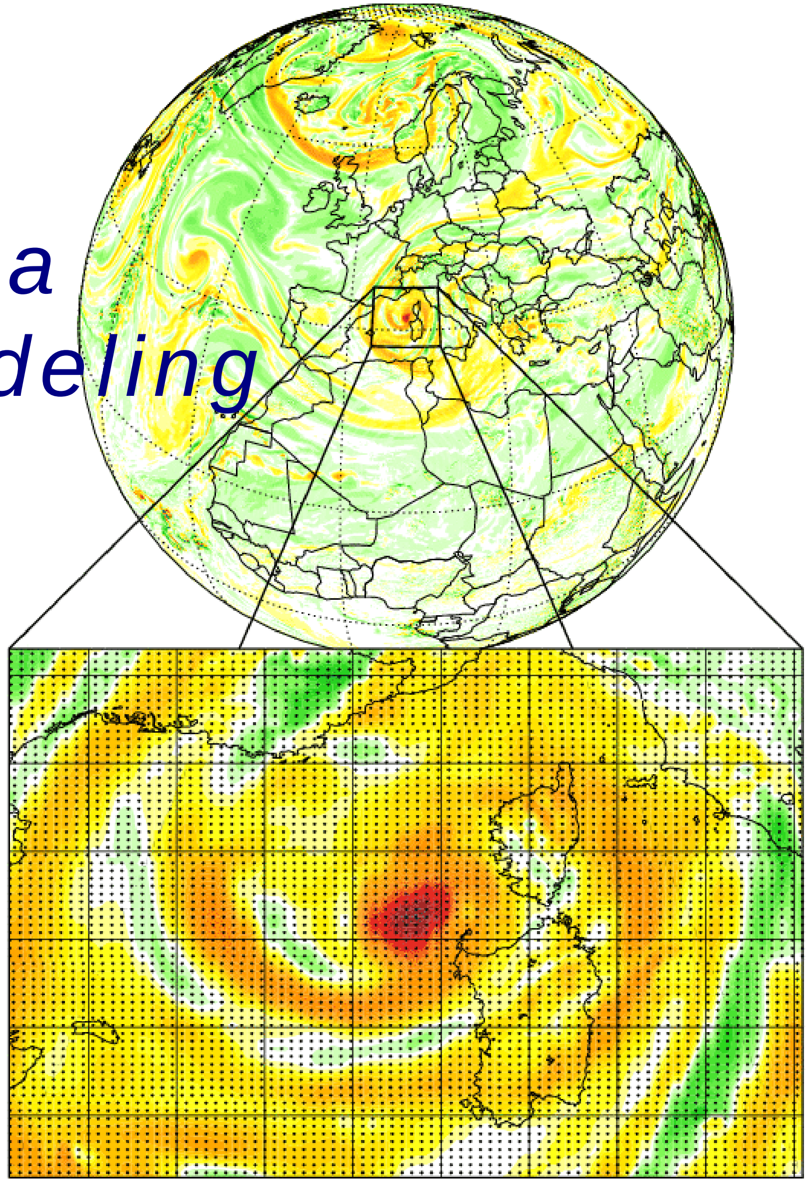
Recent and planned developments of data assimilation and modeling systems at ECMWF

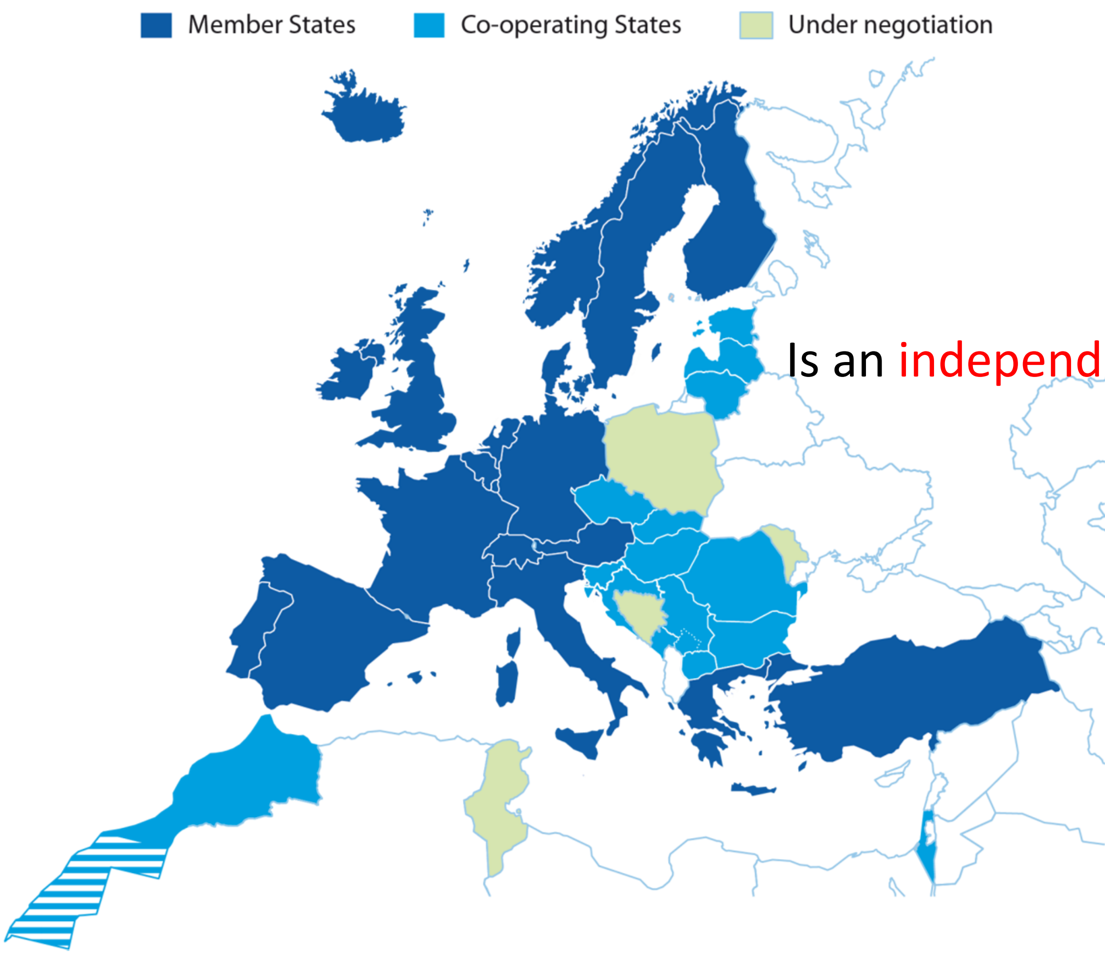


Peter Bauer

and many colleagues at ECMWF

ECMWF

ECMWF



Is an independent intergovernmental organisation

established in 1975

with

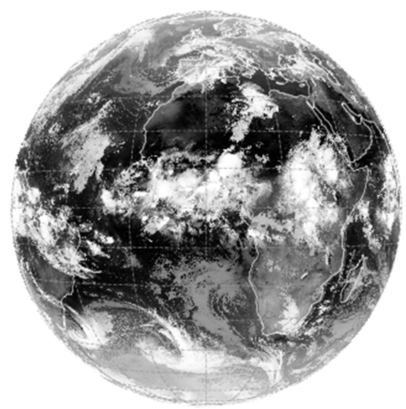
227 Employees
19 Member States
15 Co-operating States
Budget: £43 million per annum

Contributions by Member States and Co-operating States:
£39.8 million per annum

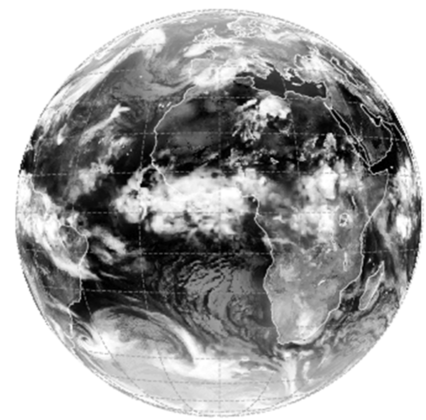
The operational forecasting system

- **High resolution deterministic forecast: twice per day**
  16 km 91-level, to 10 days ahead
- **Ensemble forecast (EPS): twice daily**
  51 members, 30/60 km 62-level, to 15 days ahead

Meteosat 9 IR10.8 20080525 0 UTC



ECMWF Fc 20080525 00 UTC+0h:



- **Monthly forecast EPS extension: twice a week (Mon/Thursdays)**
  51 members, 30/60 km 62 levels, to 1 month ahead
- **Seasonal forecast: once a month (coupled to ocean model)**
  41 members, 125 km 62 levels, to 7 months ahead

System updates

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

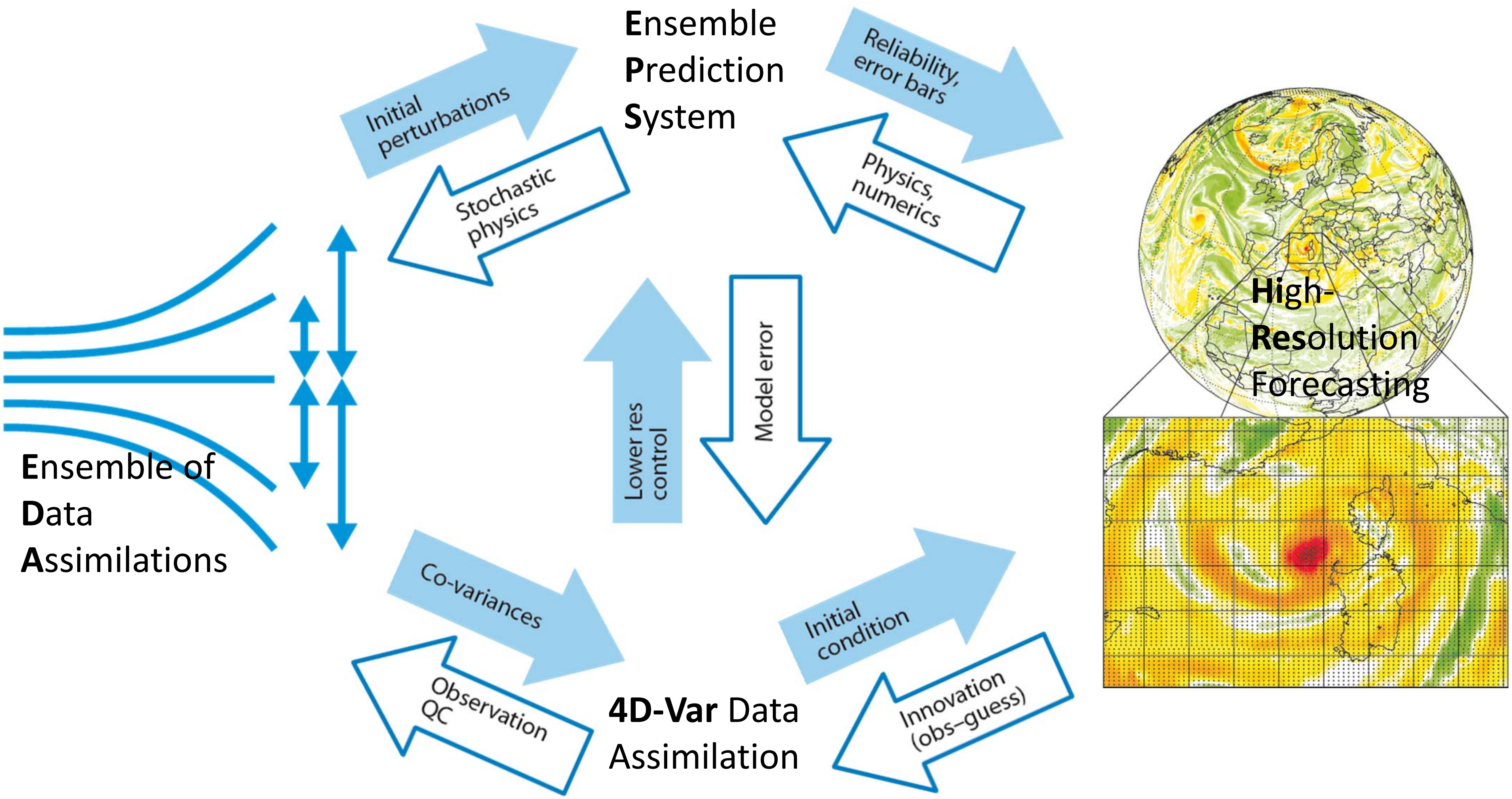
- **November 2012 (38R2*): L137**
- **May 2012 (38R1): New Jb, EDA-filtering, clouds/convection**
- **November 2011 (37R3): Rev. cloud scheme, aircraft b/c, NEXRAD assimilation**
- **June 2011 (37R2): AMSU-A obs. error, EDA variances in 4D-Var**
- **November (36R4): New cloud scheme, SEKF soil moisture analysis, SKEB**
- **June 2010 (36R2): Initial perturbations for EPS from EDA**
- **January 2010 (36R1): T1279 L91, EPS T639 L62**

A few examples:

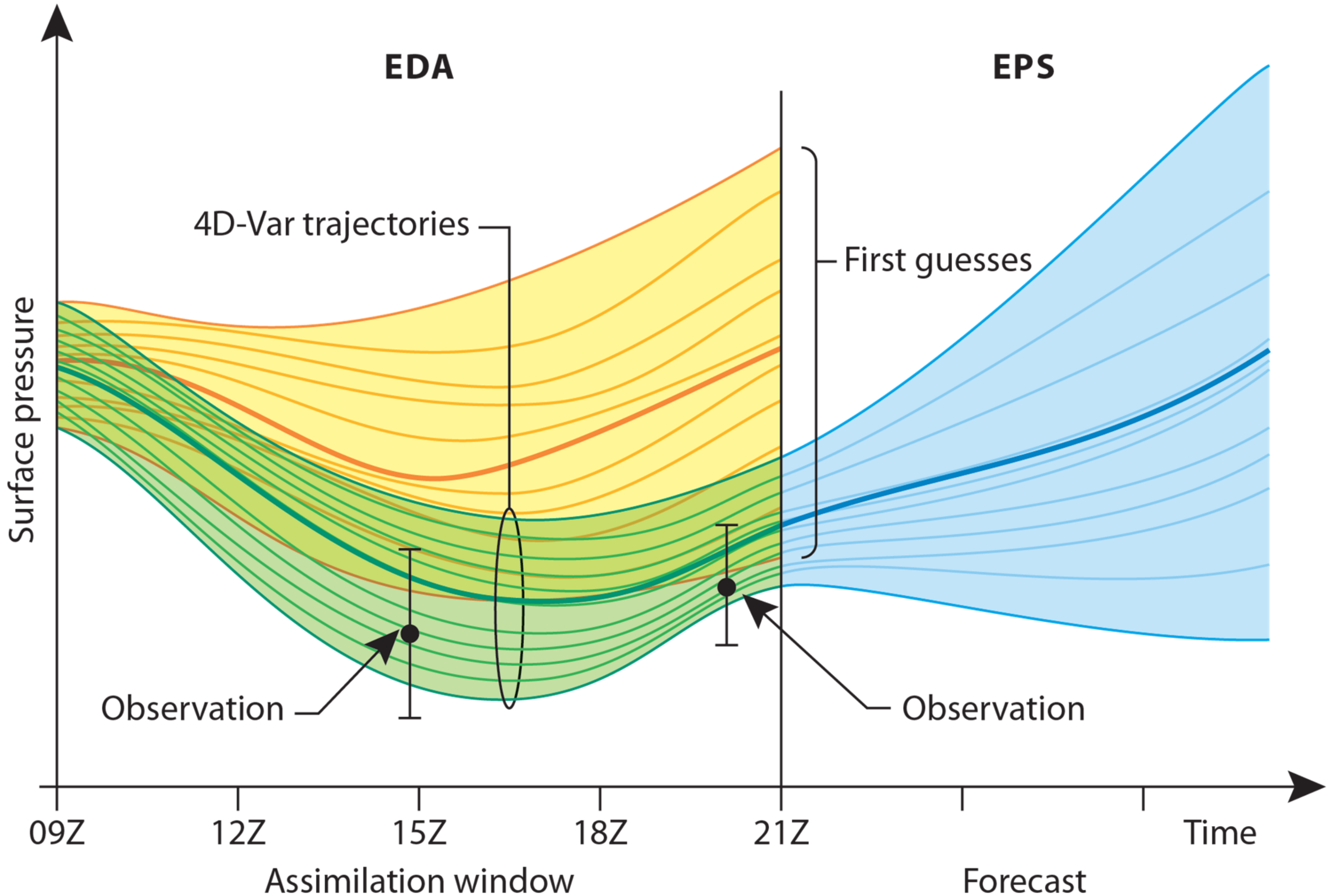
1. **Ensemble of data assimilation**
2. **Microwave sounder observation errors**
3. **New cloud scheme**
4. **Data monitoring**

* ‘38’ denotes numbering of common cycles with Météo-France, ‘R2’ denotes internal version

