ECMWF Forecasting System Research and Development

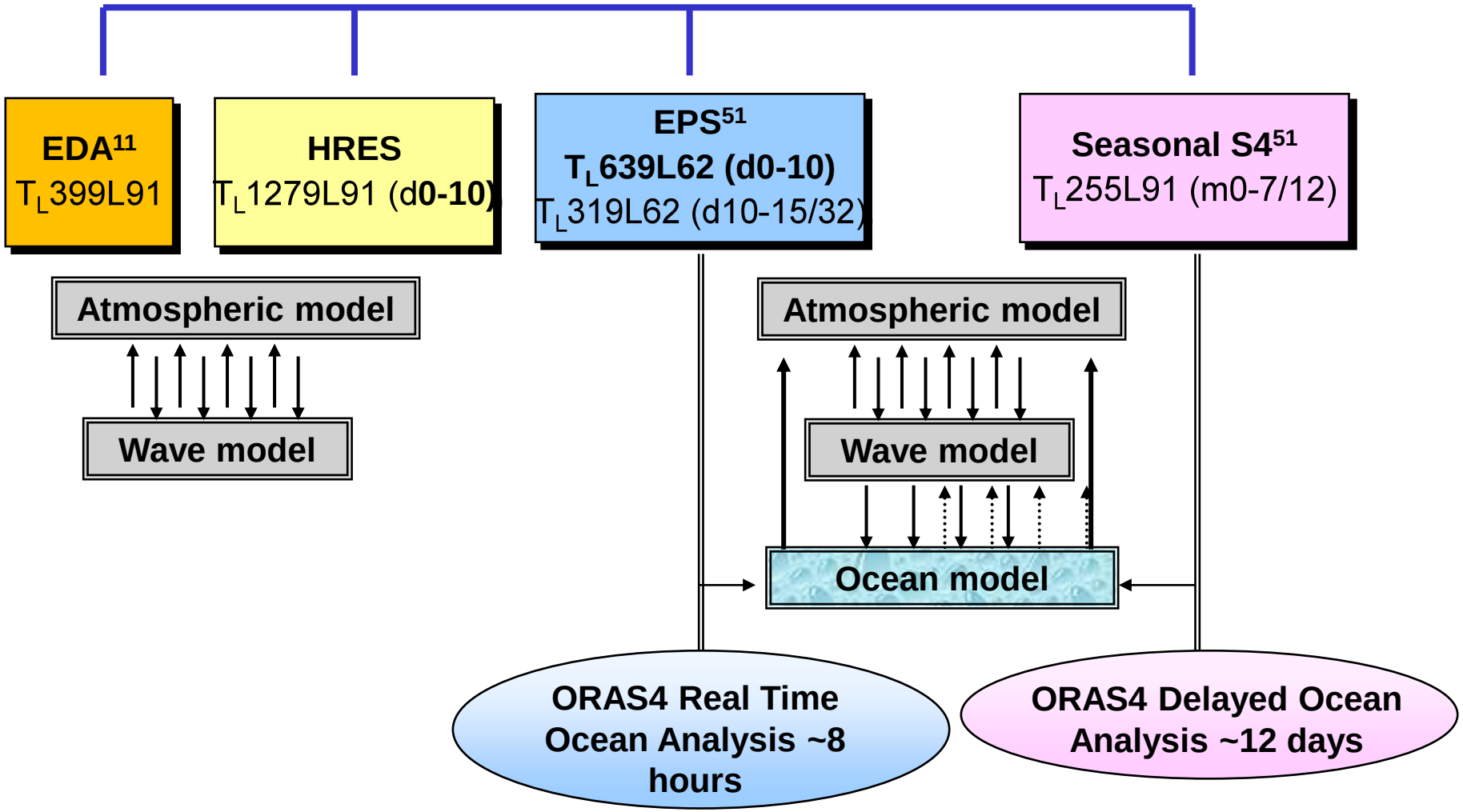
Jean-Noël Thépaut

ECMWF

October 2012

and many colleagues from the Research Department

The ECMWF Integrated Forecasting System (IFS)



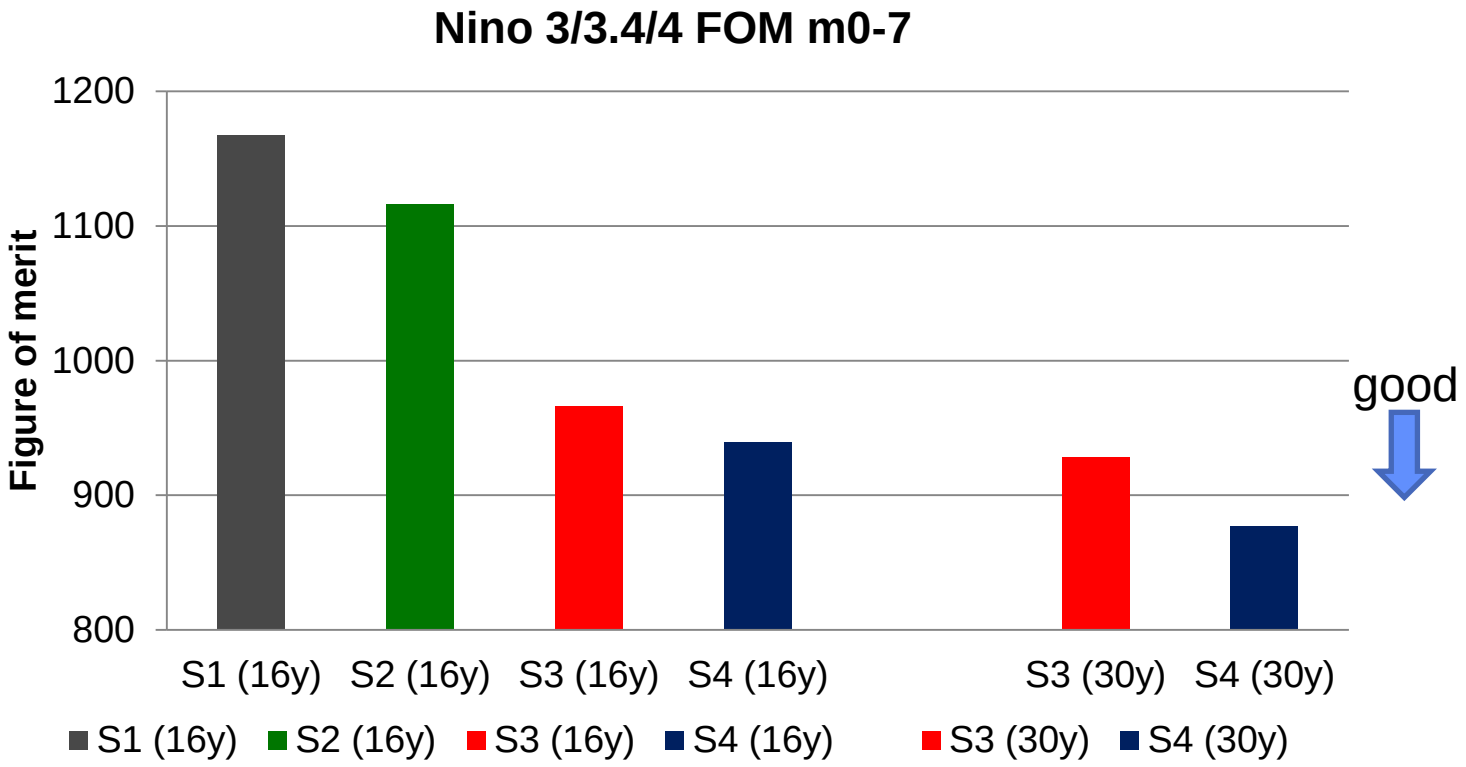
System updates

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

- **Early 2013 (38R2): 137 level model**
- **September 2012: NCEP joins ECMWF/UKMO/MF in EUROSIP**
- **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 (*covered last year*)**
- **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***

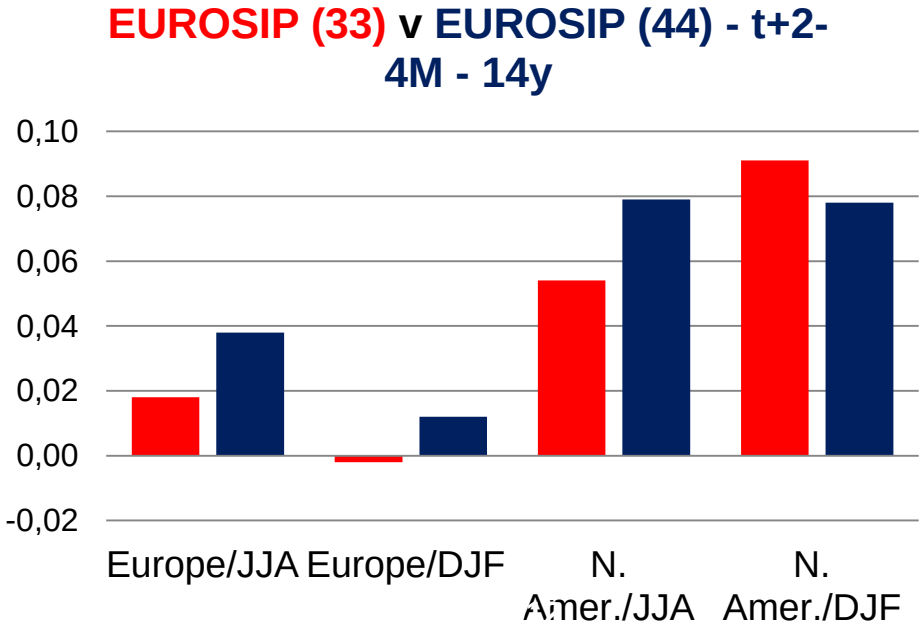
S4 (Nov ’11): progress in seasonal prediction (S1 to S4)

