Data assimilation at ECMWF

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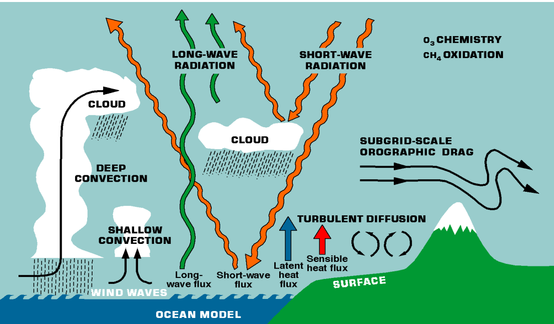
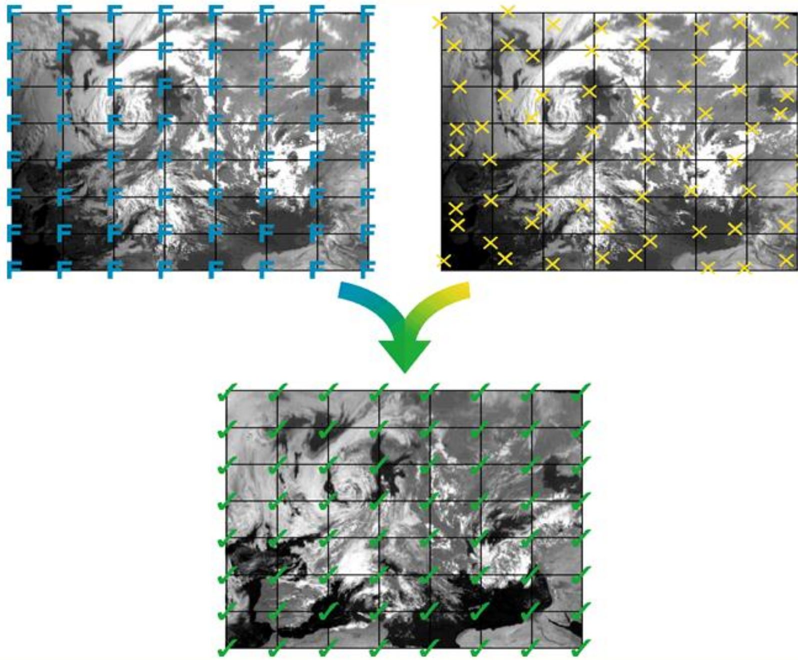
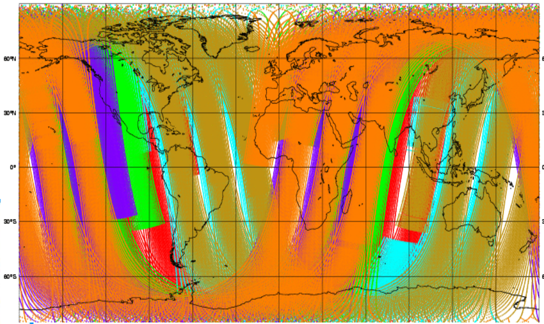
Data assimilation at ECMWF