Inter-dependent analysis & forecasting system



1. Ensemble of data assimilation

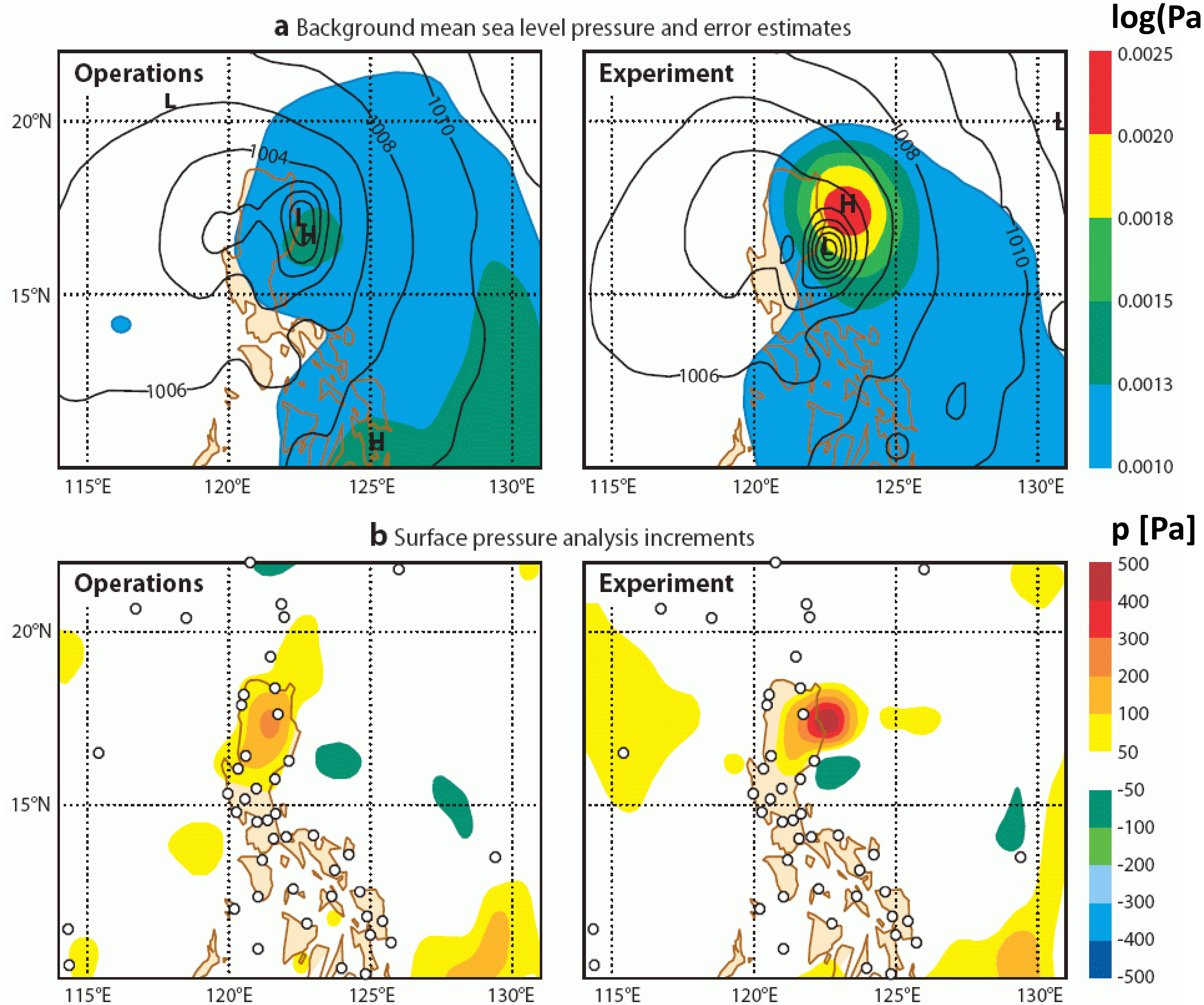


- 10 members of 2 inner-loop 4D-Var's at T95/159 L91, T399 outer lops
- Perturbations from observations, SST, SPPT; noise filtering, scaling

1. Ensemble of data assimilation

Impact in analysis

9 May 2011 00 UTC analysis, TC Aere



(L. Isaksen et al.)

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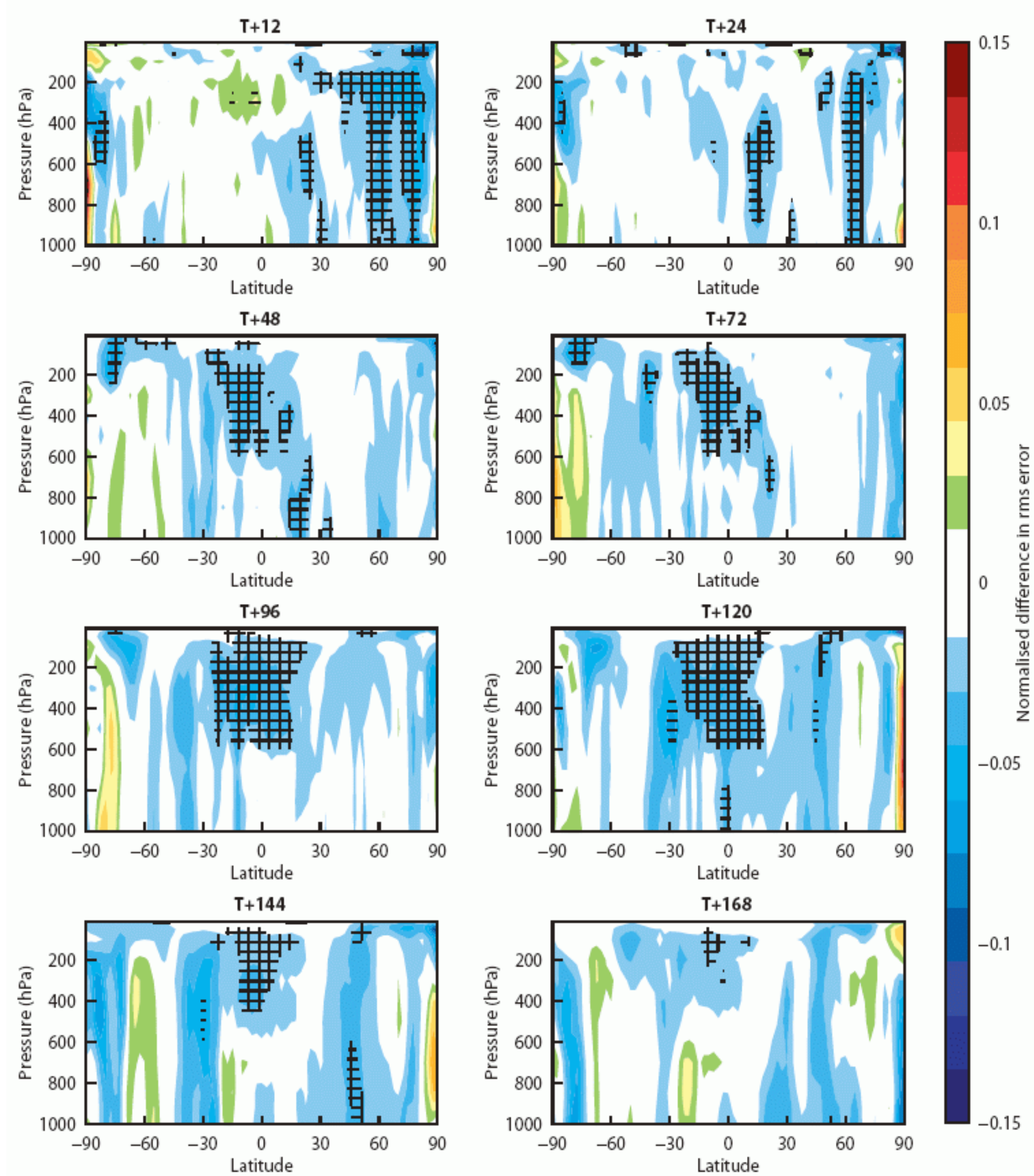
1. Ensemble of data assimilation

Impact on high-resolution forecast skill

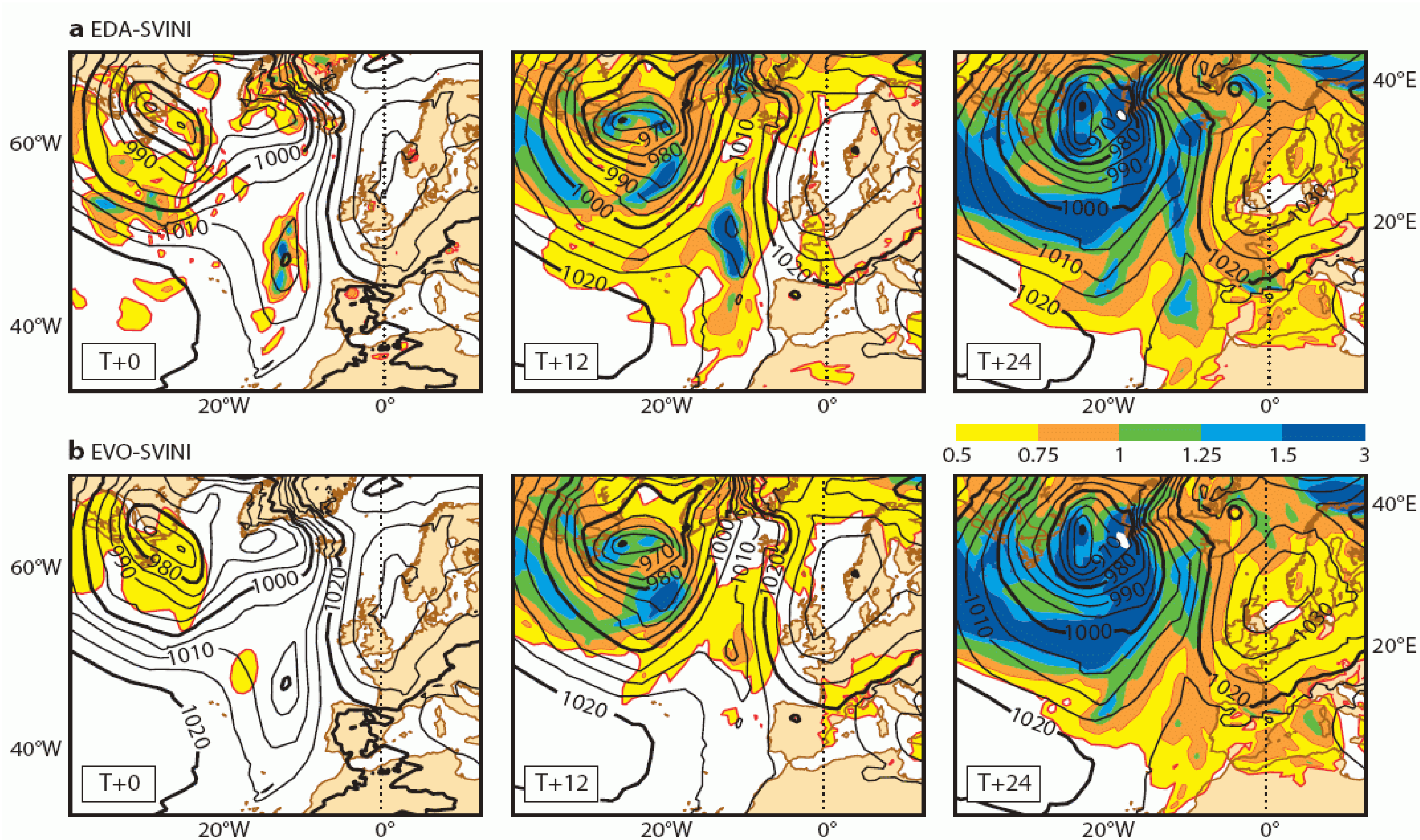
Geopotential height normalized forecast error differences experiment-control
11 Jan – 30 Mar 2010



(L. Isaksen et al.)

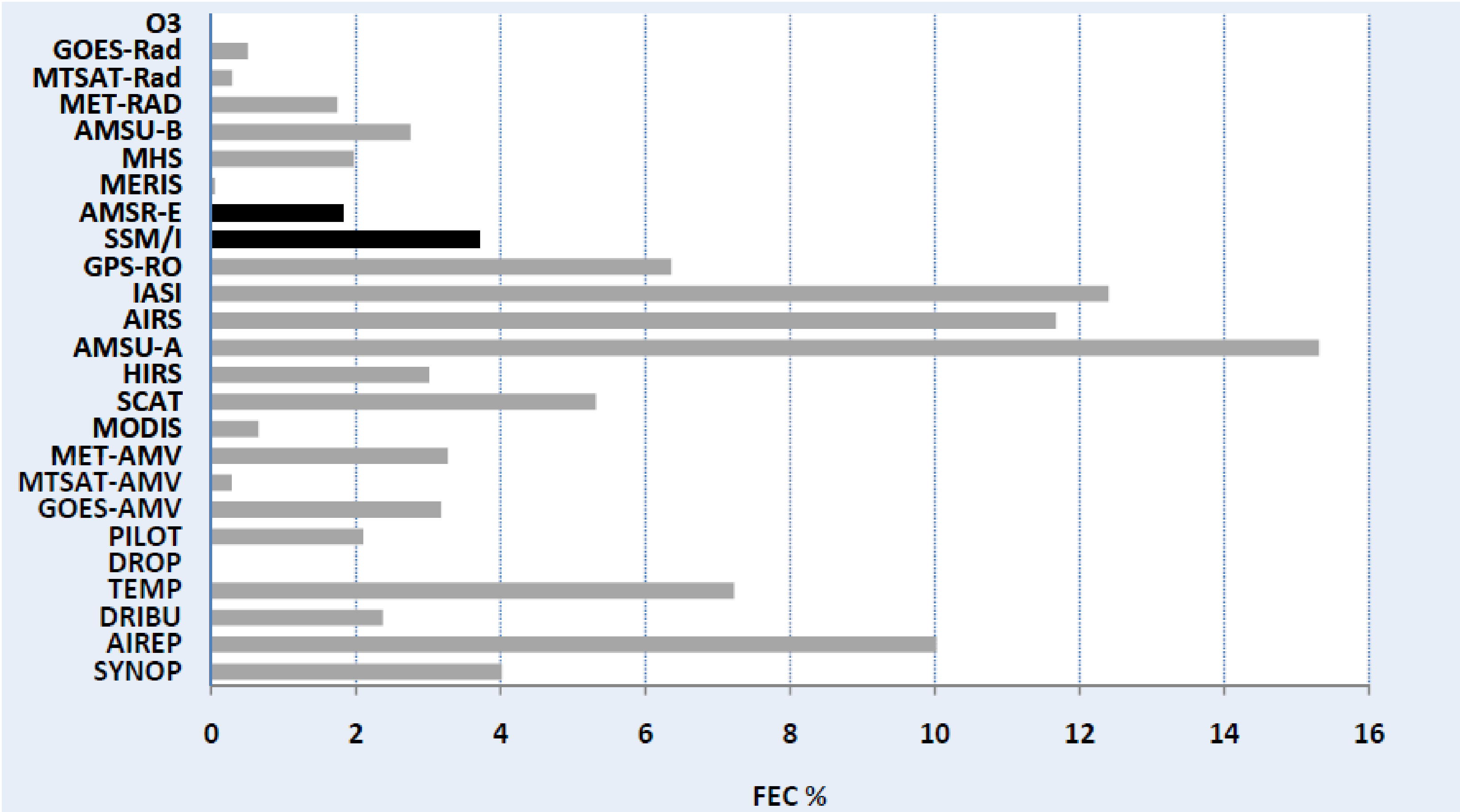
1. Ensemble of data assimilation

MSLP ensemble mean and standard deviation for forecasts initialized on 11 Dec 2009



(L. Isaksen et al.)

2. Microwave sounder observation errors

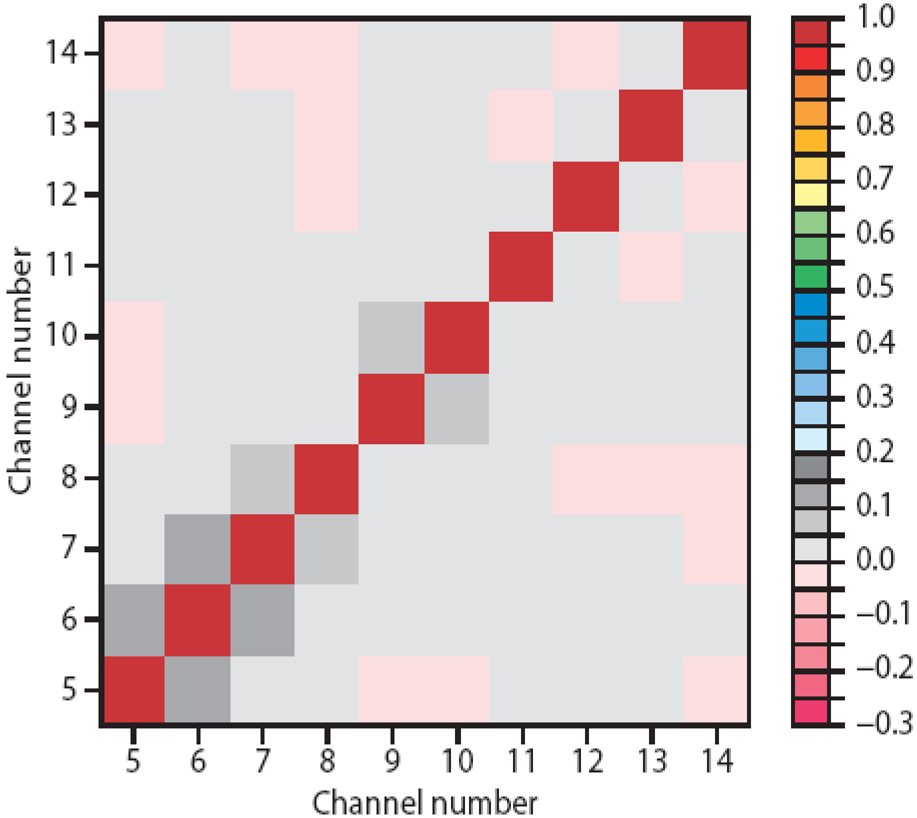


- AMSU-A currently most important single observing system (5 satellites)
- = fct. (data volume, single observation impact, synergy with others)
- Data thinning of 125 km to reduce volume & risk of spatial error correlation

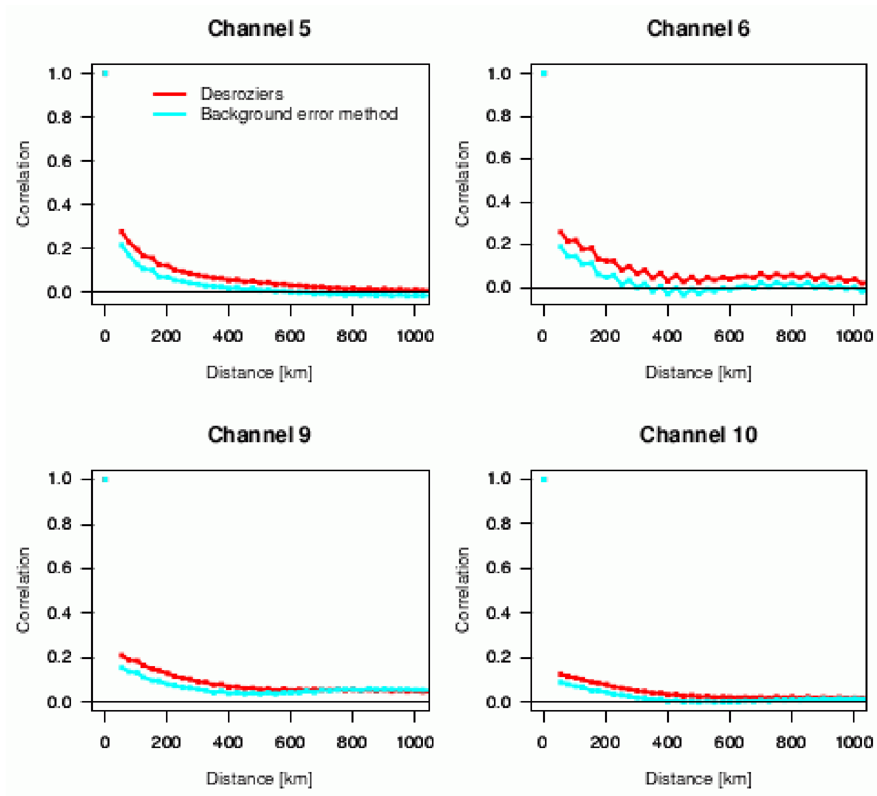
(C. Cardinali)

2. Microwave sounder observation errors

Inter-channel



Spatial



Comprehensive study on spatial and spectral observation error correlations for AMSU-A/B, MHS, AIRS, IASI, SSM/I, AMSR-E, TMI by Bormann et al. (QJRMS).

