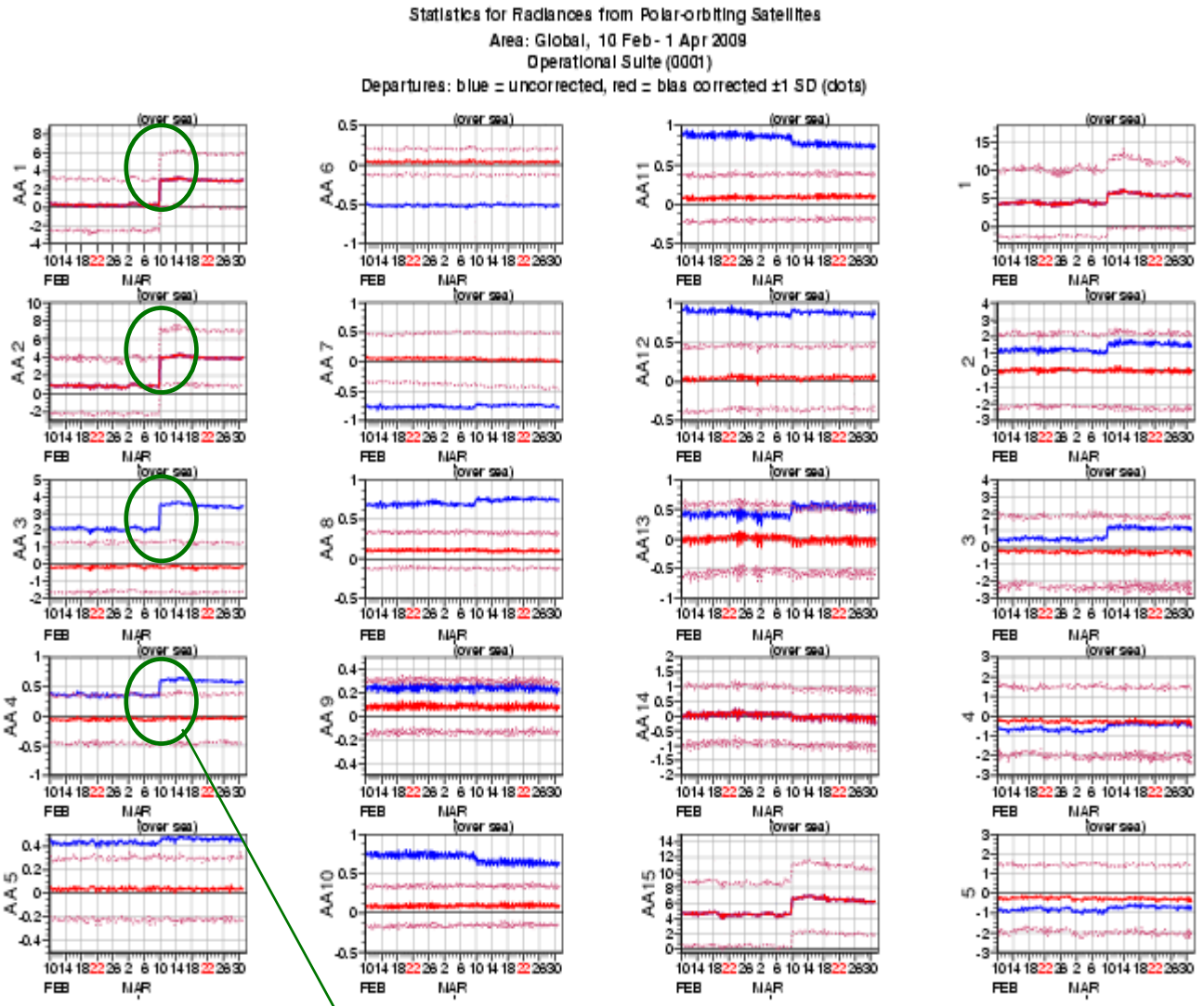
- **Satellite data amounts to 99% in screening and 95% in assimilation.**
- **Radiance data dominates assimilation with 90%.**

Observation monitoring for radiances

Time evolution of statistics for several channels

Useful for quick and routine verifications

Impractical for IASI and AIRS !



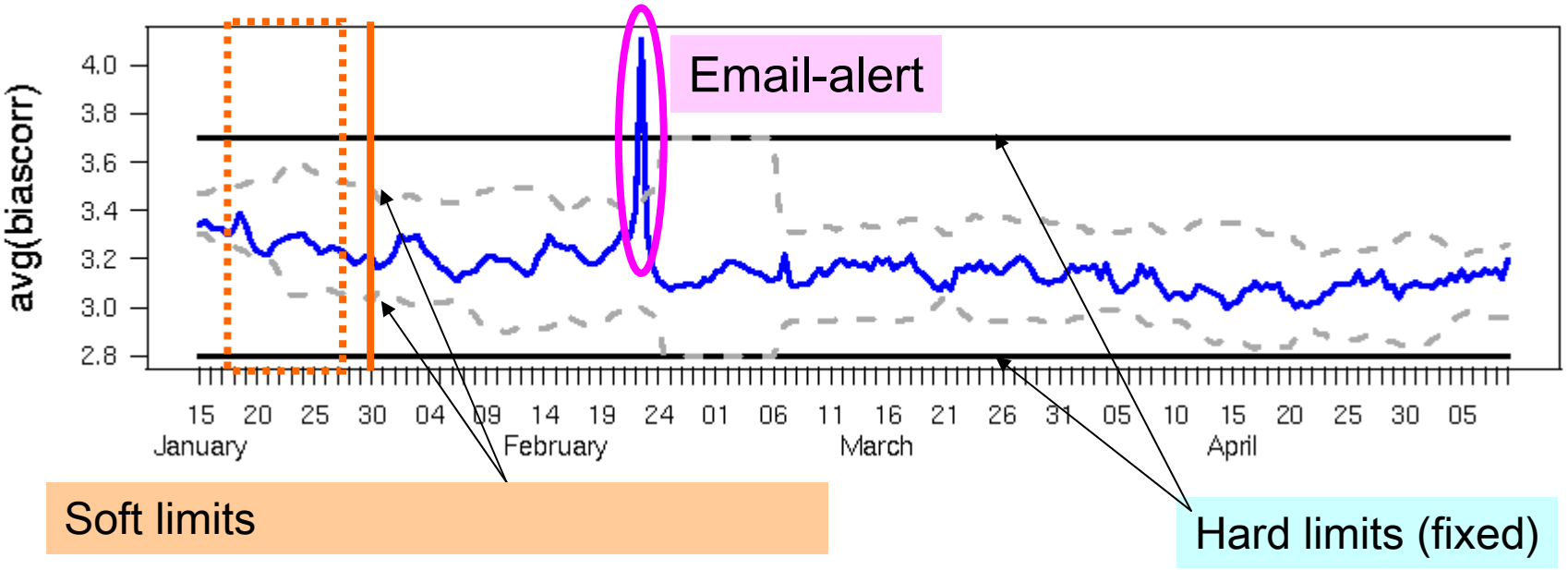
RTTOV version upgrade

ECMWF

Monitoring – automated warnings

Selected statistics are checked against an expected range.

E.g., global mean bias correction for GOES-12 (in blue):

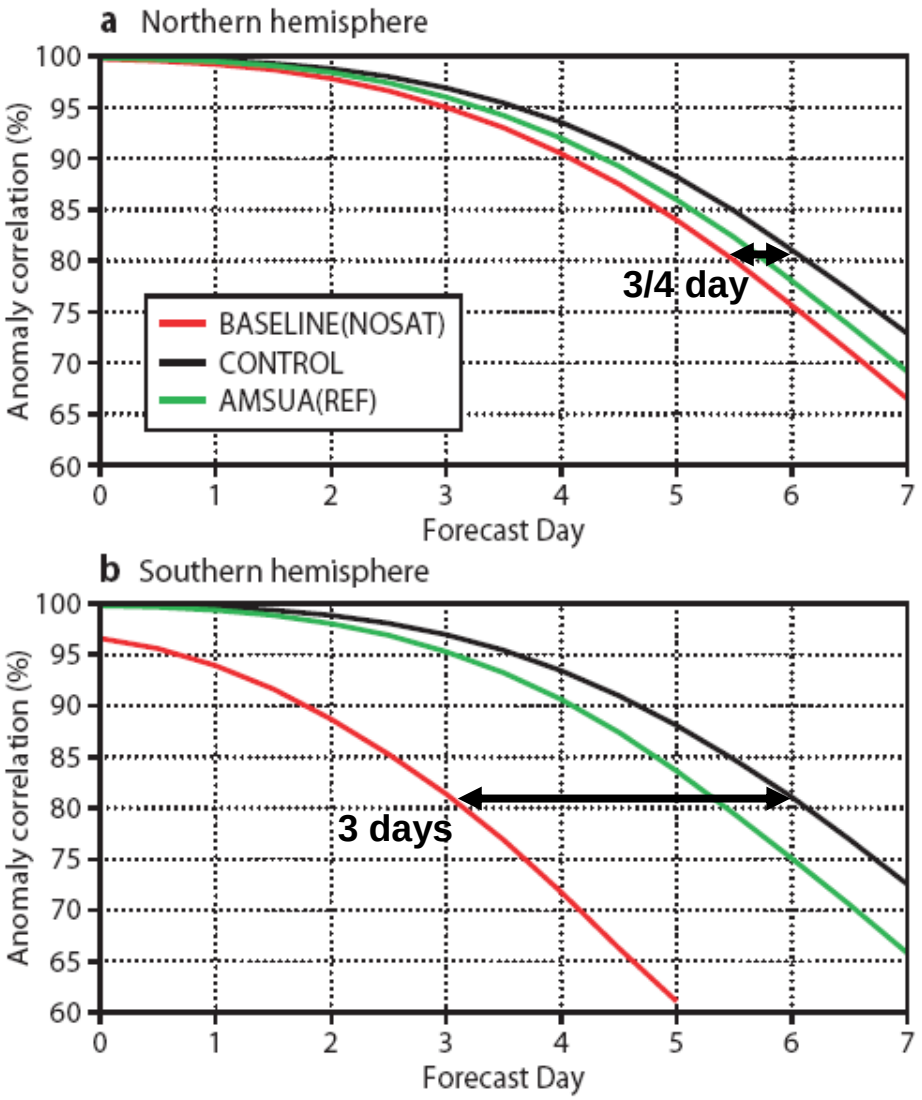


Email alert:

```
GOES-12 GOESIMG 2 clear radiances : out of range:
   avg(fg_depar)=1.34775547847879,  expected range: -0.38 0.47
   avg(biascorr)=4.10498646958382,  expected range: 3.0 3.4
```


ECMWF

Combined impact of all satellite data



EUCOS Observing System Experiments (OSEs):

