ECMWF Forecasting System Research and Development

Jean-Noël Thépaut

ECMWF

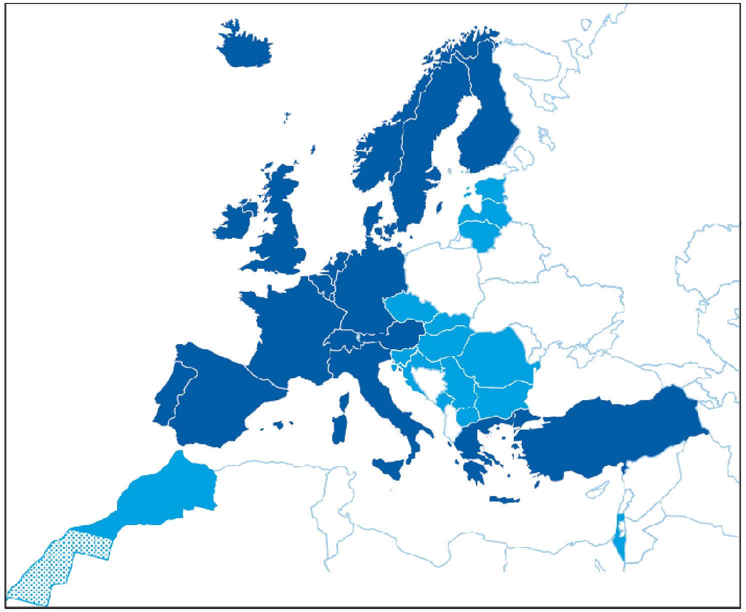
October 2012

and many colleagues from the Research Department

Global observation system

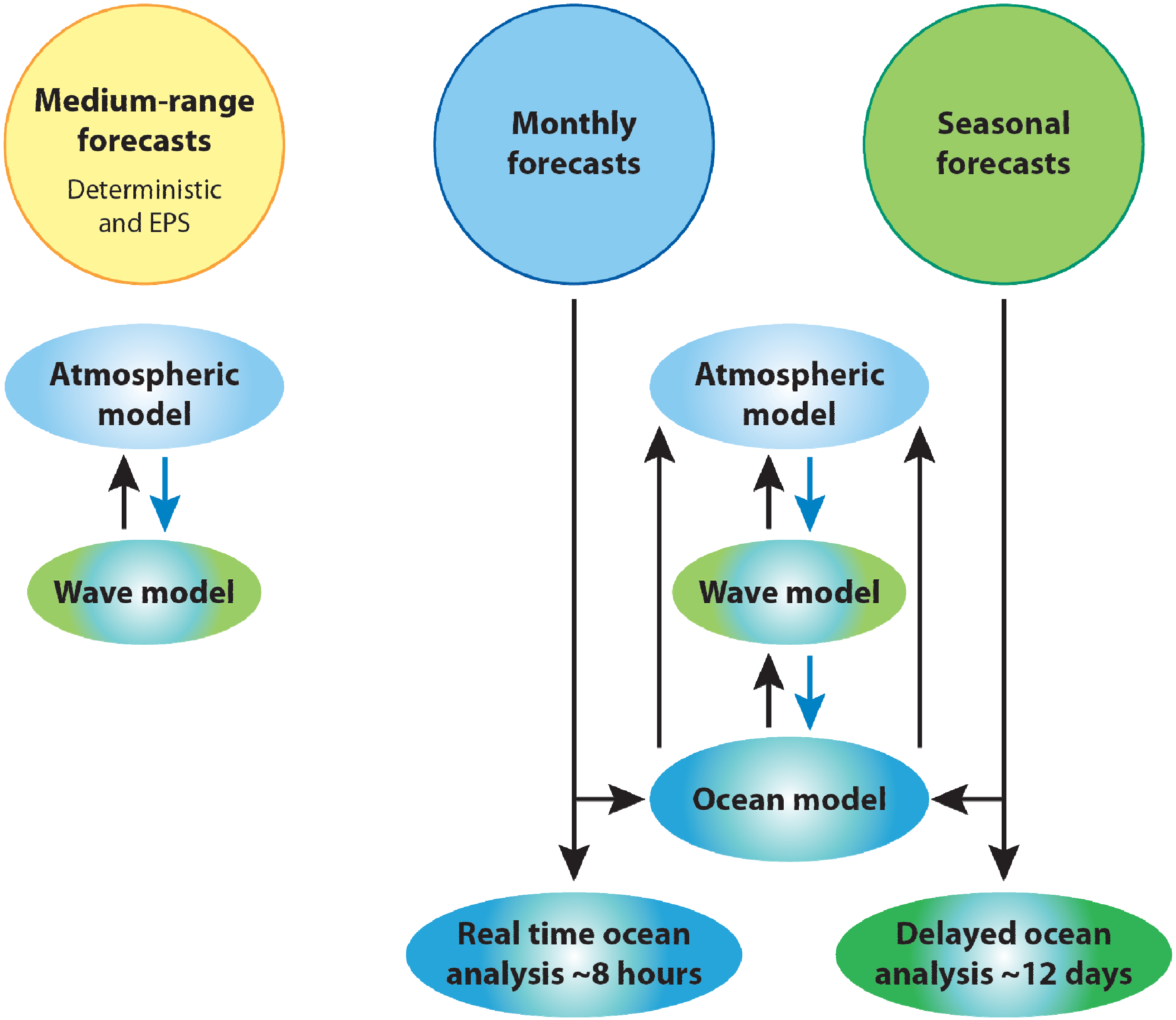
Global numerical weather forecasts

National weather services

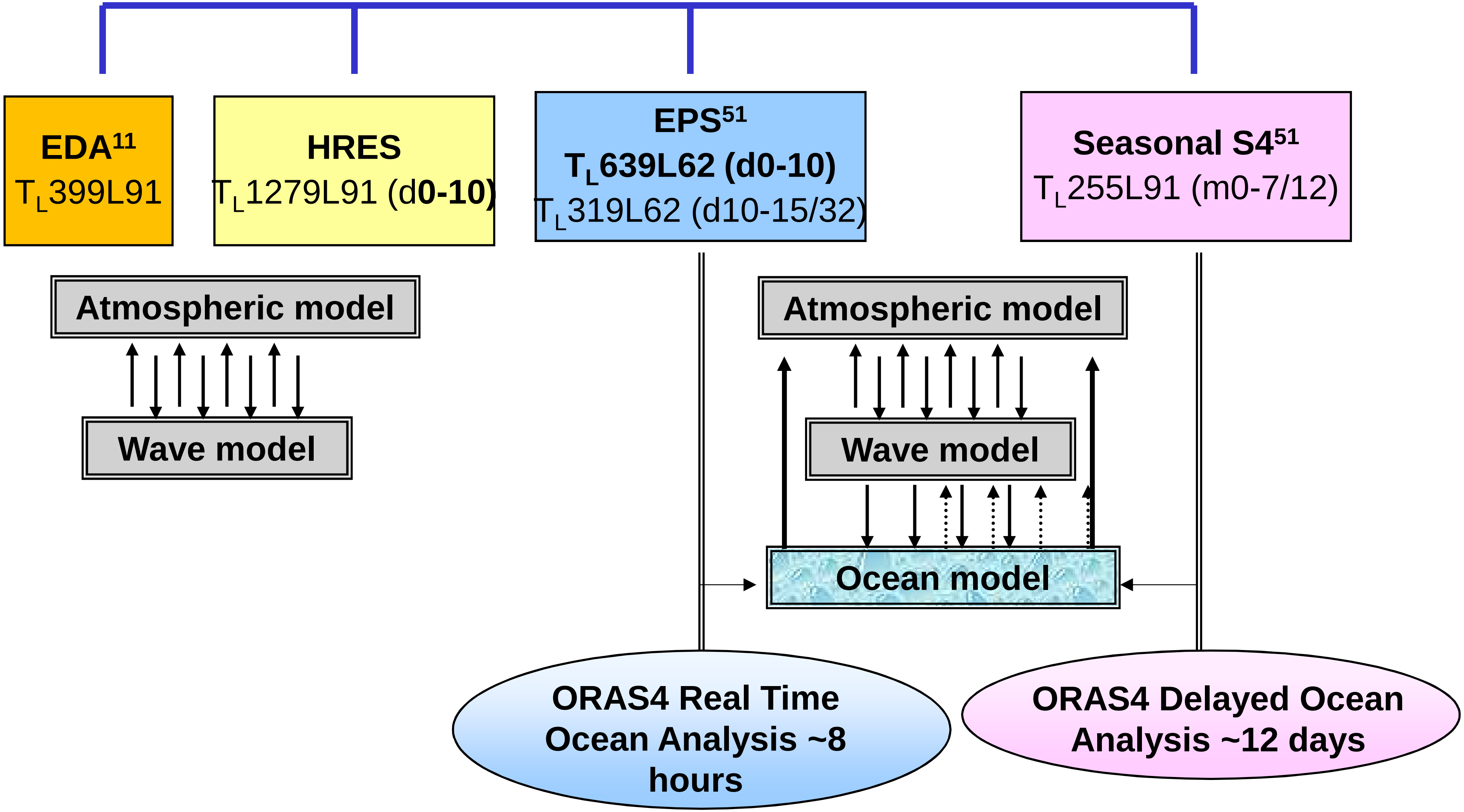


Users

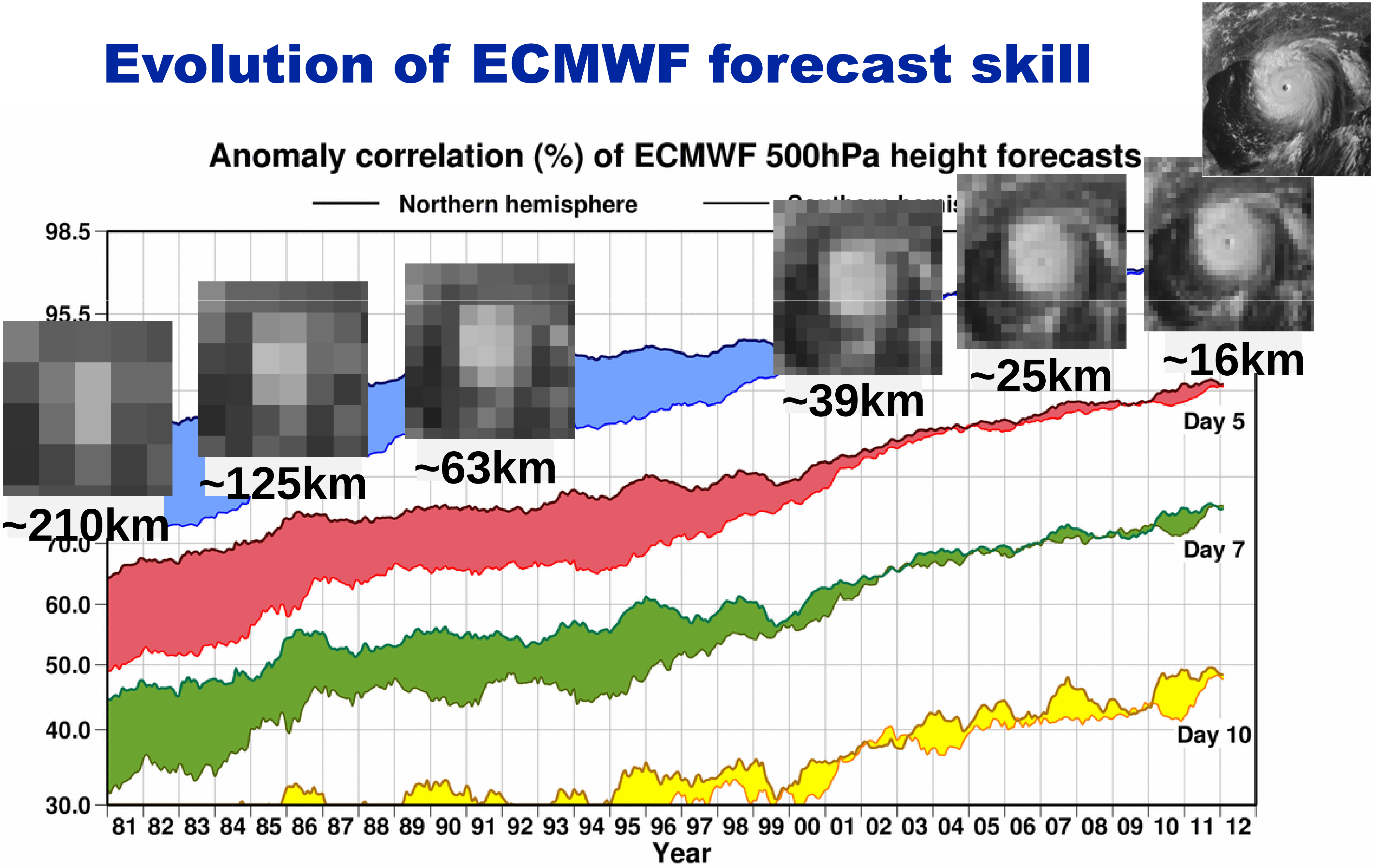
ECMWF forecasting systems



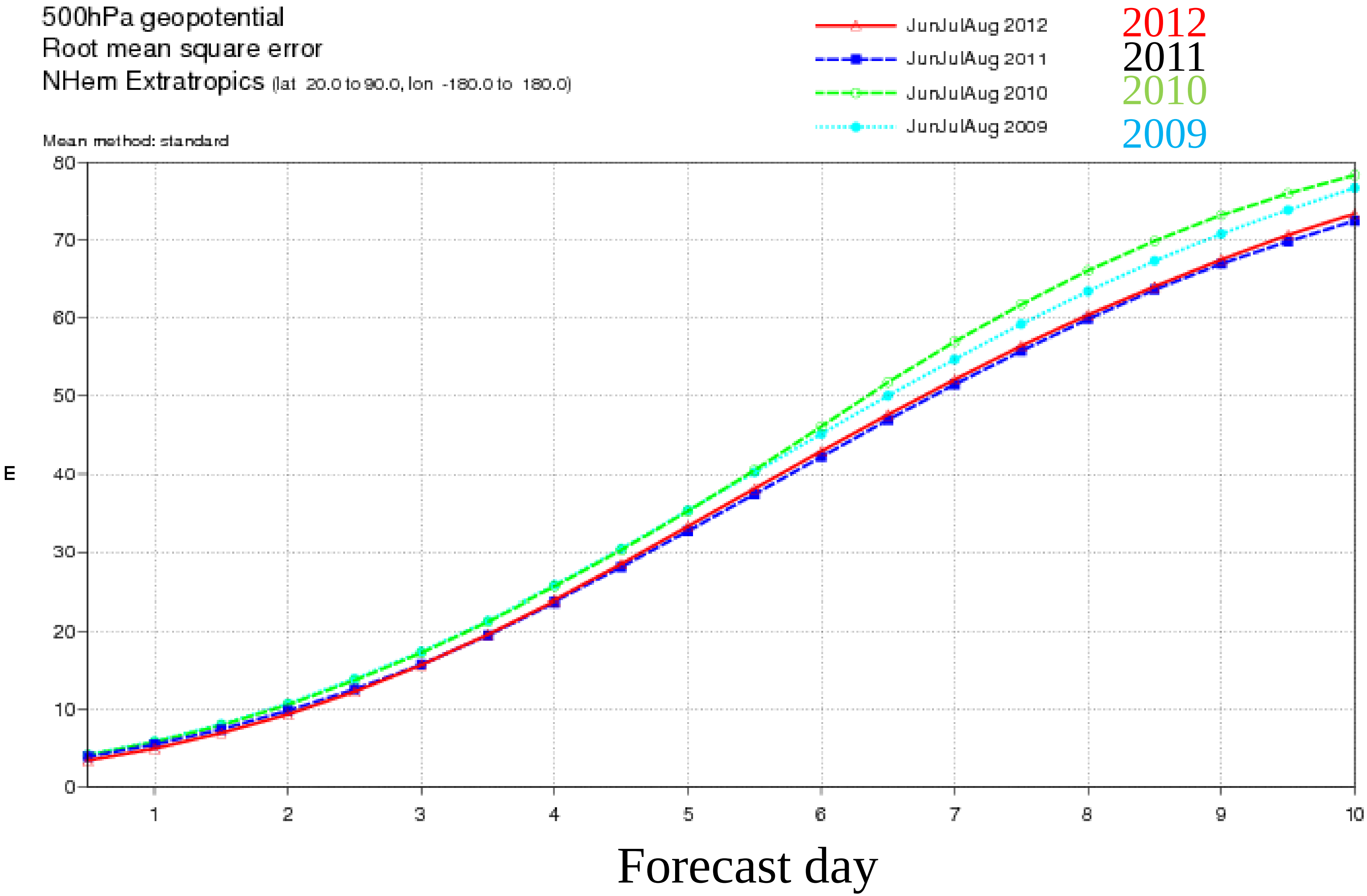
The ECMWF Integrated Forecasting System (IFS)