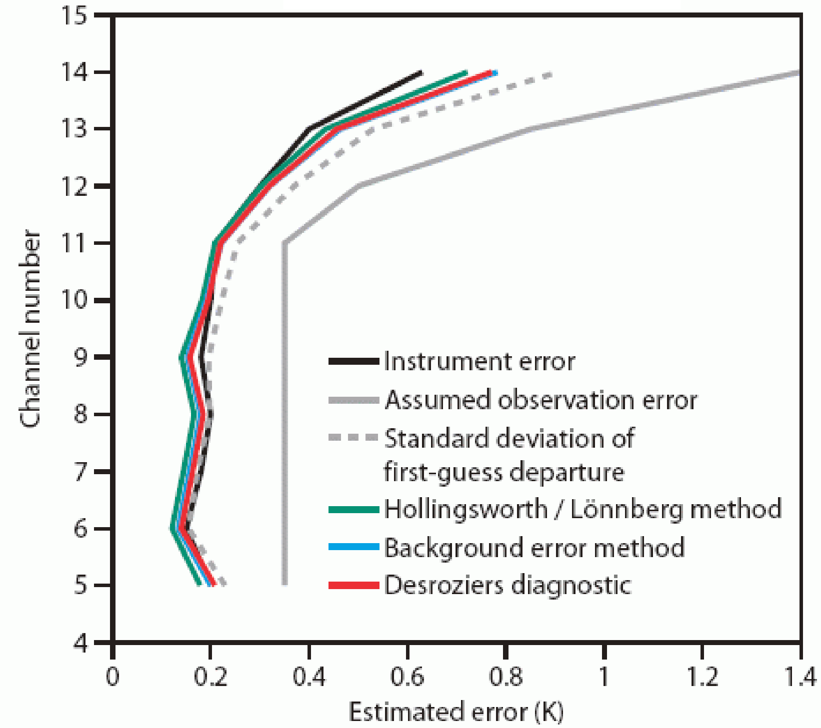
(N. Bormann et al.)

2. Microwave sounder observation errors

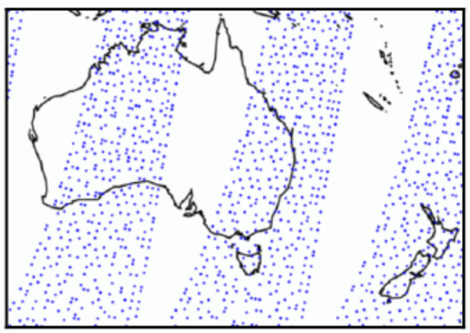
Weight in analysis mostly driven by:

- sensitivity,
- observation/background errors, →
- data density

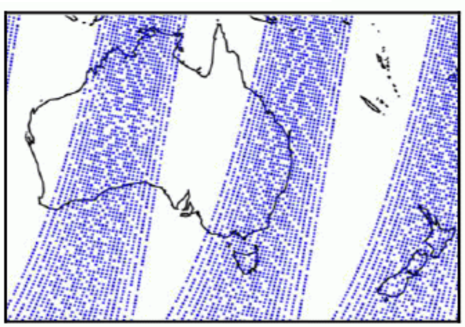
Error estimates



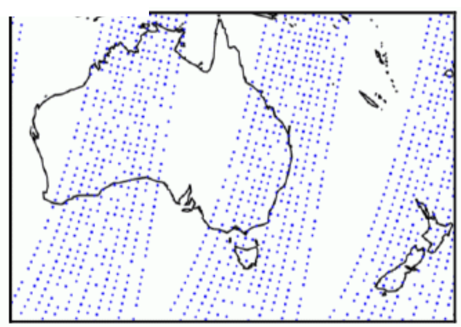
125 km thinning due to spatial observation error correlation



Revised thinning to 60 km for channels 5-10



channel 11



(N. Bormann et al.)

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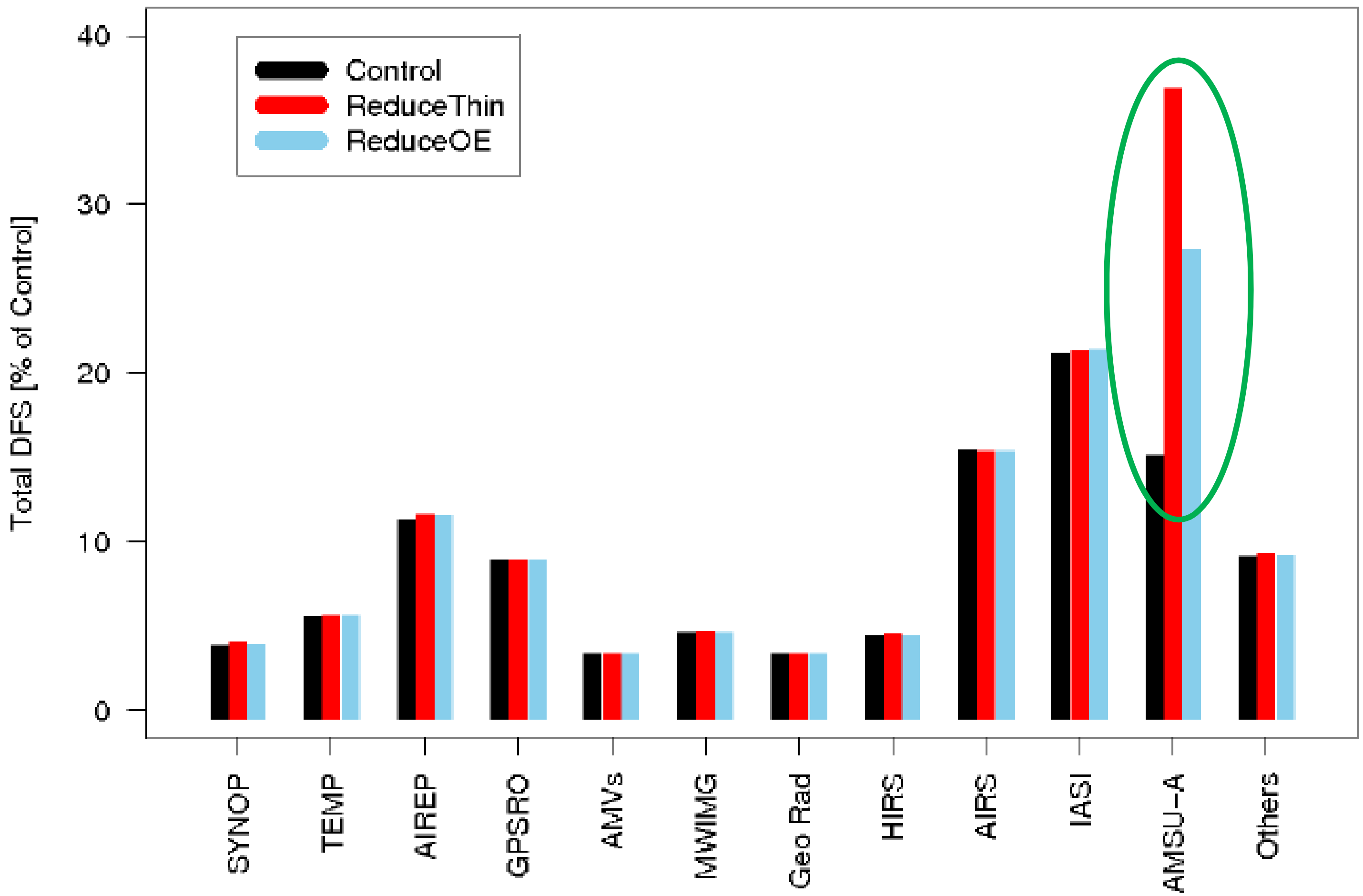
2. Microwave sounder observation errors

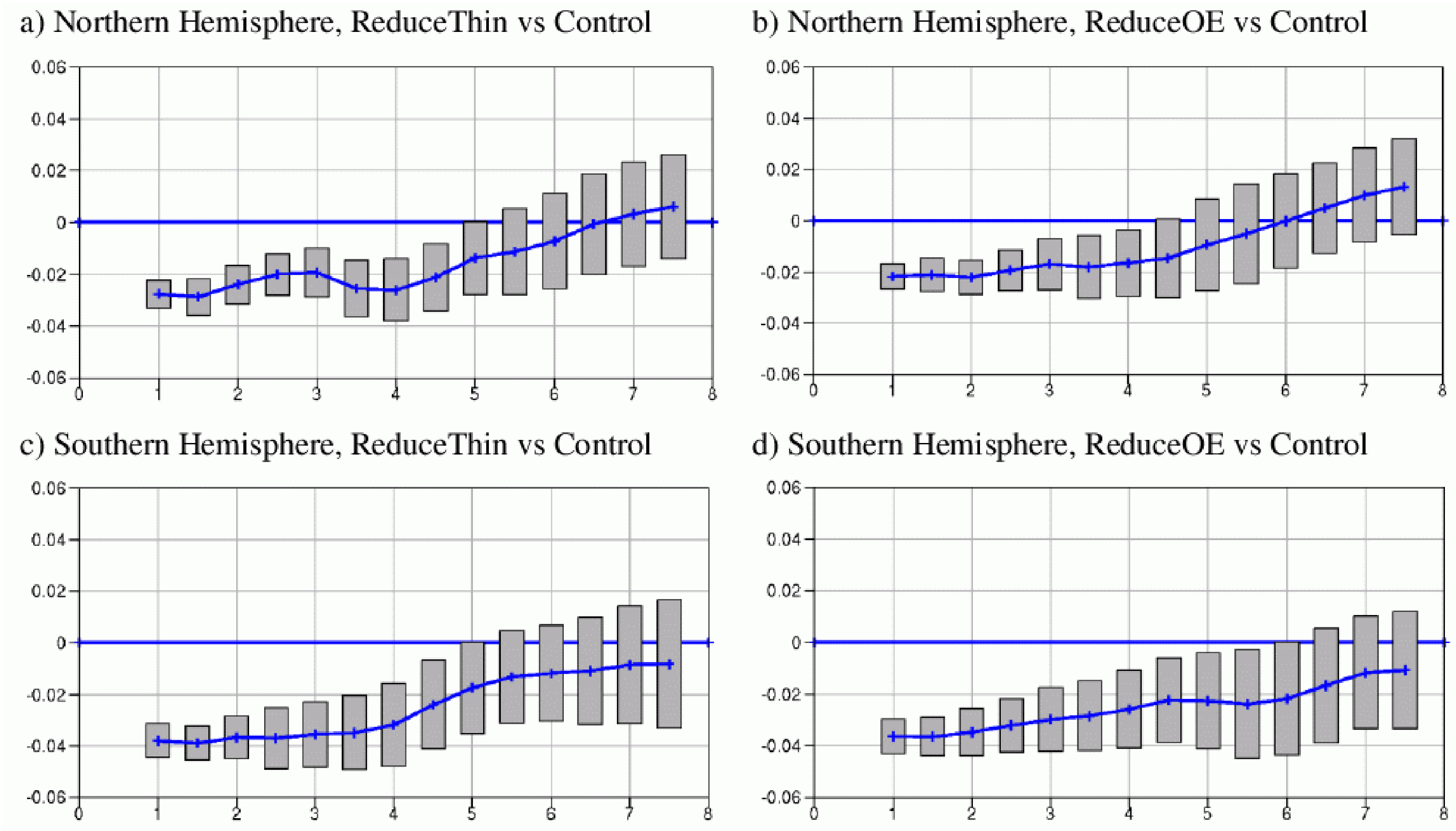
Increase in AMSU-A information content in analysis
= trade-off between volume and single observation impact



(N. Bormann & C. Cardinali)

2. Microwave sounder observation errors

Increase in 500 hPa geopotential height forecast impact
= trade-off between volume and single observation impact



(N. Bormann et al.)

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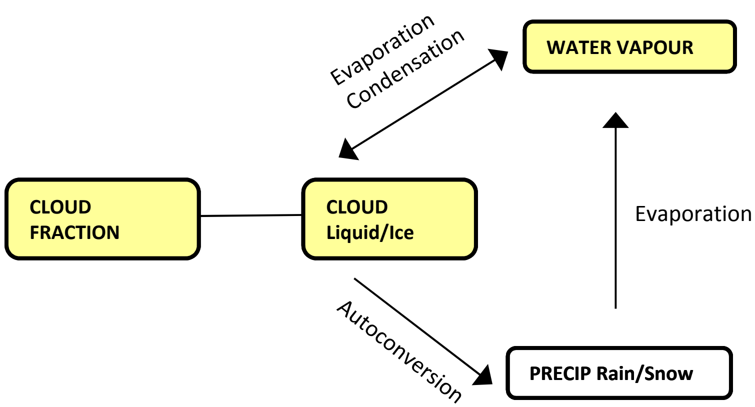
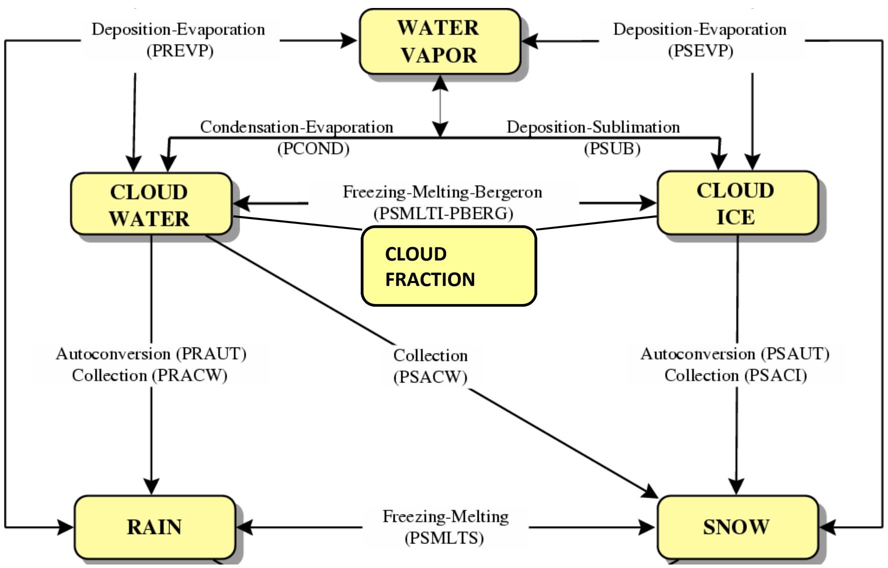
3. New cloud scheme

Old Cloud Scheme



- 2 prognostic cloud variables + w.v.
- Ice/water diagnostic fn(temperature)
- Diagnostic precipitation

New Cloud Scheme (since 11/2010)

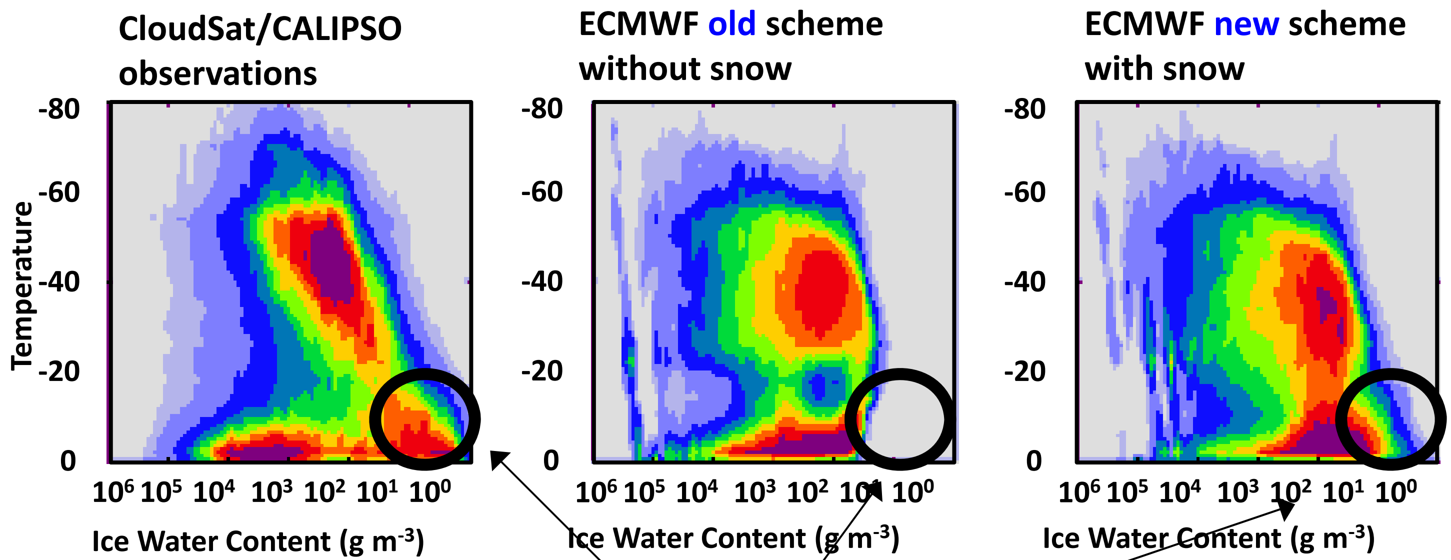


- 5 prognostic cloud variables + water vapour
- Ice and water now independent
- More physically based, greater realism
- Significant change to degrees of freedom
- Change to water cycle balances in the model
- More than double the lines of “cloud” code!