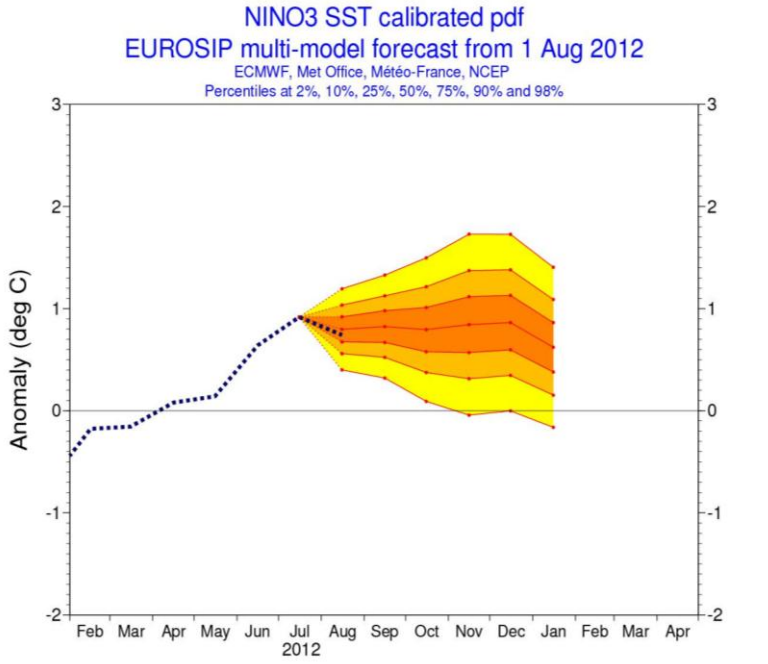
Progress from S1 (1997-2002), S2 (2002-2007), S3 (2007-2011) to S4 (Nov 2011): sustained improvements in ENSO forecast skill is evident from the Figure Of Merit (FMO, mean absolute error of SST M0-7 fcs over Nino 3, Nino 3.4 and Nino 4 area).



EUROSIP (Sep '12): NCEP joins ECMWF, MF and UKMO

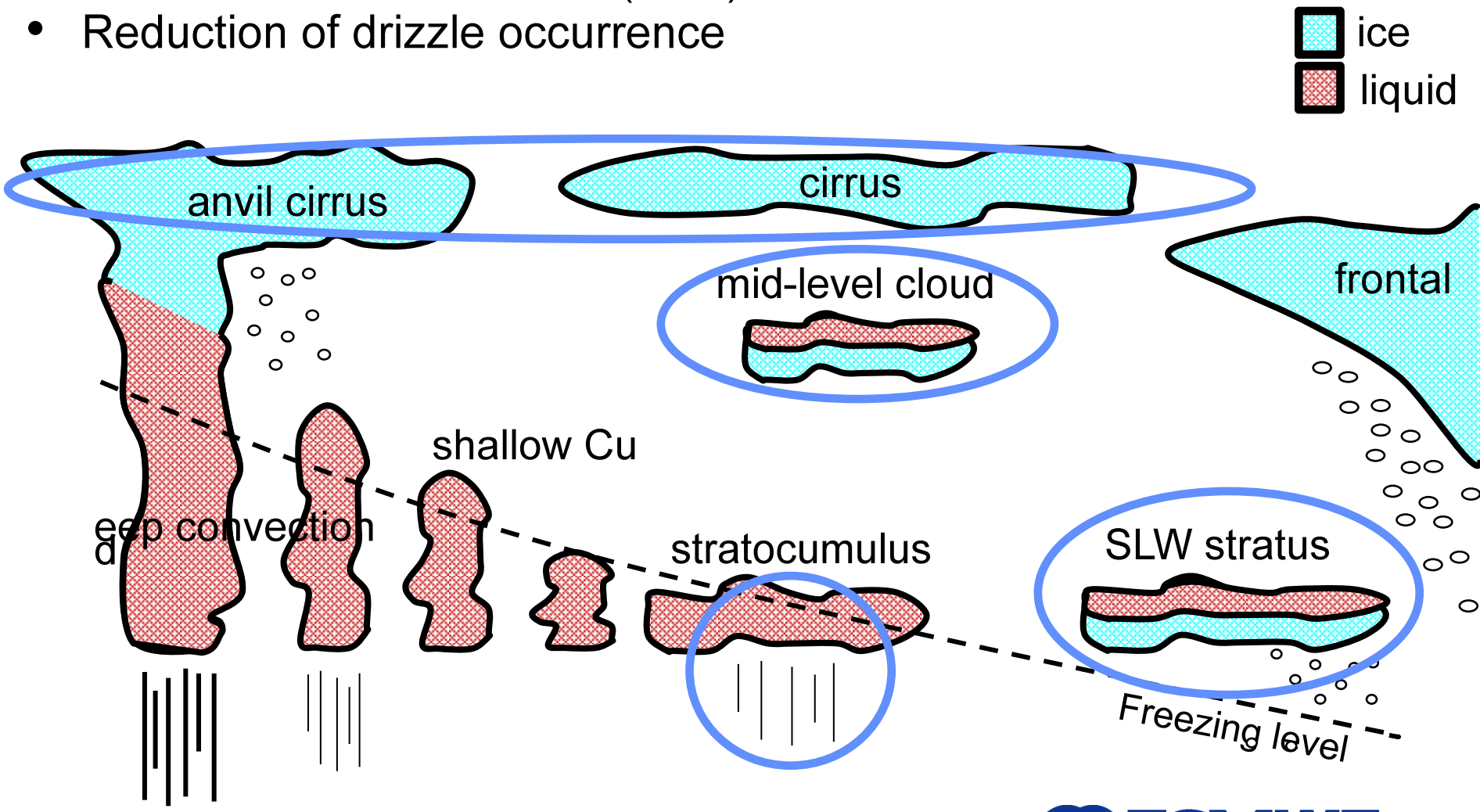
For the first time, European (ECMWF, Meteo France and UK Met Office) and American (NCEP) ensemble systems are used to generate operational products. This follows research that has shown that better and more reliable seasonal forecasts can be created by combining the output from several models.



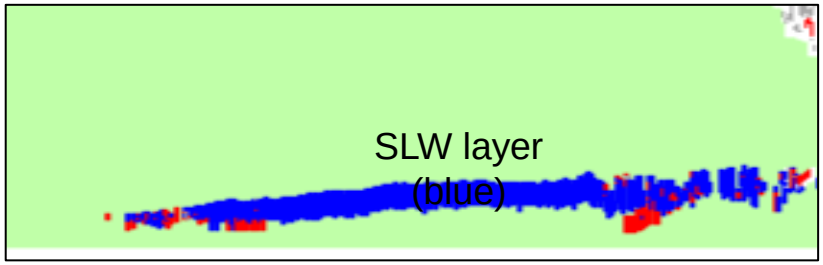


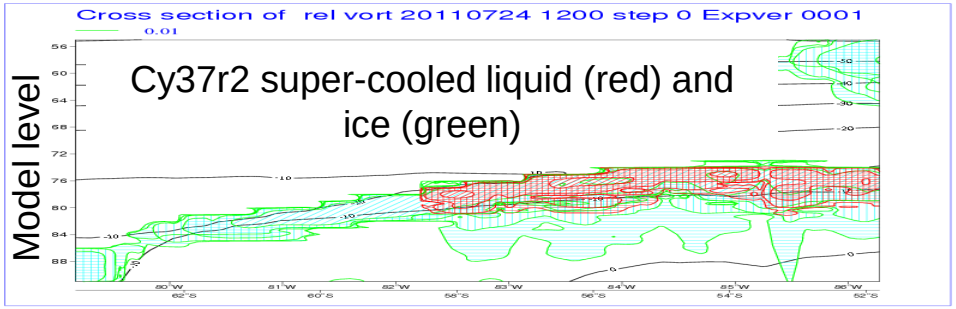
Focus on improved parametrization for 2011/12:

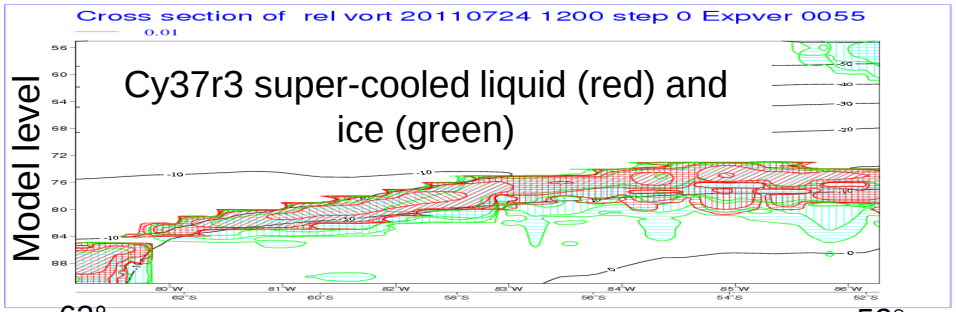
- Super-cooled liquid layers in mixed phase stratiform cloud (37r3)
- Ice water content in cirrus (38r1)
- Reduction of drizzle occurrence



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







63° S

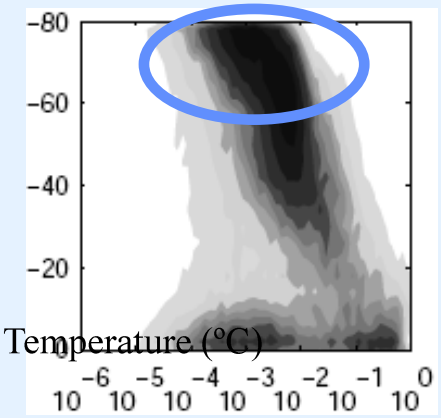
52° S

- Super-cooled liquid water (SLW) cloud frequently occurs in atmosphere down to -30°C 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).

Addressing model systematic errors – cirrus (medium-range)

Too little ice cloud (cirrus) at cold temps/high altitudes.