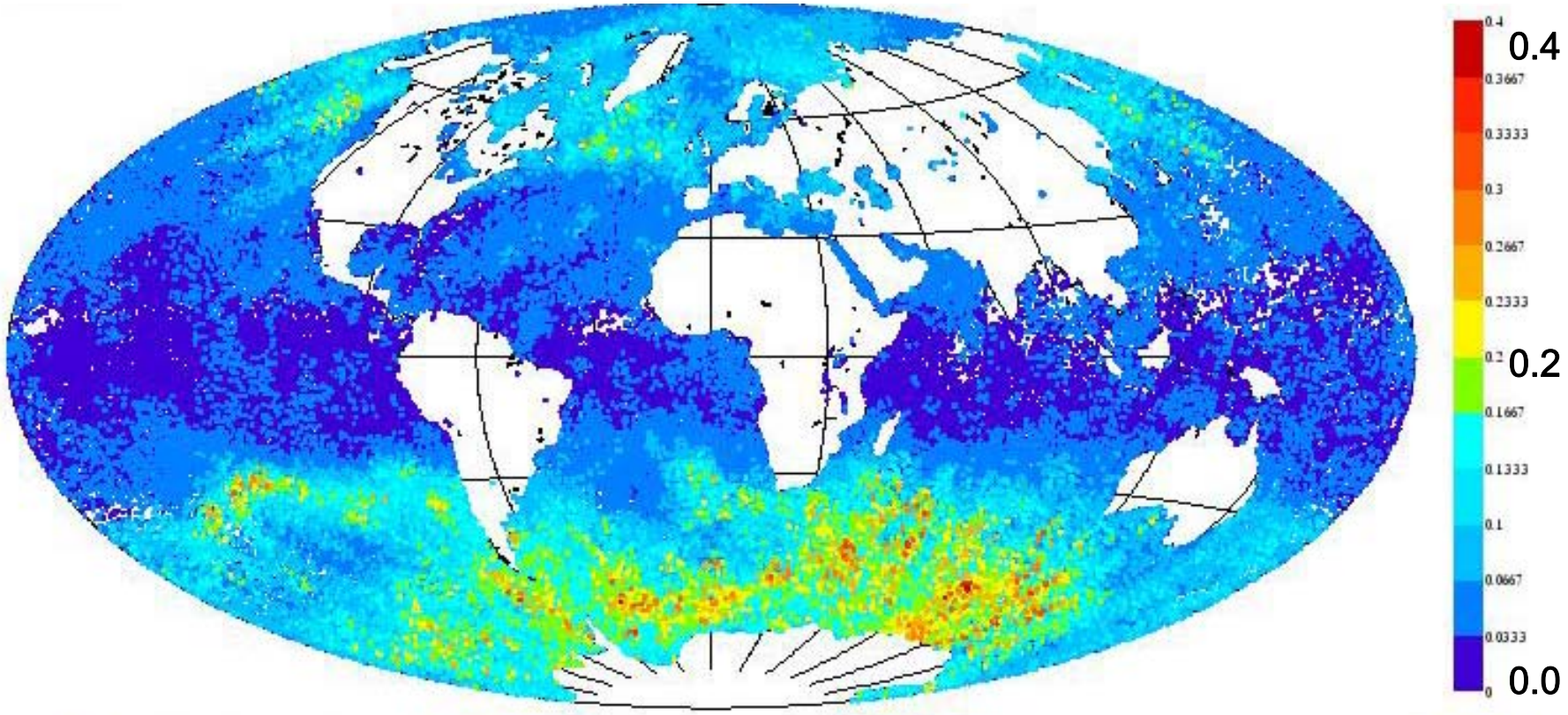
- 2007 ECMWF forecasting system,
- winter & summer seasons,
- Three experiments:
  1) no satellite data (NoSAT),
  2) NoSAT + AMVs,
  3) NoSAT + 1 AMSU-A

← 500 hPa *geopotential height* anomaly correlation

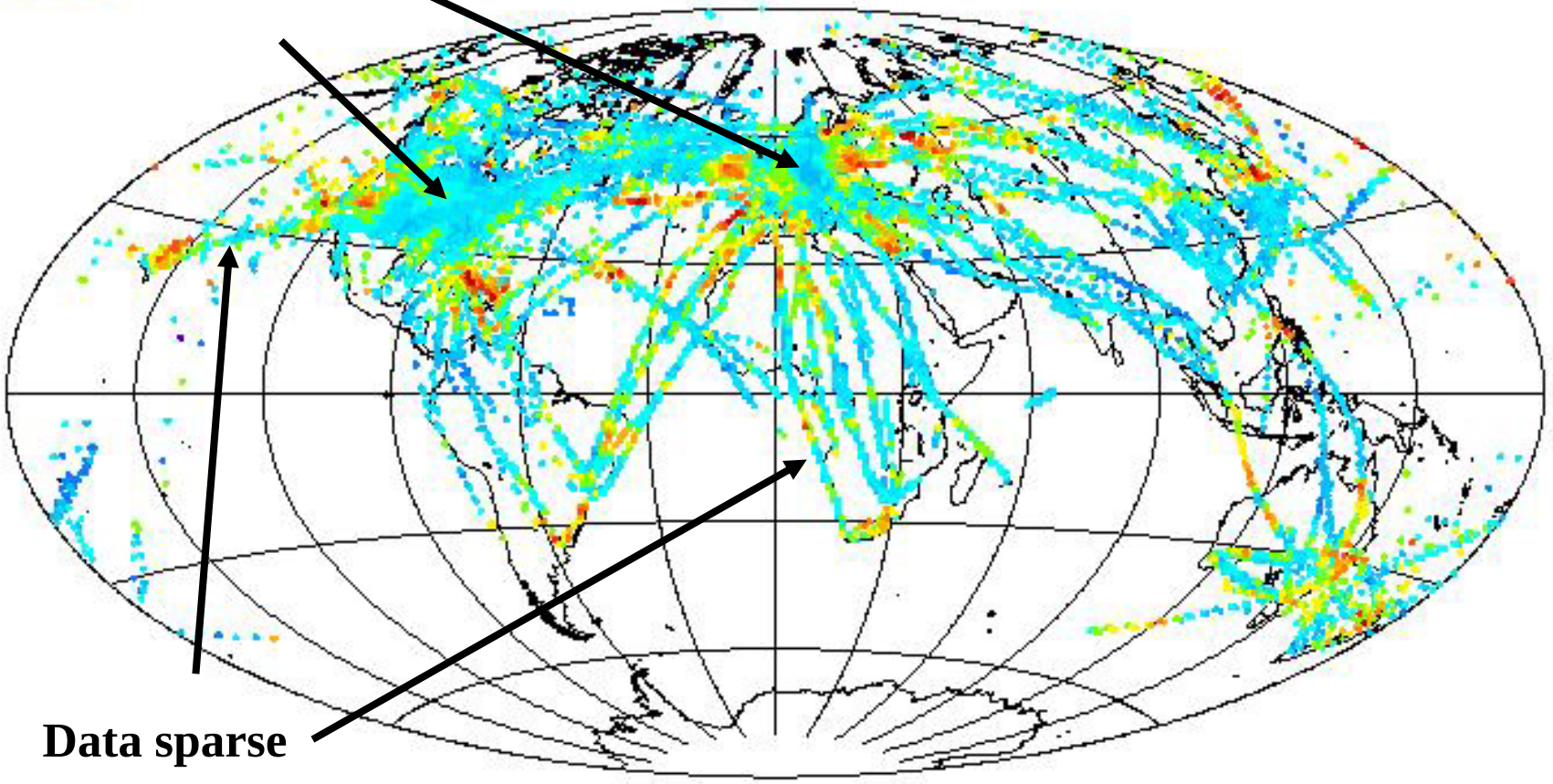
Observation handling project

- **Observation data base (ODB)**
  - **Increasing number of observation types**
  - **Increasing data volumes**
  - **Increasing complexity of data contents**
- **Monitoring / Graphics**
  - **Requirements are more and more demanding**
  - **Automation**
  - **Interactive plotting tools**
- **Archiving/retrieval**
  - **Post-mortem investigations**
  - **Performance assessments (AN/FC/Obs systems/Sensors)**
  - **Climate reanalyses**
- **Advanced data assimilation diagnostics**

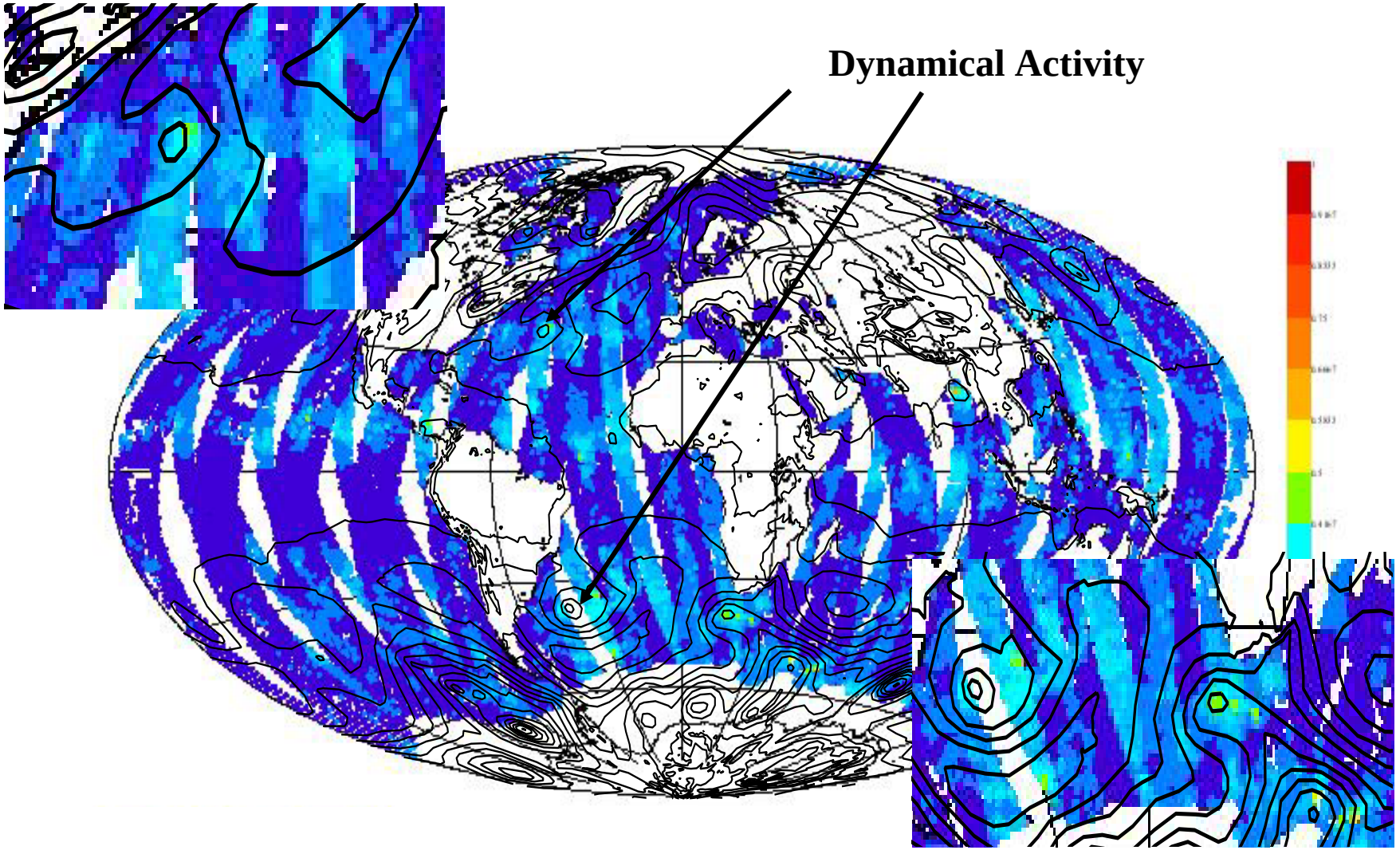
Sensitivity of analysis to observations
IASI – channel 212 (250 hPa)