(R. Forbes)

3. New cloud scheme – how good is it?

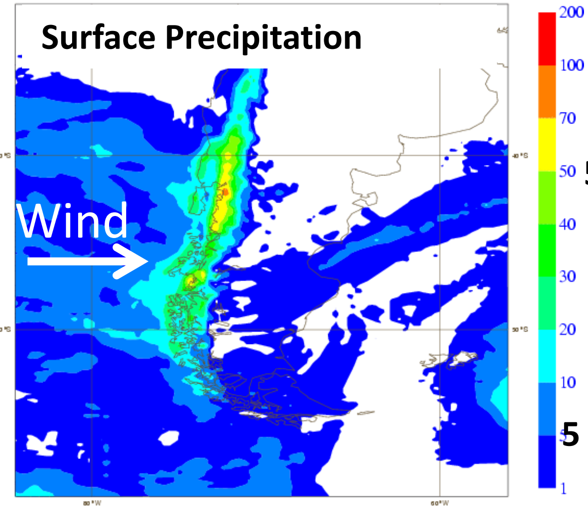
Relative frequency of occurrence of ice/snow for NH mid-latitudes in June 2006: ECMWF model vs. Cloudsat/Calipso retrievals

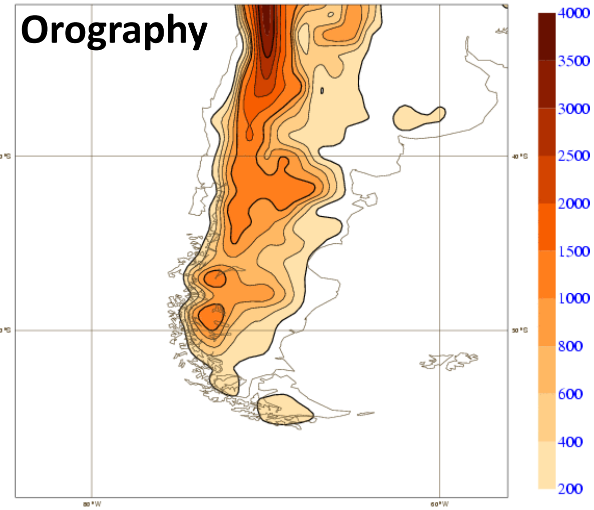


New scheme with prognostic ice and snow allows much higher ice water contents (seen by the radiation scheme)

(R. Forbes et al.)

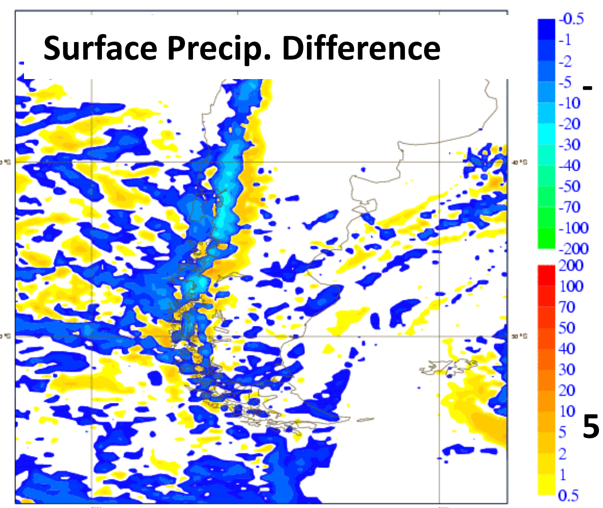
3. New cloud scheme – how good is it?

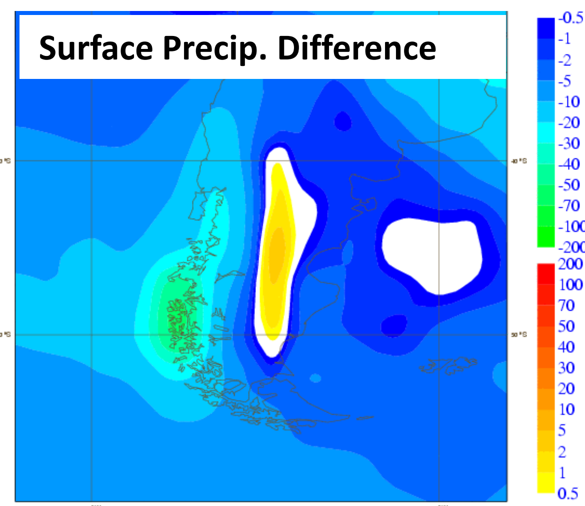




July 2007 case study (36 hour accumulation)

1 year average





“Prognostic snow” minus “Diagnostic snow”　　“Prognostic snow” minus “Diagnostic snow”

(R. Forbes)

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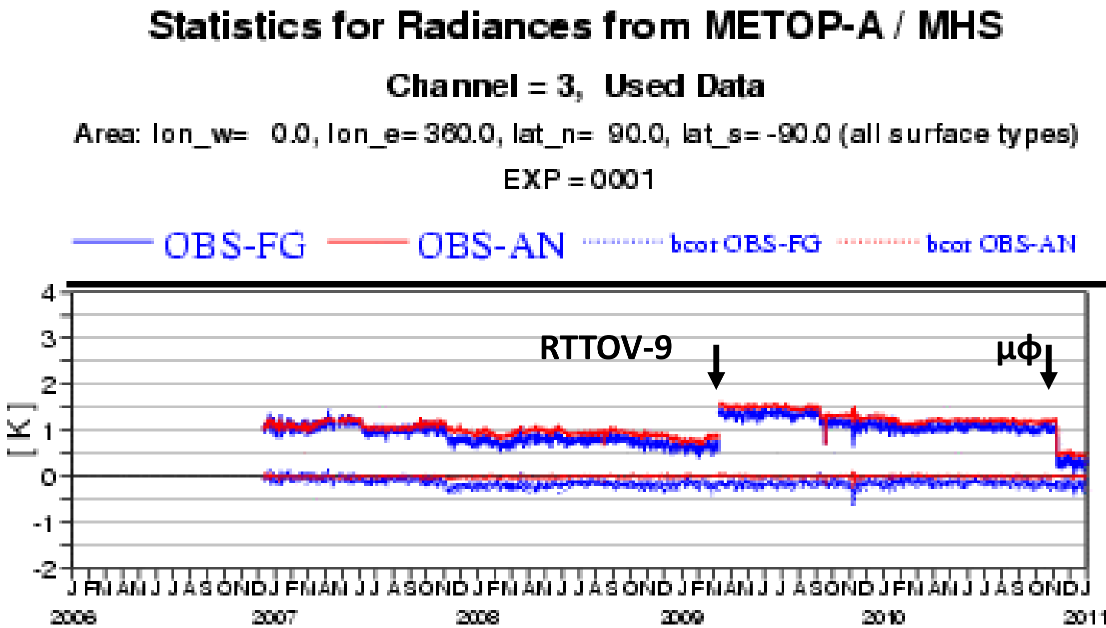
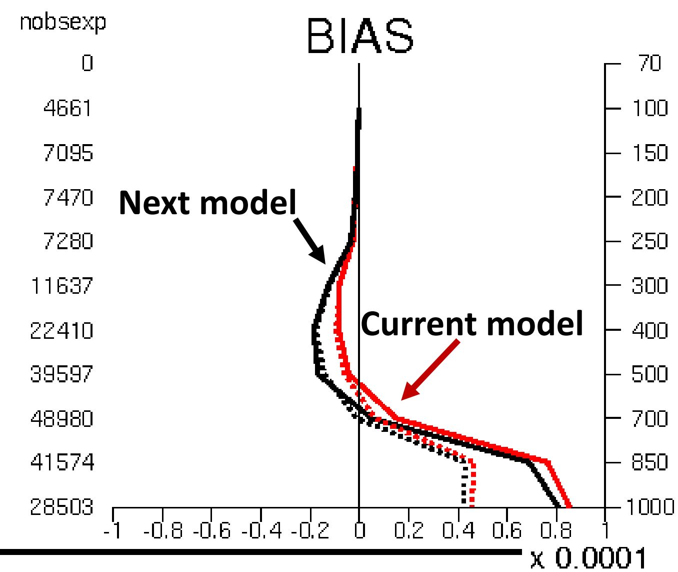
3. New cloud scheme - side effect No. 1

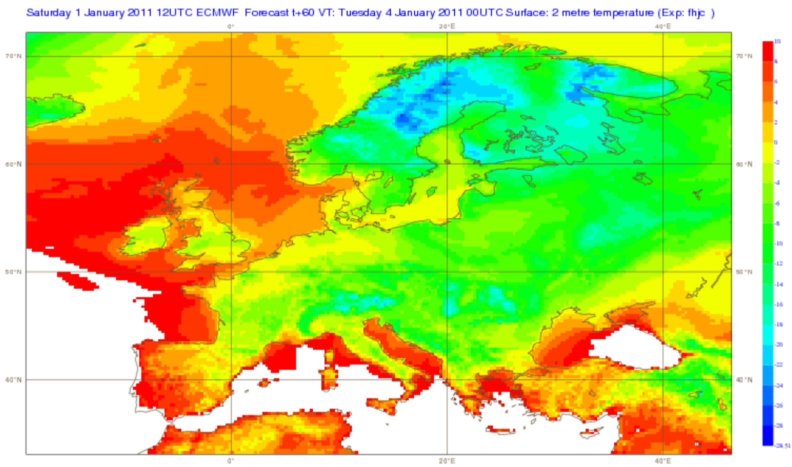
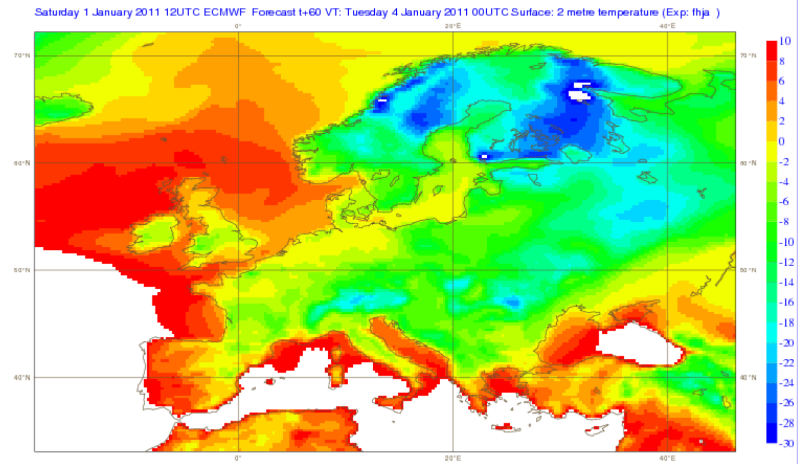
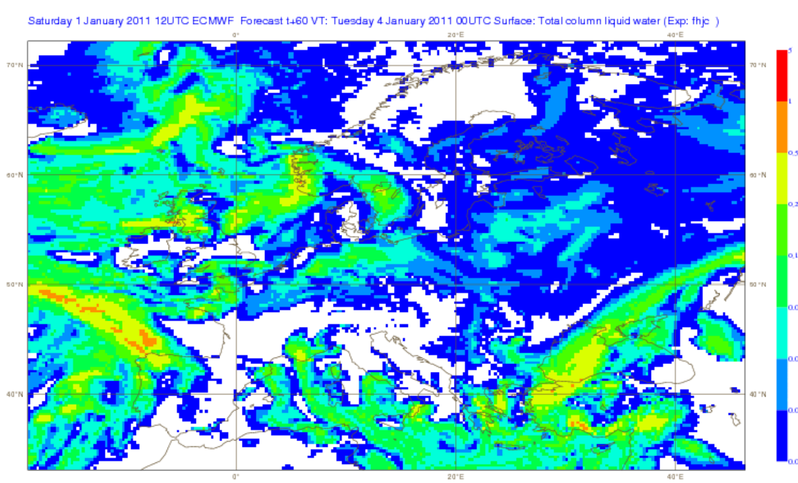
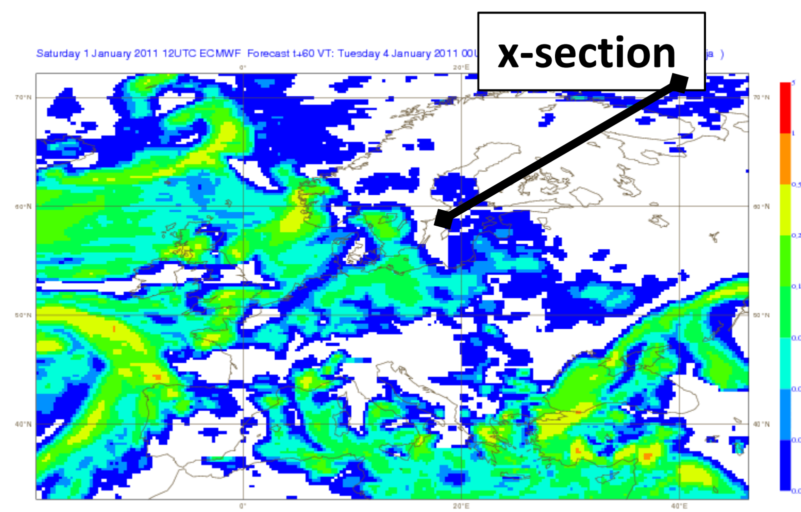


Time series of fit between upper tropospheric MHS and model radiances



Systematic difference between radiosonde and model specific humidity (kg/kg; NH 01/2011)

3. New cloud scheme - side effect No. 2

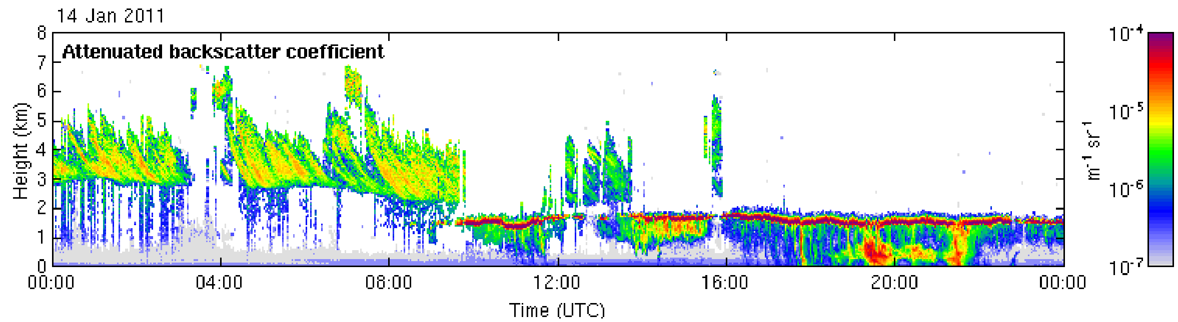
	Old Cloud Scheme	New Cloud Scheme
T2m		
TCLW		

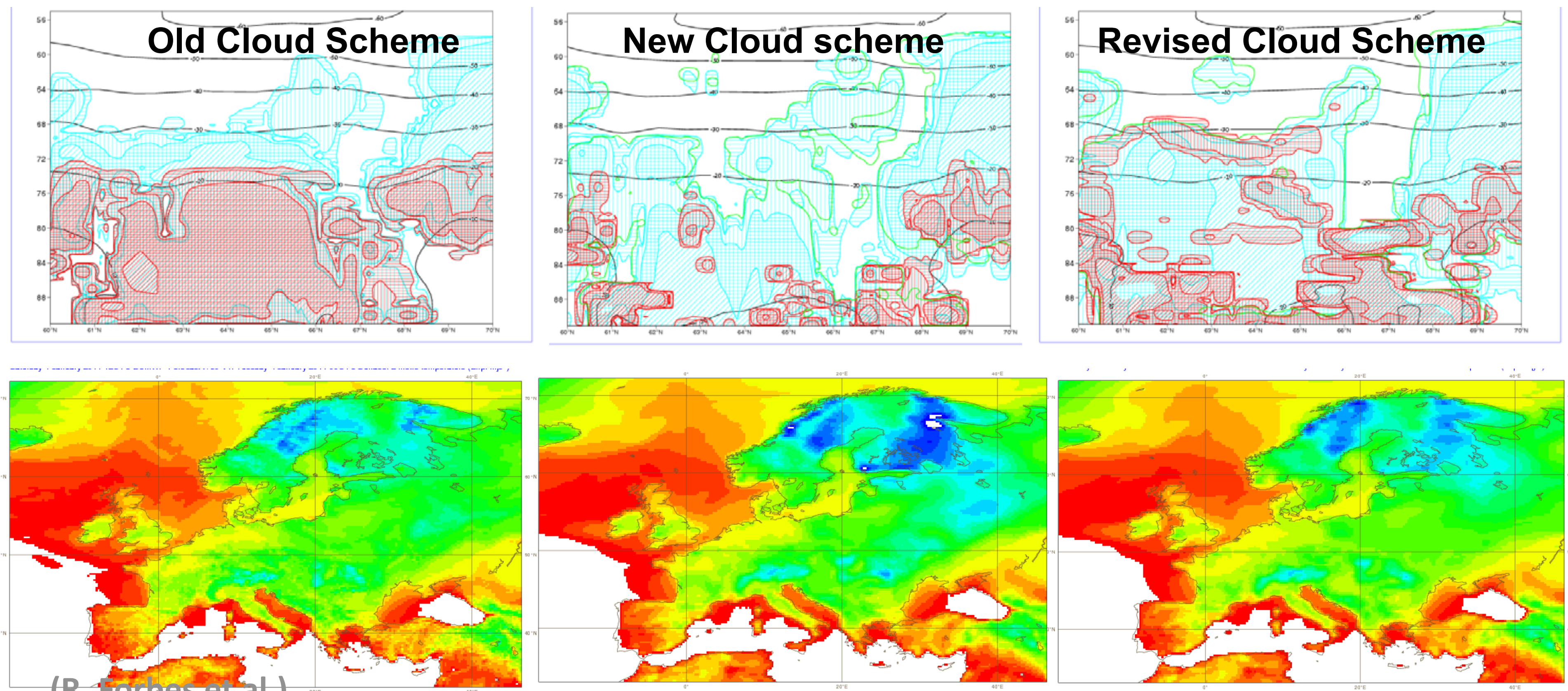
(R. Forbes et al.)