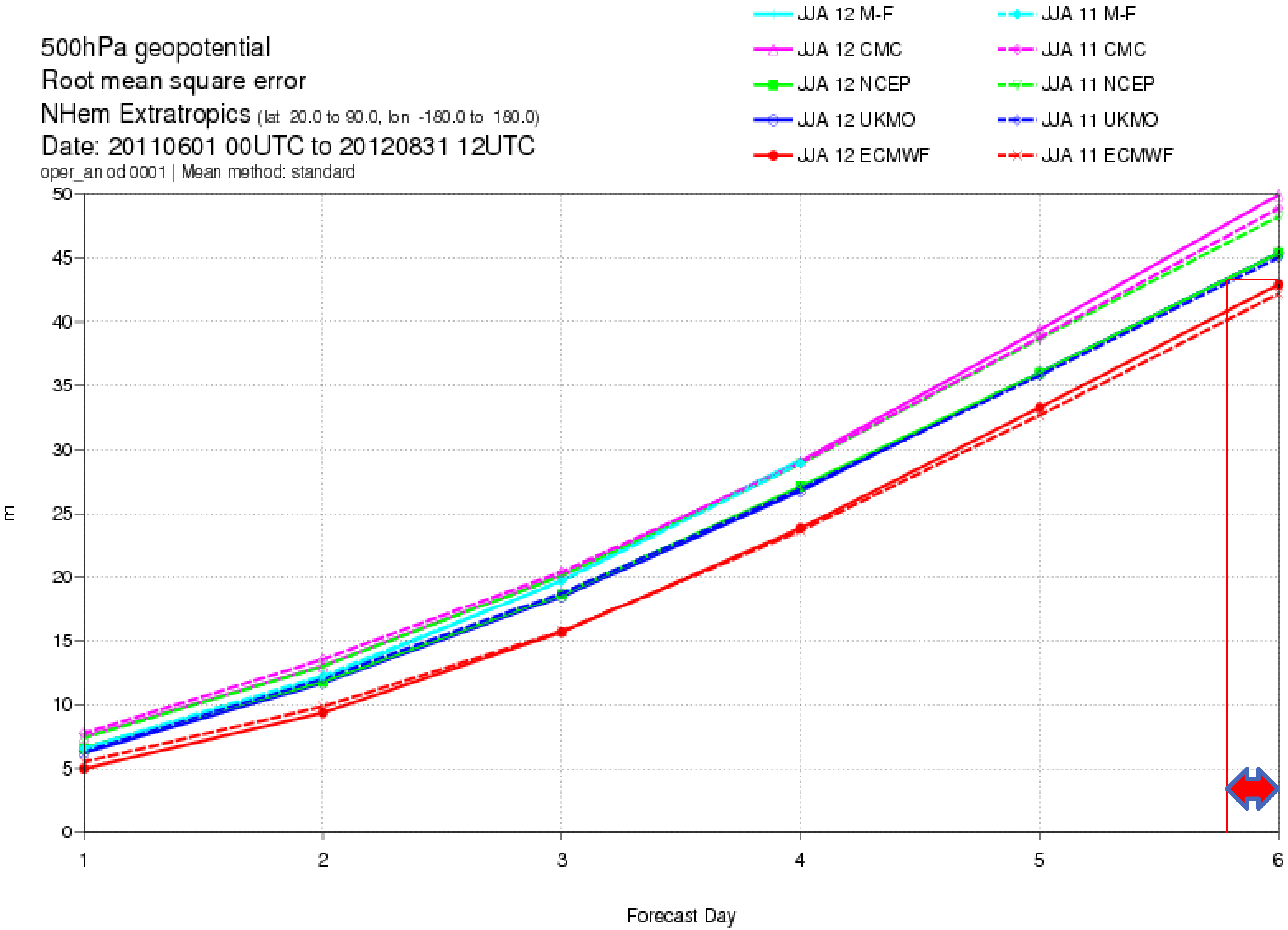
Evolution of ECMWF forecast skill



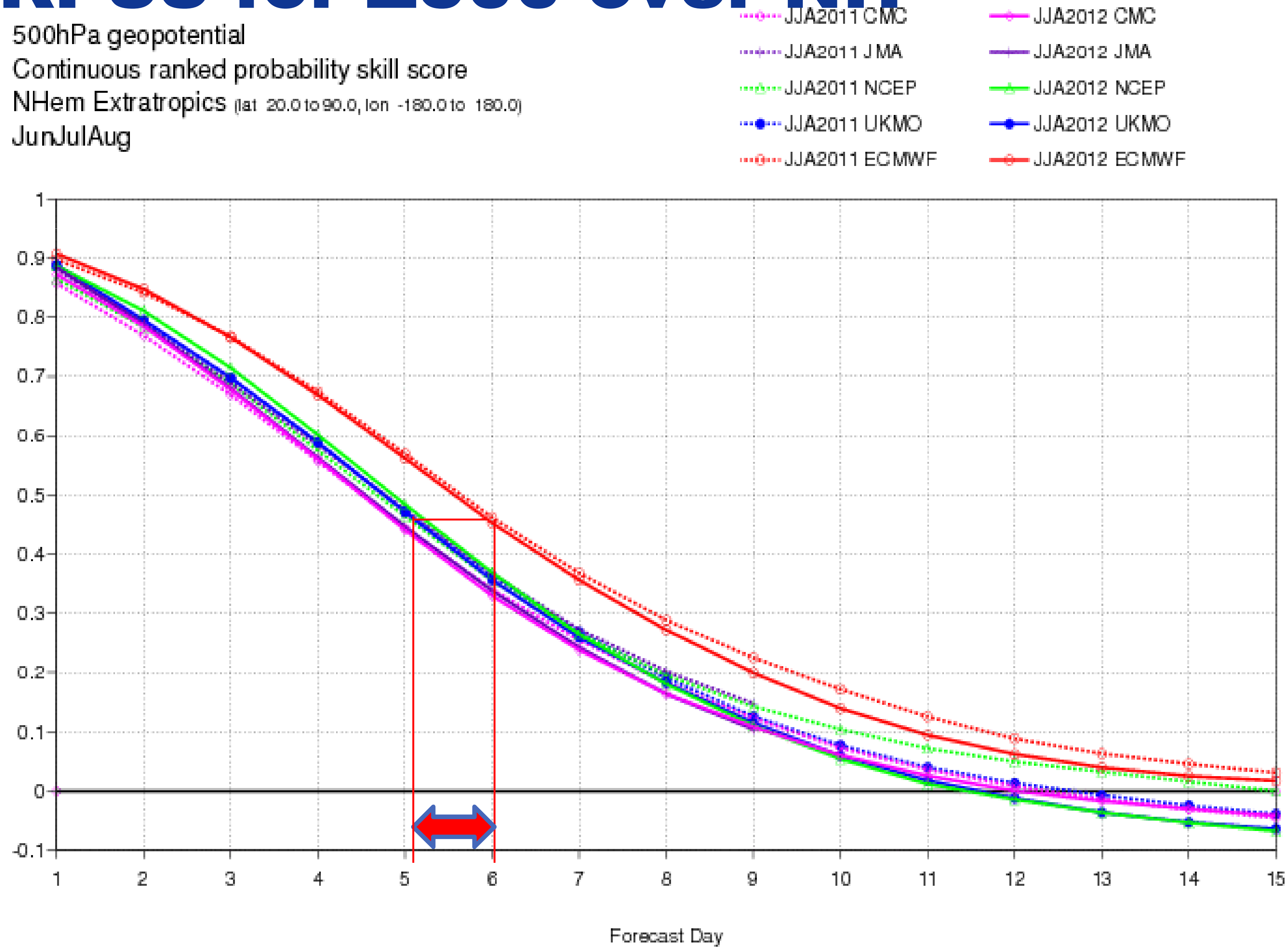
Root mean square 500 hPa forecast error Northern Hemisphere summer



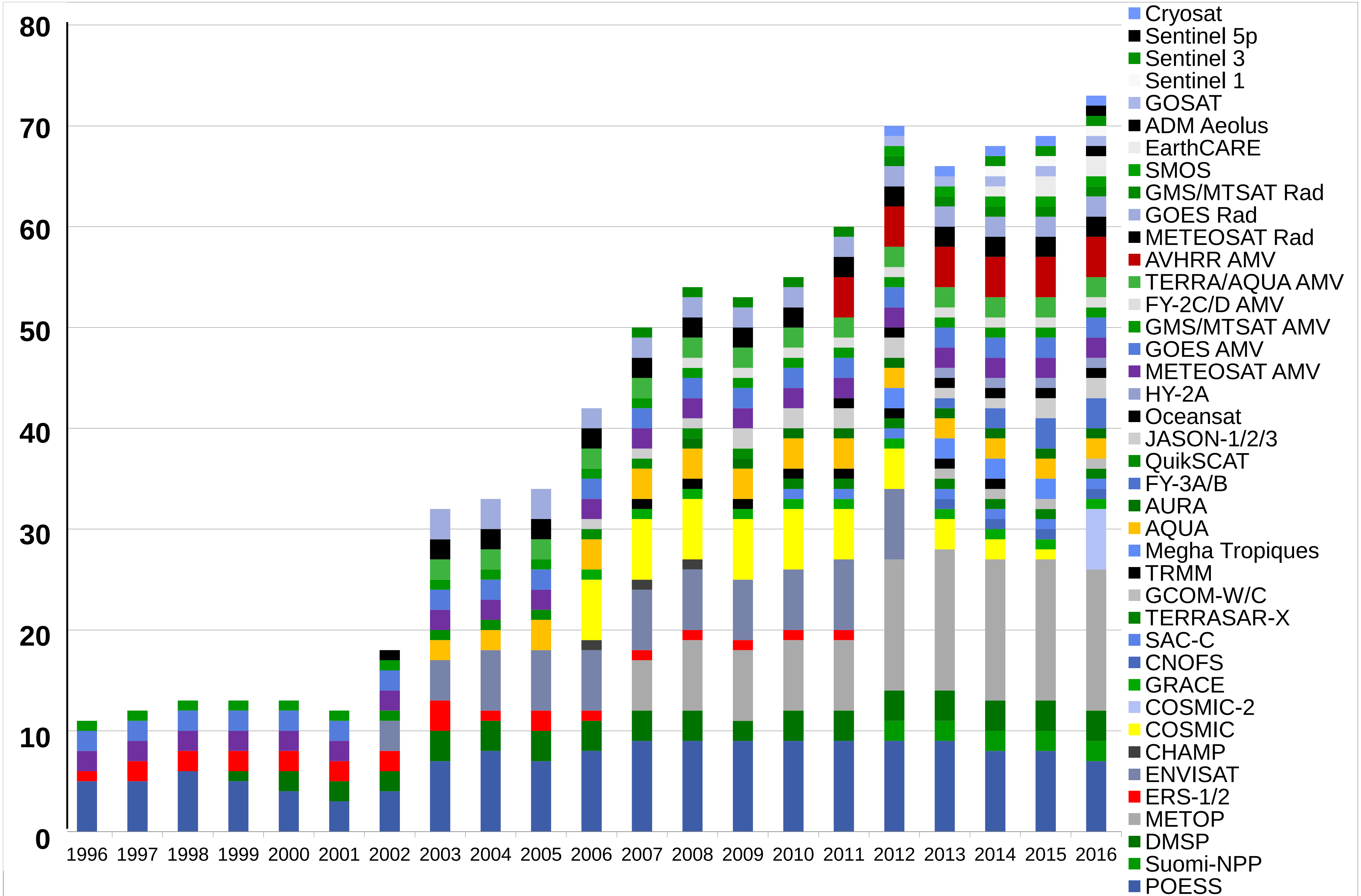
Latest HRES scores: JJA 2012, ACC for Z500 over NH



Latest EPS scores: JJA 2012, CRPSS for Z500 over NH



Number of satellite instruments

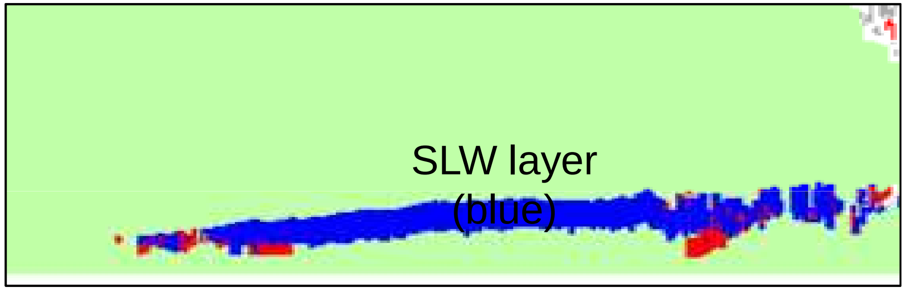


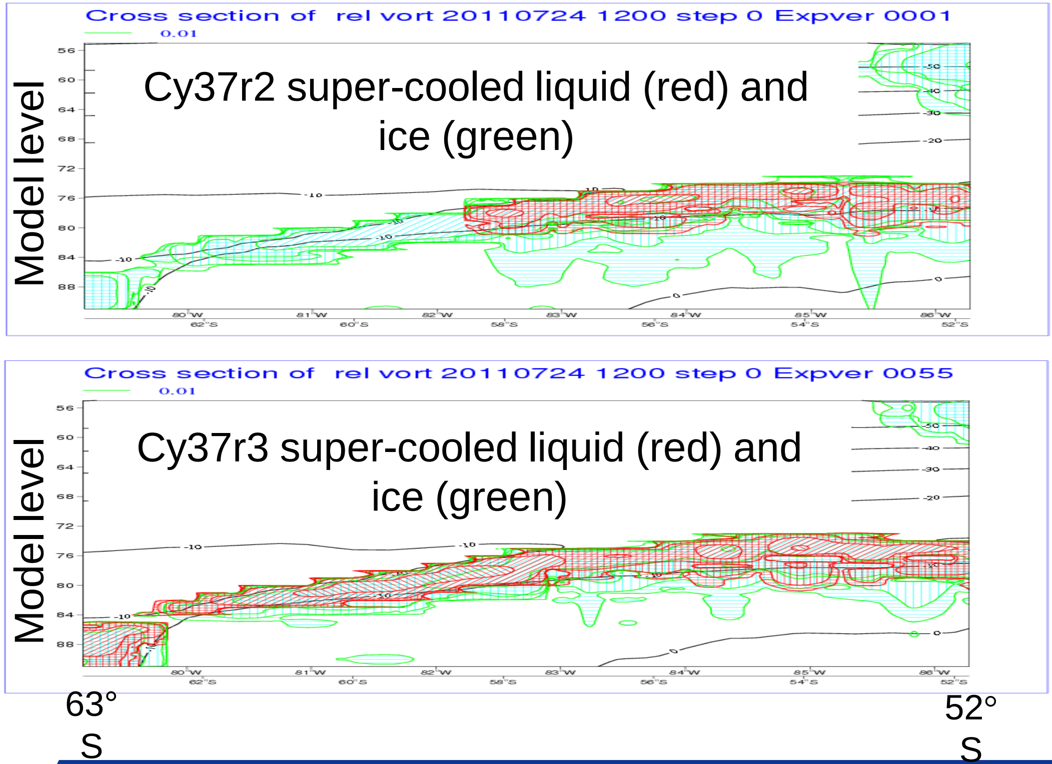
System updates

About 2 updates per year revising data usage, model, data assimilation & technical aspects:

- Late 2012 or early 2013 (38R2): 137 level model
- June 2012 (38R1): New Jb, EDA-filtering, clouds/convection, wave model
- April 2012: European Floods Awareness System (EFAS) computational centre
- November 2011 (37R3): Rev. cloud scheme, aircraft b/c, NEXRAD assimilation
- November 2011: Seasonal System-4 (higher resolution, updated model cycle, more members, NEMO ocean model 15 members for 30 year hindcasts)
- June 2011 (37R2): AMSU-A obs. error, EDA variances in 4D-Var
- November 2010 (36R4): New cloud scheme, SEKF soil moisture analysis
- June 2010 (36R2): Initial perturbations for EPS from EDA
- January 2010 (36R1): T1279 L91, EPS T639 L62

Cy37r3 (Nov '11): revised cloud scheme (SLW)

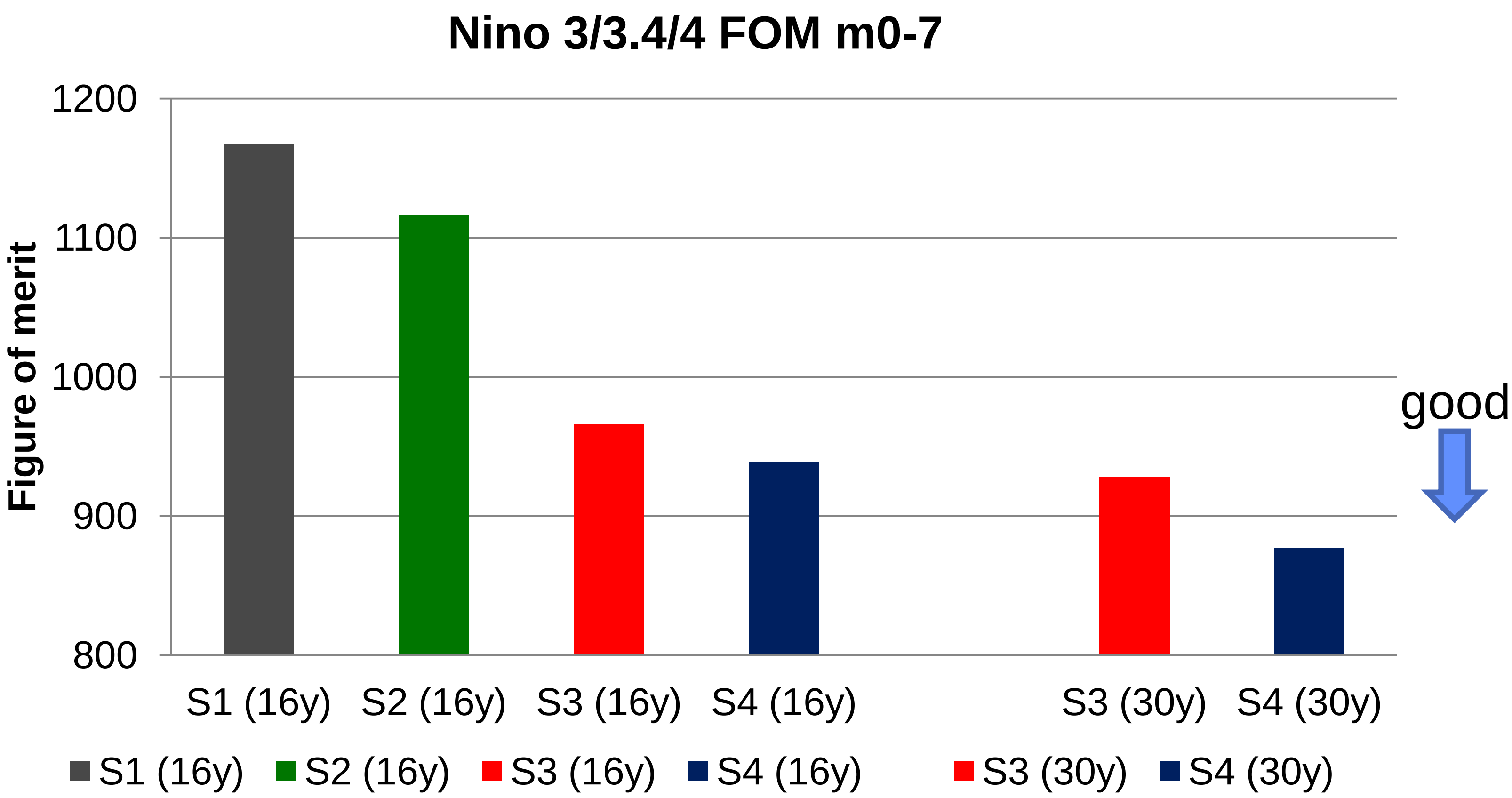




- Super-cooled liquid water (SLW) cloud frequently occurs in atmosphere down to -30℃ and below (as seen in aircraft obs, lidar etc.)
- Fine balance between turbulent production of water droplets, nucleation of ice, deposition growth and fallout.
- New cloud scheme represents microphysical processes in mixed-phase cloud rather than a diagnostic.
- Cy36r4/Cy37r2 had less SLW, Cy37r3 increases SLW, particularly at cloud top (as often observed).

S4 (Nov ’11): progress in seasonal prediction (S1 to S4)

Progress from S1 (1997-2002), S2 (2002-2007), S3 (2007-2011) to S4 (Nov 2011): sustained improvements in ENSO forecast skill is evident from the Figure Of Merit (FMO, mean absolute error of SST M0-7 fcs over Nino 3, Nino 3.4 and Nino 4 area).



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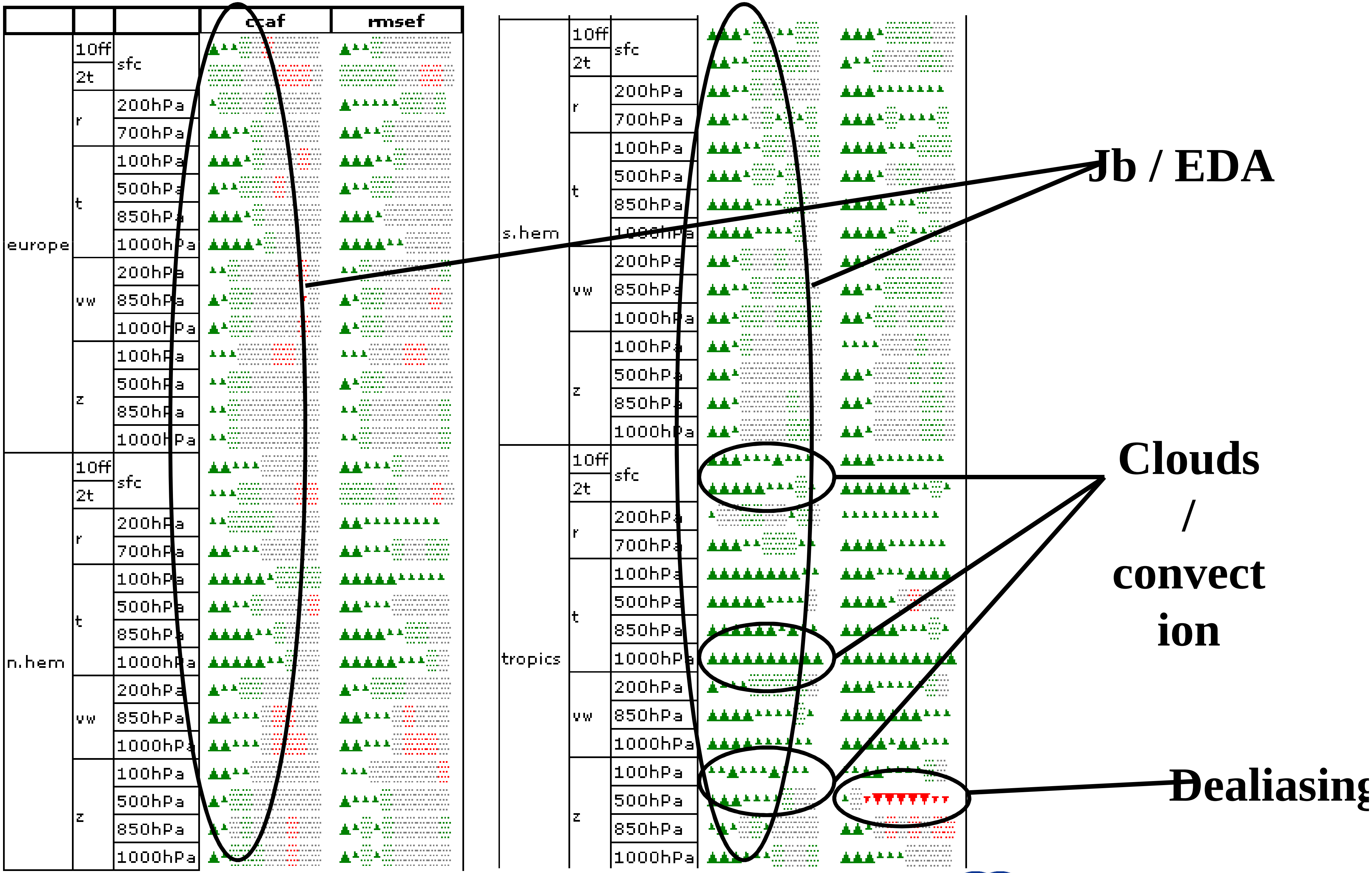
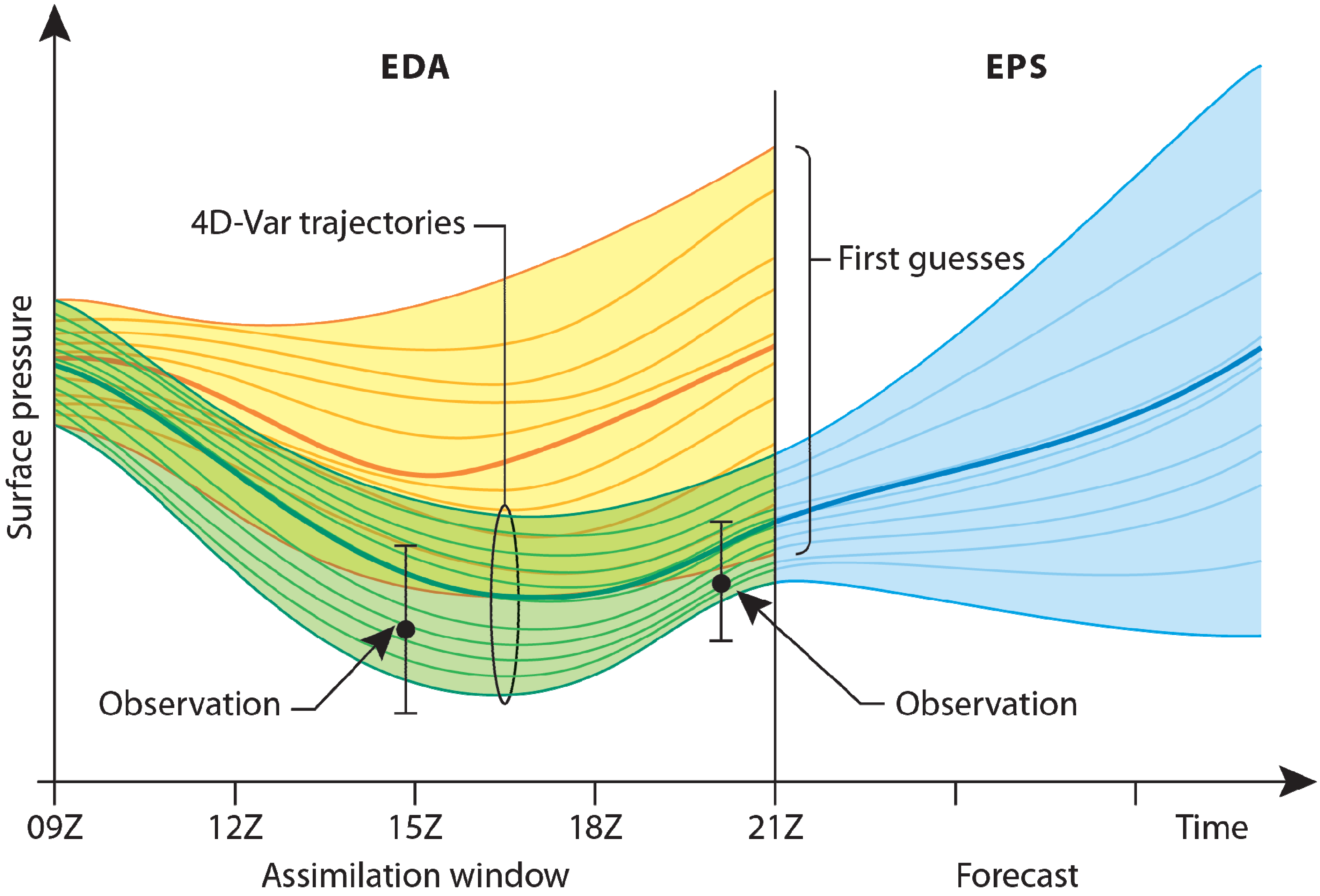
Cycle 38R1: High-resolution scores