Sensitivity of analysis to observations
Aircraft 250 hPa U-Comp



Sensitivity of analysis to observations
Scatterometer U-Comp Influence

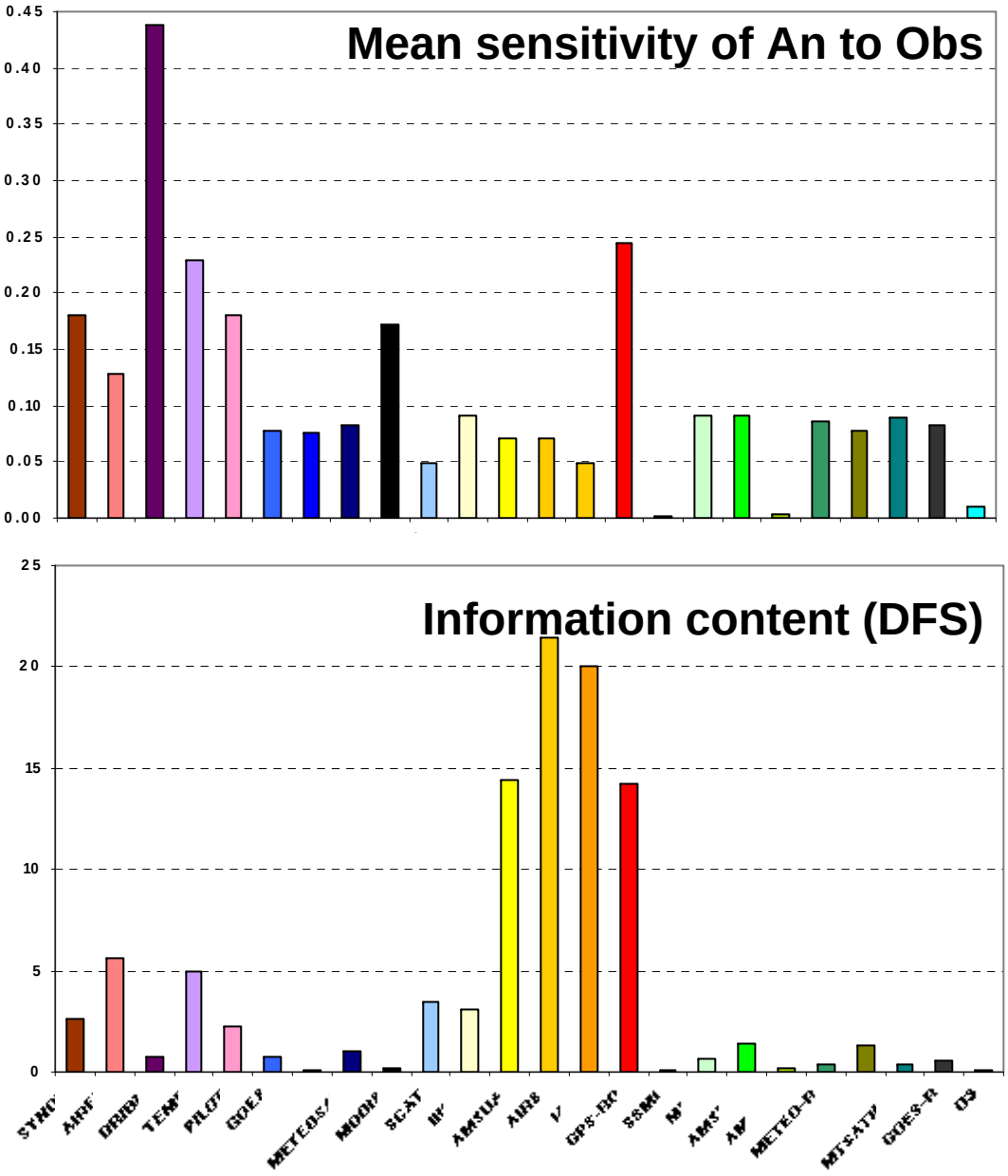


ECMWF

Summary statistics by observation type

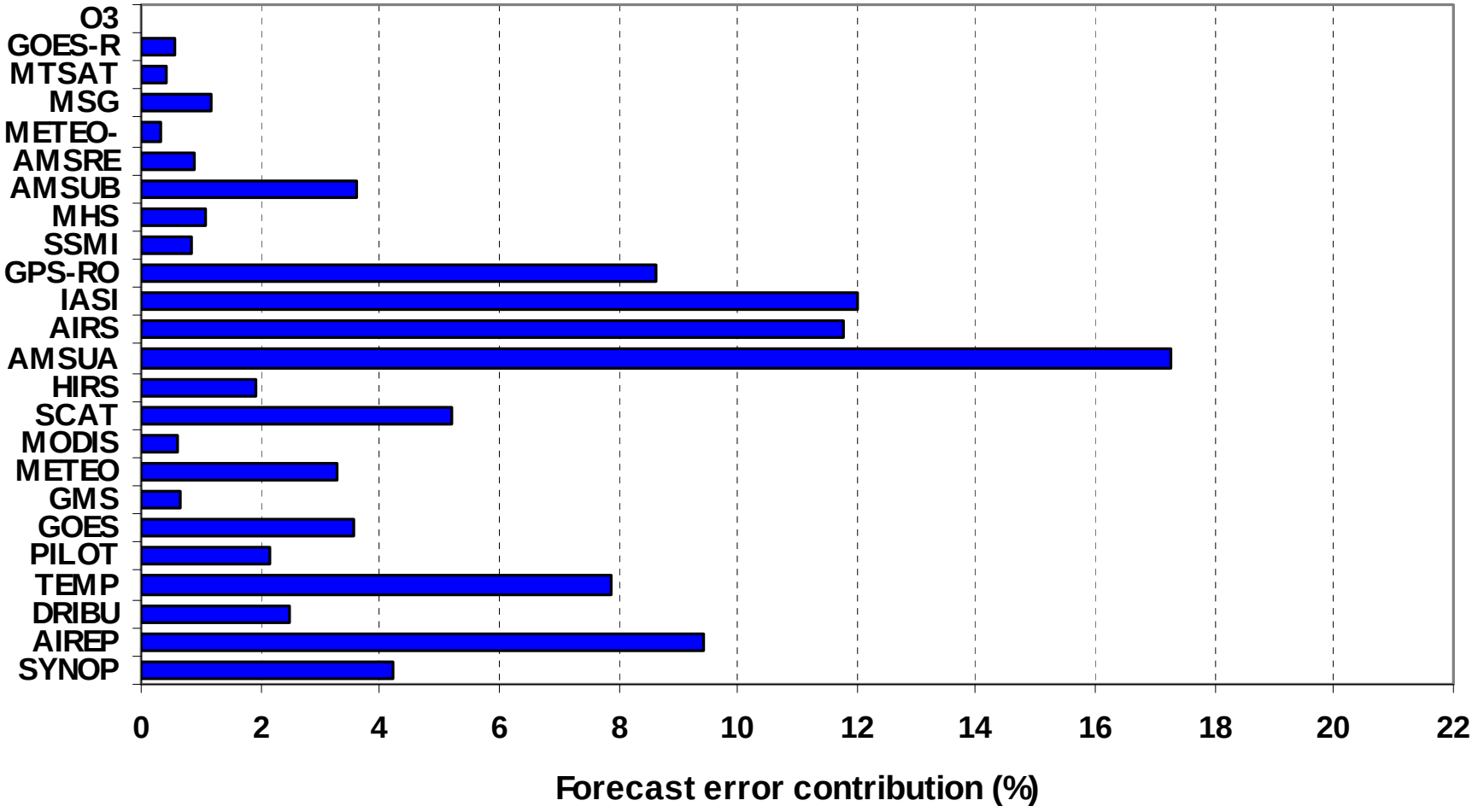
Global observation influence on analysis: GI=7%