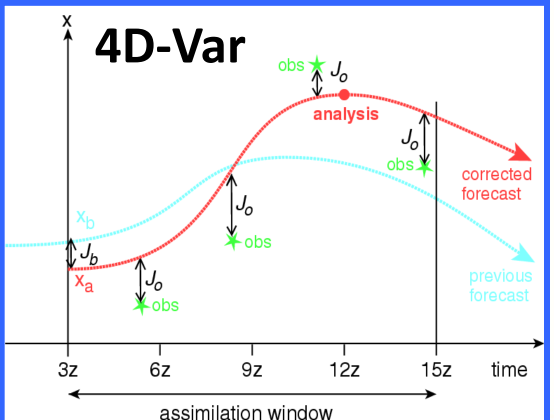


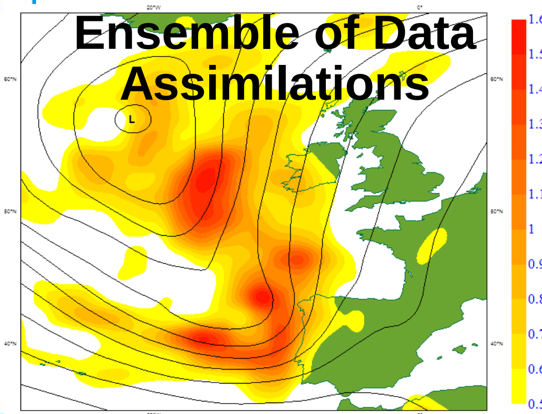
Forecast model

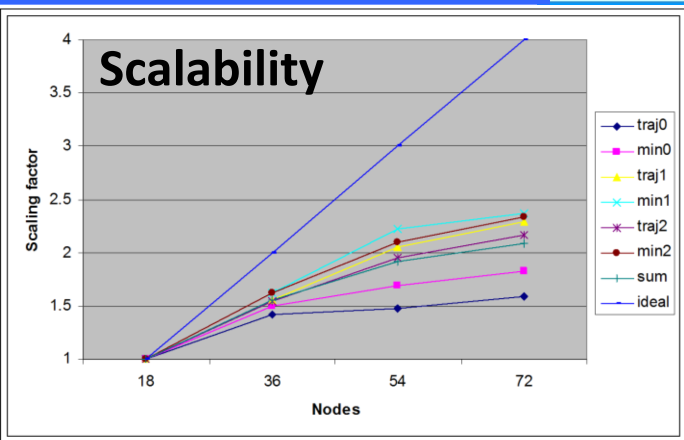




Observations

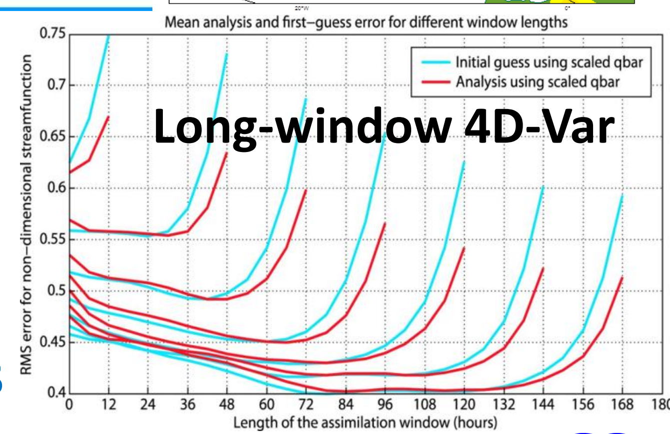






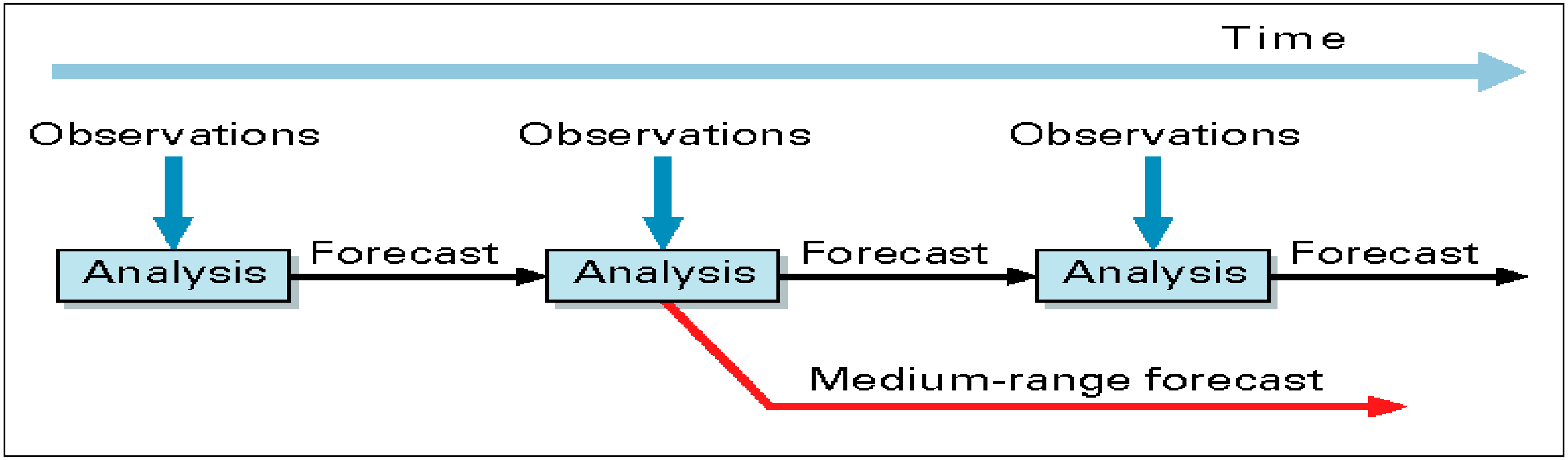
Methods

Progress and plans



ECMWF

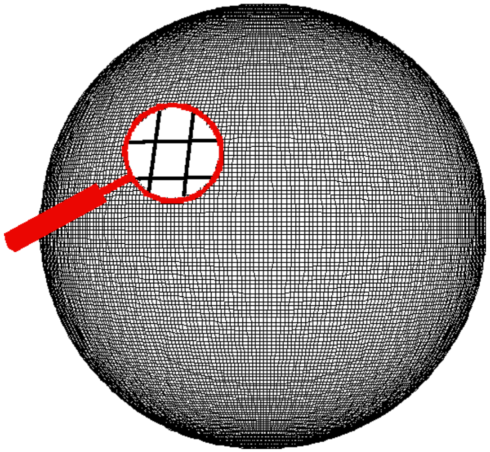
Data assimilation

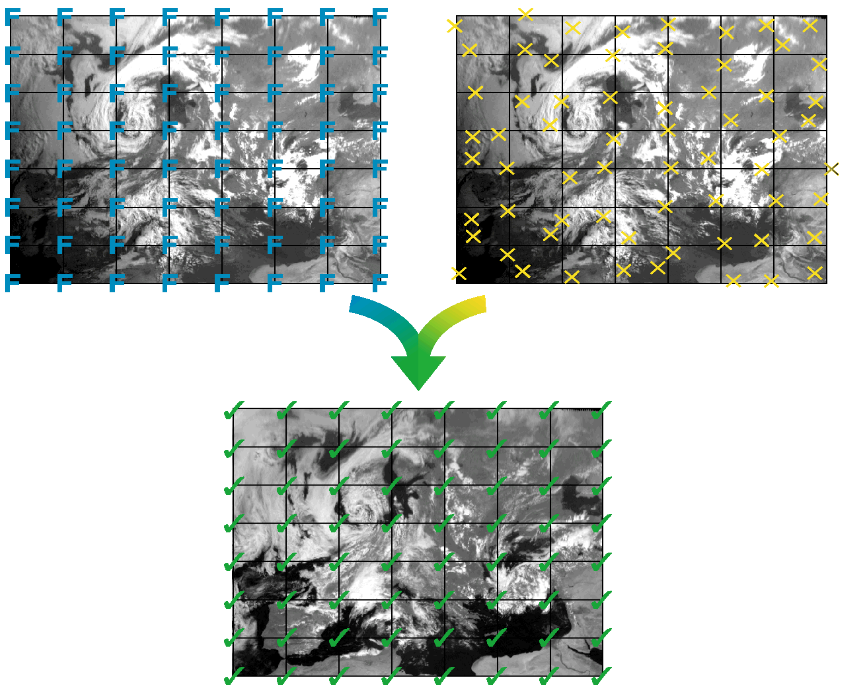


- The observations are used to correct errors in the short forecast from the previous analysis time.
- At ECMWF, twice a day 11 – 13,000,000 observations are used to correct the 80,000,000 variables that define the model's virtual atmosphere.
- This is at ECMWF done by a careful 4-dimensional interpolation in space and time of the available observations; this operation takes as much computer power as the 10-day forecast.