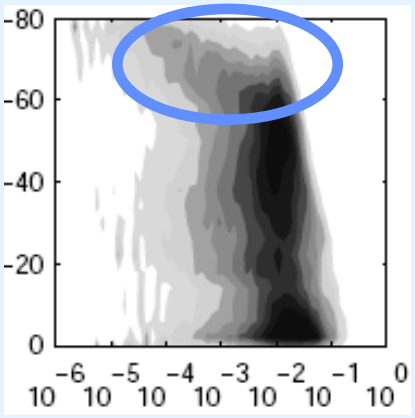
Revised ice fall in CY38R1 increases high altitude ice cloud…



CloudSat/CALIPSO

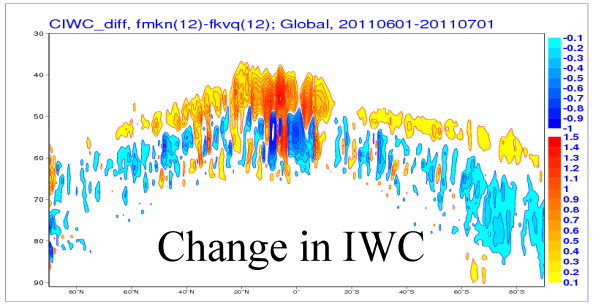
Delanoë et al. 2011

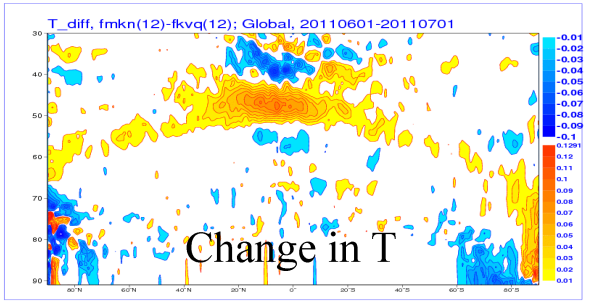
Ice water content PDF (g m^{-3})



IFS model

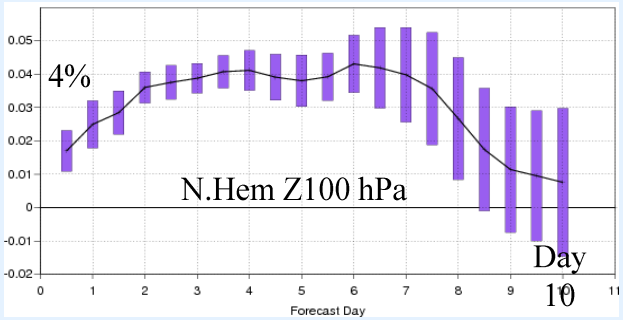
…radiatively warms upper troposphere

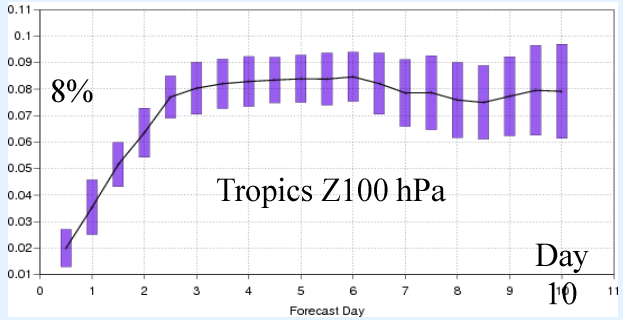




Impact on mean (June 2011) T+12 ice water content and temperature (T511)

…significantly improves 100hPa/200hPa geop. height

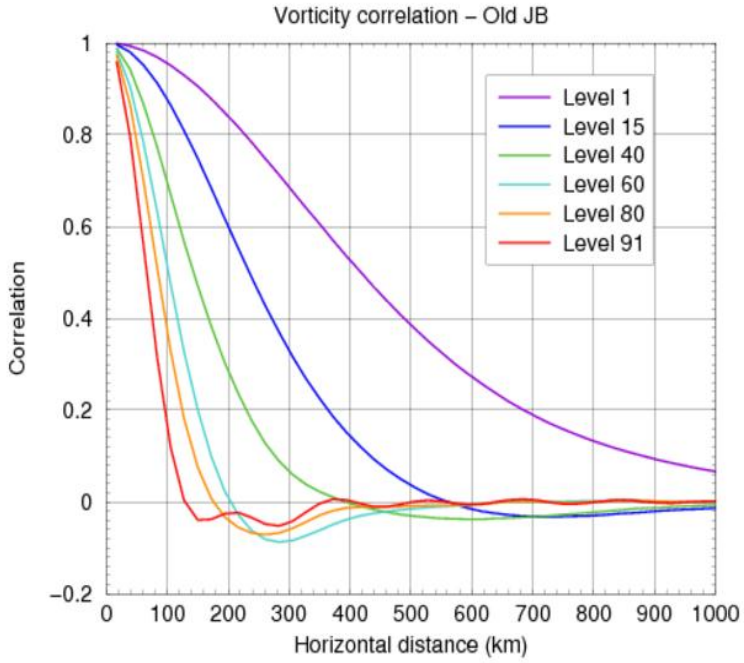


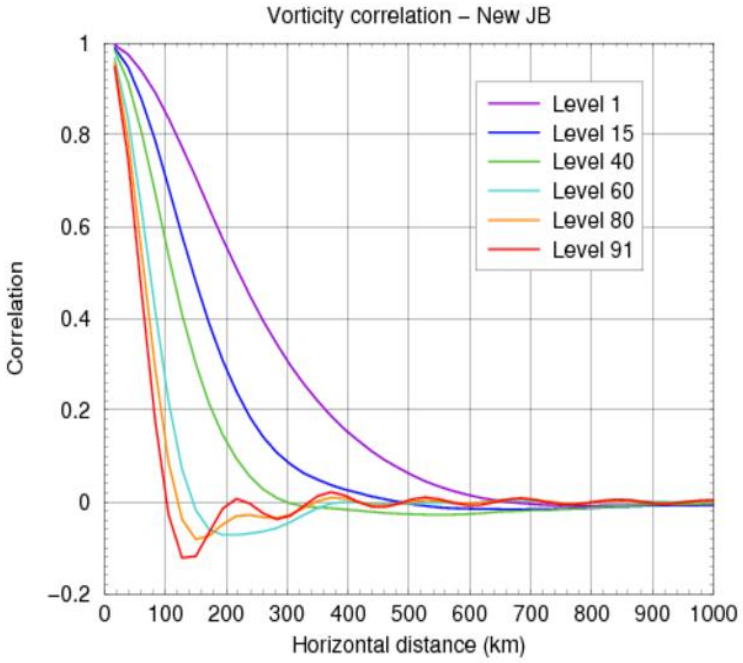


Relative r.m.s.e change for T511 analysis for June 2011

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.