Global background influence I-GI=93%



Observations' contributions to decreased forecast error

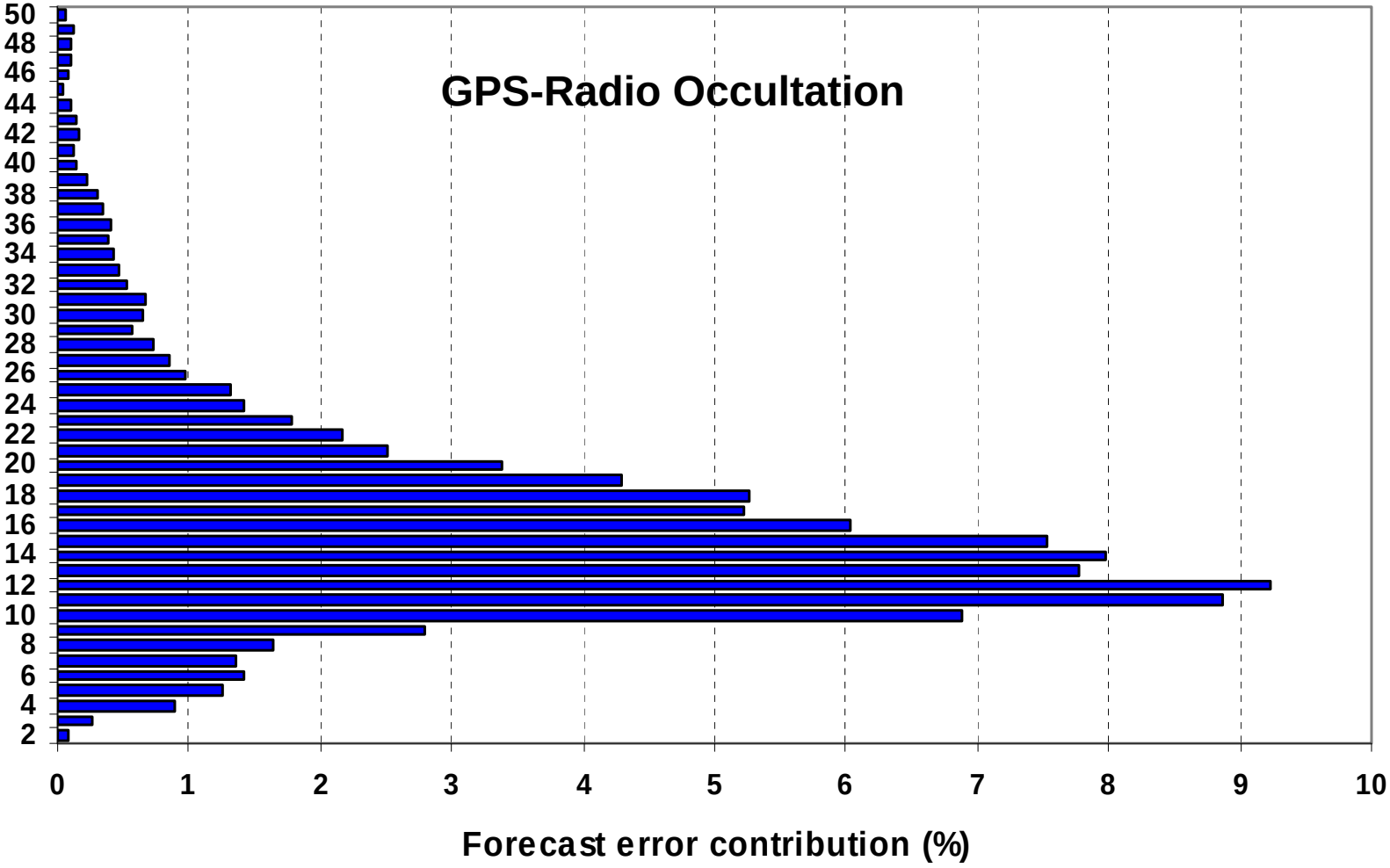
Operational FC system, Sept-Dec 2008



ECMWF

Observations' contributions to decreased forecast error

Operational FC system, Sept-Dec 2008



Outline

- The operational forecast system
- Performance of ECMWF forecasts
- Increased horizontal resolution (16 km)
- Observation handling
  - **Ensembles of data assimilations**
- Workshop: focus on observations

Why Ensembles of Data Assimilations?

- **To estimate analysis uncertainty**
- **To improve the initial perturbations in the EPS**
- **To calculate background error statistics**
- **To enhance the case-to-case variation of observation weight**
- **To improve QC decisions**

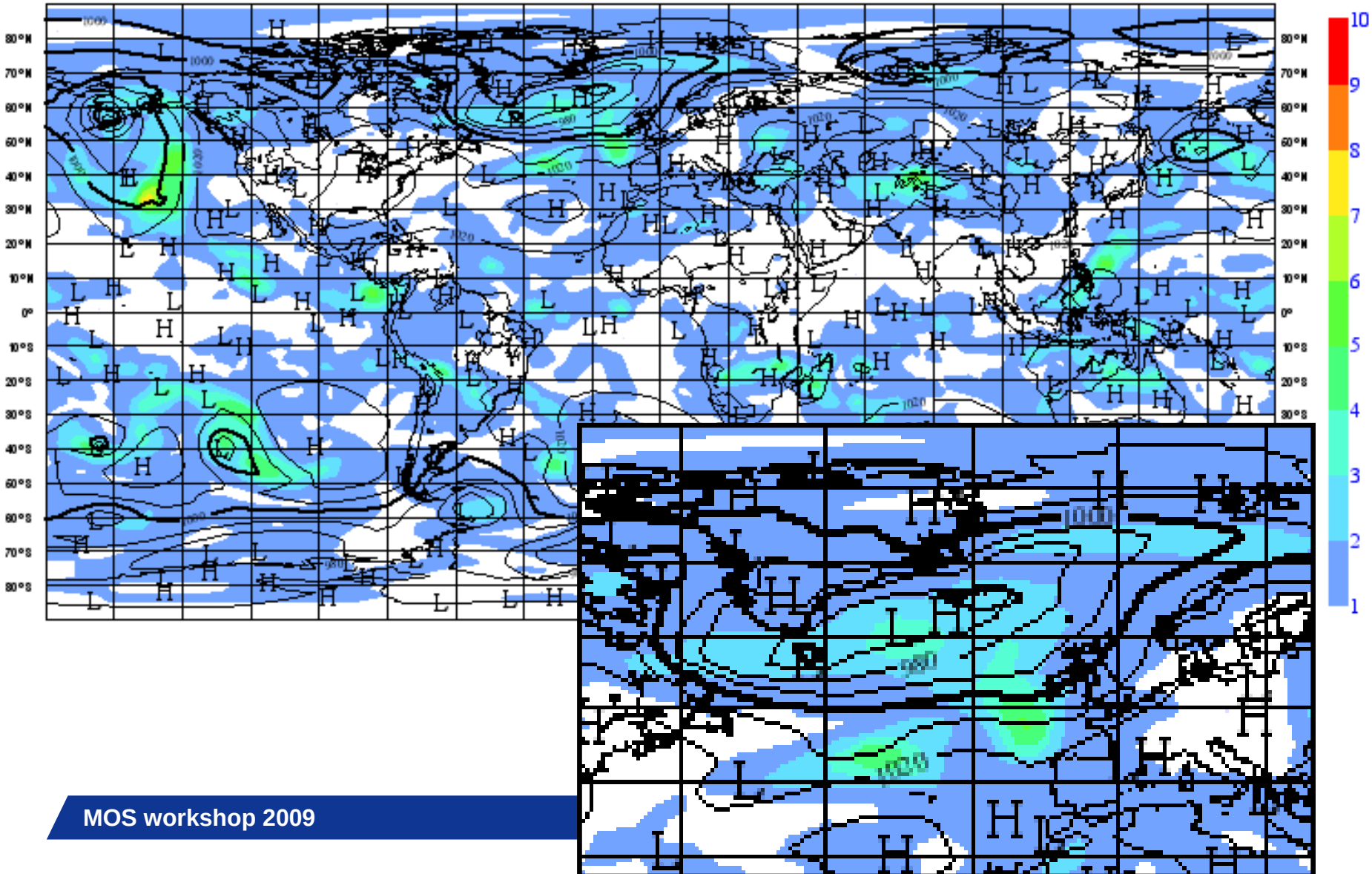
- **Demanding on observation handling …**

Ensembles of data assimilations (EnDA)

- **Randomly perturbed observations and SST fields**
- **Control + 10 ensemble members using 4D-Var assimilations**
  - **T399 outer loop**
  - **T95/T159 inner loop (reduced number of iterations)**
- **Model error**
  - **Spectral backscatter (SPBS) method**
  - **Stochastically Perturbed Parametrization Tendencies**
- **Plan for implementation early 2010**

EnDA: Spread indicates analysis uncertainty

Vorticity at 500 hPa, +9h

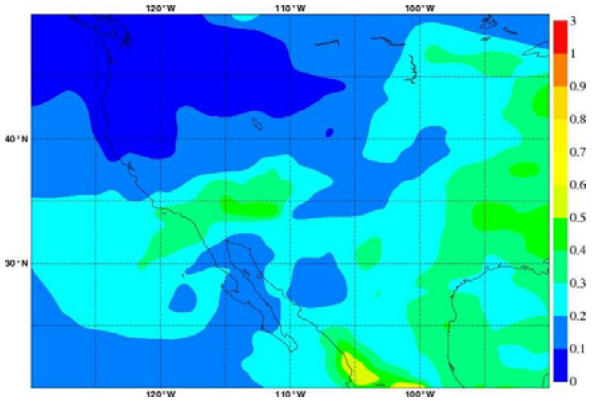


Summary

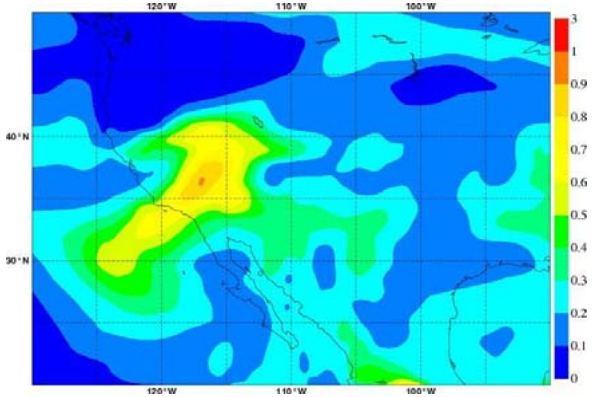
- **Good performance of the forecasting system**
- **Several recent upgrades of the forecasting system – the next one is the horizontal resolution increase to 16 km**
- **Many new observation types – their use in DA has proven to be very beneficial (IASI, GPS-RO, …)**
- **Need for improved observation handling: *monitoring*, *graphics* and *archiving***
  - **Advanced forecast system diagnostics**
  - **Ensembles of data assimilations**
  - **Re-analysis, GEMS/MACC, verification … activities**
- **“Focus on observations”… in talks and working groups**

California fires of July 2008 from the near real-time forecast

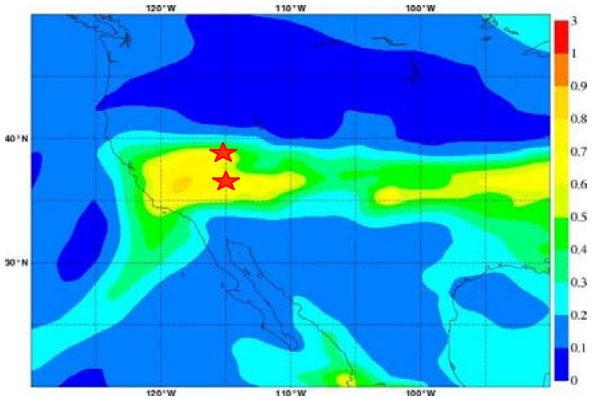
Free running forecast for July 11, 06UTC