ECMWF

3. New cloud scheme - side effect No. 2

Ceilometer observations Sodankyla/Finland:





(R. Forbes et al.)

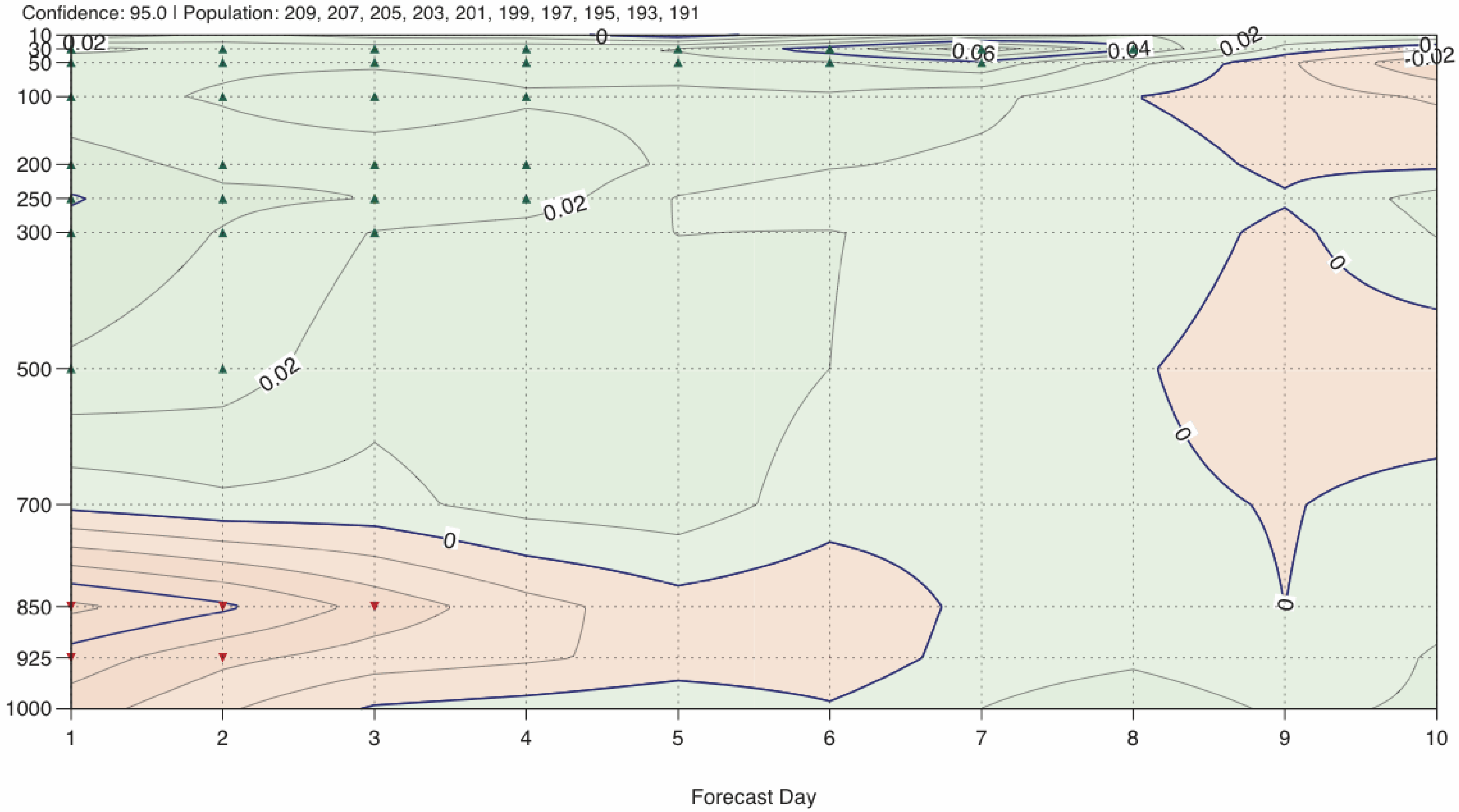
ECMWF

3. New cloud scheme - side effect No. 3

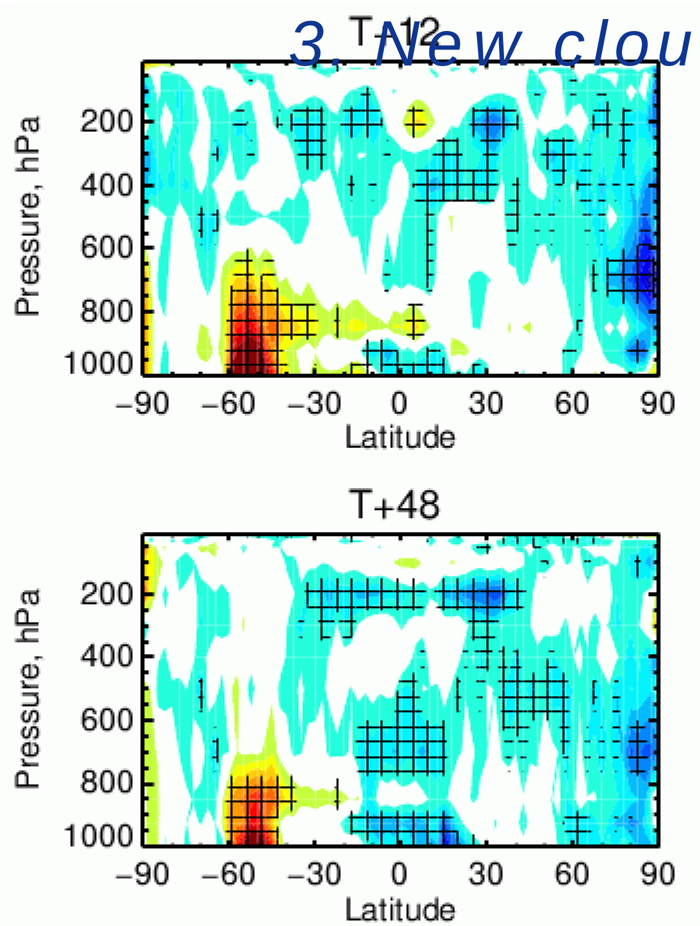
New cloud scheme produces also more liquid water in low-level clouds over Southern hemisphere oceans:

➔ systematic change in MW-imager departures

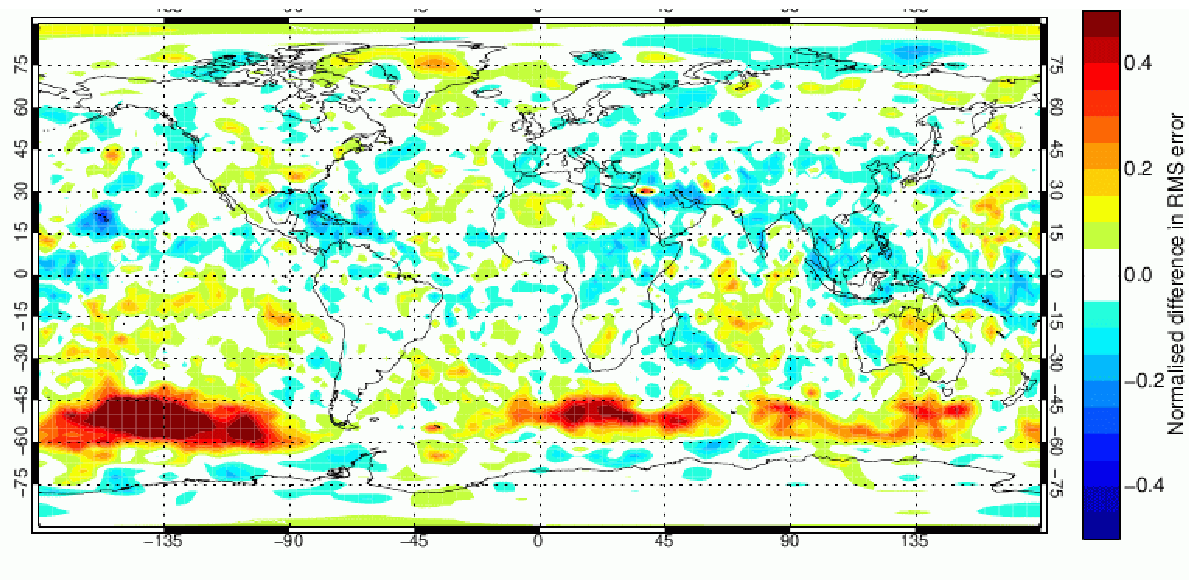
➔ systematic temperature increments (not so much moisture, dry)

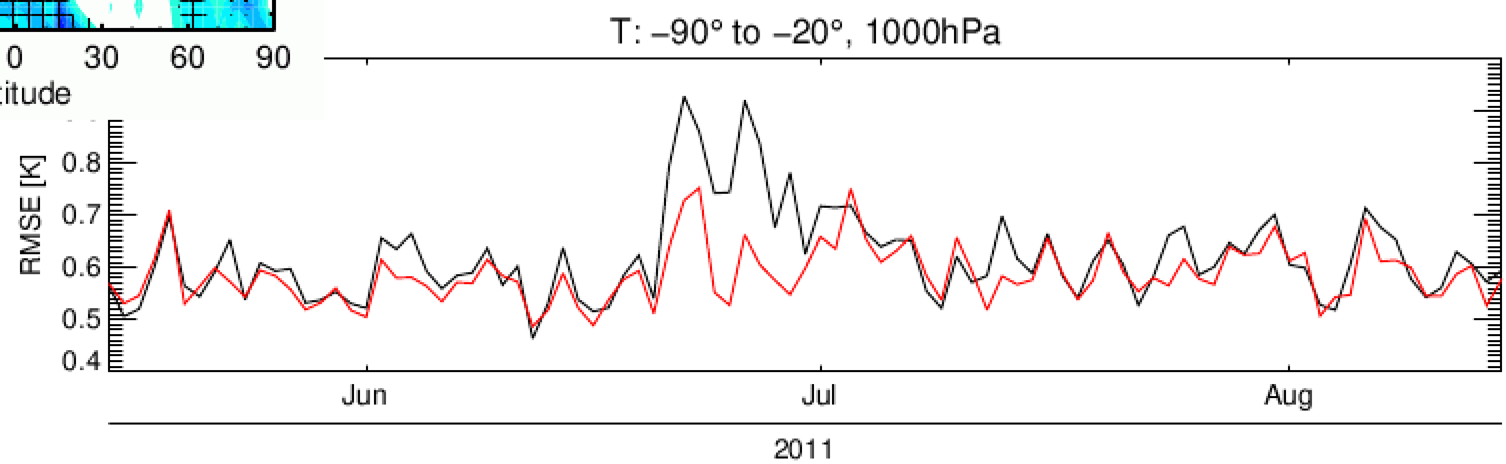


3. New cloud scheme - side effect No. 3



Normalized T-forecast error difference (e-o)





(A. Geer)

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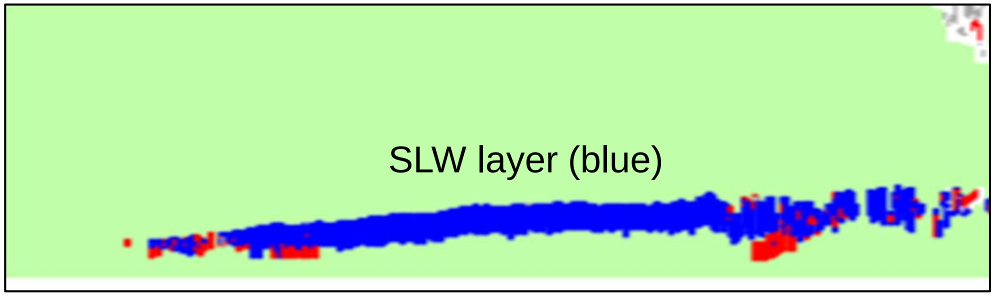
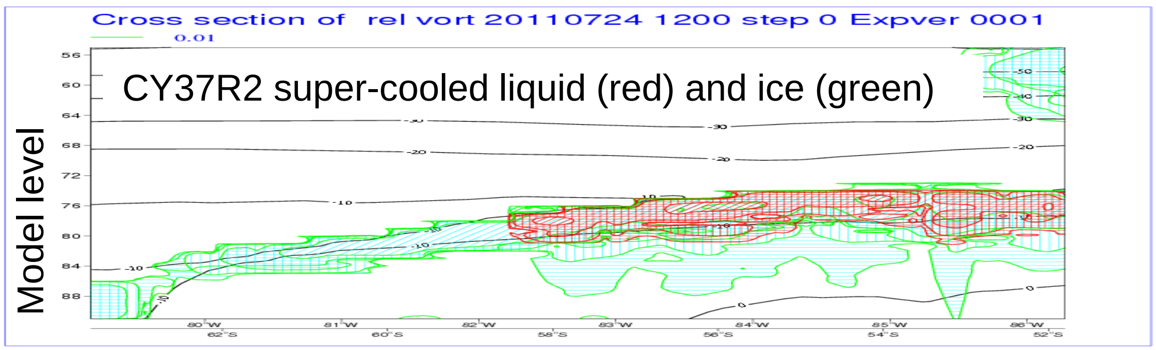
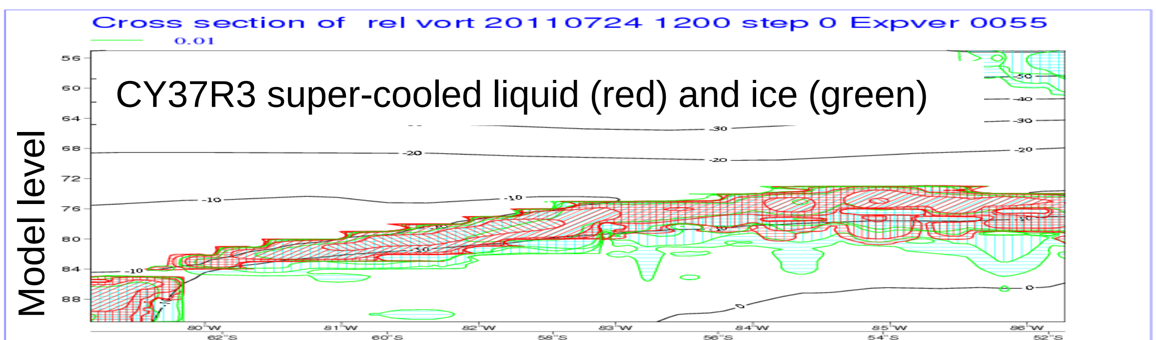
3. New cloud scheme - side effect No. 3







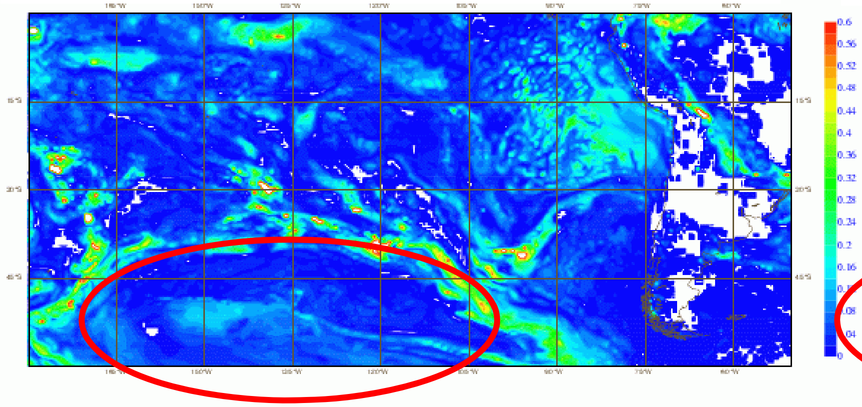
(R. Forbes)

- 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).