Data assimilation for weather prediction

The FORECAST is computed on a quasi-regular grid over the globe.
The meteorological OBSERVATIONS comes from any location on the globe.
The computer model's prediction of the atmosphere is compared against the available observations, in near real time





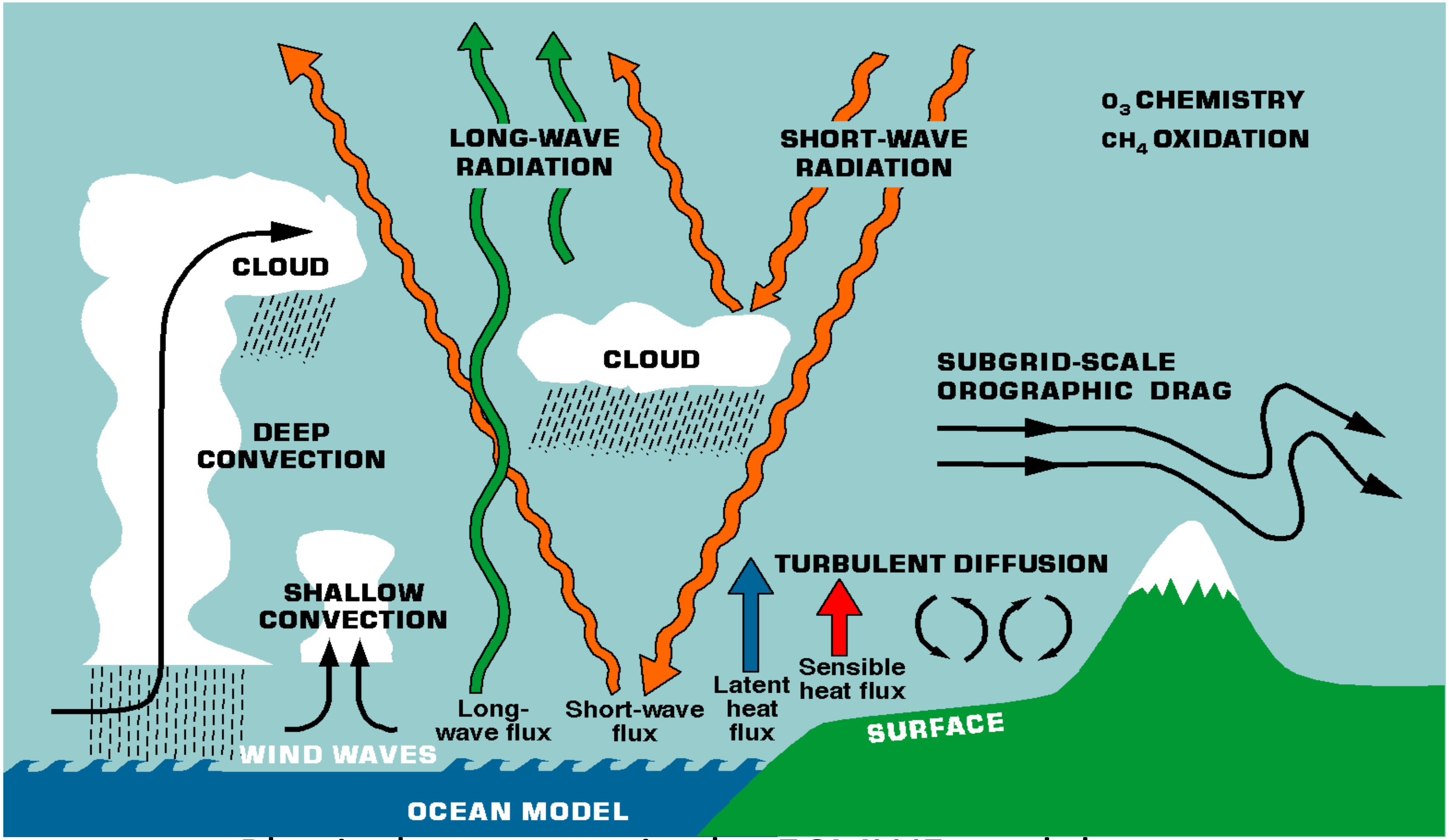
A short-range forecast provides an estimate of the atmosphere that is compared with the observations.