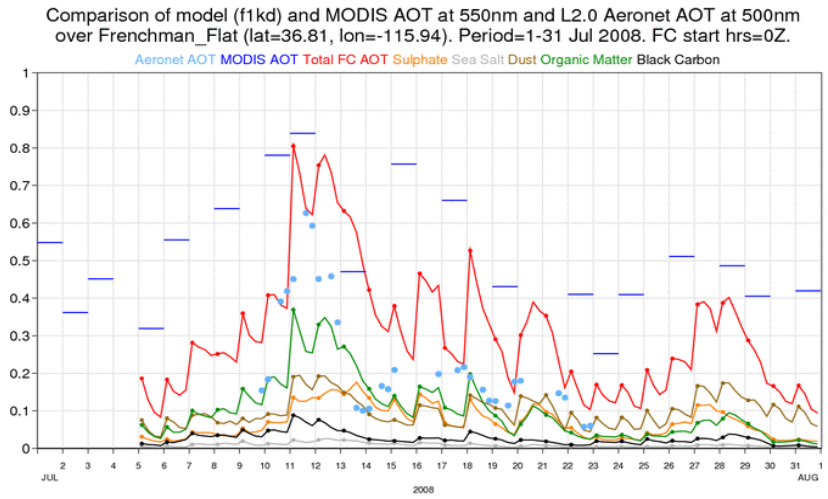
Forecast from AN for July 11, 06UTC

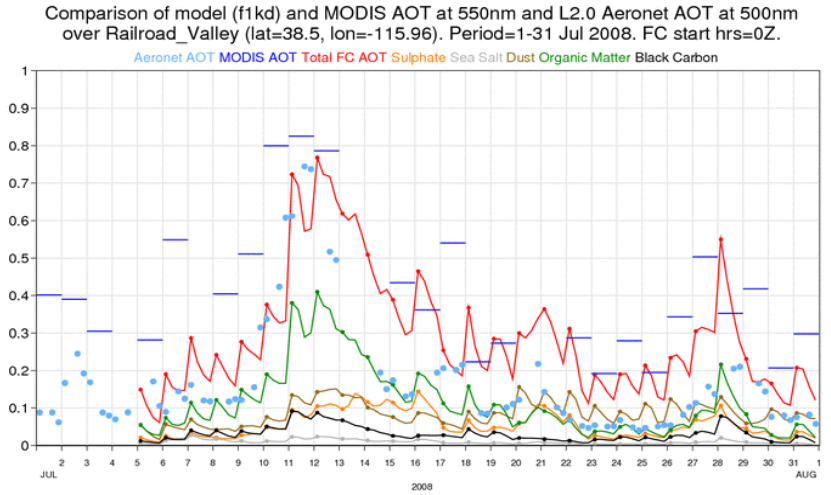


Forecast from AN for July 14, 00UTC



Verification using downwind AERONET stations ★

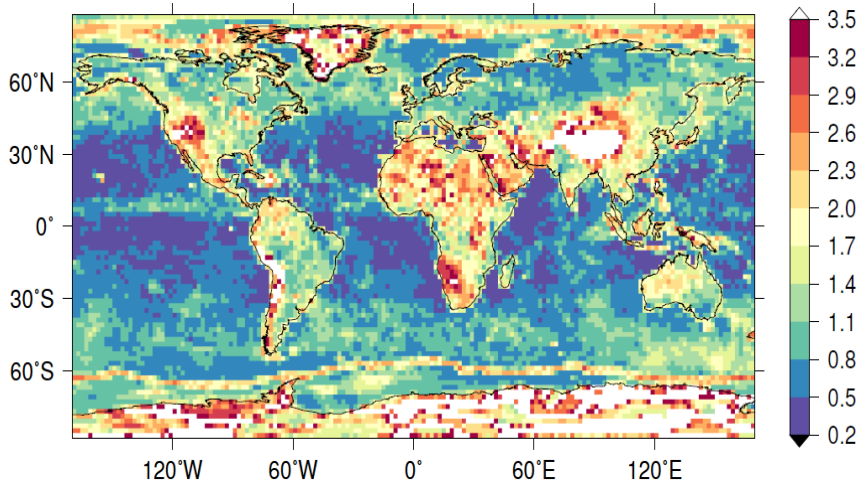




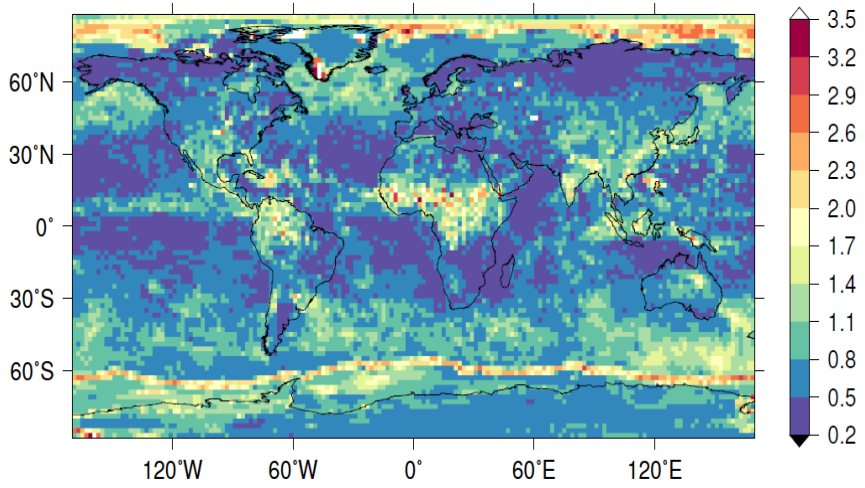
Performance summary

- **Upper-air scores maintained at a high level – slight drop for Europe**
- **Consistent performance: anomaly correlation above 60% to at least day 7 for Europe every month except one since 2007**
- **Probabilistic skill good for T850 and precipitation**
- **Precipitation scores improved further. Night-time T2m bias in Europe**
- **Maintained world lead for deterministic, EPS and wave FC**
- **TCs: excellent performance in terms of position error and core pressure error last two years**
- **Positive trend in monthly forecast skill for day 12-18, for T2m**
- **Good forecast of El Nino, early 2009**

Reduced first guess departures for surface sensitive channels (AMSU-A, ch4 in Kelvin)



Old emissivity

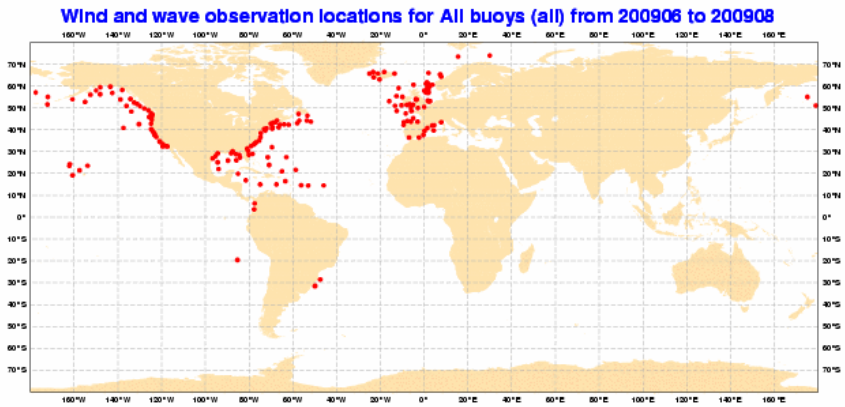


New dynamic emissivity

“Freak waves”

Max wave height (Hmax) verification:

- **Maximum wave height (Hmax) has been an operational parameter since June 2008.**
- **Comparison with a limited set of buoys that observes Hmax is quite satisfactory.**



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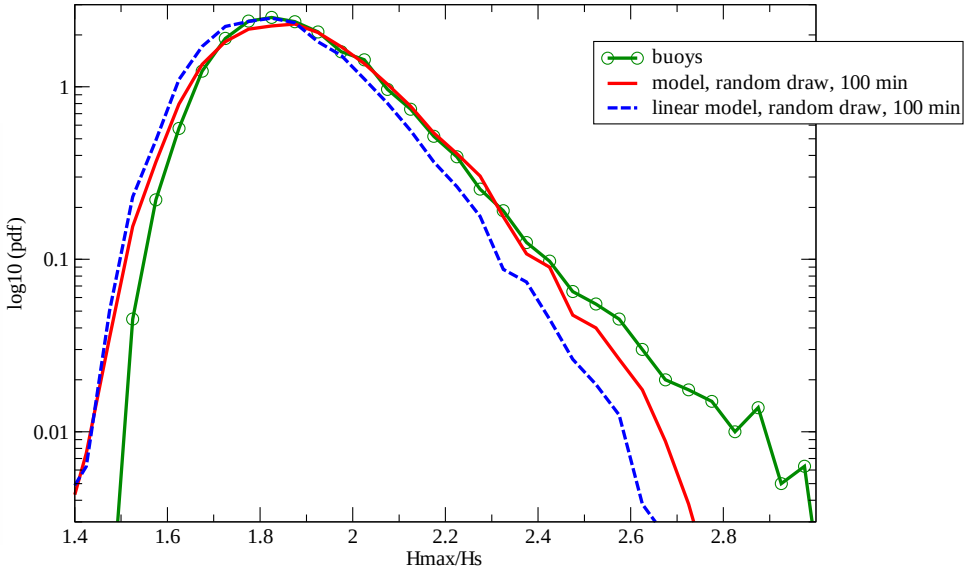
e.g: Comparison of observed pdf of Hmax/Hs with model based on nonlinear theory and model based on simple Gaussian statistics.