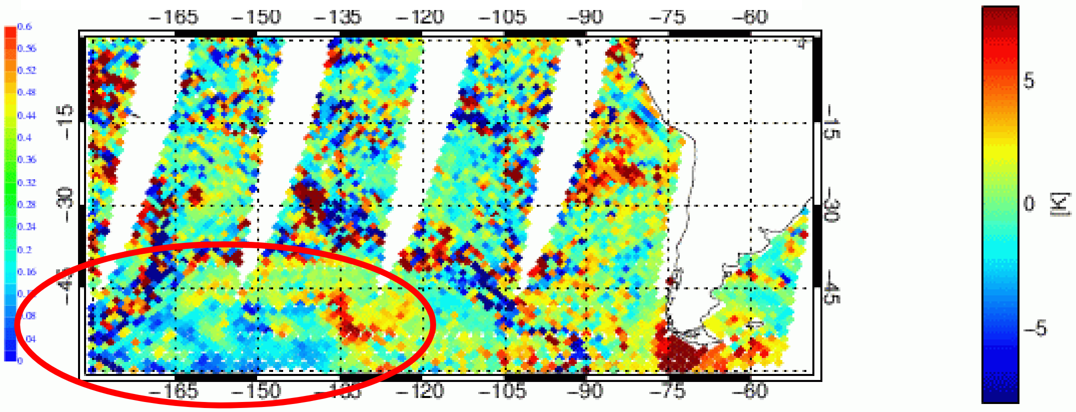
ECMWF

3. New cloud scheme - side effect No. 4

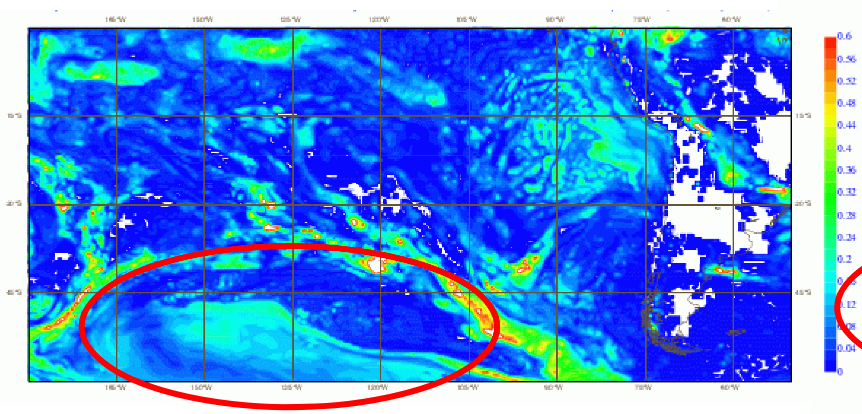
Cloud liquid water o-suite



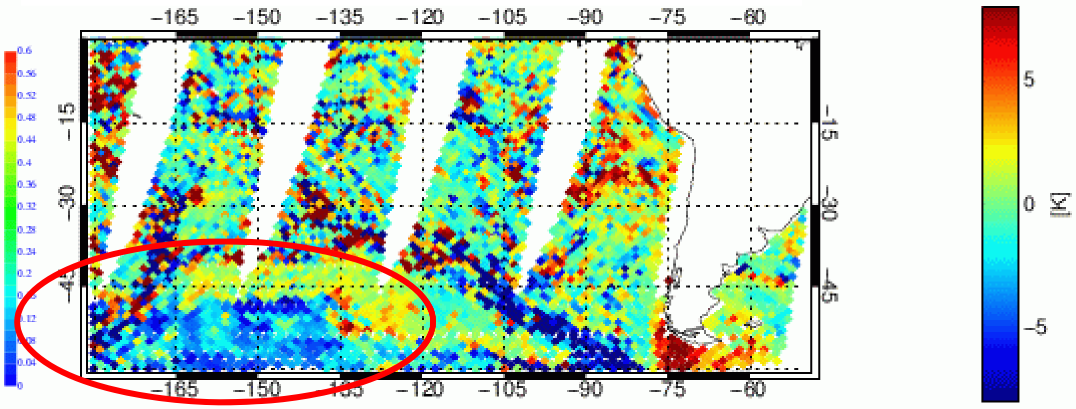
37GHz FG-departure o-suite



Cloud liquid water e-suite



37GHz FG-departure e-suite



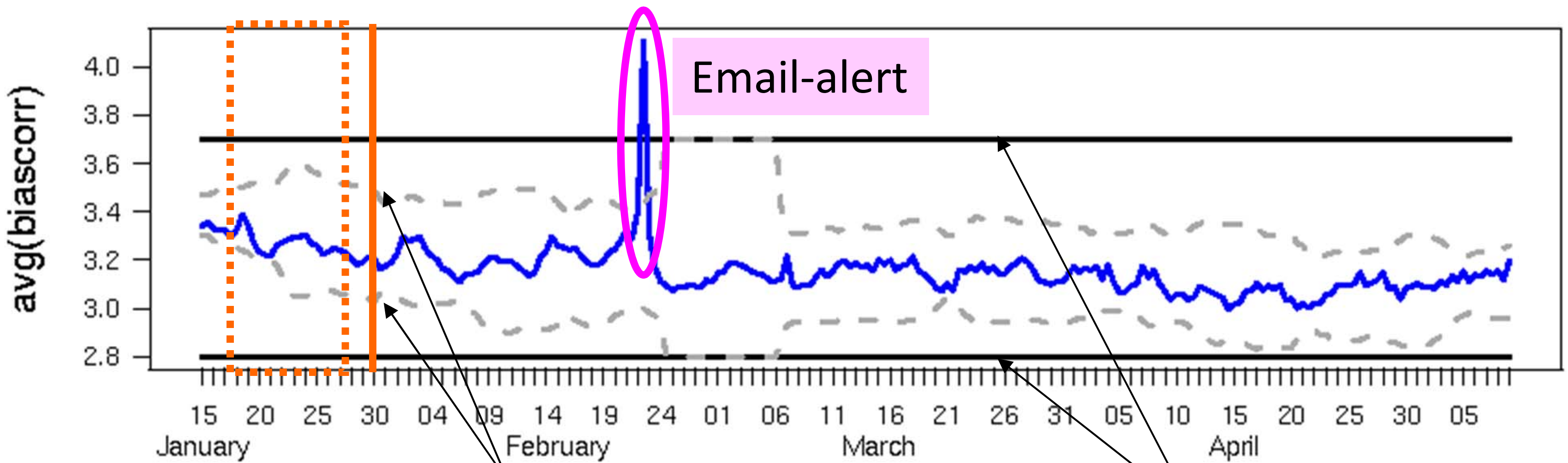
(A. Geer)

ECMWF

4. Data monitoring – automated warnings

Selected statistics are checked against an expected range:

- First-guess/analysis departures
- Bias corrections
- Data counts
- Forecast error contribution



Soft limits (mean ± 5 stdev being checked, calculated from past statistics over a period of 20 days, endi earlier)

Hard limits (fixed)