The two kinds of information are combined to form a corrected atmospheric state: the analysis.

Corrections are computed and applied twice per day. This process is called 'Data Assimilation'.

The ECMWF forecast model is a very important component of the data assimilation system

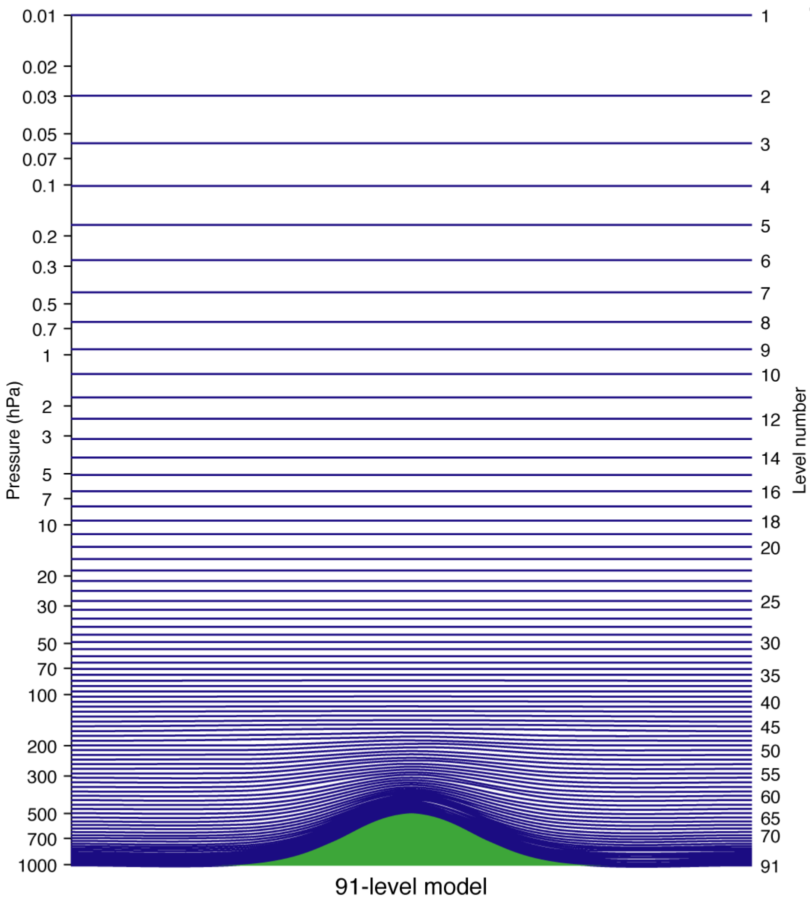
(Peter Bechtold discussed the model physics Wednesday morning)