2011/09/02-2011/12/21, verified with own analysis



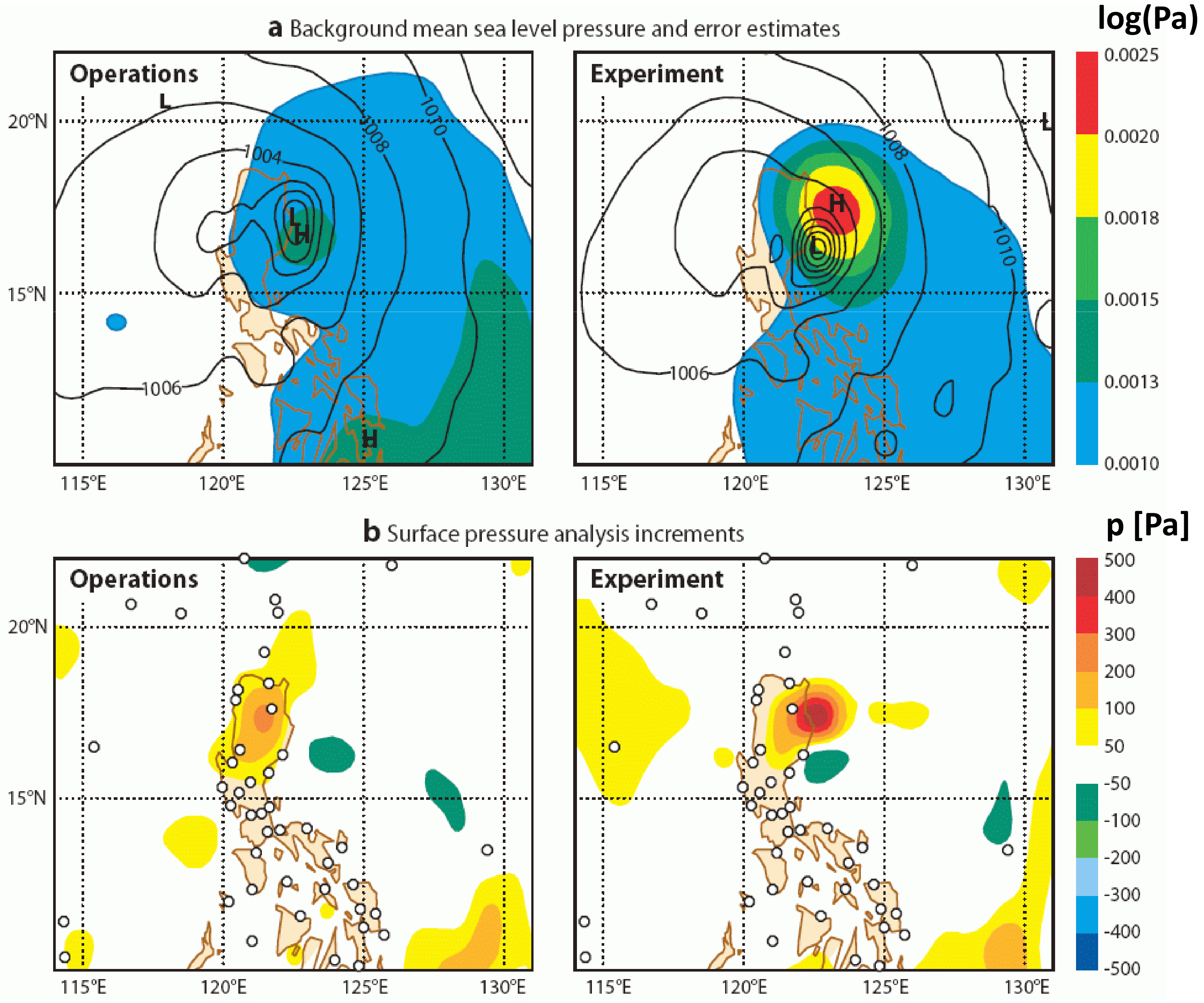
Ensemble assimilation and prediction



Ensemble of data assimilation

Impact in analysis

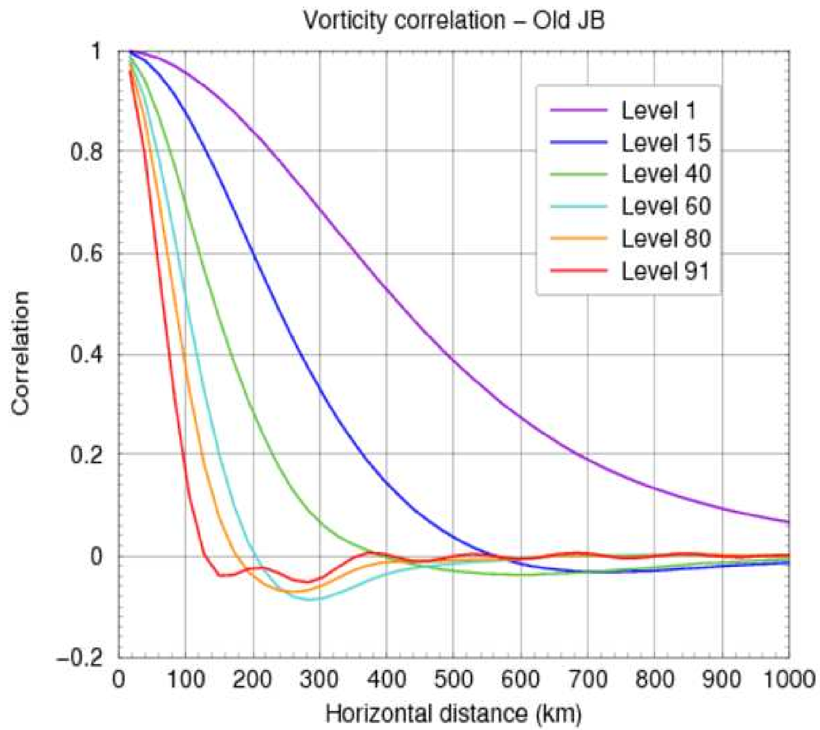
9 May 2011 00 UTC analysis, TC Aere

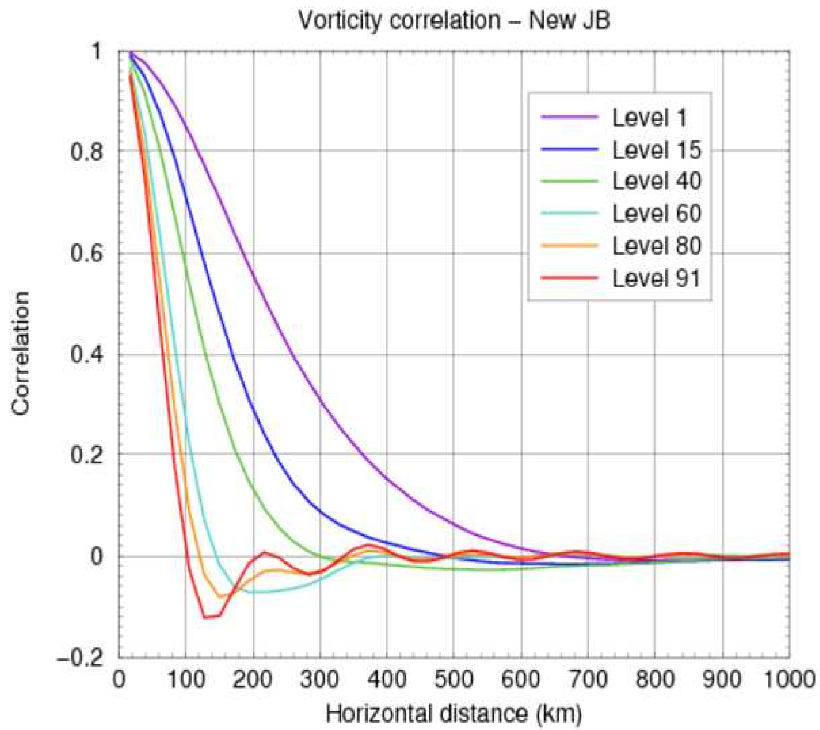


(L. Isaksen et al.)

Cy38r1 (Jun ‘12): new Jb statistics

The climatological structure of the background errors, B, has been using 38r1 EDA. The new error correlations are noticeably sharper than the old ones. This means that the analysis now will be able to make better use of high resolution observations like, e.g. radiosonde data, surface pressure data and aircraft measurements.

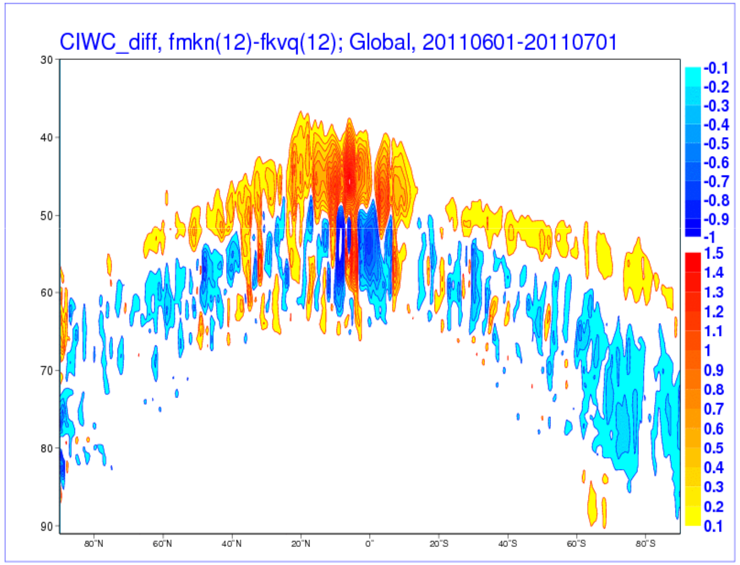




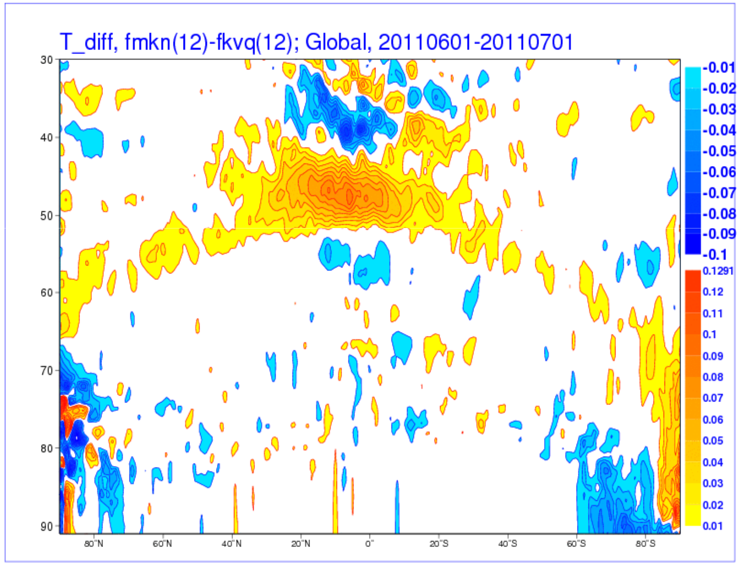
Cy38r1 (Jun '12): revision of cloud properties

Diagnostic studies indicated that in cy37r3 there was too little ice cloud (cirrus) at cold temps/high altitudes. Revised ice-fall properties in cy38r1 led to a warmer upper troposphere and improvements at 100-200 hPa.

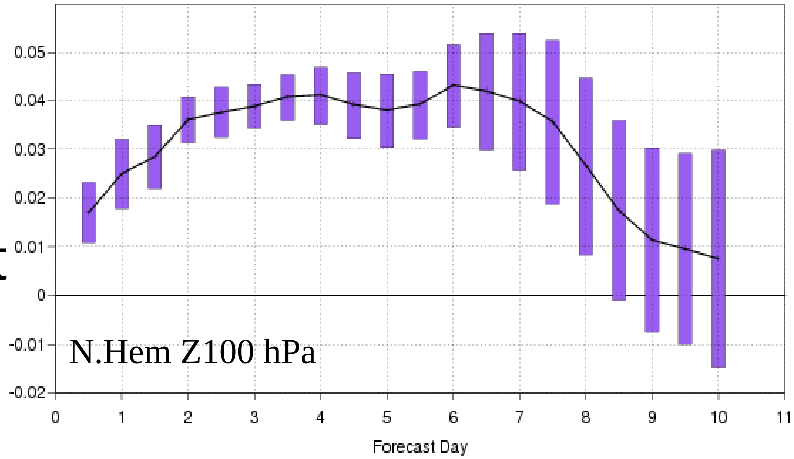
Change in IWC

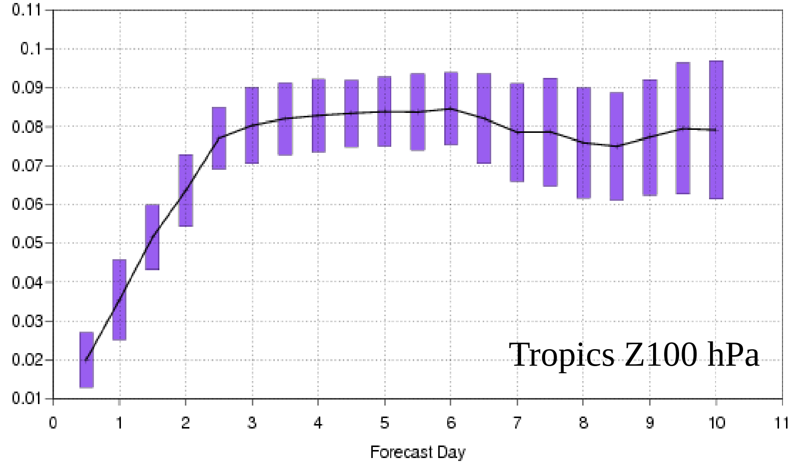


Change in T



Impact on mean (June 2011) T+12 ice water content and temperature (T511)



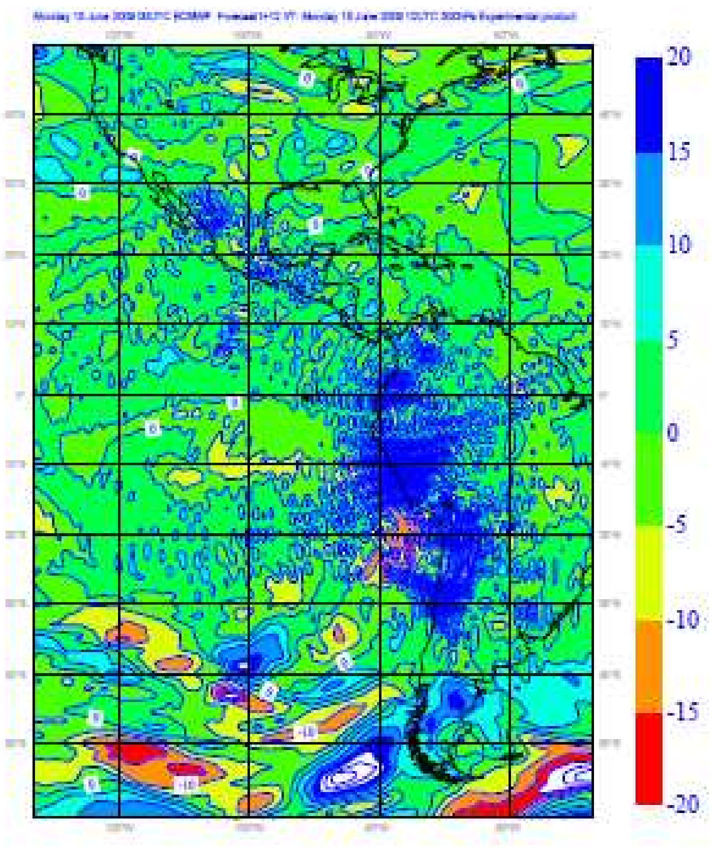


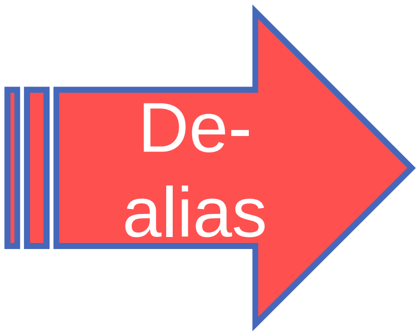
Relative rmse change for T511 analysis for June 2011

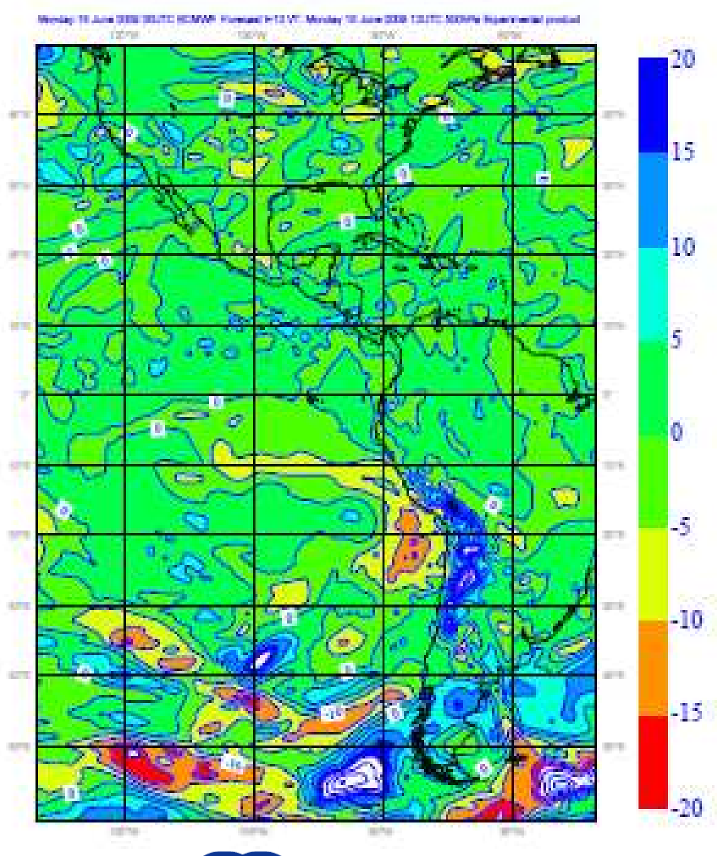
De-aliasing and noise reduction

A new de-aliasing procedure leads to reduced numerical noise.