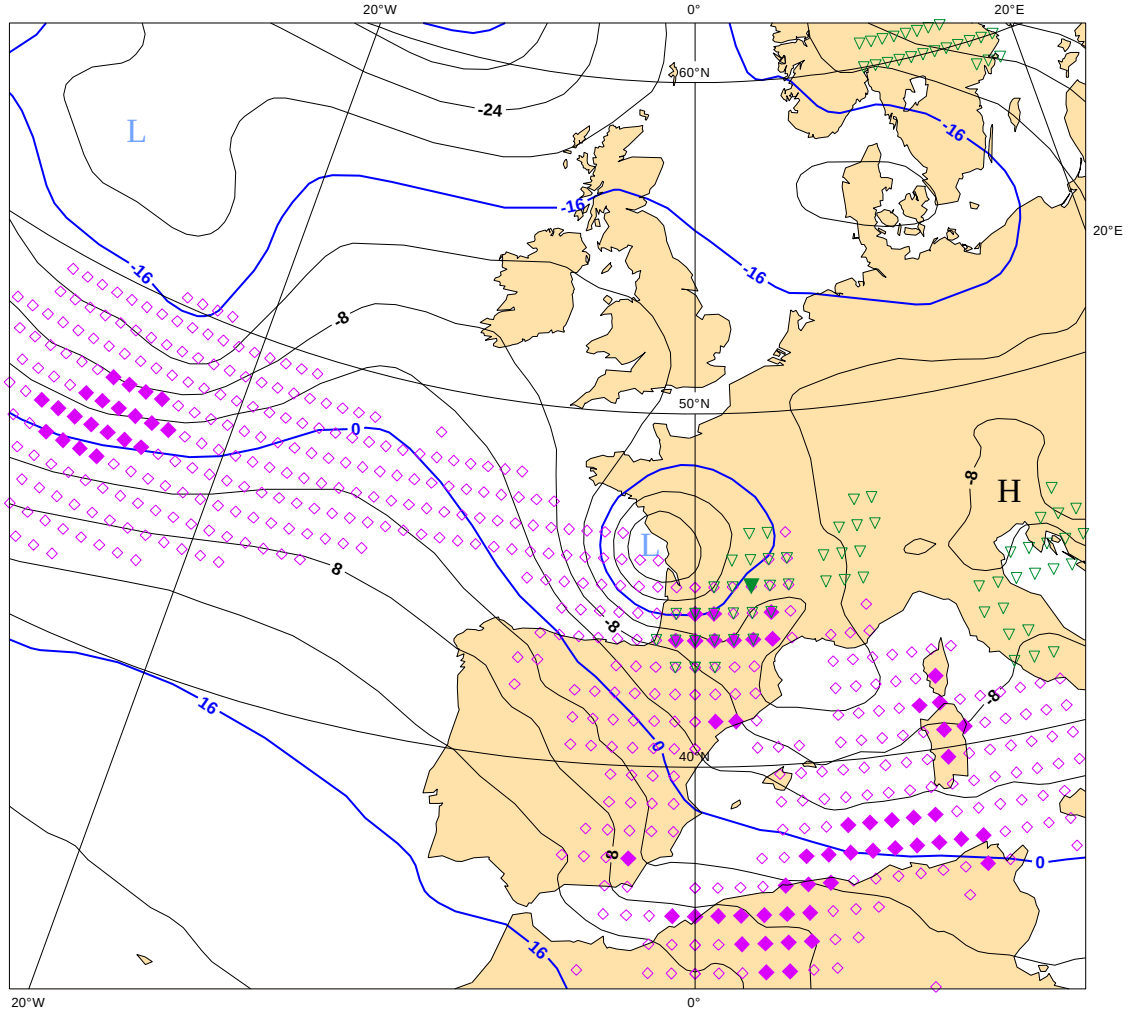


Hmax/Hs

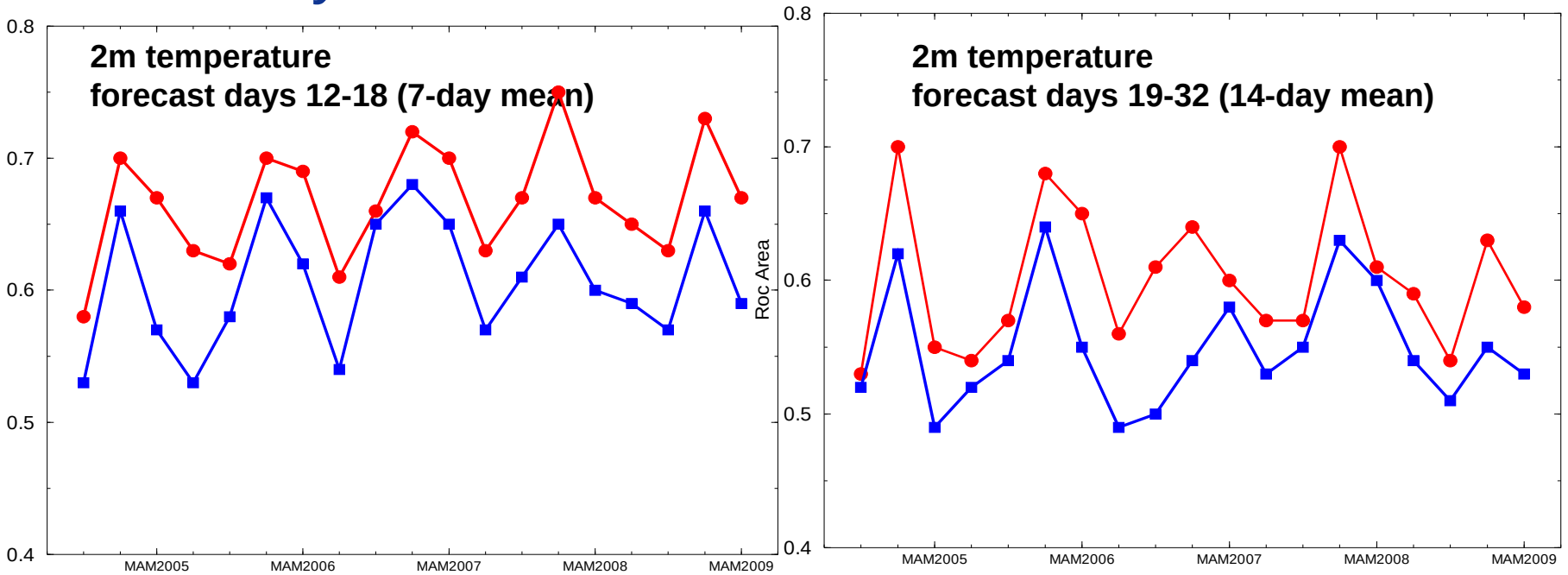
Winter storm Klaus, 24 January 2009

EFI gave a clear early warning

3-day EFI forecast is shown on the right, with verifying analysis at 06 UTC on 24 January



Monthly forecast



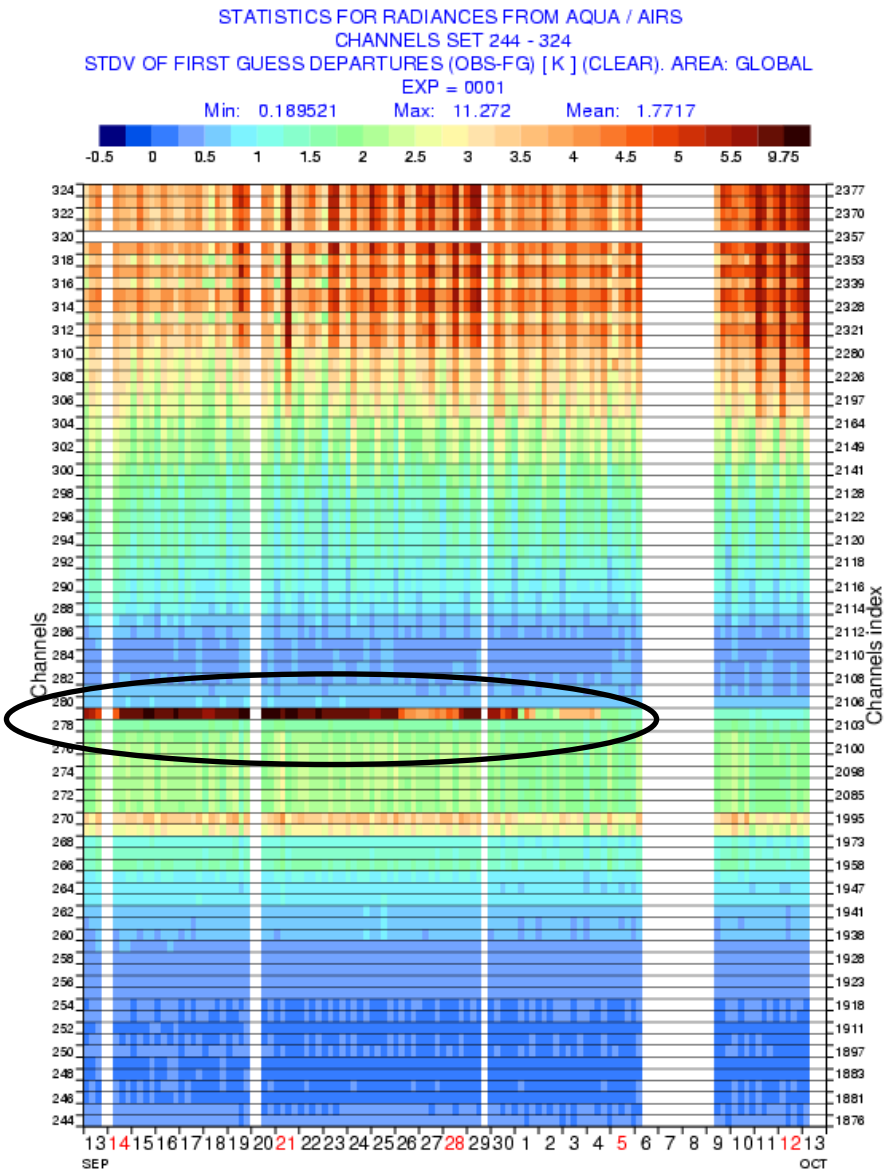
ROC-are for the probability that T2m is in the upper third of the climate distribution, for each 3-month season since autumn 2005 for all land points in the extra-tropical N.Hem.

red line: score of the monthly forecasting system for forecast days 12-18 (7-day mean) and 19-32 (14-day mean).

blue line: score using persistence of the preceding 7-day or 14-day period of the forecast.

Data monitoring – overview plots, advanced sounders

Time series compact product for high spectral resolution sounders



Increase of the noise of AIRS channel 2104

When a problem is spotted, individual time series and Hovmöller diagrams can be checked.

(M. Dahoui)

Data sources: Conventional

SYNOP/SHIP/METAR:

- Meteorological surface weather stations
- Ships

→ **temperature, dew-point temperature, wind (land: 2m, ships: 25m)**

BUOYS:

- Moored buoys
- Drifting buoys

→ **temperature, pressure, wind**

TEMP/TEMPSHIP/DROPSONDES:

- Radiosondes
- ASAPs (commercial ships replacing stationary weather ships)
- Dropsondes released from aircraft

→ **temperature, humidity, pressure, wind profiles**

PROFILERS:

- UHF/VHF Doppler radars (Europe, US, Japan)

→ **wind profiles**

Aircraft:

- AIREP (manual reports from pilots)
- AMDARs, ACARs, etc. (automated readings)

→ **temperature, pressure, wind (profiles and flight-level)**

Data sources: Satellites

Radiances (→ **brightness temperature**):
- AMSU-A on NOAA-15/18/19, AQUA, Metop
- AMSU-B/MHS on NOAA-17/18, Metop
- SSM/I on F-13/15, AMSR-E on Aqua
- HIRS on NOAA-17/19, Metop
- AIRS on AQUA, IASI on Metop
- MVIRI on Meteosat-7, SEVIRI on Meteosat-9, GOES-11/12, MTSAT-1R imagers