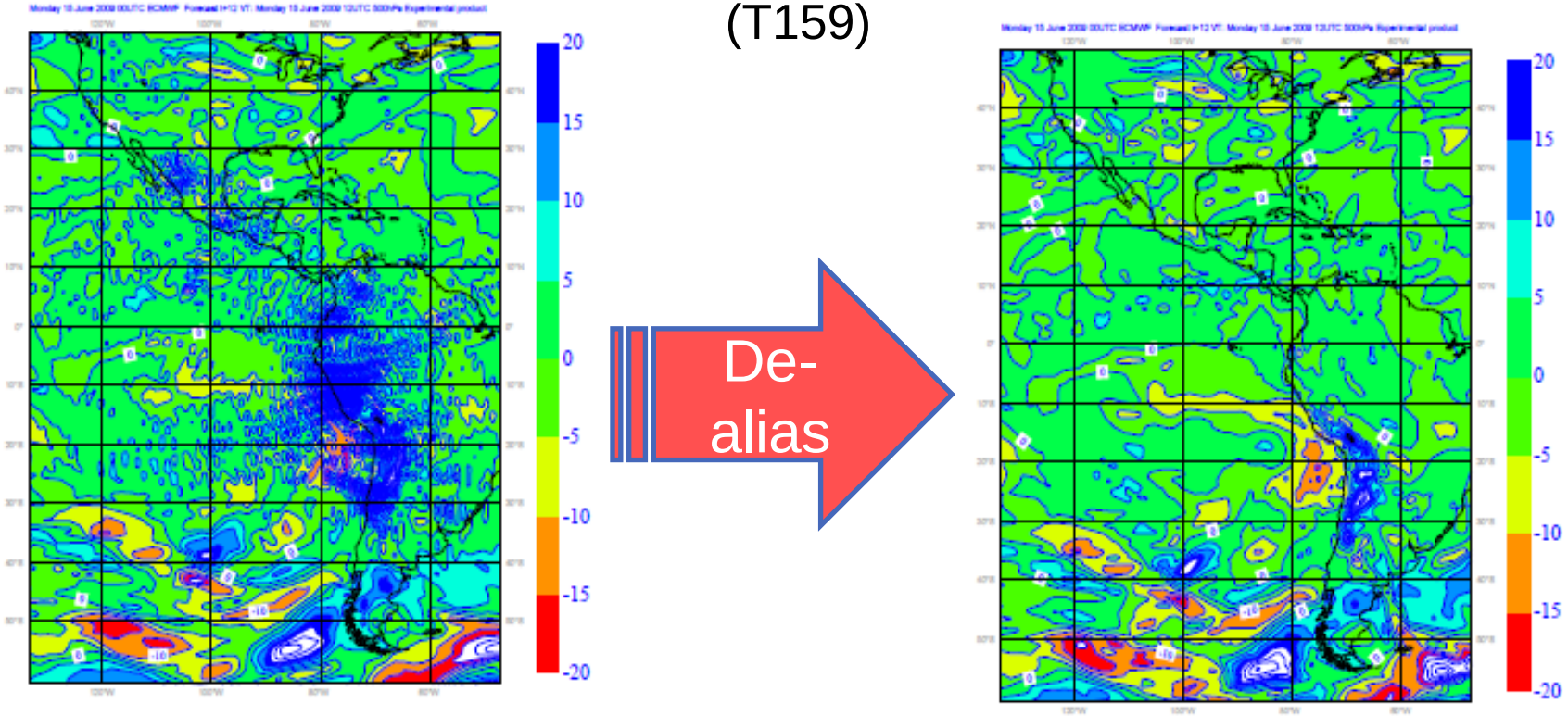




De-aliasing and noise reduction

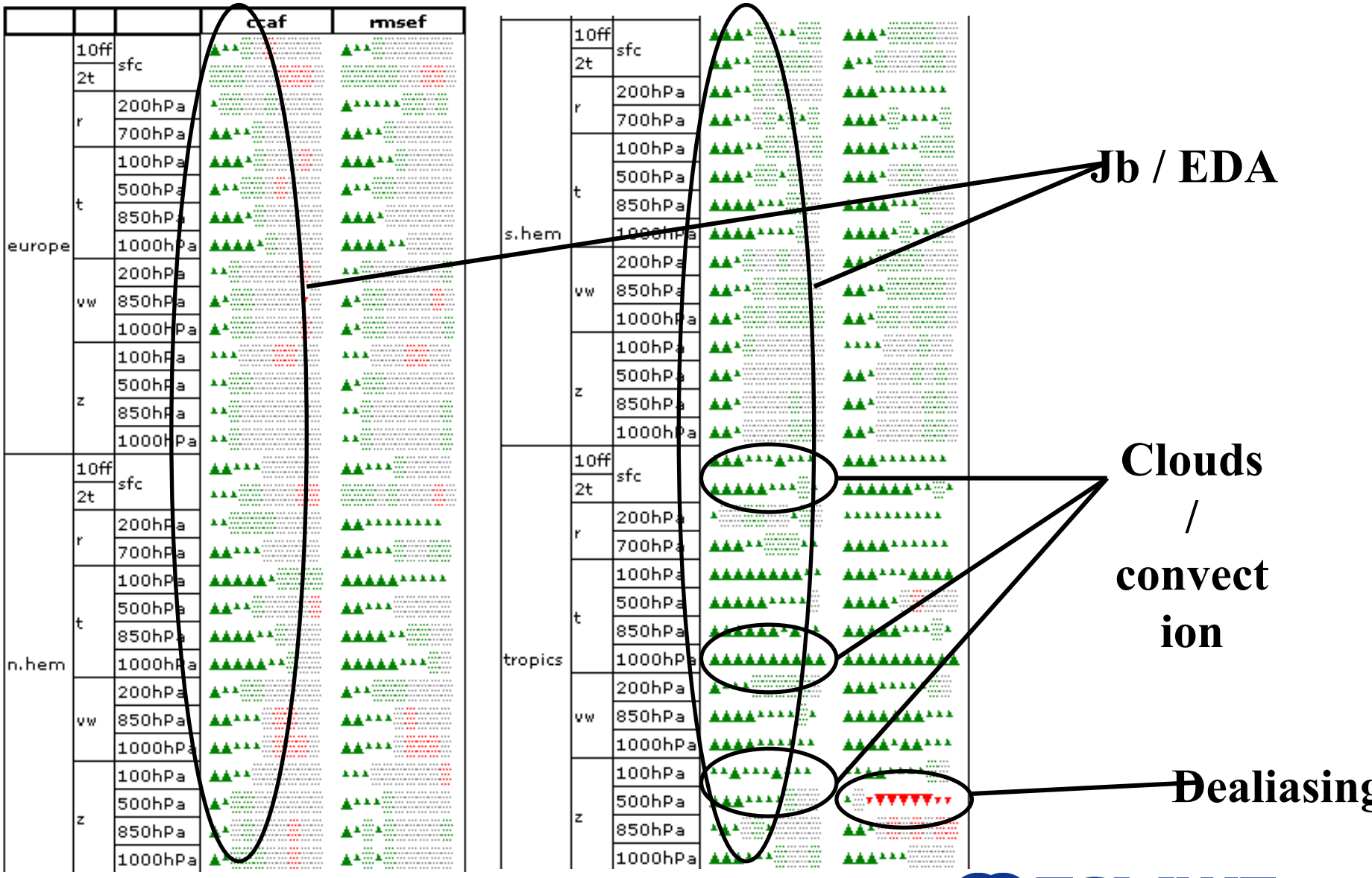
A new de-aliasing procedure leads to reduced numerical noise.

500hPa adiabatic - zonal wind tendencies (T159)



Cycle 38R1: High-resolution scores

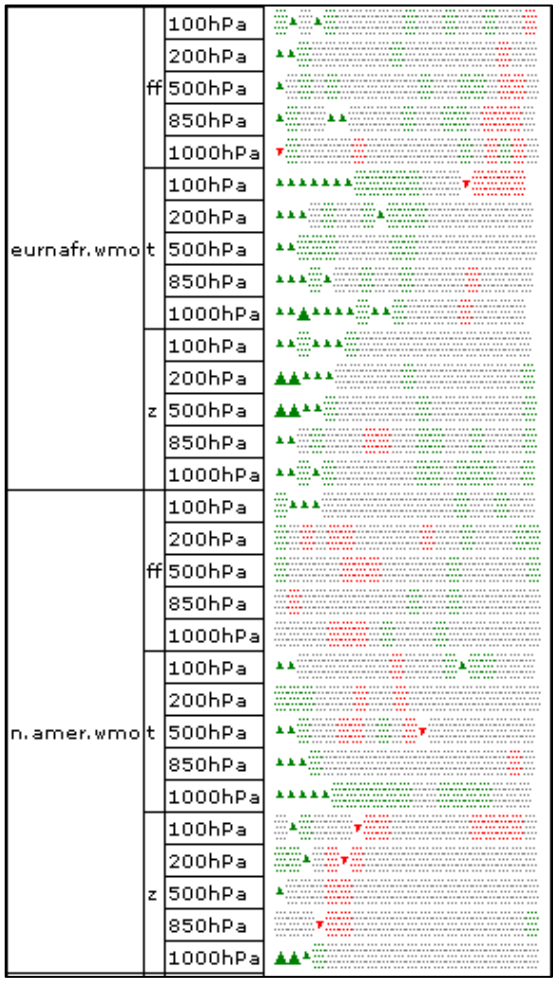
2011/09/02-2011/12/21, verified with own analysis

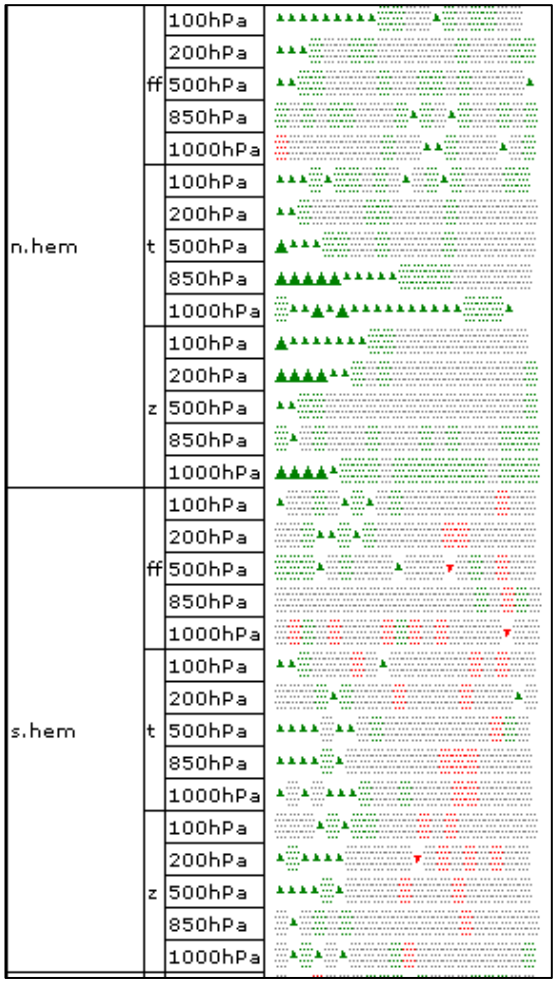


Cycle 38R1: High-resolution scores

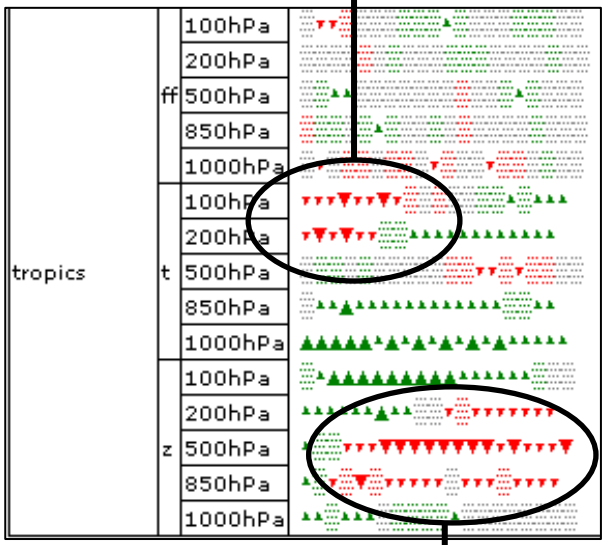
2011/09/02-2011/12/31, verified with observations