500hPa adiabatic - zonal wind tendencies (T159)

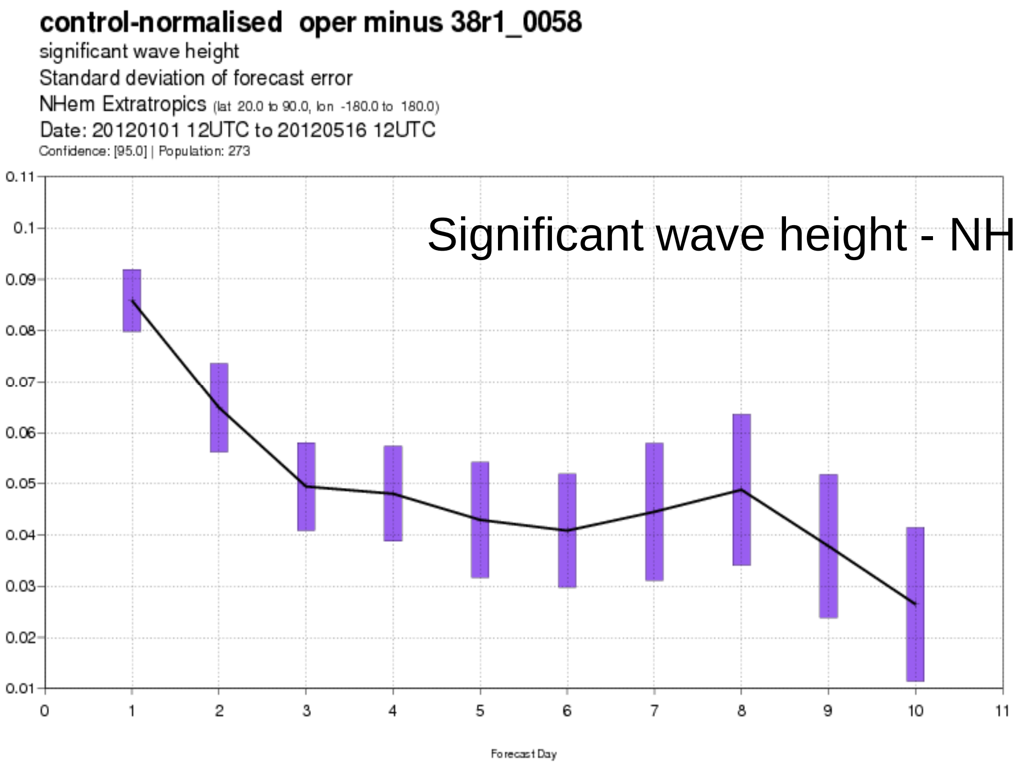


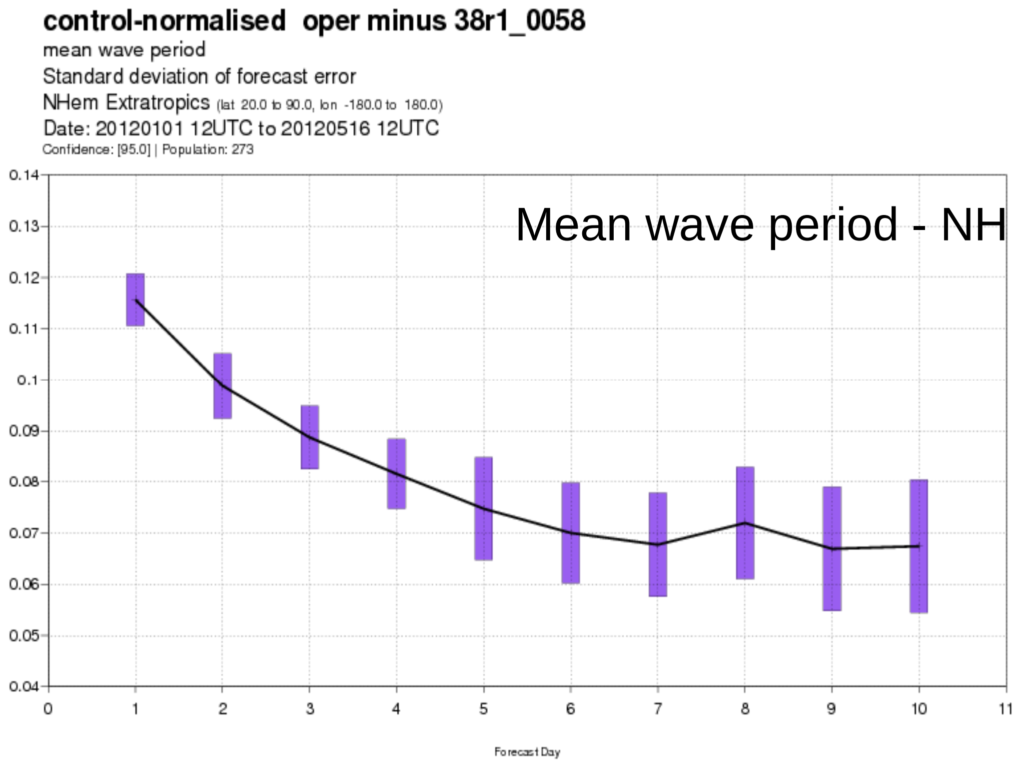




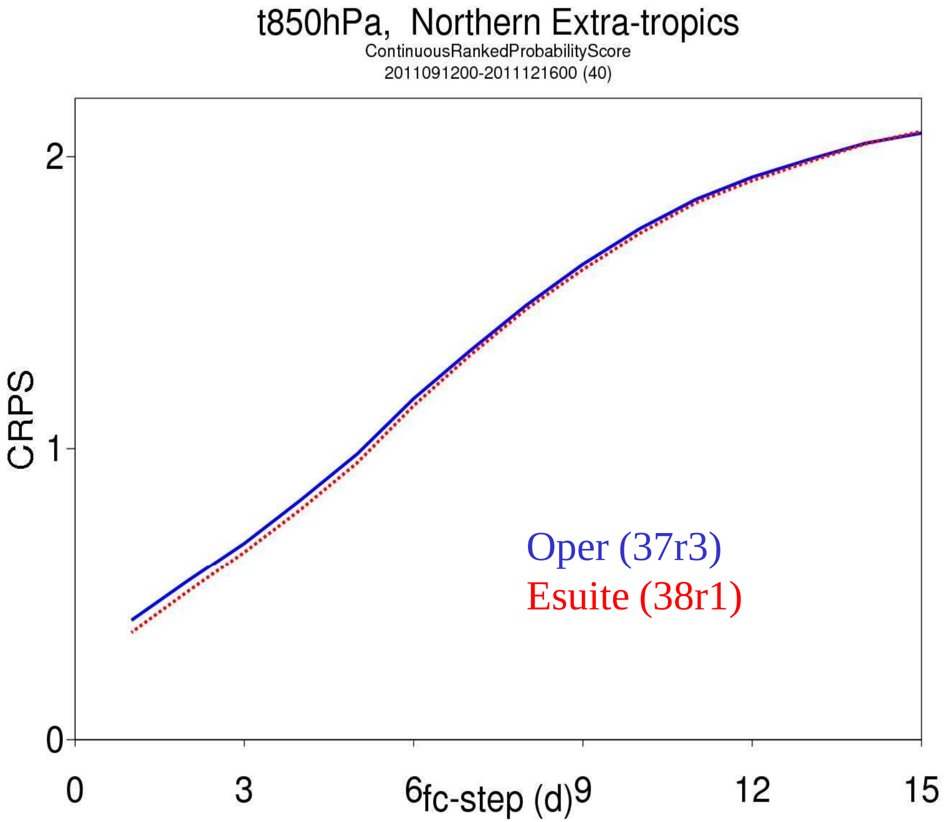
Cy38r1 (Jun ‘12): revision of wave source function

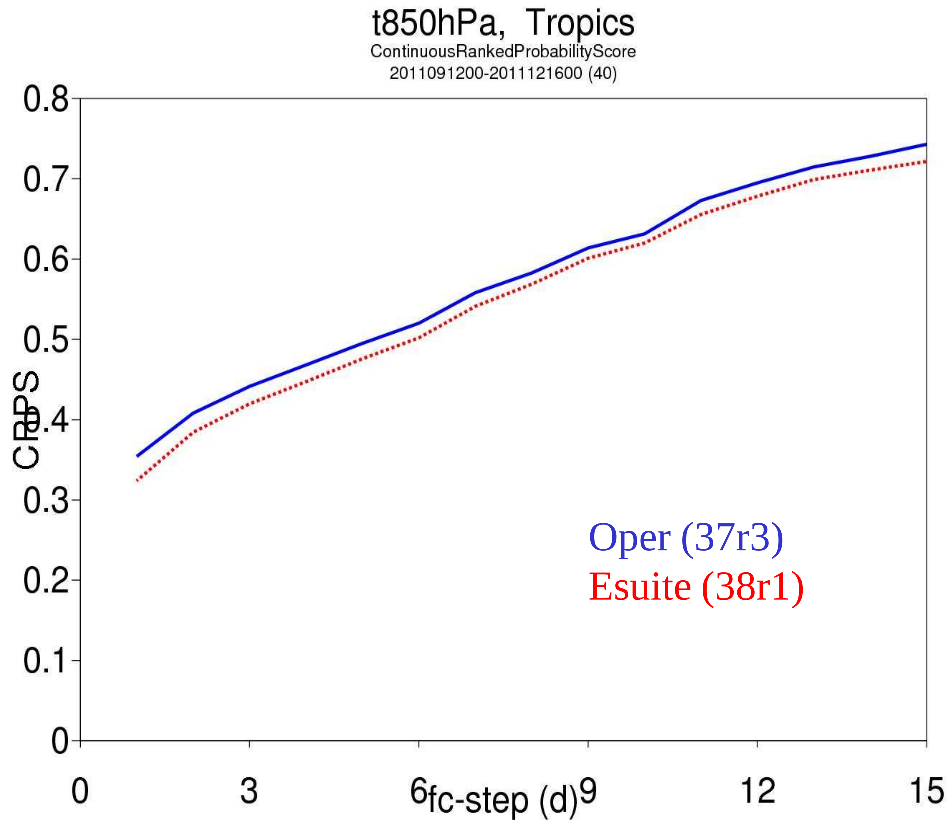
A revised formulation for wind input source term that limits the amount of energy that is transferred to low frequency combined with an adjustment to the dissipation source term led to large improvements.



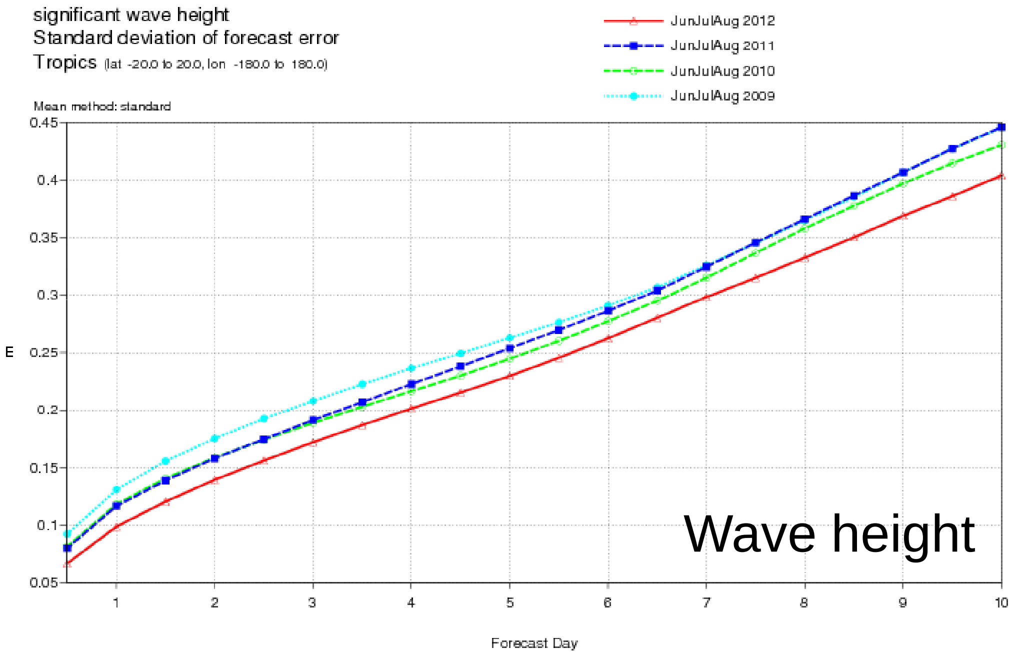


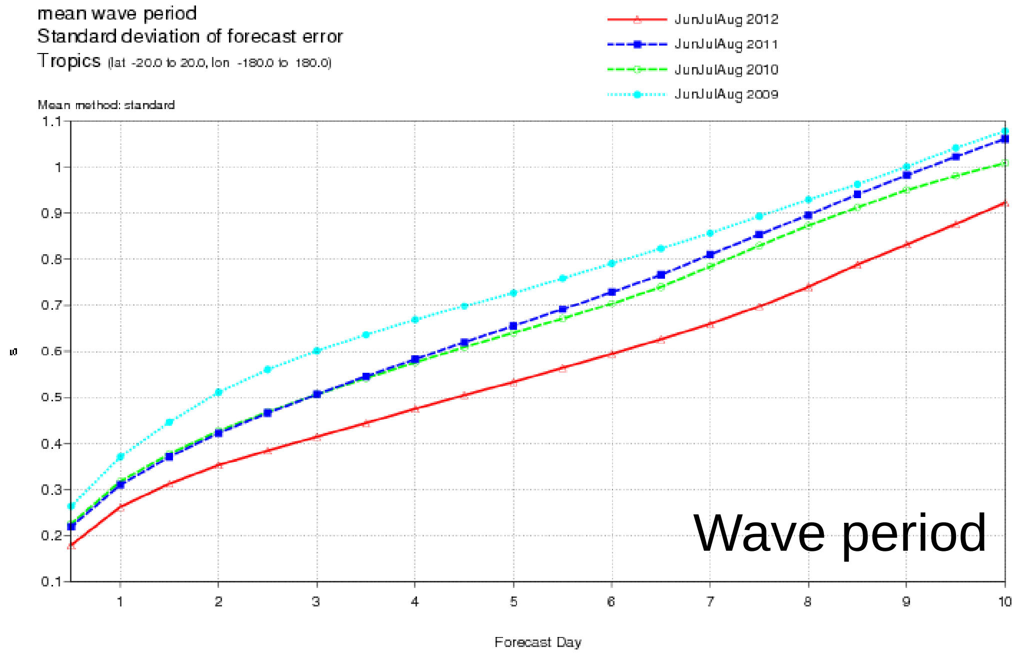
Cy38r1 (Jun '12): Impact of changes on EPS skill

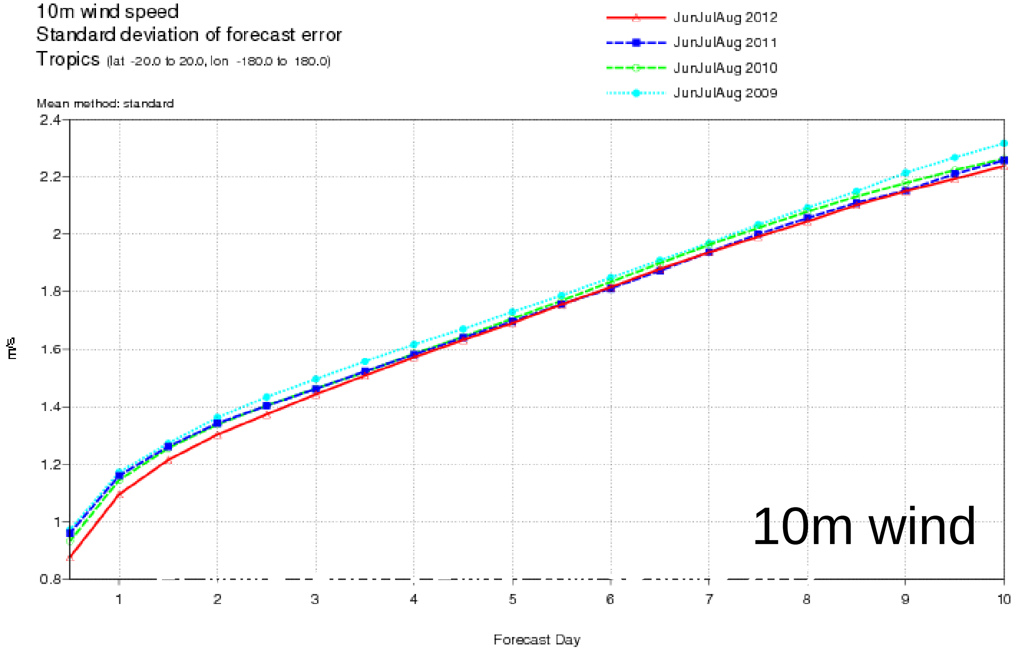




Cy38r1 (Jun '12): Impact of changes on waves







ECMWF

Current projects

Model Division:

- Resolution upgrades (2012: L137, 2015: T2047, etc.)
- Non-hydrostatic model core
- Physical parameterizations: Radiation, clouds, convection, land surface, boundary layer, gravity wave drag; linearized models

Data Division:

- Long-window 4D-Var (model error), EDA, EnKF
- New instruments (NPP, MSG-3, Metop-B, GCOM-W1, etc.), sampling, errors
- Reanalysis: ERA-Clim (coupling)

Predictability Division:

- Resolution upgrades (2013: L92, 2016: T1023, etc.)
- Link EDA-EPS, stochastic physics
- Ocean/sea-ice model, coupling

Atmospheric Composition Division:

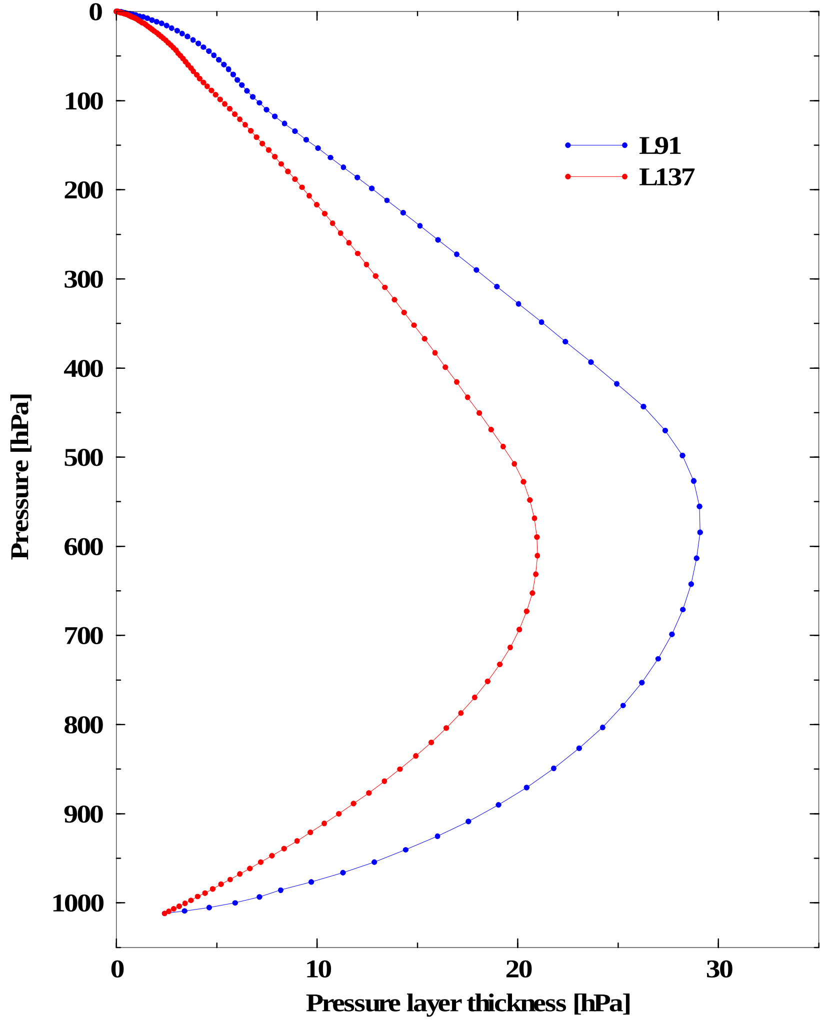
- MACC-II → GMES Atmospheric Service

Technical:

- Scalability (data assimilation, model)
- COPE , OOPS, OpenIFS

L137 (CY38R2)

- Vertical level upgrade for high-resolution forecast model and data assimilation + … plus many technical contributions and modifications preparing future upgrades



Thanks to Agathe Untch

Cycle 38R2: Status

- Contributions:
  - **137 Levels**
  - + Some technical and minor scientific changes

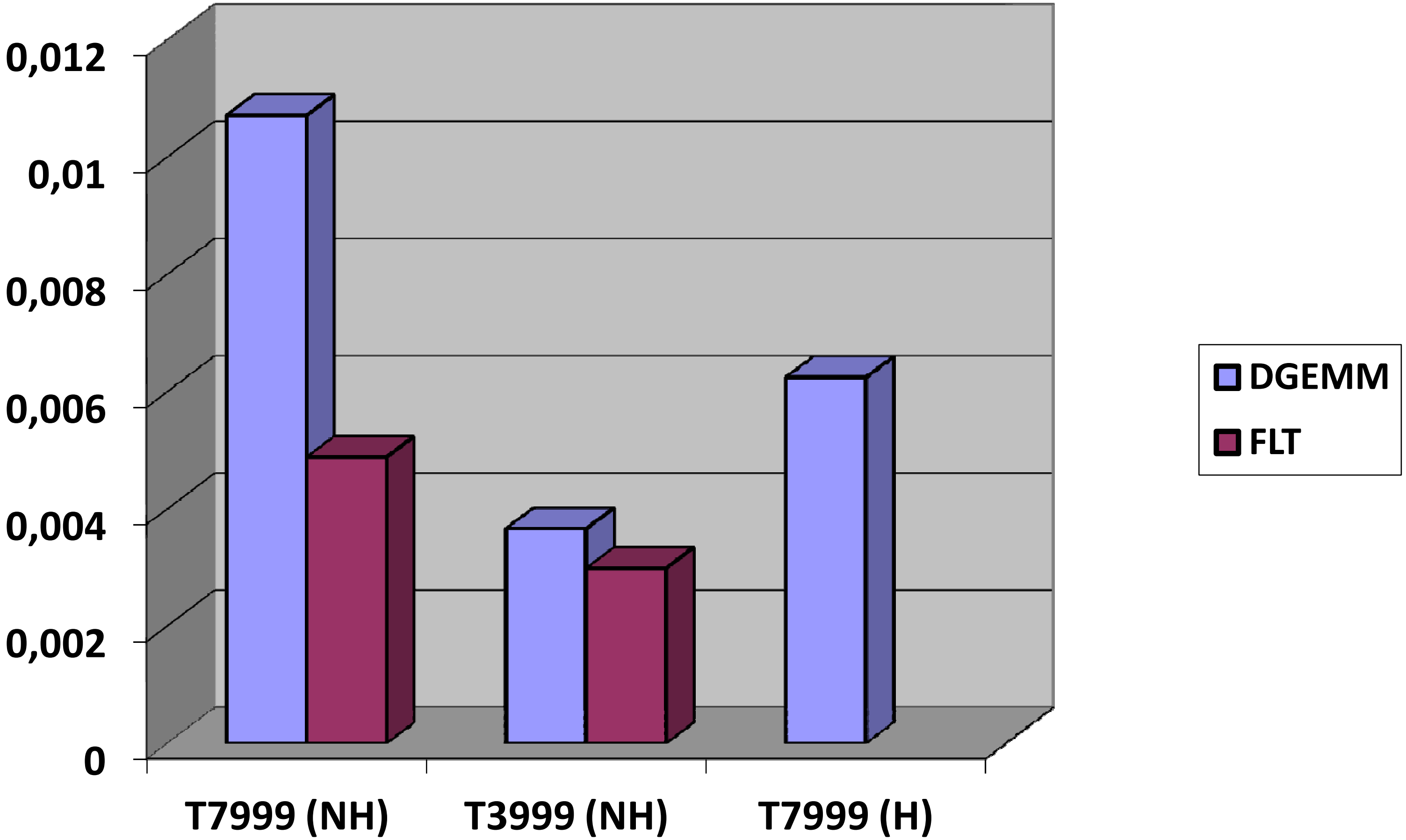
- Model climate simulations:
  - Better T-biases, better QBO, Net TOA SW mixed, less surface stress
  - Scores off L91 analyses less good

- Preparation of background error covariances:
  - 2 x 1.5 months 10xT399L91 EDAs to produce first iteration of **B**

- Timeline:
  - 38R2 RD-testing is well underway but there are issues yet to be fully resolved
  - Implementation date therefore uncertain, late 2012 or early 2013 likely

Fast Legendre transform for high-resol computing

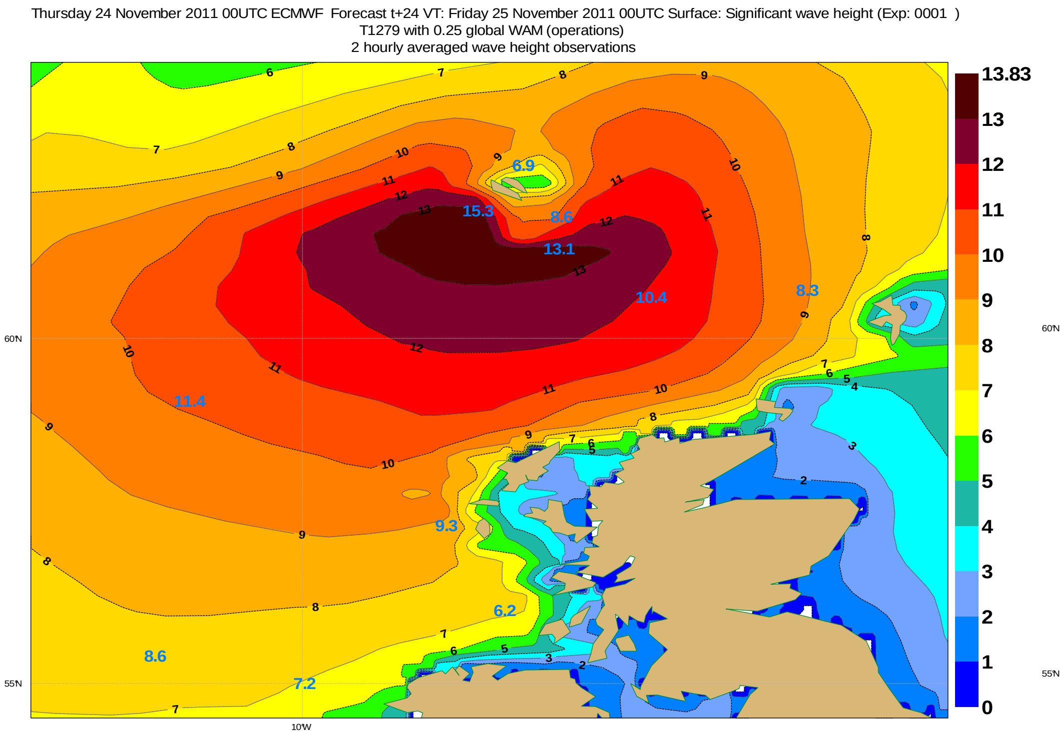
The use of the ‘butterfly’ algorithm has shown to remove the disproportionally growing cost of the Legendre transforms with increasing resolution.

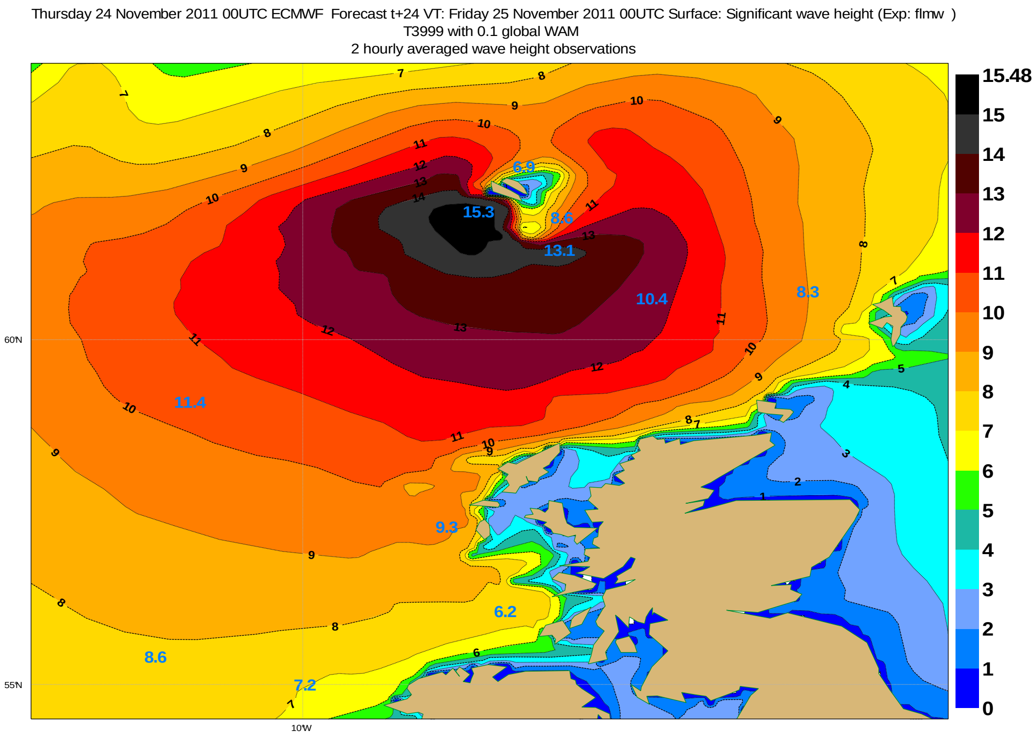


Going higher resolution: T_L3999 (5 km) wave fc (+24h)

24-hour forecast for significant wave height (colour shadings in metres) for 00 UTC on 25 November 2011:

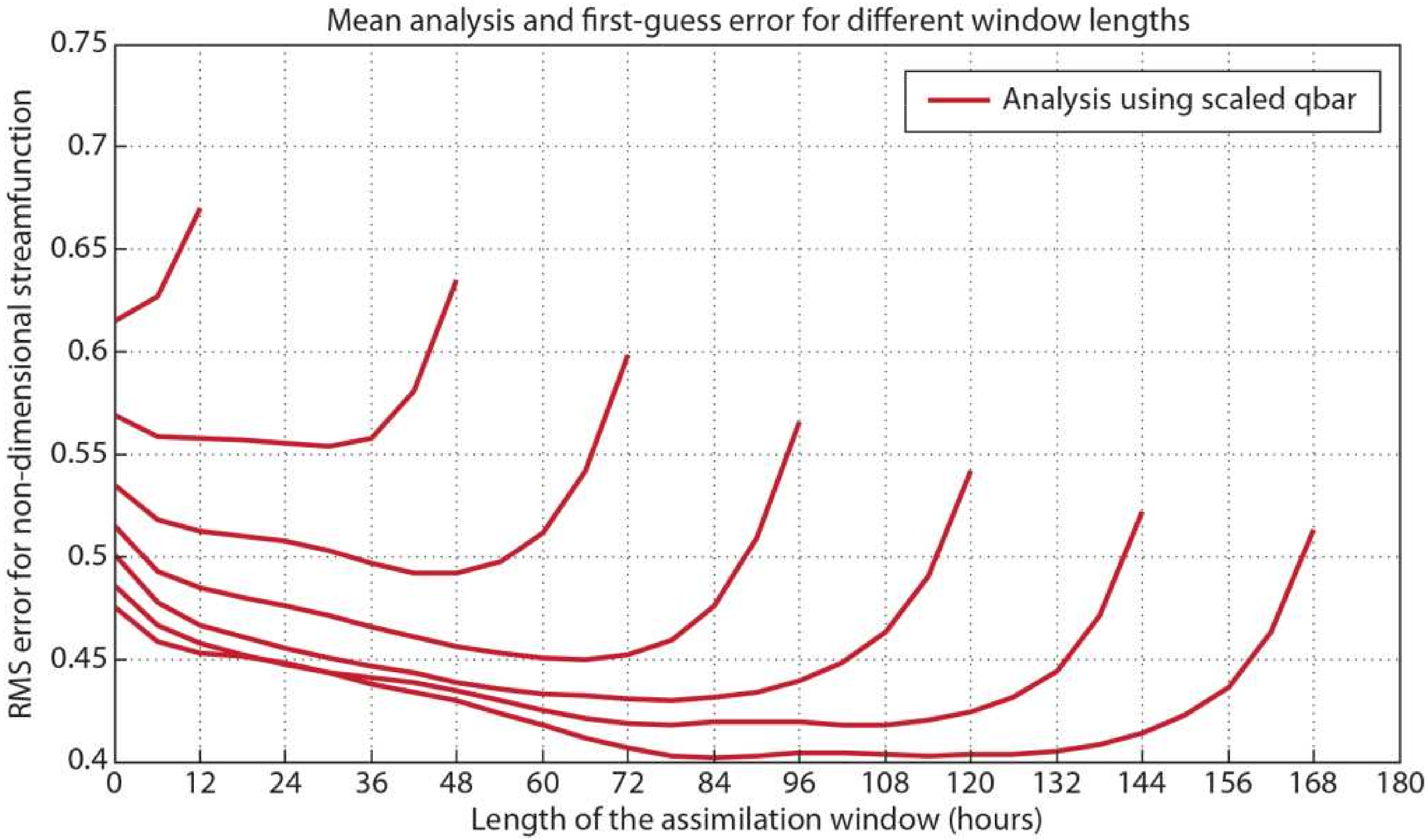
- T1279 model coupled to a 0.25° global wave model (ope rational configuration, left)
- T3999 model coupled to a 0.1° global wave model.