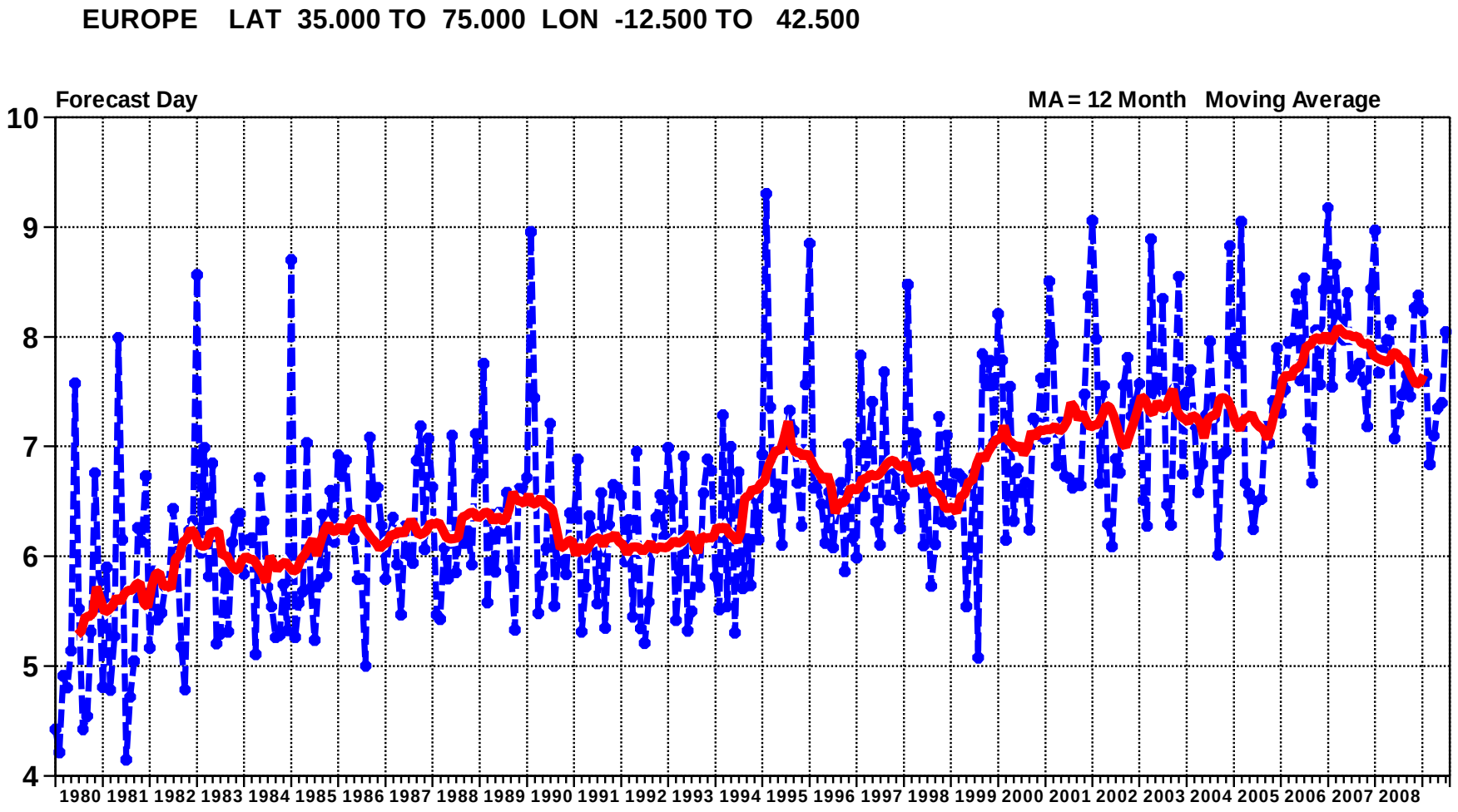
Ozone (→ **total column ozone**):
- Total column ozone from SBUV on NOAA-17/18, OMI on Aura

Bending angles (→ **bending angle**):
- COSMIC (6 satellites), GRAS on Metop

Atmospheric Motion Vectors (→ **wind speed**):
- Meteosat-7/9, GOES-11/12, MTSAT-1R, MODIS on Terra/Aqua

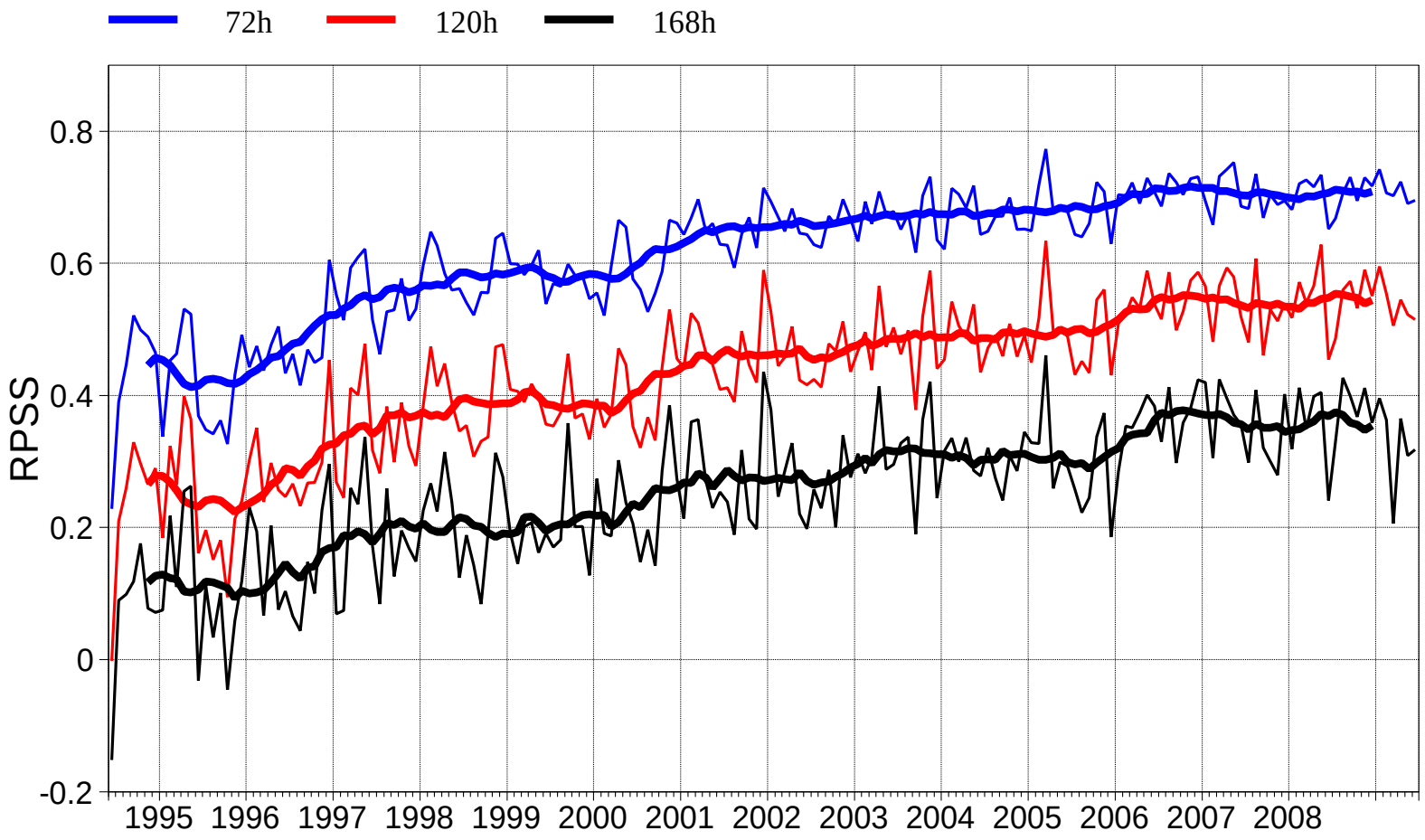
Sea surface parameters (→ **wind speed and wave height**):
- Significant wave height from QuikSCAT, ERS-2 and ASCAT
- Near-surface wind speed from RA-2/ASAR on Envisat, Jason altimeter

Z500, Time series of ACC=0.6 Europe



ECMWF

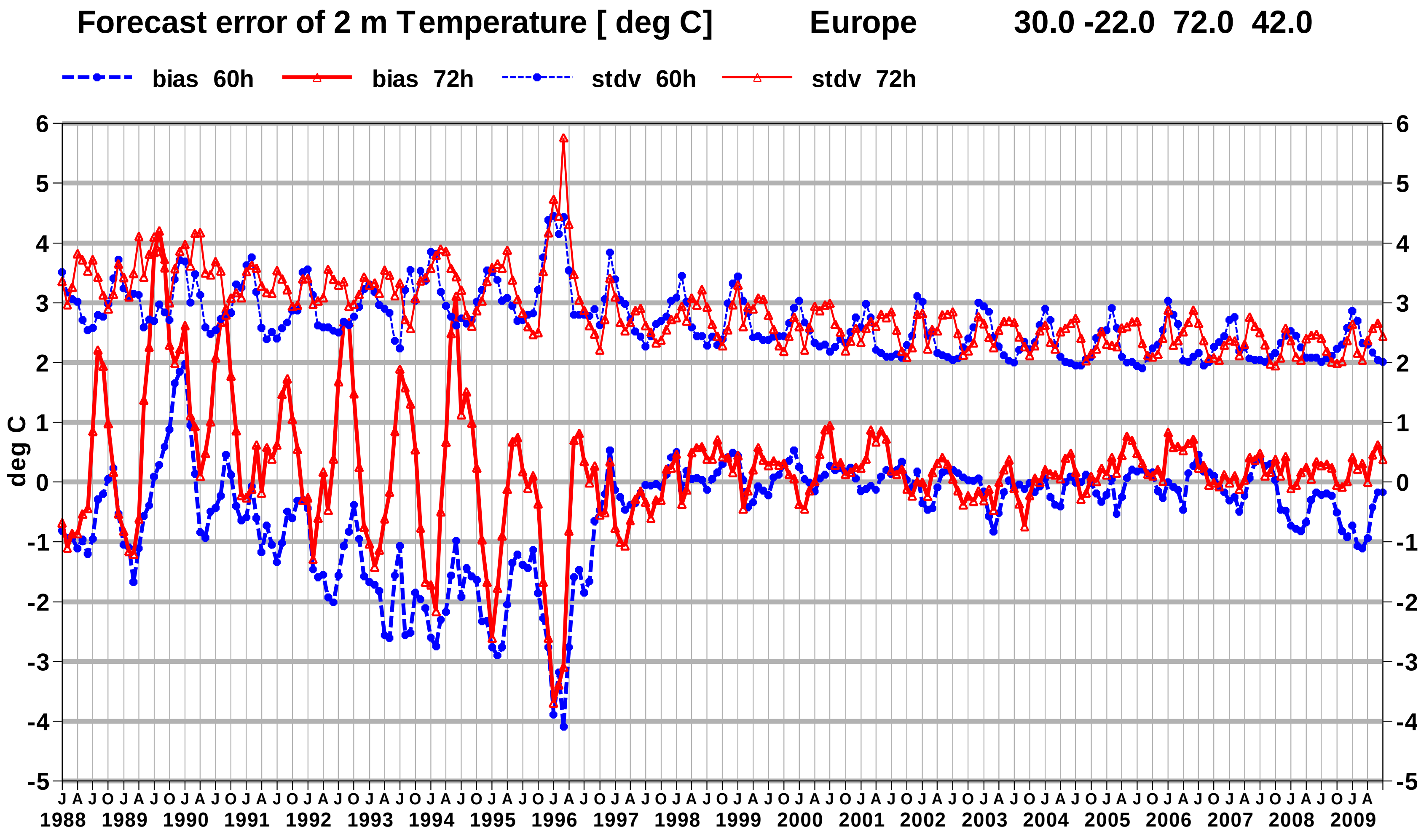
EPS probability skill, RPSS, T850 Europe