only 12-hourly rmse





Analysis

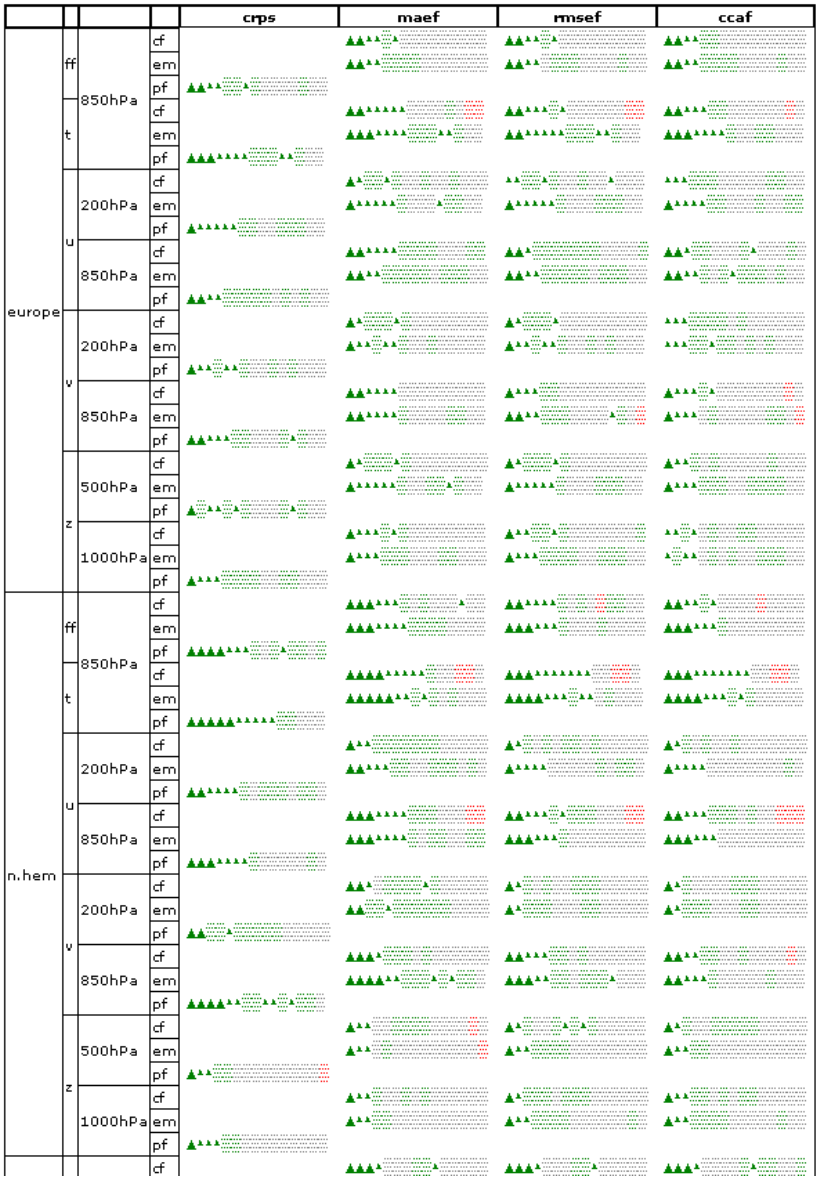


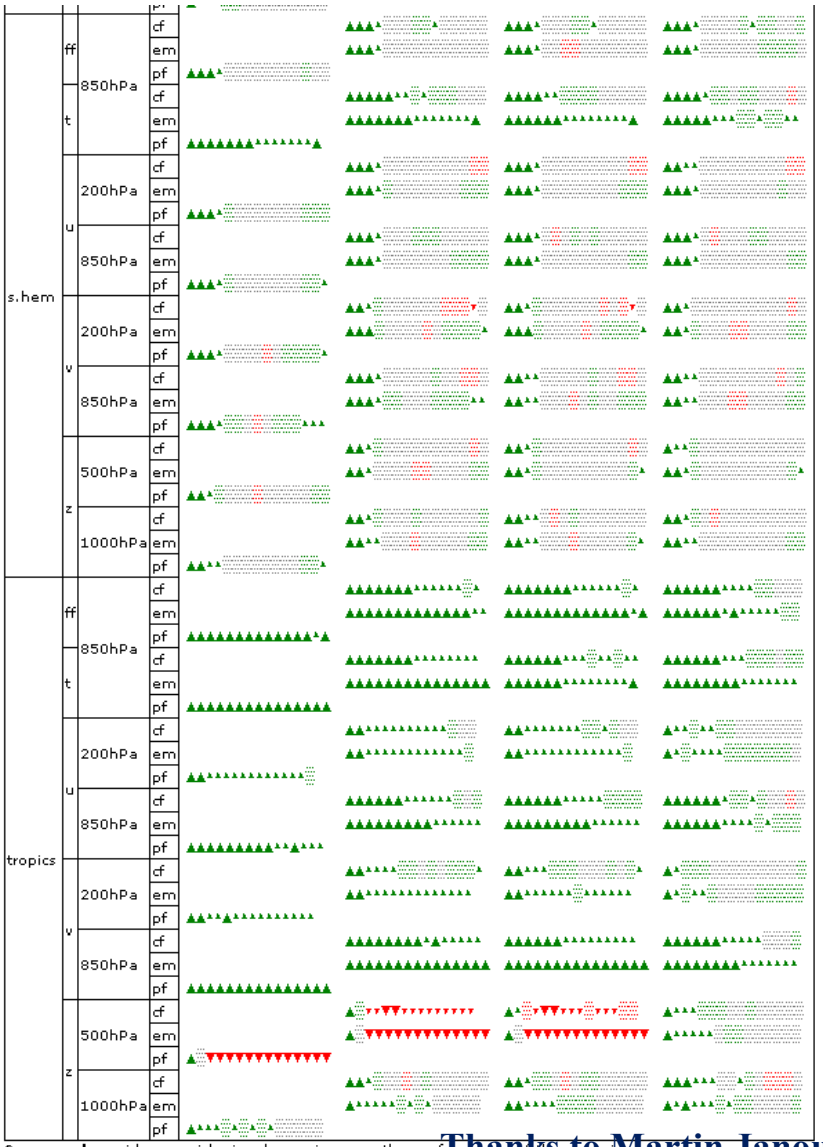
Dealiasing

Thanks to Martin Janousek

Cycle 38R1: Ensemble scores (RD)

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





Thanks to Martin Janousek

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:

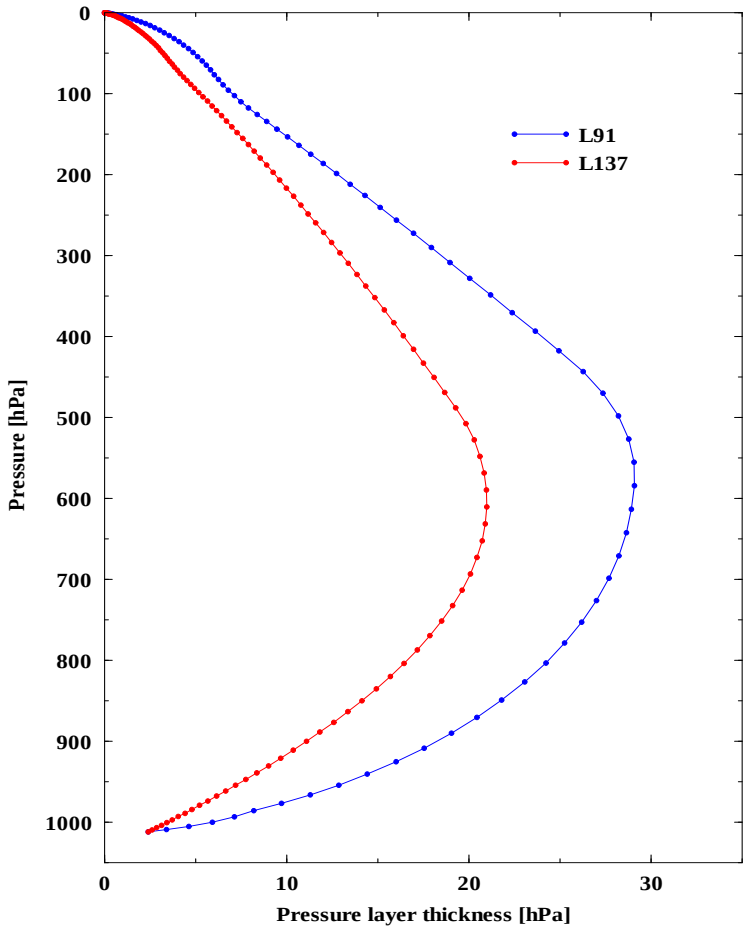
- MACC-II → GMES Atmospheric Service

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: L137

Model climate:

- Warmer stratosphere, colder mid-lower troposphere,
- Better QBO, excessive vertical momentum transport? (diffusion)
- Net TOA SW mixed in stratocumulus areas (fix: shallow convection, diffusion),
- Slightly less convective precipitation, but regional differences
- Surface stress too resolution dependent (fix: blocking height formulation)

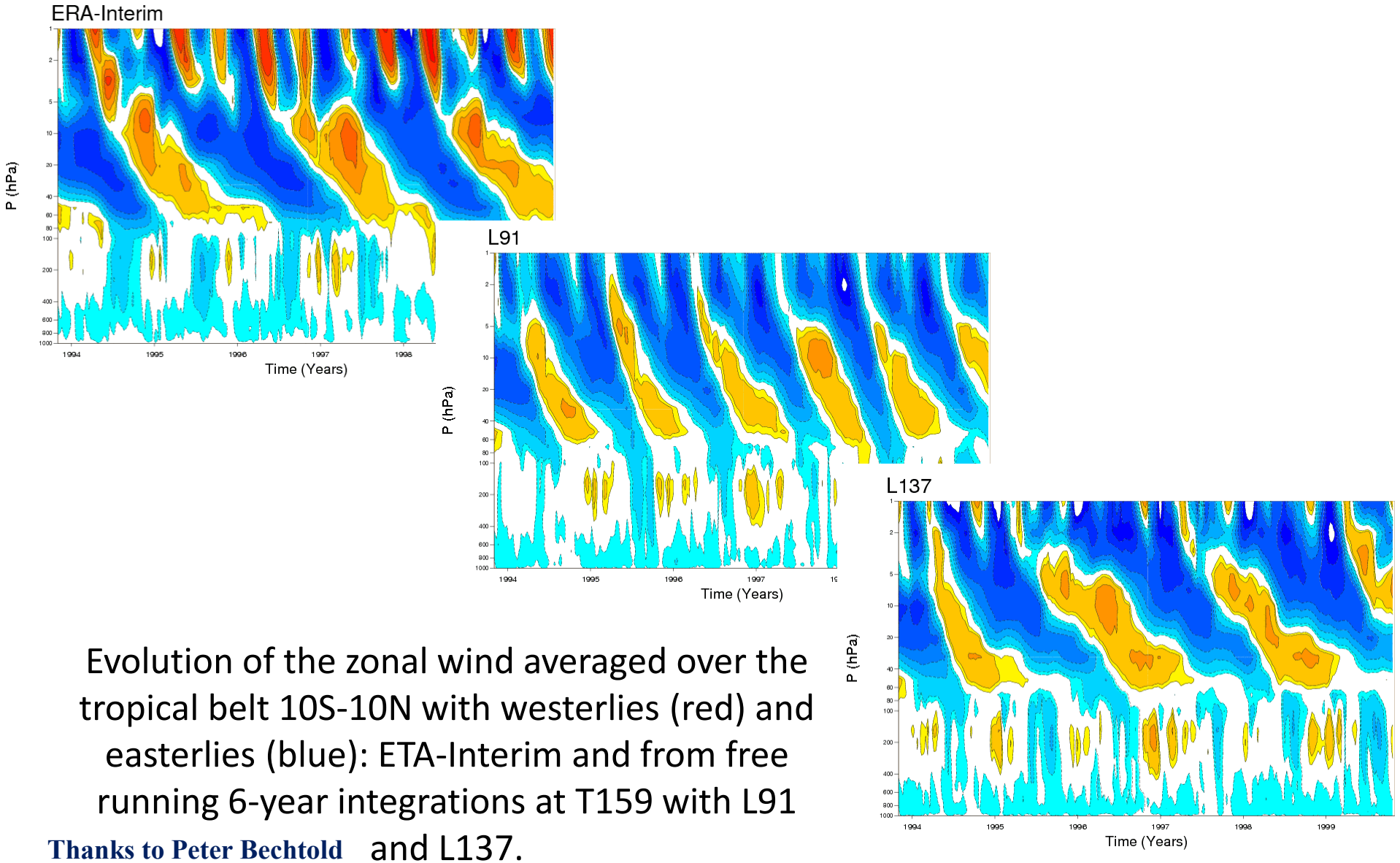
Analyses:

- Background errors slightly different
- Model error cycling, balance operator
- Fit to radiosonde T better in stratosphere, worse in mid/lower troposphere
- Wind increments smaller near 200 hPa, larger above; moisture increments large above ITCZ

Scores:

- Increased RMS in short-range for 100-500 hPa z; global
- Increased RMS in short-medium range tropospheric z, T; Tropics
- Mostly related to mean error, less to variability

Cycle 38R2: L137



Evolution of the zonal wind averaged over the tropical belt 10S-10N with westerlies (red) and easterlies (blue): ETA-Interim and from free running 6-year integrations at T159 with L91 and L137.

Thanks to Peter Bechtold

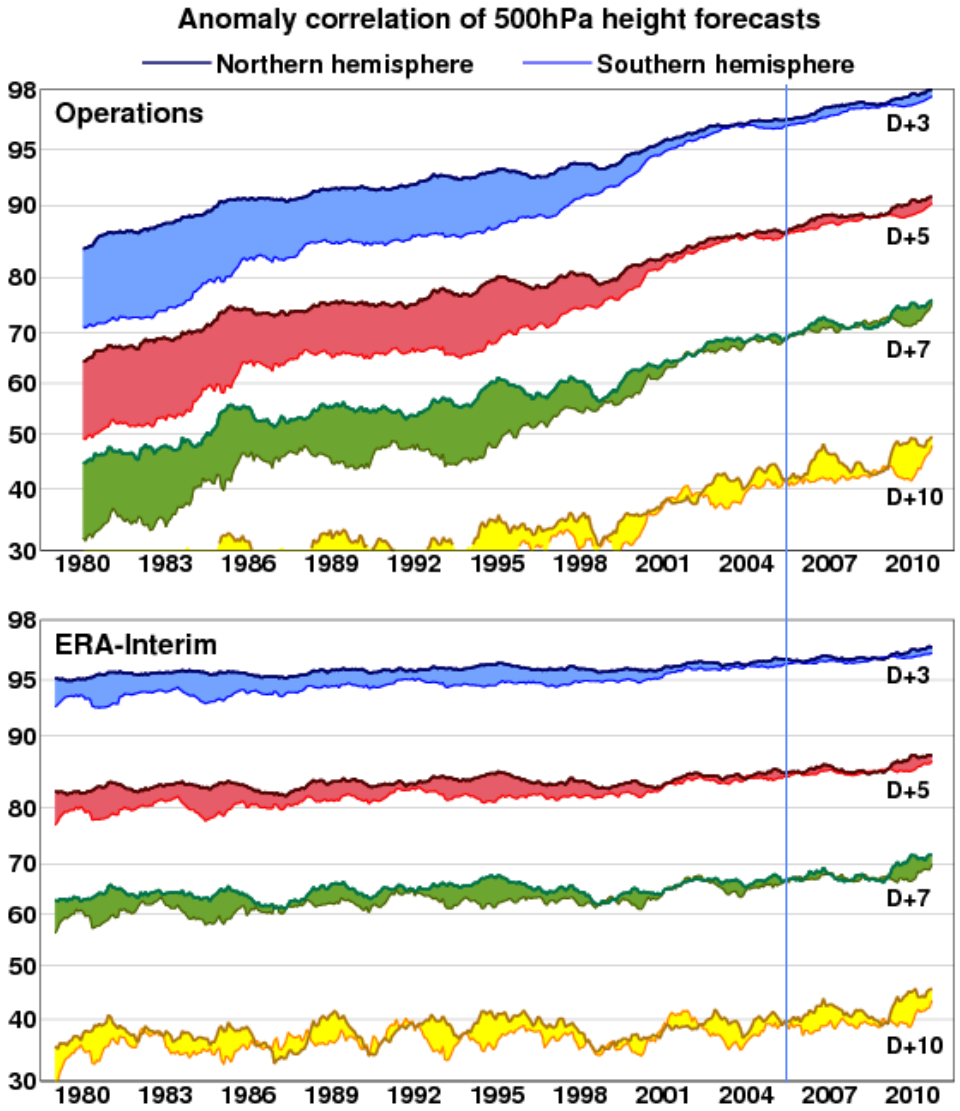
ERA-Interim extension: 1979-2012

Reanalysis makes use of data assimilation systems designed for weather forecasting

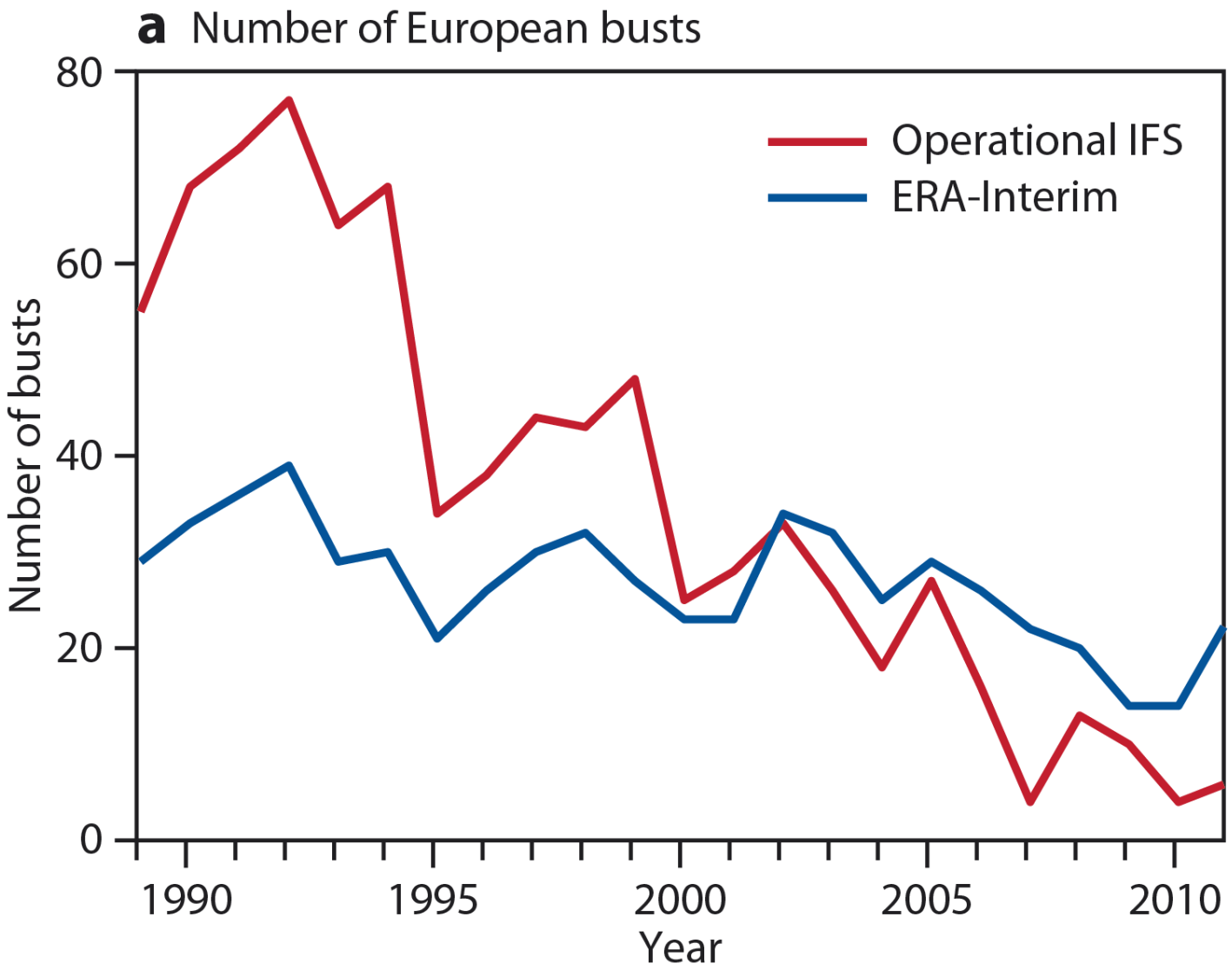
Reanalysis uses a single model and data assimilation method for a consistent re-analysis with past observations

Consistency in time is the key challenge for climate reanalysis

Difficulties arise from biases in models and observations



ERA-interim: core tool for model developments: Investigation: Forecast busts over Europe