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
```

(M. Dahoui & N. Bormann)

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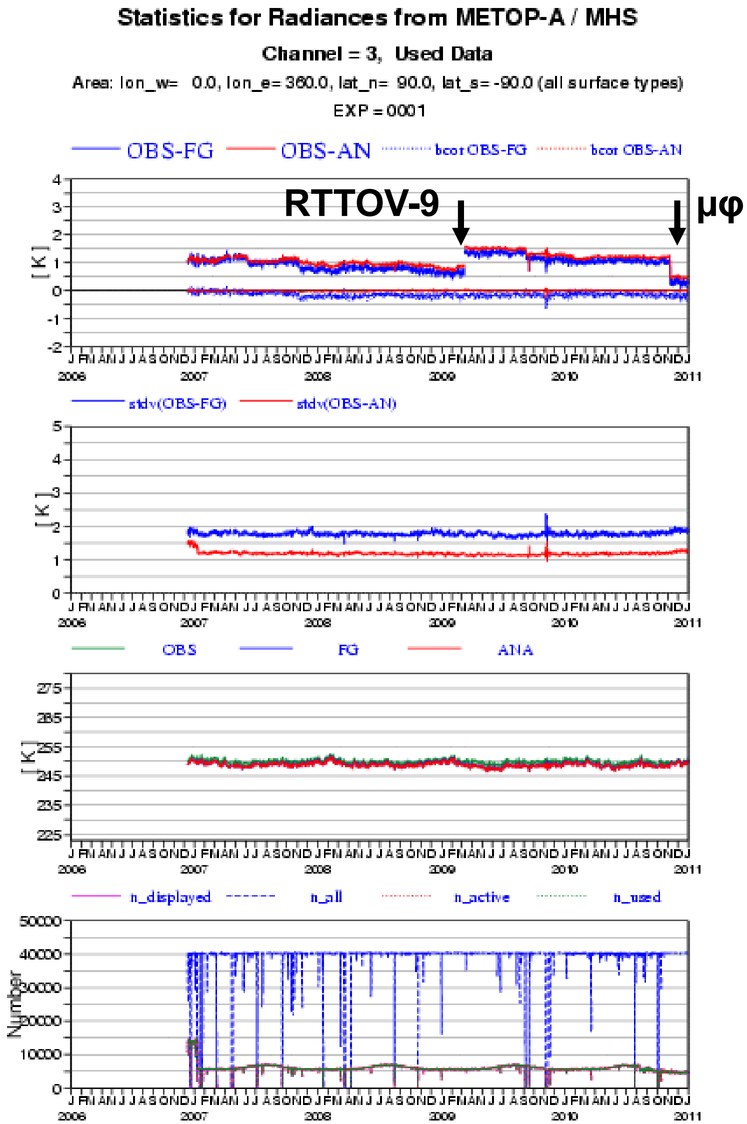
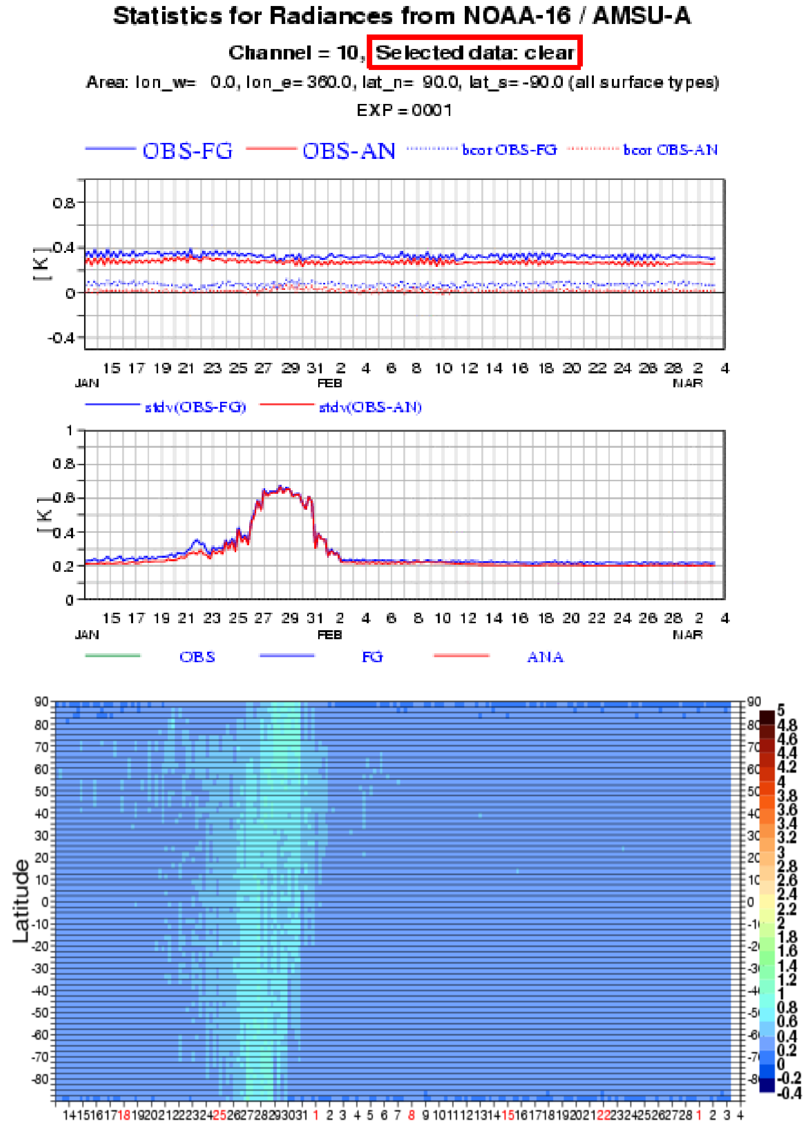
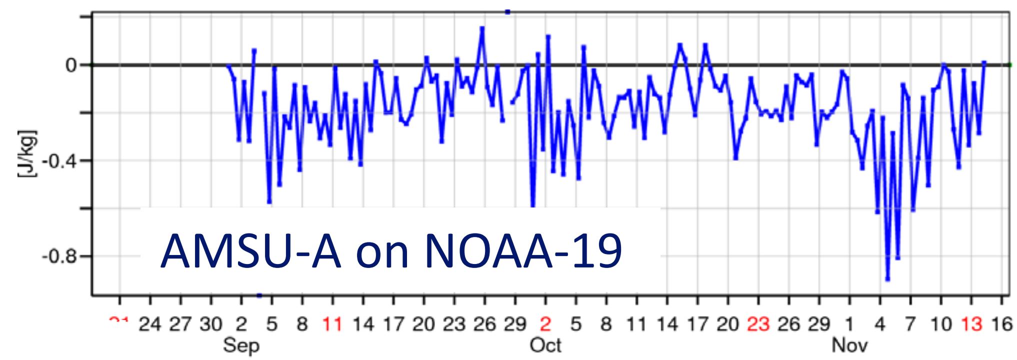
4. Data monitoring – model vs data issues

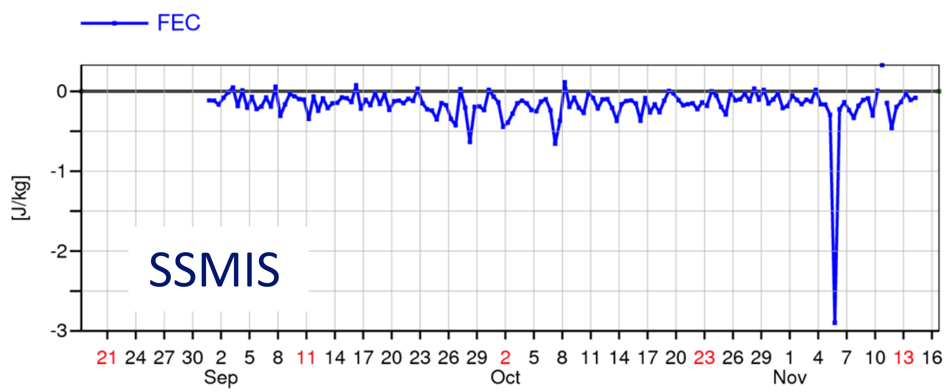


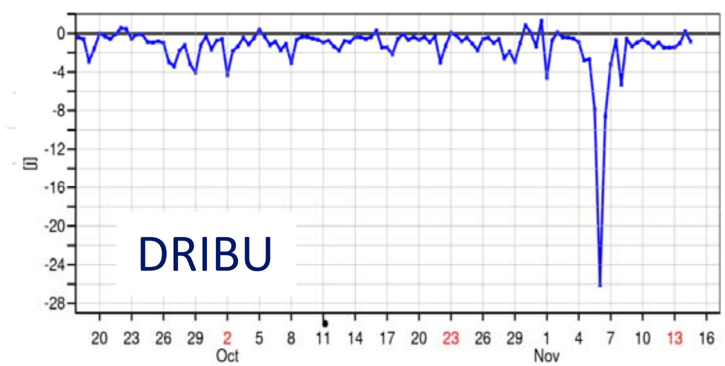


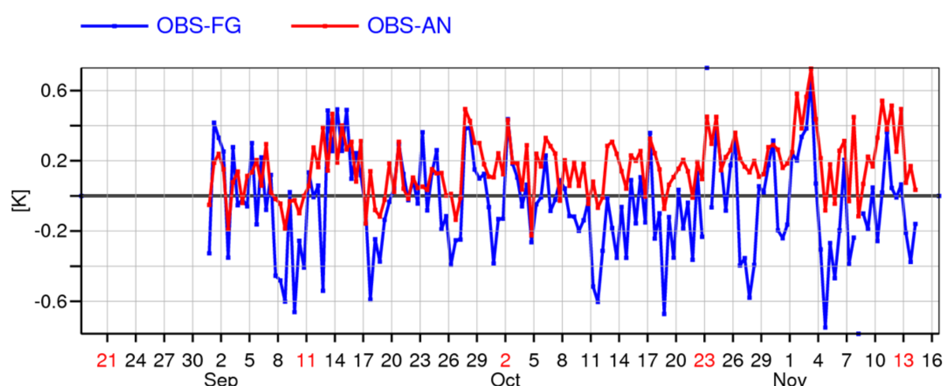
4. Data monitoring – North Atlantic storm

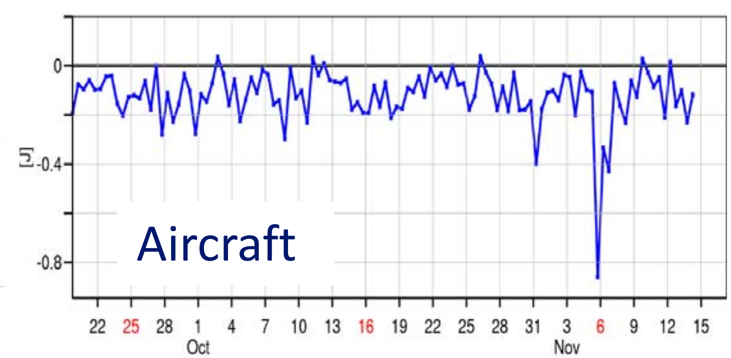
FEC = contribution of observation to reduce short-range forecast error (= dry energy norm, moist adjoint)











(A. Geer et al.)

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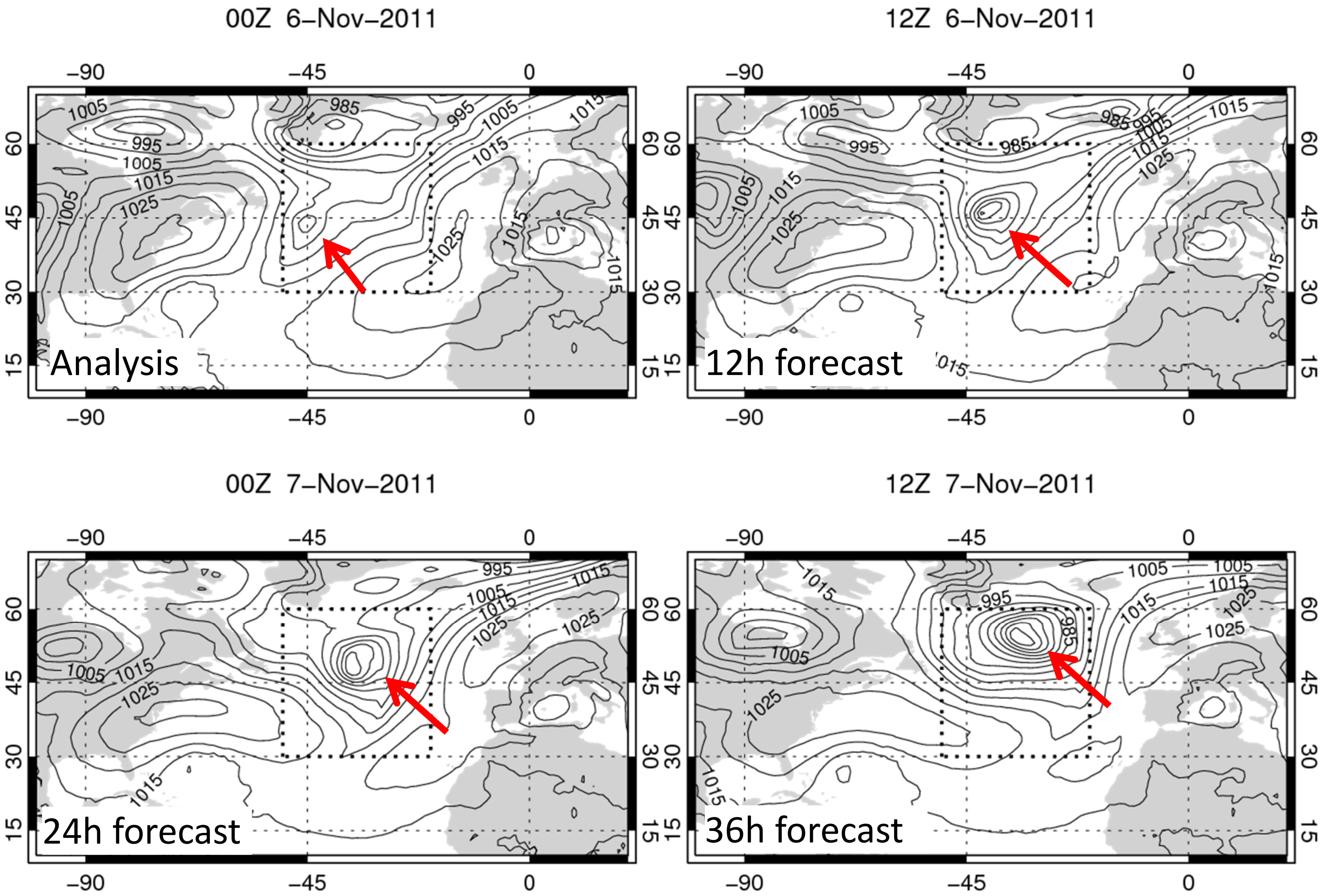
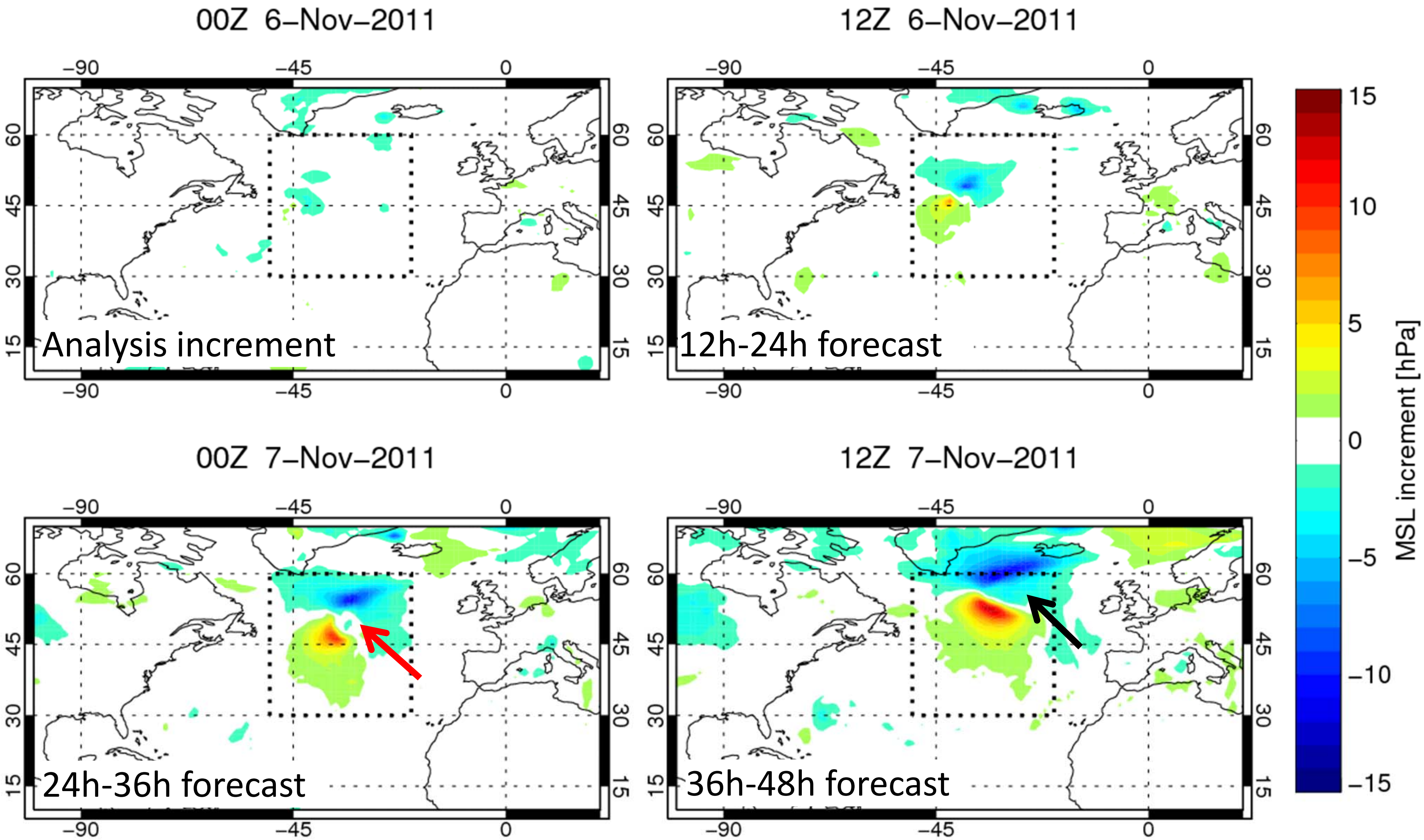
4. Data monitoring – North Atlantic storm



Minimum pressure evolves from 990 hPa to 950 hPa in 40 hours

(A. Geer et al.)

4. Data monitoring – North Atlantic storm



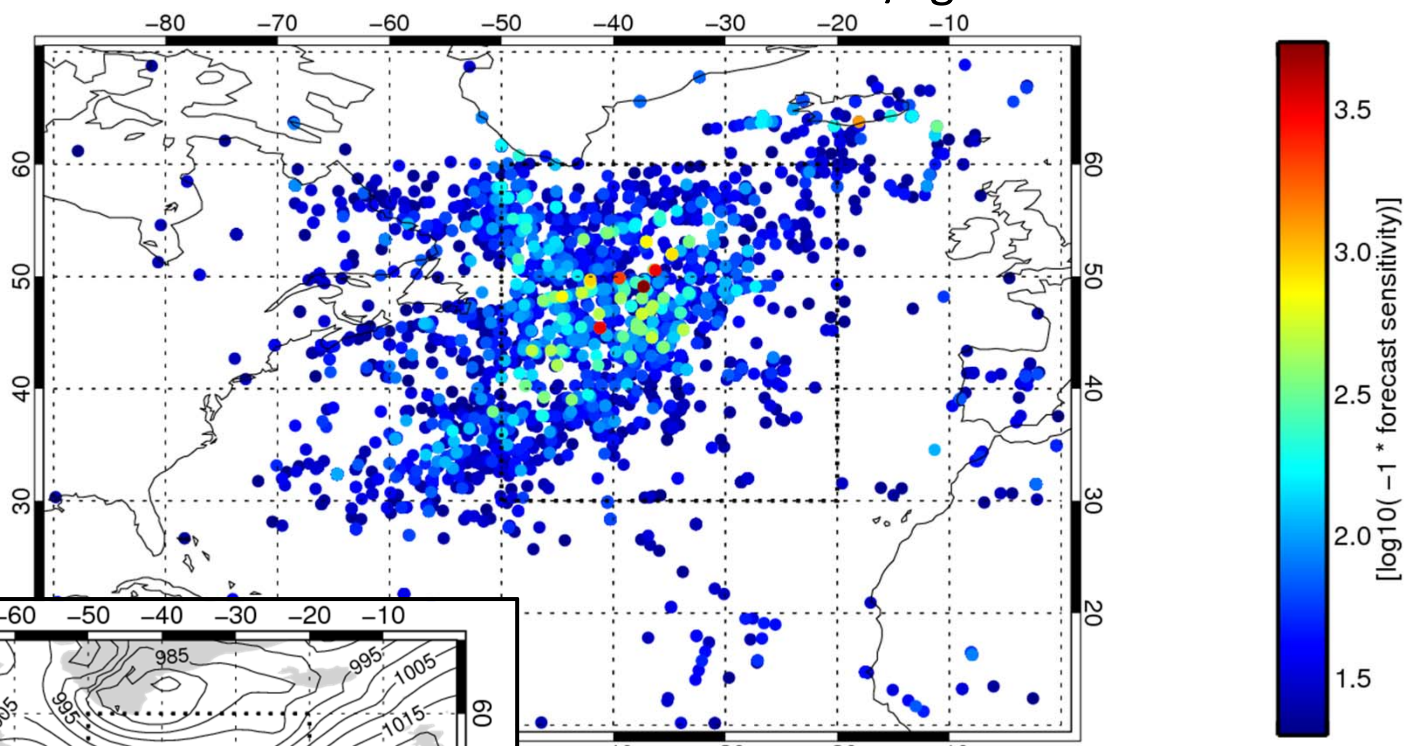
00Z 6th Nov analysis shifts the storm to the NW

(A. Geer et al.)

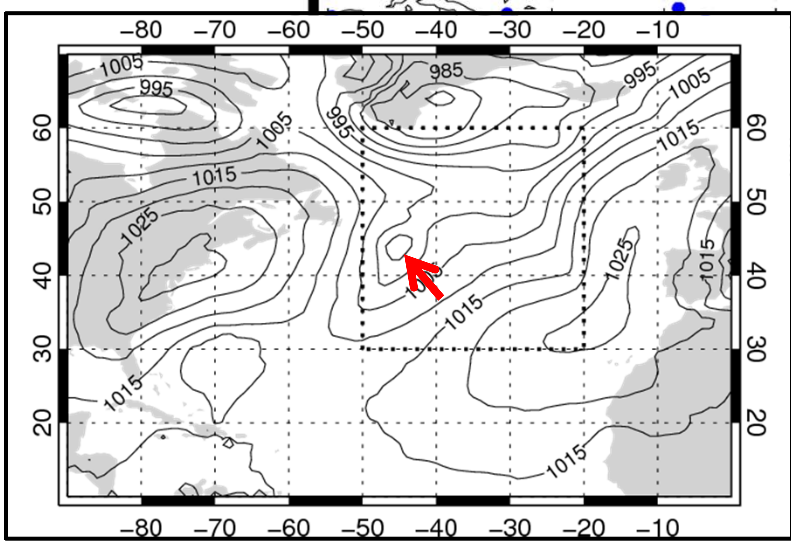
ECMWF

4. Data monitoring – North Atlantic storm

All observations with FEC < -20 kJ/kg



FEC: Log-scale

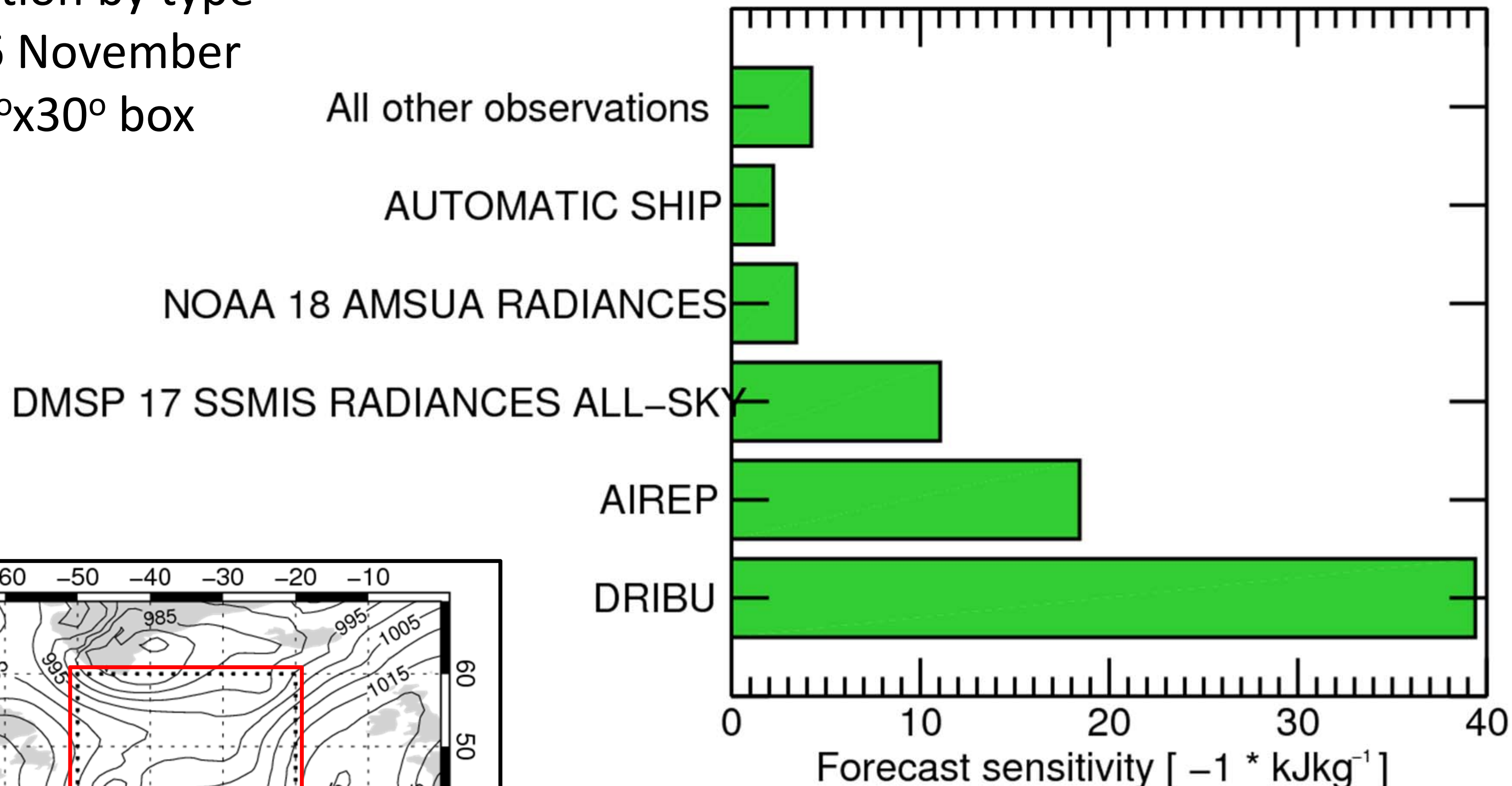


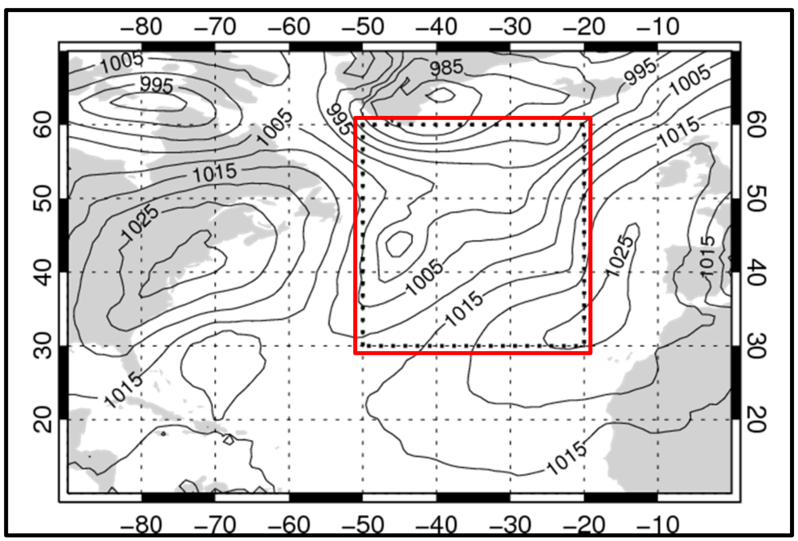
MSLP

(A. Geer et al.)

4. Data monitoring – North Atlantic storm

FEC-contribution by type for analysis 6 November 00 UTC in 30ºx30º box





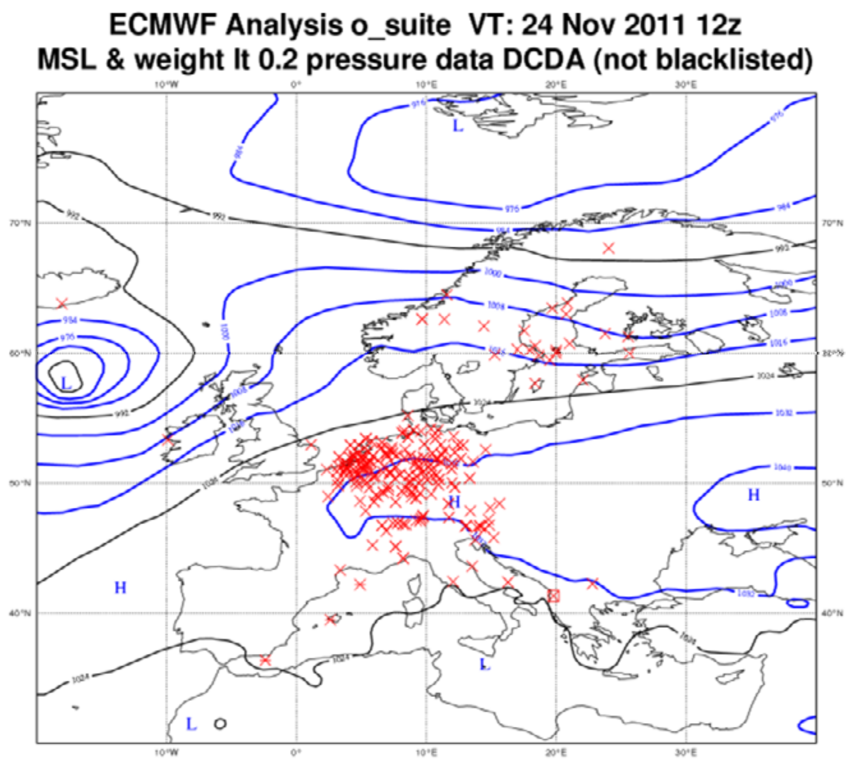
MSLP

(A. Geer et al.)

ECMWF

4. Data monitoring – Surface pressure observations

- RMS (Observation-Analysis) frequently larger than RMS (Observation - Background) for SYNOP surface pressure averaged over N. Hem (and particularly over Europe).
- The DCDA analysis was drawing away from the observations.
- The data rejections (low weights) were a symptom of an underlying problem that has been in the system since the resolution upgrade to T1279 (January 26th 2010).

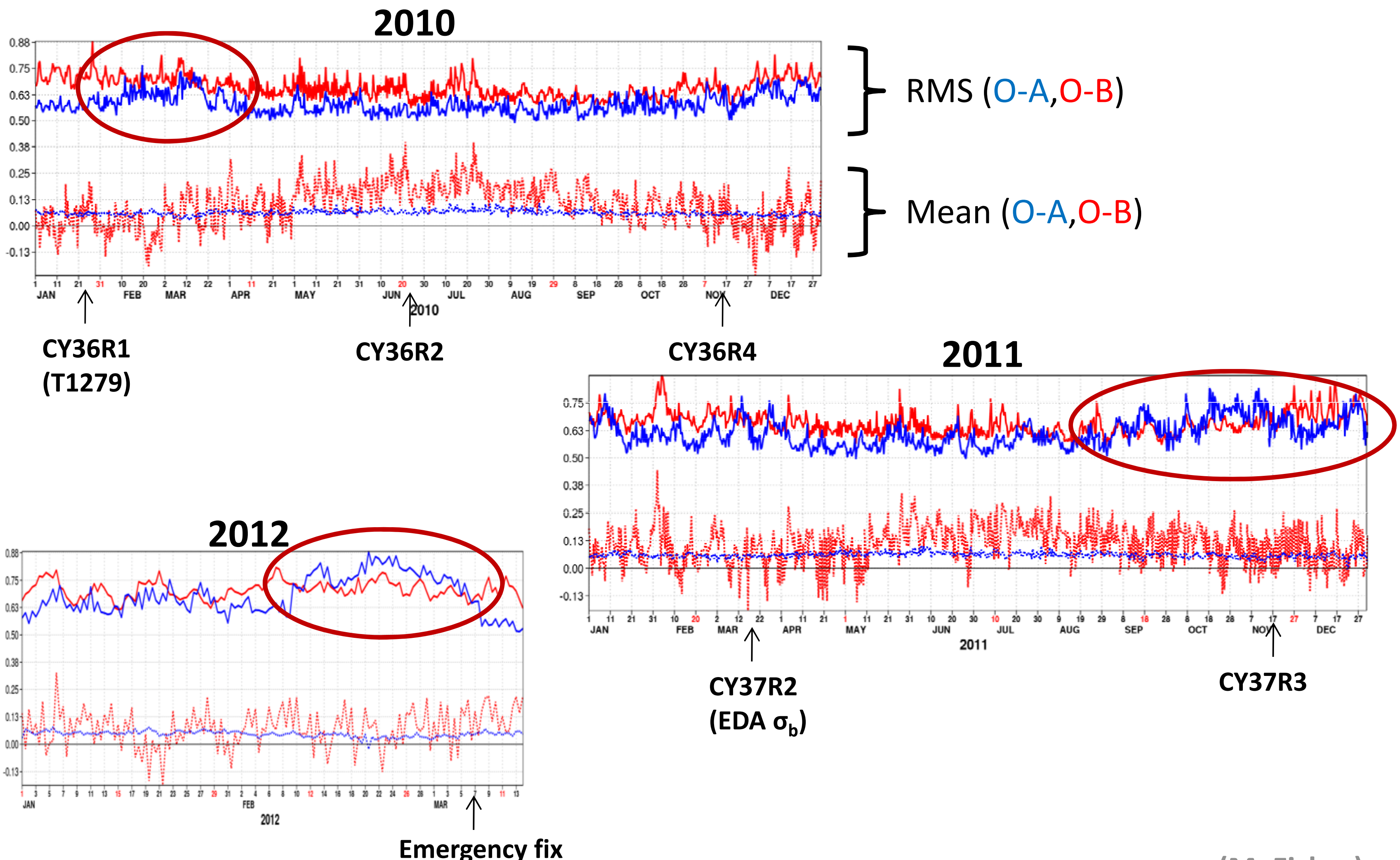