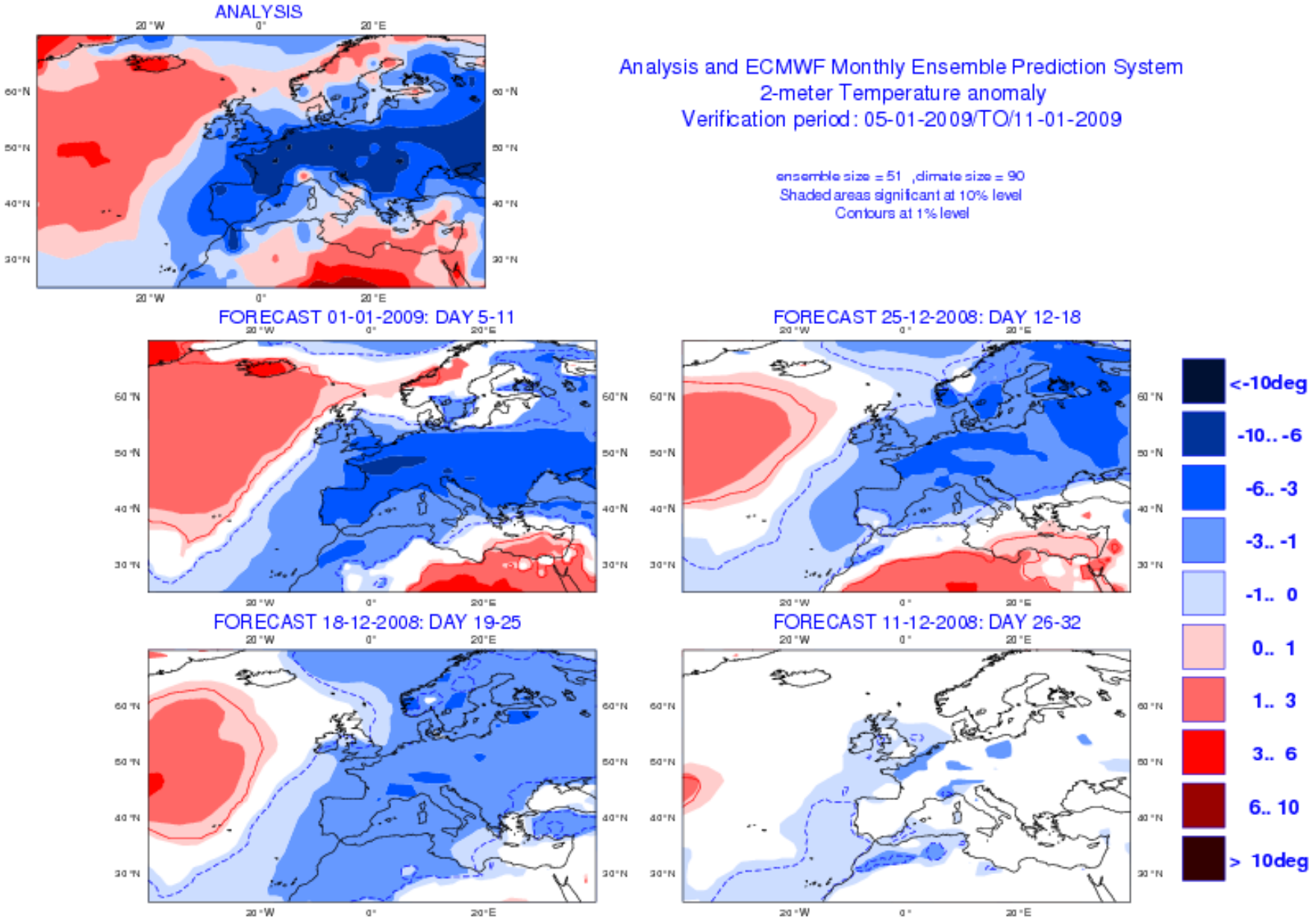
Monthly score and 12-month running mean (bold) of Ranked Probability Skill Score for EPS forecasts of T850 at day 3 (blue), 5 (red) and 7 (black) for Europe

ECMWF

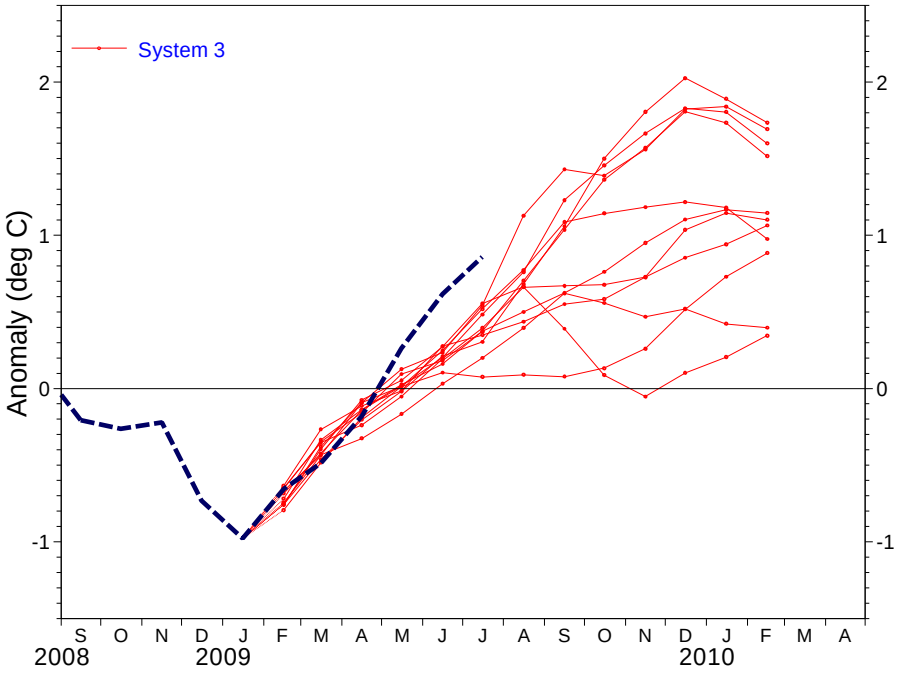
Temperature at 2 meter

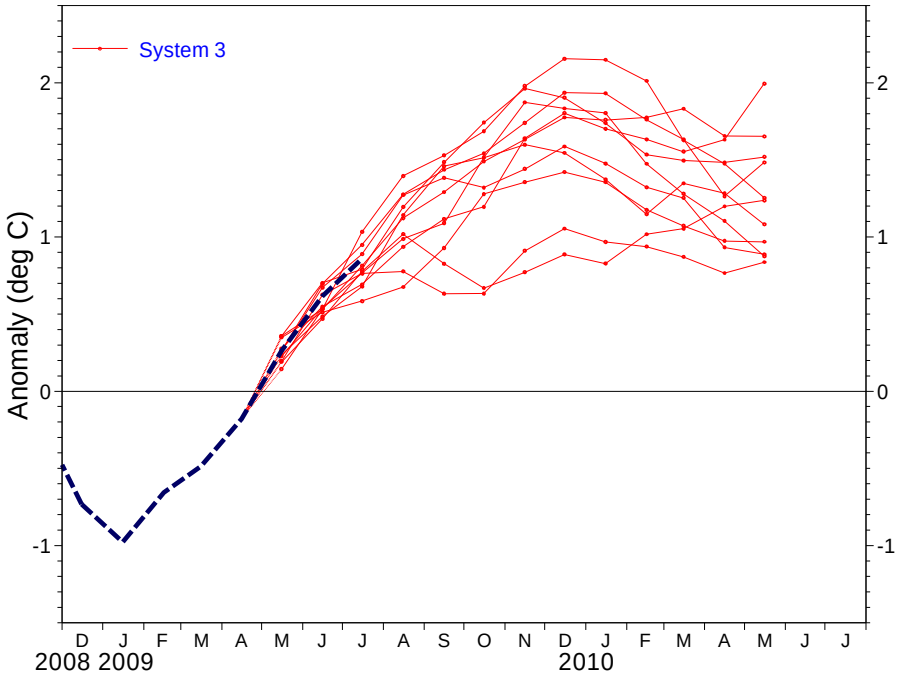


ECMWF


ANALYSIS
Analysis and ECMWF Monthly Ensemble Prediction System
2-meter Temperature anomaly
Verification period: 05-01-2009/TO/11-01-2009
ensemble size = 51 ,climate size = 90
Shaded areas significant at 10% level
Contours at 1% level
FORECAST 01-01-2009: DAY 5-11
FORECAST 25-12-2008: DAY 12-18
FORECAST 18-12-2008: DAY 19-25
FORECAST 11-12-2008: DAY 26-32
<-10deg
-10.. -6
-6.. -3
-3.. -1
-1.. 0
0.. 1
1.. 3
3.. 6
6.. 10
> 10deg

Seasonal forecast – Nino SST, annual range

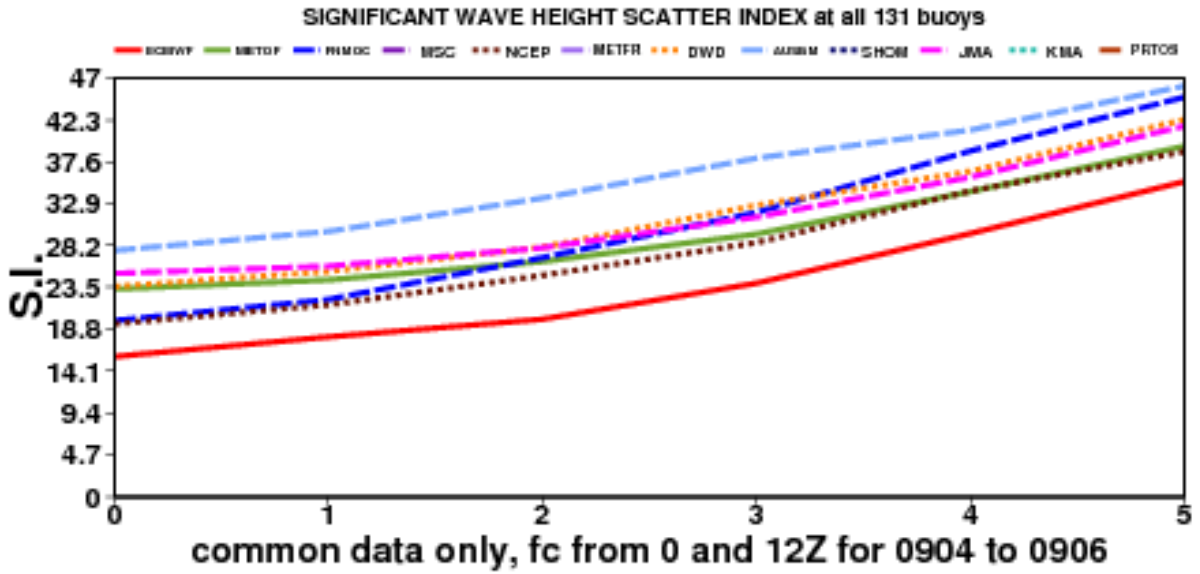




ECMWF forecasts of SST anomalies over the NINO 3.4 region of the tropical Pacific from February (left) and May (right) 2009. The red lines represent the 40 ensemble members; dashed blue lines show the subsequent verification

Waves forecasts – comparison to other centres

- **Wave height**



- **10m wind**