D+6
RMSE > 60m
ACC < 0.40

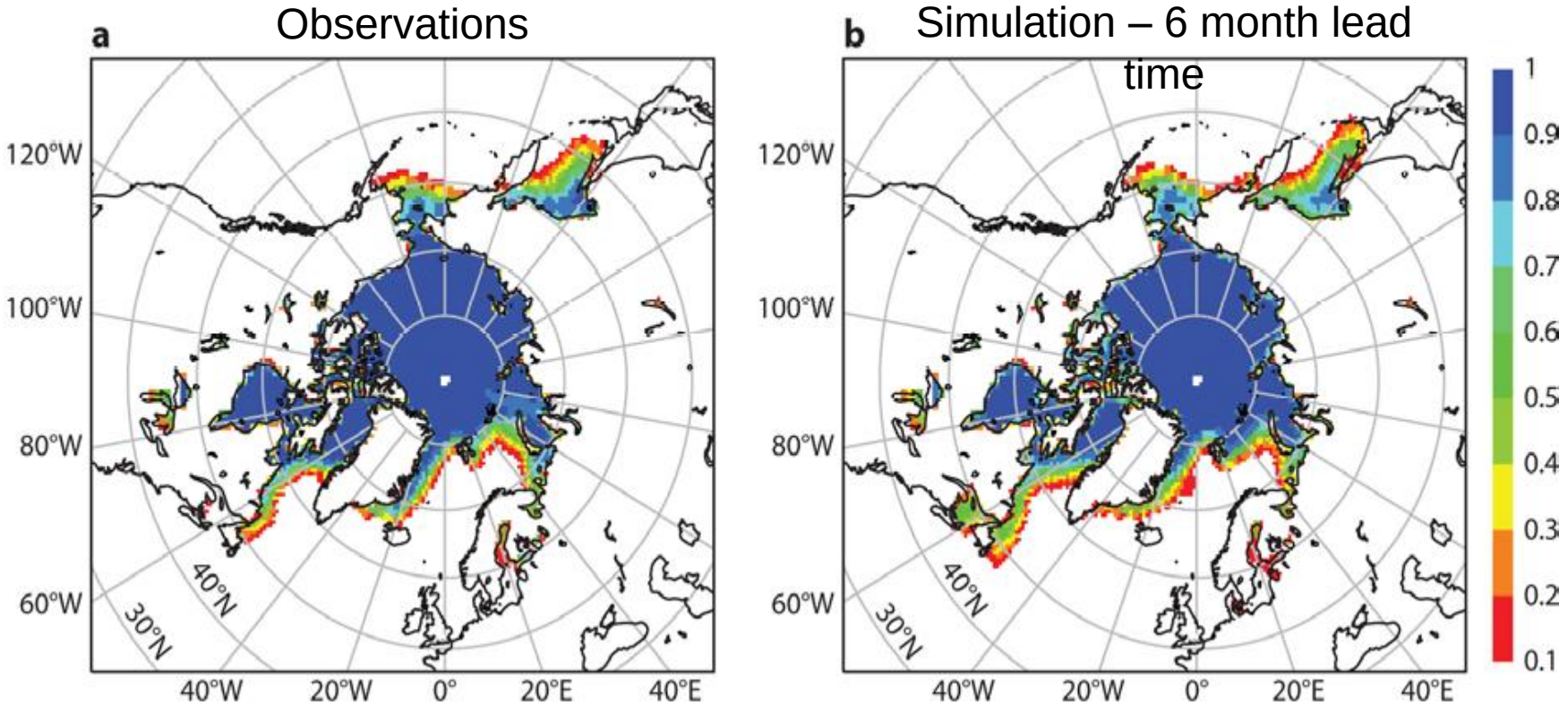
ERA-Clim

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

Sea-ice modelling

Preliminary seasonal integrations with LIM (the Louvain-la Neuve Ice Model) shows a fair agreement between the forecast and the observed ice cover.