Long-window, weak-constraint 4D-Var

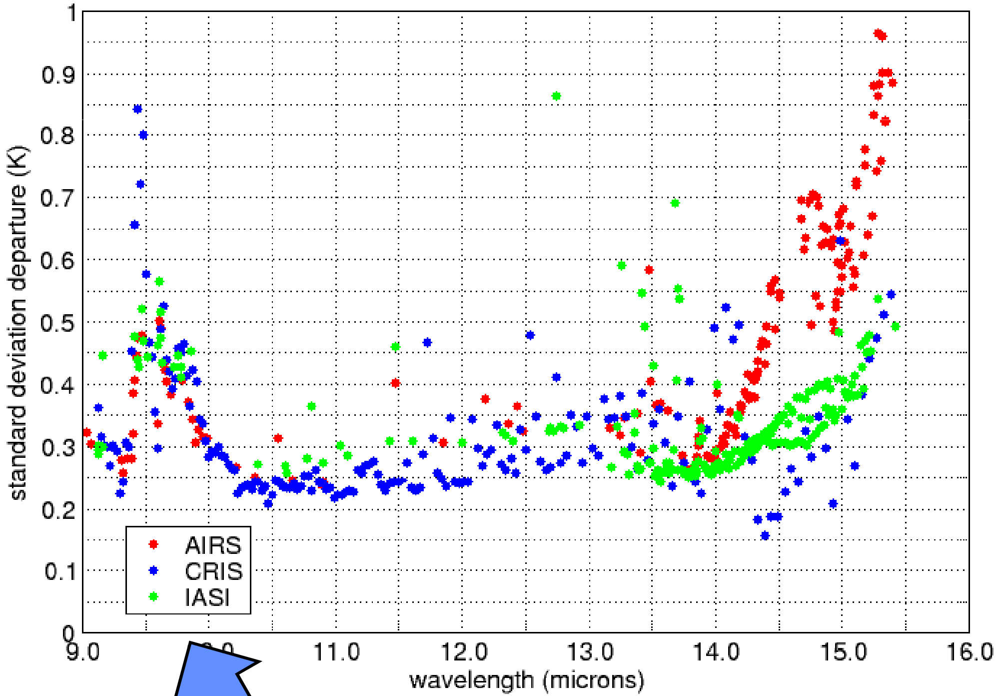
Results based on a two-layer quasi-geostrophic model indicate that increasing the length of the analysis window is beneficial, even with a simple model error representation.

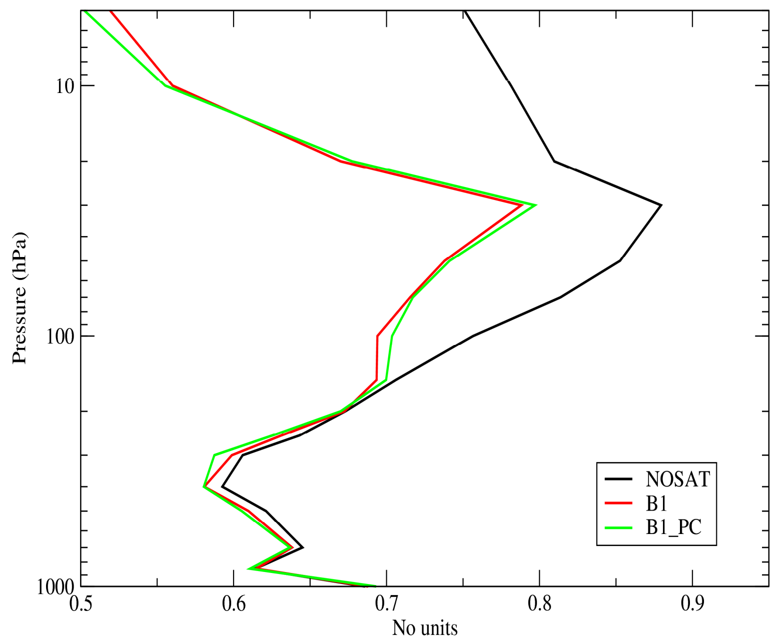


(M. Fisher)

Recent results from Satellite Section

1. Hyperspectral IR (McNally/Matricardi/Eresmaa)





• New sensors: CrIS, Metop-B suite
• Principal component RT and assimilation
• Improved cloud screening
• Use of shortwave and ozone channels

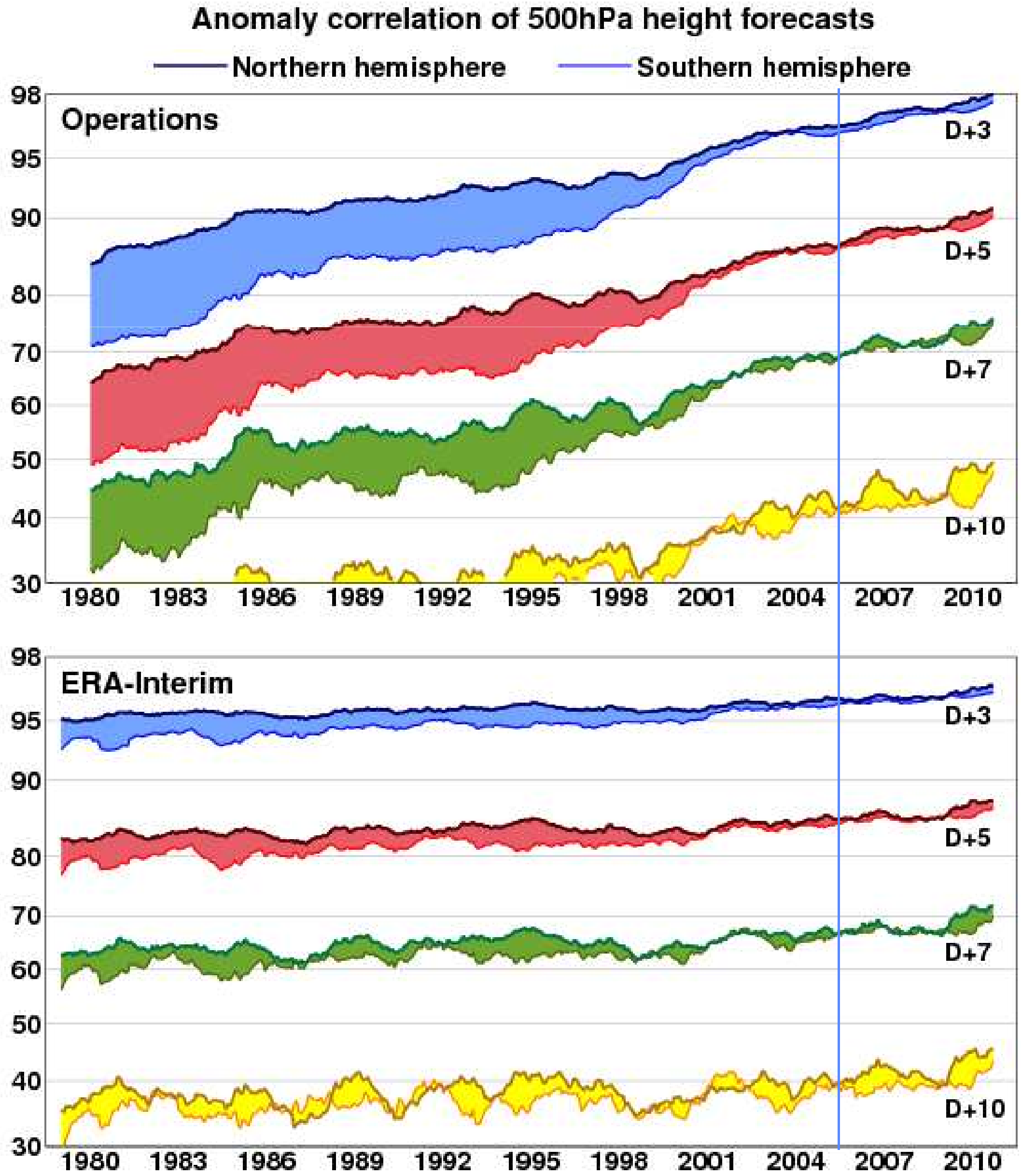
ERA-Interim extension: 1979-2012

Reanalysis makes use of data assimilation systems designed for weather forecasting

Reanalysis uses a single model and data assimilation method for a consistent re-analysis with past observations

Consistency in time is the key challenge for climate reanalysis

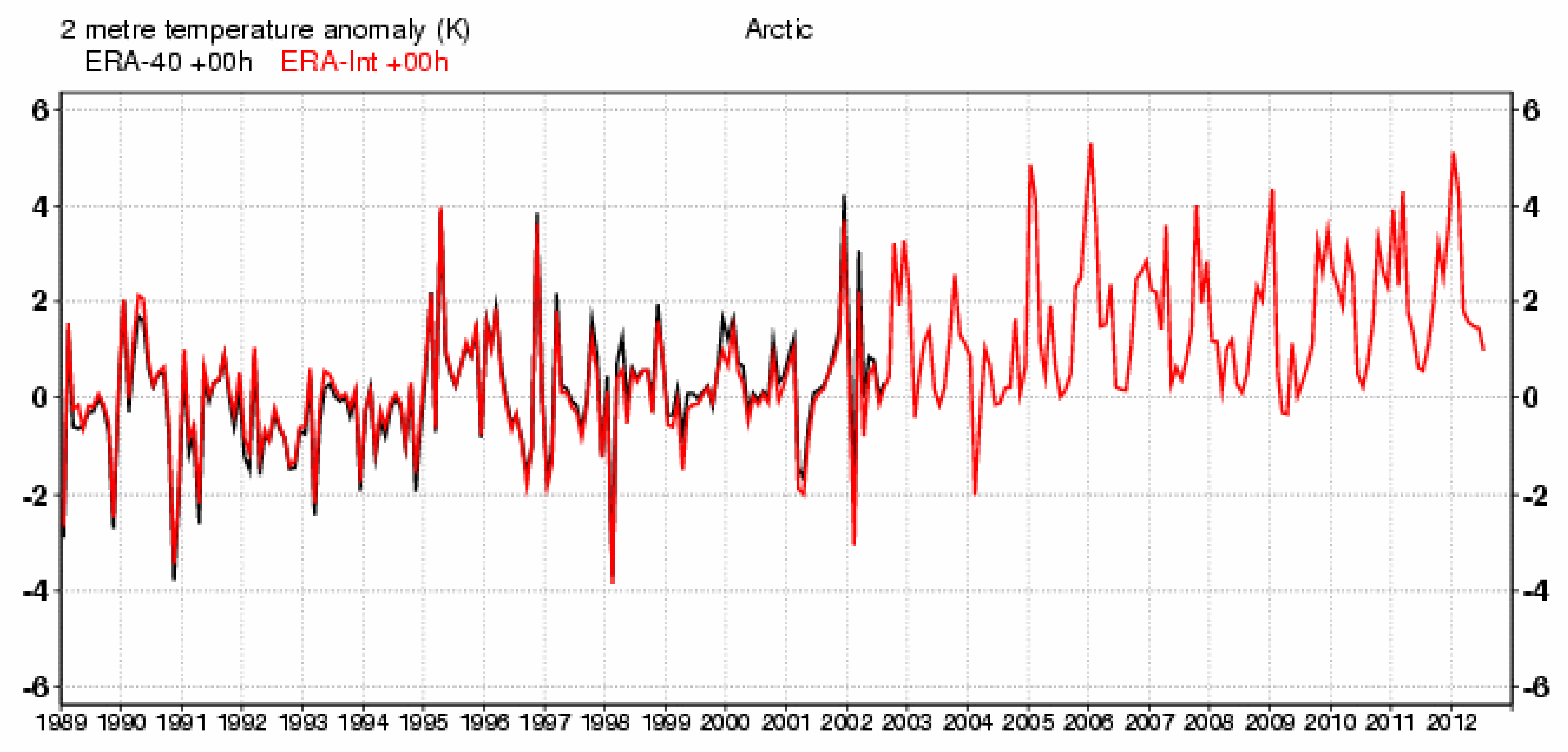
Difficulties arise from biases in models and observations



ECMWF

Reanalysis – climate monitoring

Arctic temperature anomaly



ERA-Clim

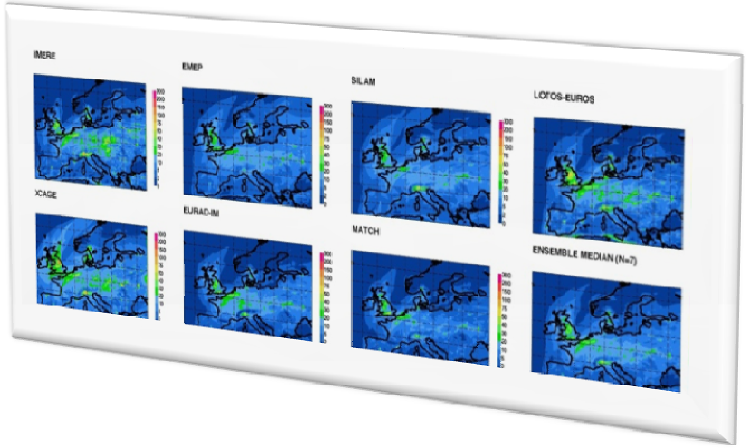
3-year collaborative research project coordinated by ECMWF, supported by the EC's FP7: Prepare input observations, model data, and data assimilation systems for a global (coupled) atmospheric reanalysis of the 20th century – to begin production in 2014 (**ERA-Clim-II project**)

ERA-20CM	Ensemble of model integrations, using HadISST2 and CMIP5 forcing	T159 10 members	done
ERA-20C	Reanalysis of surface pressure observations	T159 10 members	Available end 2013
ERA-20CL	Land-surface only; forced by ERA-20C	T799 10 members	Available end 2013
ERA-SAT	New reanalysis of the satellite era	T511 (?) To replace ERA-Interim	Available end 2014