- Data rejections increased after the introduction of flow-dependent background-error statistics in May 2011, because rejection limits were sometimes tighter than previously.

(M. Fisher)

ECMWF

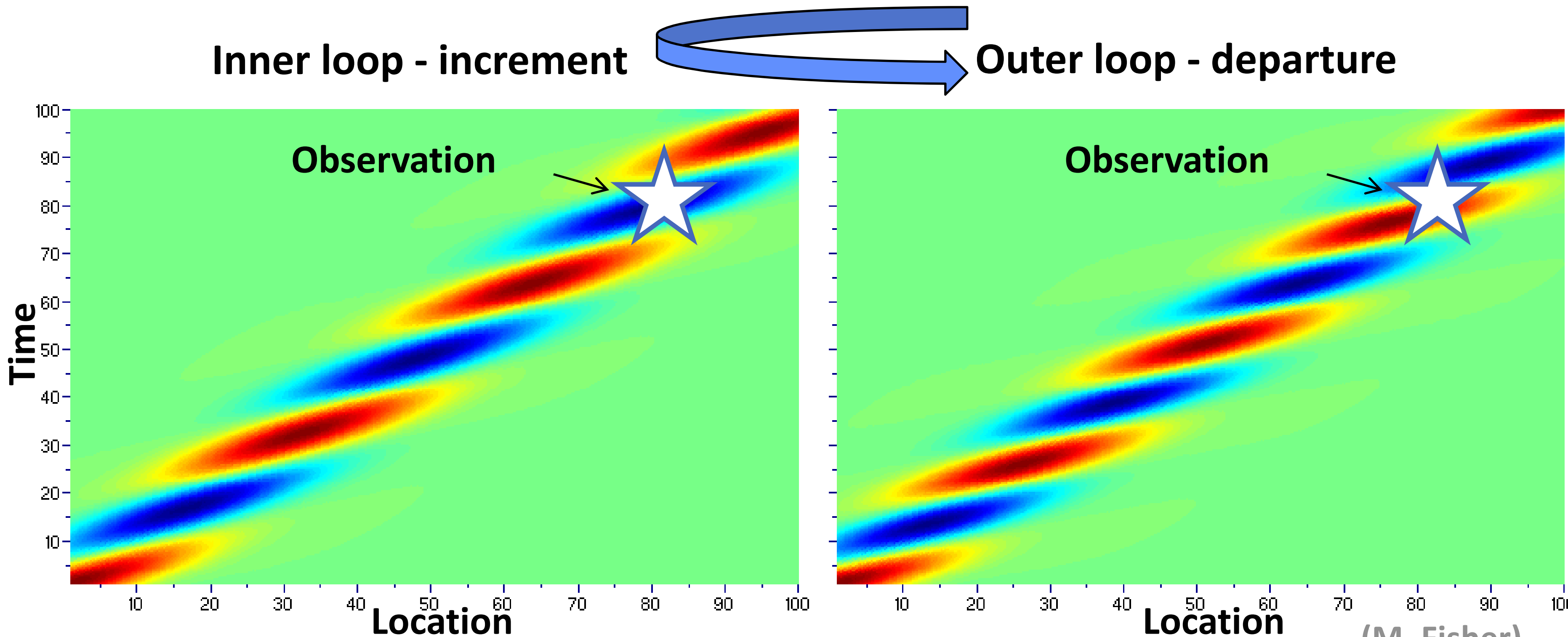
4. Data monitoring – Surface pressure observations



(M. Fisher)

4. Data monitoring – Surface pressure observations

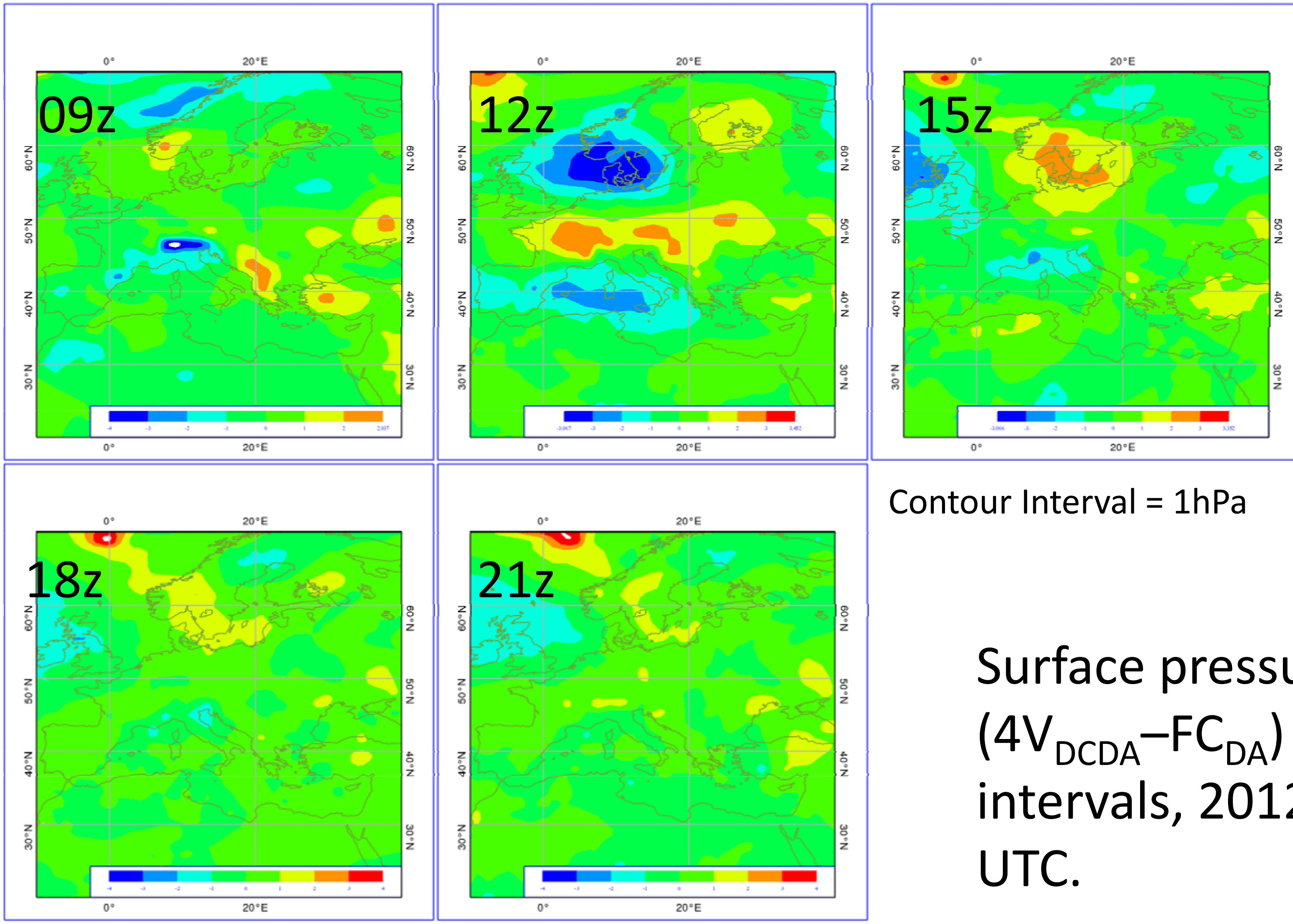
- Diverging outer loop caused by difference in gravity phase speeds between inner and outer loops due to different time steps (30' vs 10').
- T1279L91 upgrade in model resolution also included outer loop time step reduction.



(M. Fisher)

ECMWF

4. Data monitoring – Surface pressure observations

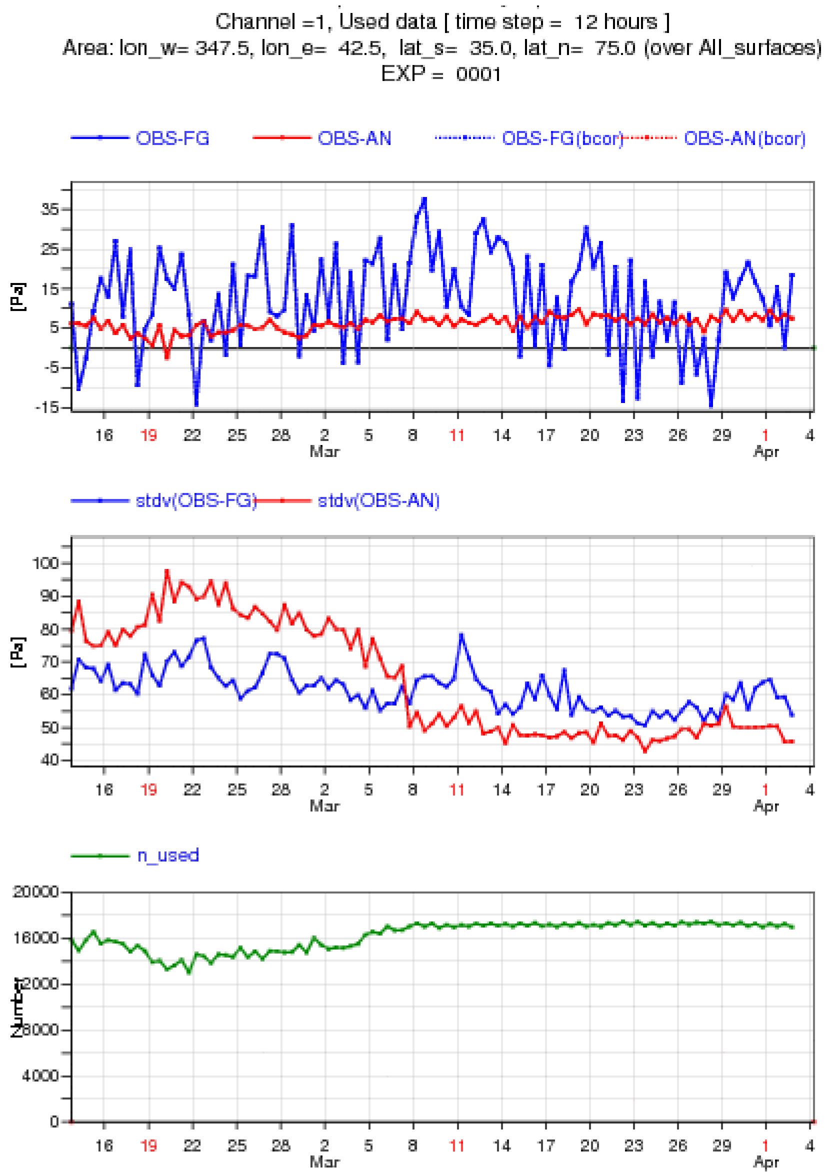


Contour Interval = 1hPa

Surface pressure ($4V_{DCDA}$–FC_{DA}) at 3-hourly intervals, 20120216 09-21 UTC.

(M. Fisher)

4. Data monitoring – Surface pressure observations



Fix through:

- increase of inner loop time step (costly),
- modify semi-implicit time integration (artificial),
- penalize rapid surface pressure oscillations though Jc (efficient filter but can reduce activity).

Lessons:

- Progress time stepping in sync. between inner and outer loop.
- Importance of data monitoring, and monitoring of analysis impact!

(M. Fisher)

Summary

Complex, inter-dependent analysis and forecasting system:

- High-resolution 4D-Var analyses, 10-day forecasts, wave model
- Low-resolution EDA-EPS, 15-day forecasts
- 50+ satellite sensors, 10 million observations per day
- Extension to monthly forecasts with ocean coupling
- Seasonal forecasting system
- Reanalysis, atmospheric composition systems

Cycle updates:

- ~2 per year, affecting everything (but seasonal, reanalysis, composition)
- Comprehensive testing (~1 year of full resolution testing + RD precursors)
- Pressure on diagnostics, data (impact) monitoring

Major near-future milestones:

- Resolution (HiRes/EPS: L137/L91 in 2012/13, T2047/T1023 in 2015/16)
- 25-member EDA, inner loops, radiation
- Investment in grey zone, land surface, ocean modelling, coupled DA, etc.

ECMWF