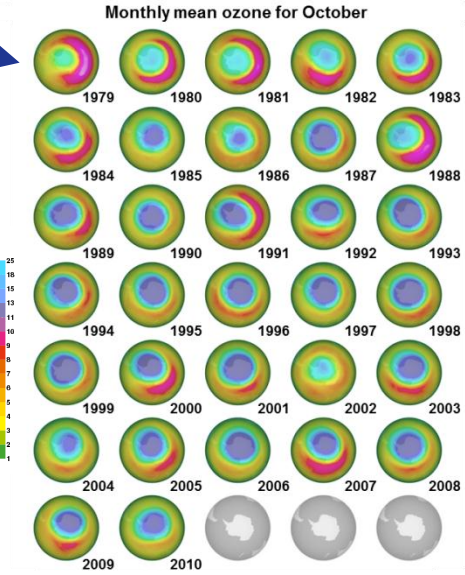
ECMWF

http://www.gmes-atmosphere.eu

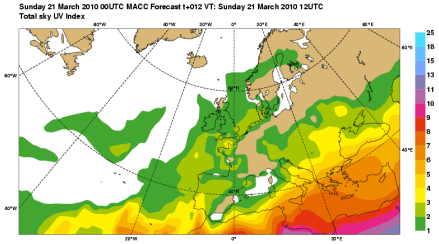
Air-quality ensemble forecasts

and (re-)analyses

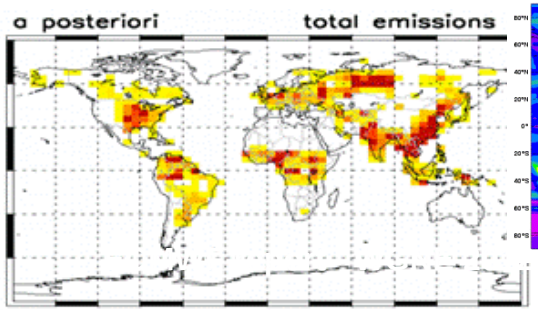
Stratospheric ozone records



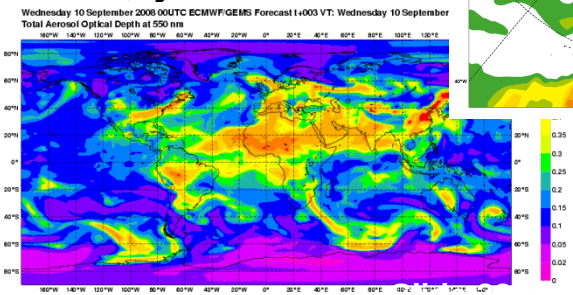
UV index



Monthly methane emissions

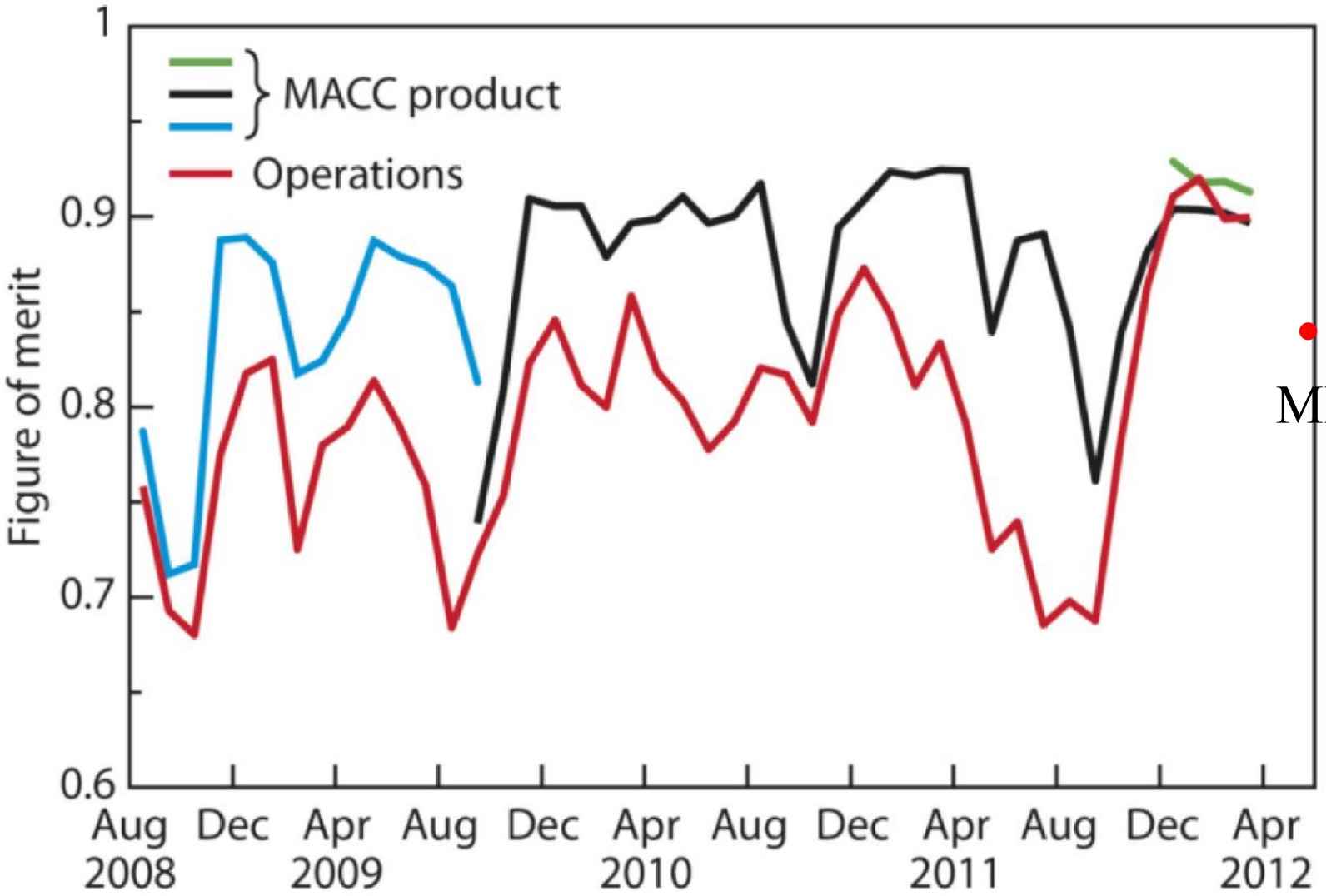


Global forecasts

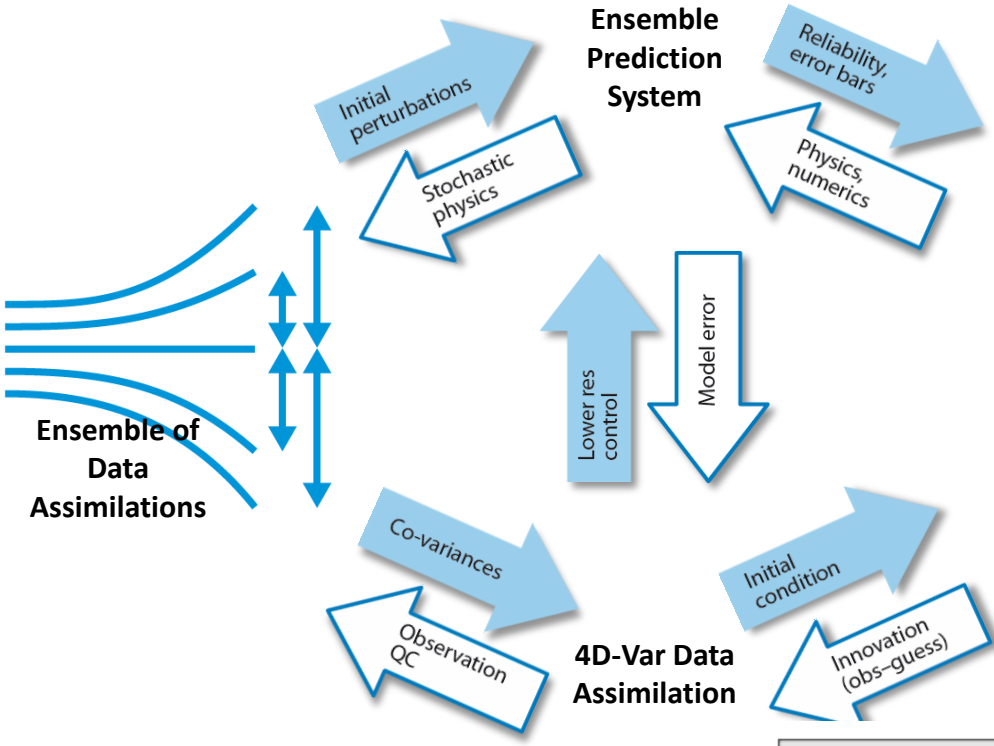


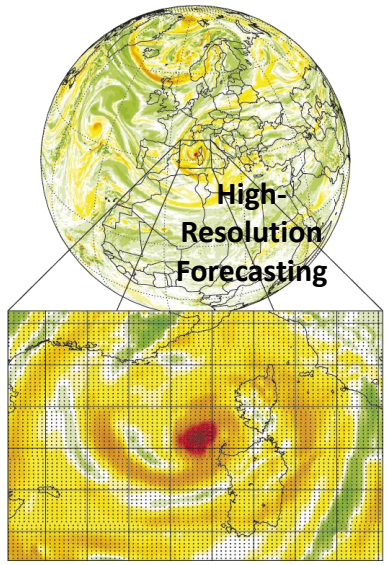
...And many more services.

Ozone headline skill score



Longer-term future





A much more integrated system …

… to cope with implications for HPC cost

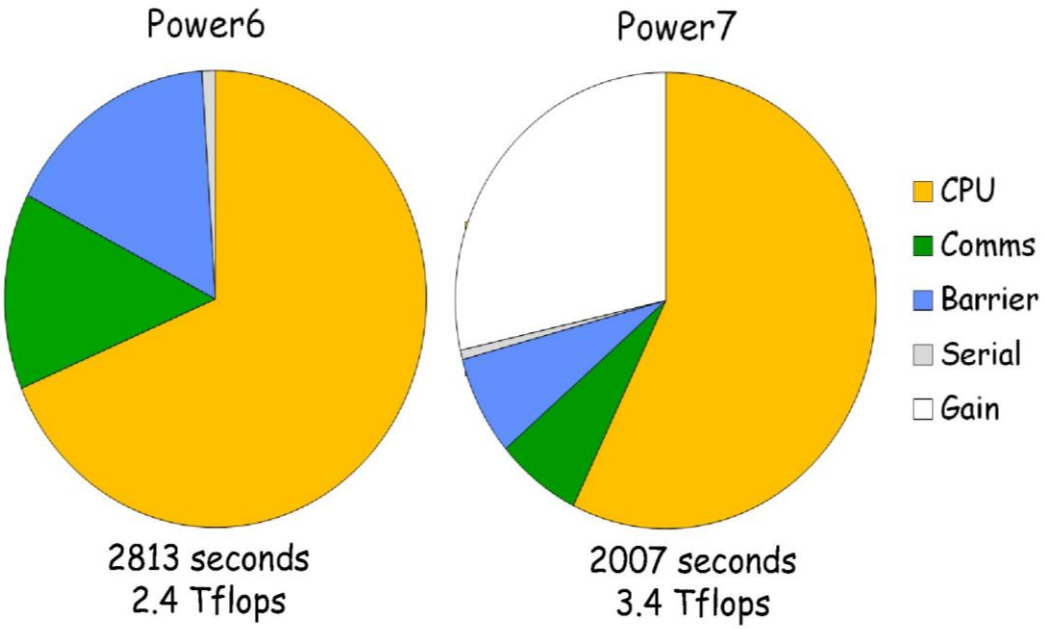
	2012	2015	2017
Deterministic forecast	T1279 L137	T2047 L137	T2047 L137
4D-Var	T159/255/255 L137 12-h window	T159/255/399 L137 24-h window	T159/255/399 L137 48-h window
Ensemble data assimilation	T399 L137 10 members 12-h window	T511 L137 25 members 12-h window	T511 L137 50 members 24-h window
Ensemble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



IFS system developments

Continuous Observation Processing Environment (COPE):

- Unified data pre-processing, blacklisting, thinning, quality control
- Quasi-continuous data processing

Object Oriented Prediction System (OOPS):

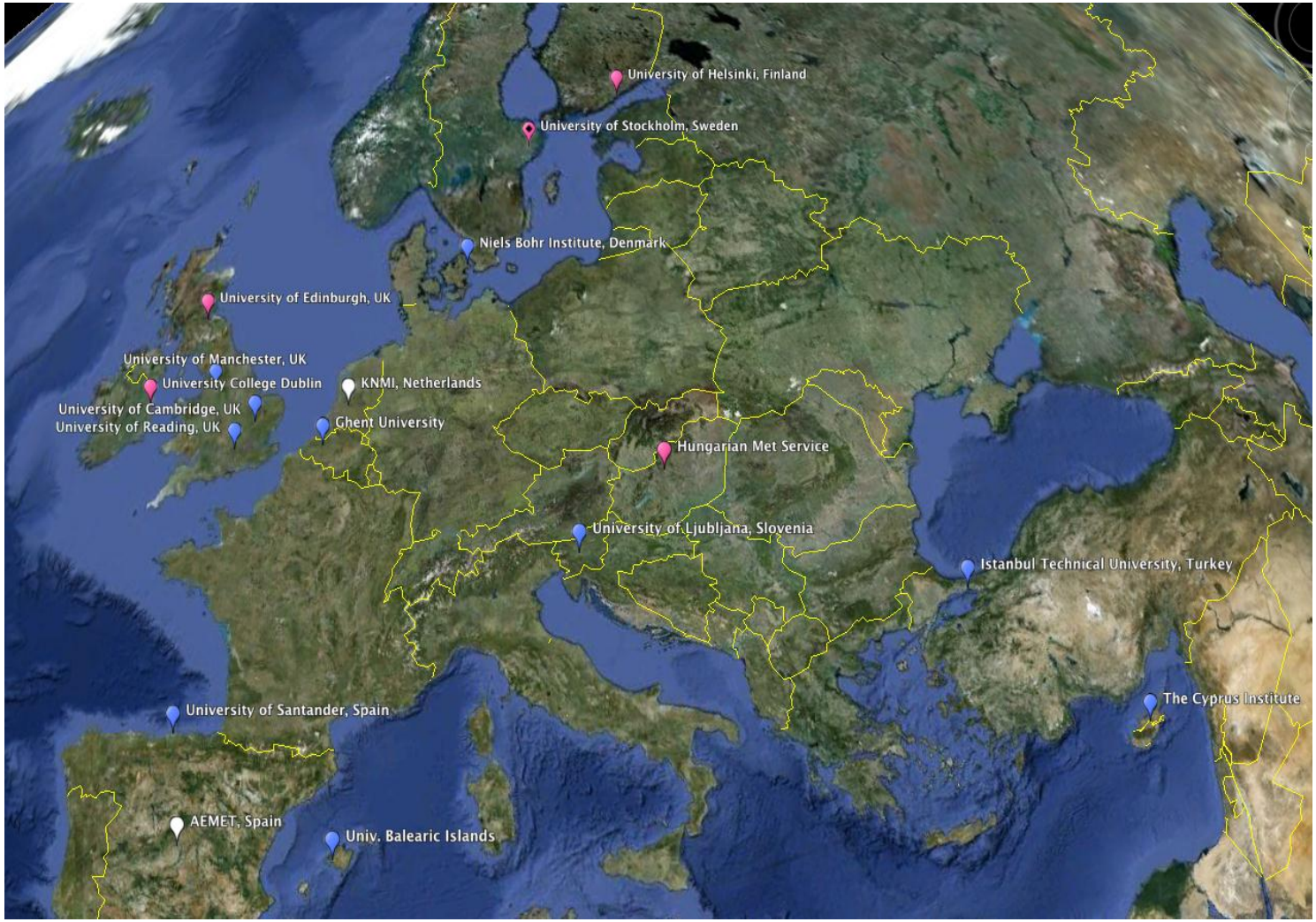
- Cleaner, more modular & scalable DA: top level in C++, lower levels in Fortran-90
- Data Assimilation algorithms manipulate a limited number of entities (objects):
  - x (state), y (observation); H (observation operator), M (model), H*, M* (adjoints); B, R, Q (covariance matrices)

OpenIFS:

- IFS model code modernization (modular, OOPS-standards)
- Access to research/education for future enhancements

A new initiative: OpenIFS active and potential users

Key: Research Teaching Technical evaluation Active



Thank You