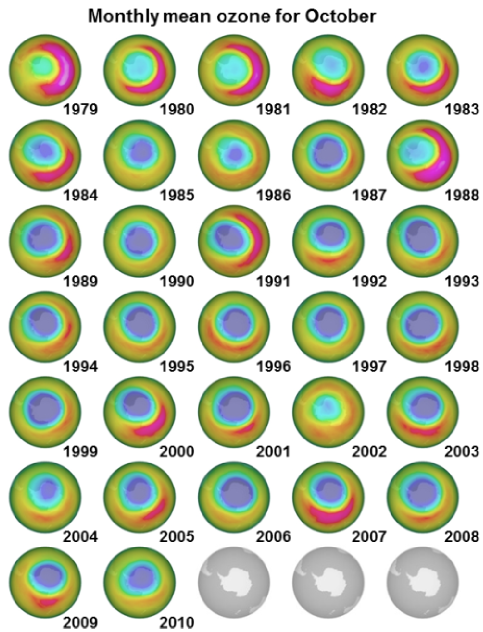
http://www.gmes-atmosphere.eu

Air-quality ensemble forecasts

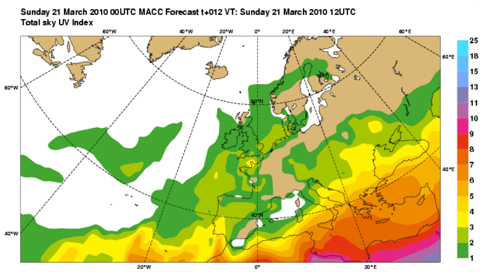
and (re-)analyses



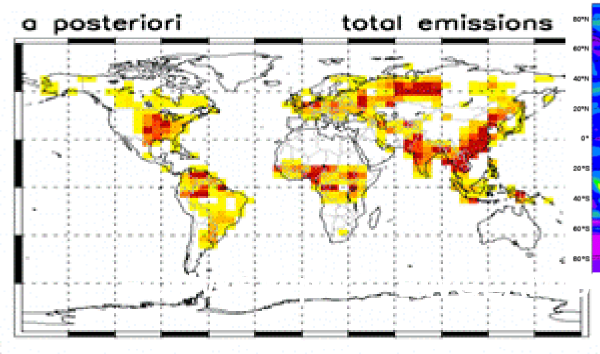
Stratospheric ozone records



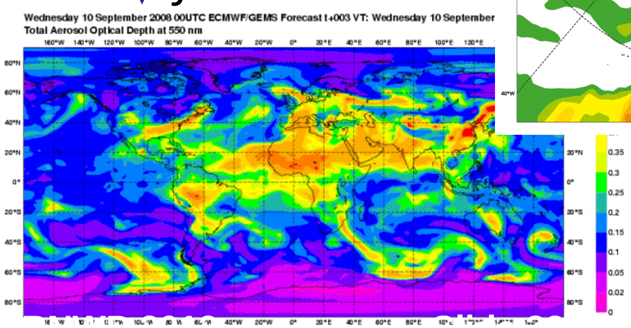
UV index



Monthly methane emissions



Global forecasts



...And many more services.

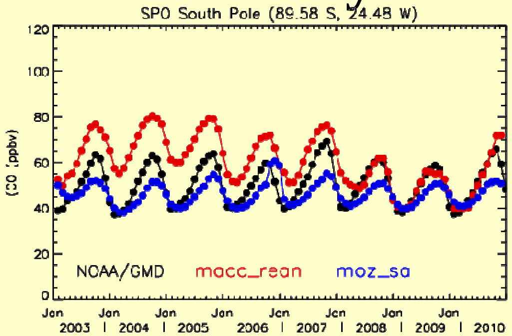
Atmospheric composition and forest fires

Simulated smoke transport from fires over Greece and Algeria.

From global model run at 25km resolution, with smoke flux derived from satellite fire observations.

Use of IASI data in MACC

IASI CO* is assimilated in the NRT MACC analysis and in the MACC reanalysis after April 2008

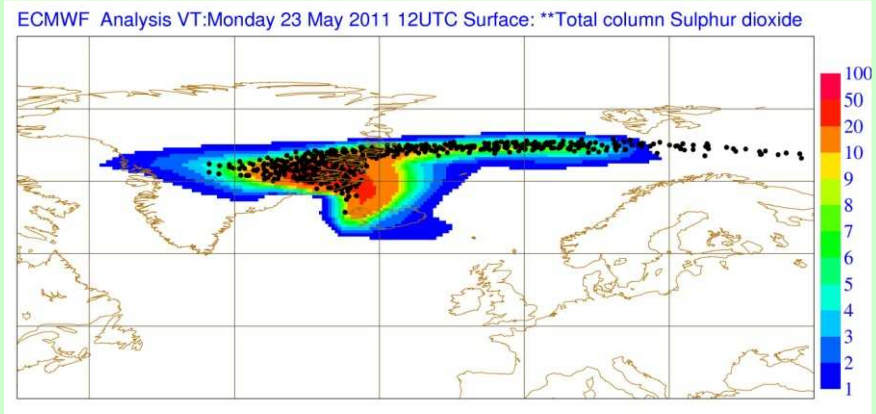


Improved agreement of reanalysis CO with surface CO at South Pole when IASI CO assimilated

Courtesy I. Bouarar

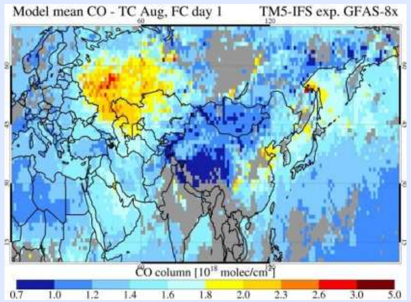
* LATMOS/ULB total column CO product

IASI SO_2 brightness temperature signal is used to validate location of SO_2 plumes from MACC (OMI or GOME-2) SO_2 analysis

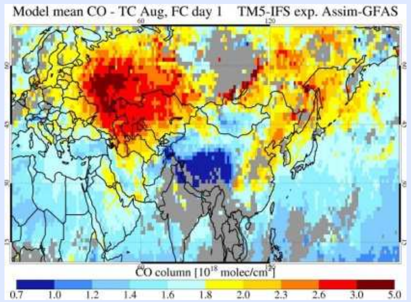


Russian fires Aug 2010: Assimilation of IASI CO* into TM5 improves CO fire signal

TM5-Control (GFASx8)



TM5-ASSIM (IASI)



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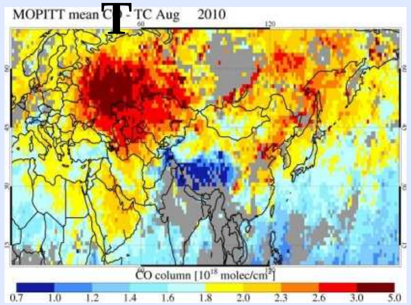
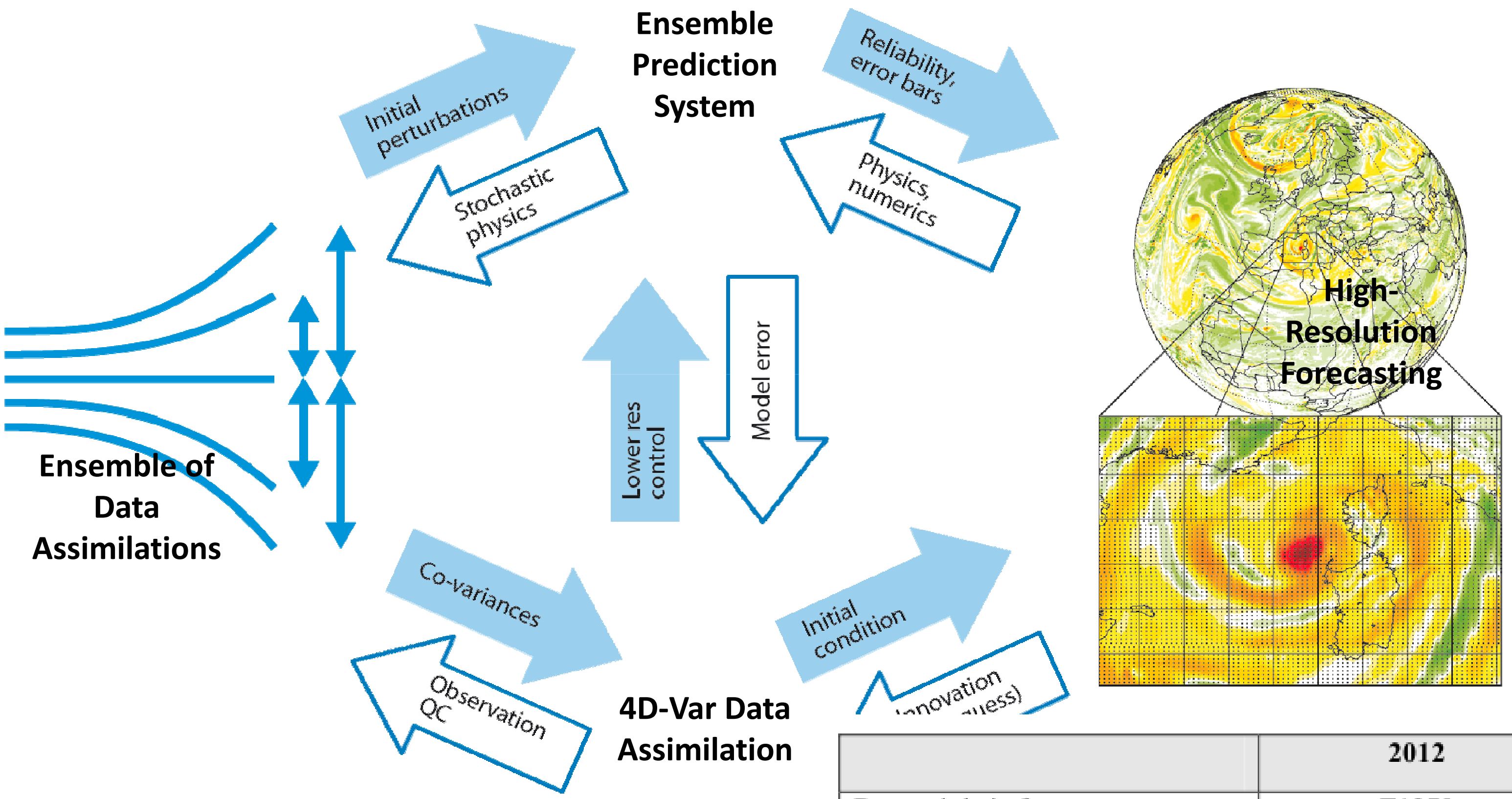


Huijnen et al. (2011)

Longer-term future



A much more integrated system …

… to cope with implications for HPC cost

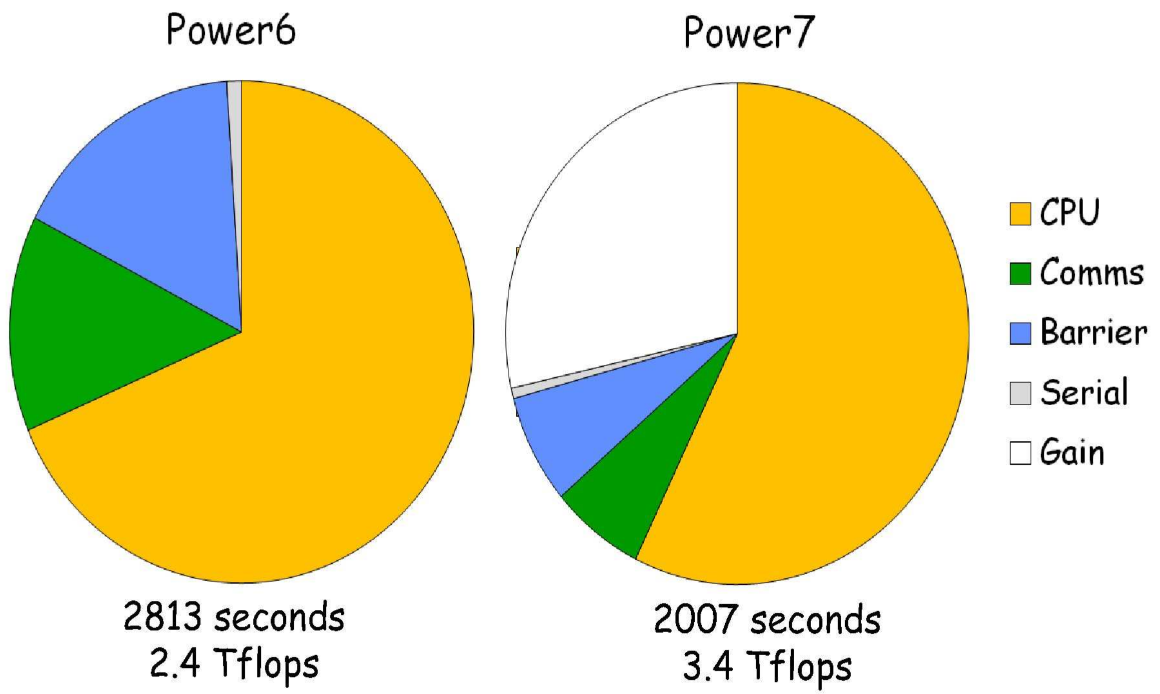
	2012	2015	2017
Deterministic forecast	T1279 L137	T2047 L137	T2047 L137
4D-Var	T159/255/255 L137 12-h window	T159/255/399 L137 24-h window	T159/255/399 L137 48-h window
Ensemble data assimilation	T399 L137 10 members 12-h window	T511 L137 25 members 12-h window	T511 L137 50 members 24-h window
Ensemble prediction system	T639v319 L62 50 members	T1023v511 L92 50 members	T1023v511 L92 50 members

All this cannot happen without a solid infrastructure

I: Getting ready for HPC upgrade to p7

Performance comparison of IFS CY38R1 T1279L91 10 day forecast on IBM Power 6 versus IBM Power 7. Both systems used 48 nodes (384 MPI tasks and 8 OpenMP threads).

The full pie corresponds to the 2813 seconds wall-clock time used to perform the forecast on p6.



II: Continuous Observation Processing Environment (COPE)

- Hub ODB serving as an interface to all our observation processing (screening, monitoring, analysis, diagnostics) and “continuously” fed by arriving observations
- Shortens the time critical path by performing observation pre-processing and screening quasi-continuously as data arrive
- Improve scalability by removing the screening and monitoring of passive data from the time critical path
- Reduce risk of potential failures in the operational analysis during the time critical path and allow for early response when observation problems occur
- Enables near real-time quality control and monitoring of observations
- More modular and simplified quality control, bias correction and screening

Partnership with Meteo-France and interest expressed by large community

III: Object-Oriented Prediction System – The OOPS project

- **Data Assimilation algorithms manipulate a limited number of entities (objects):**
  - **x (State), y (Observation),**
  - **H (Observation operator), M (Model), H*& M*(Adjoints),**
  - **B & R (Covariance matrices), etc.**
  - **To enable development of new data assimilation algorithms in IFS, these objects should be easily available & re-usable**
- **More Scalable Data Assimilation**
- **Cleaner, more Modular IFS**

Partnership with Meteo-France, Aladin and Hirlam

Final announcement:
ECMWF support for LAMEPS research

The ECMWF Research Dept. offers to run two ensemble configurations with model level output for some past cases:

Experiment	Horizontal resolution	
H	T_L1279	16 km
R	T_L639	32 km

Common settings for both experiments:

- **20+1 members, 62 levels, forecast range 168h**
- **3-hourly output, regional archiving of model level data**
- **Initial perturbations (SV & EDA), model perturbations (SPPT, SKEB) as in operational EPS**
- **Cycle 38r1 (currently operational)**

Start dates (≤56 cases, i.e. 4 weeks 00 and 12 UTC) to be agreed by the SRNWP expert team for Predictability and EPS

Thank You