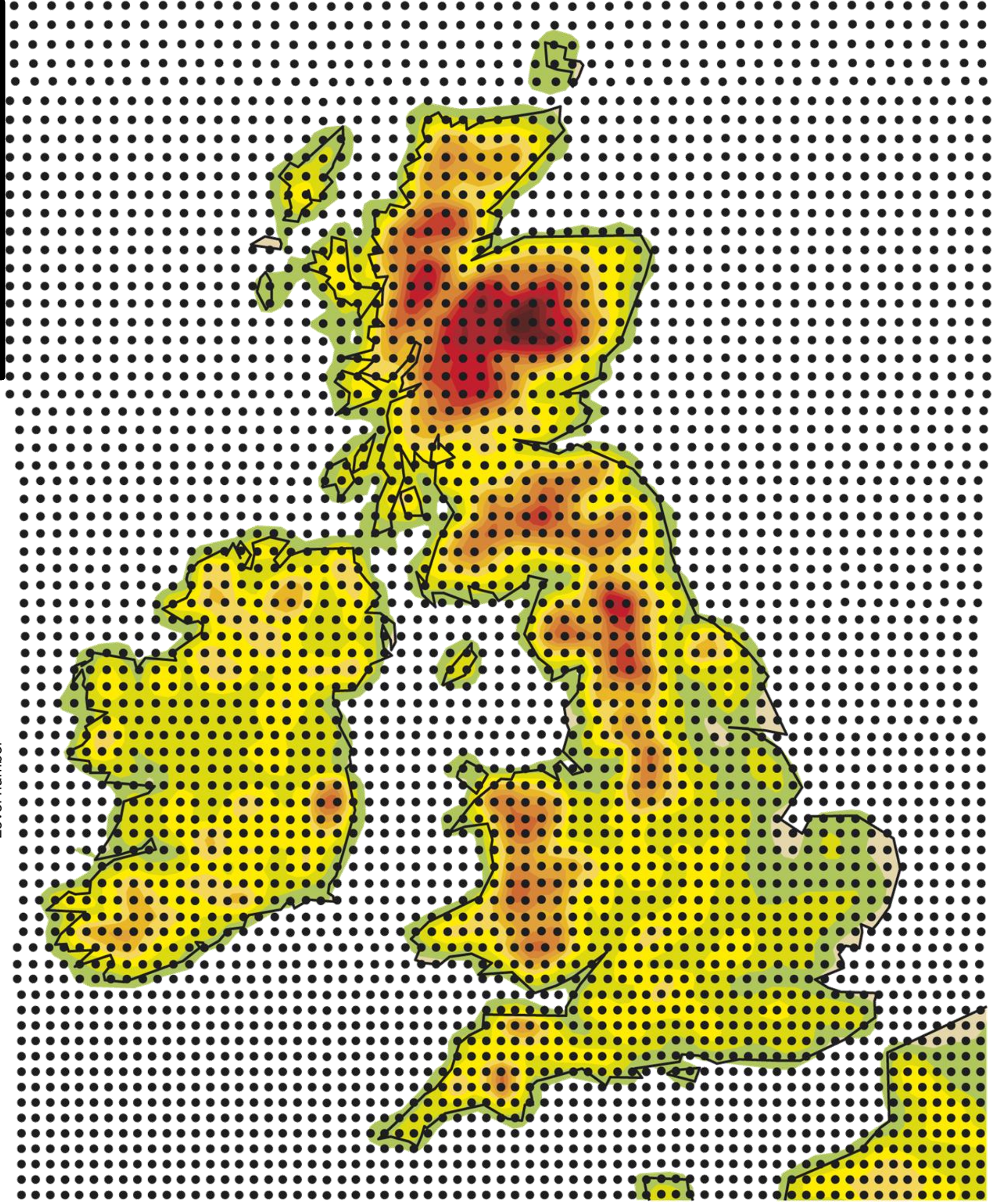


Physical processes in the ECMWF model

Model resolution matters.

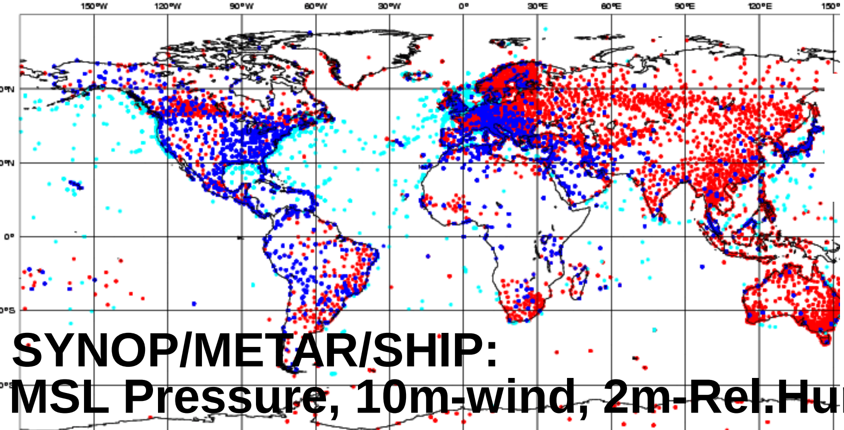
Present ECMWF system: Global model with 16 km resolution and 91 levels



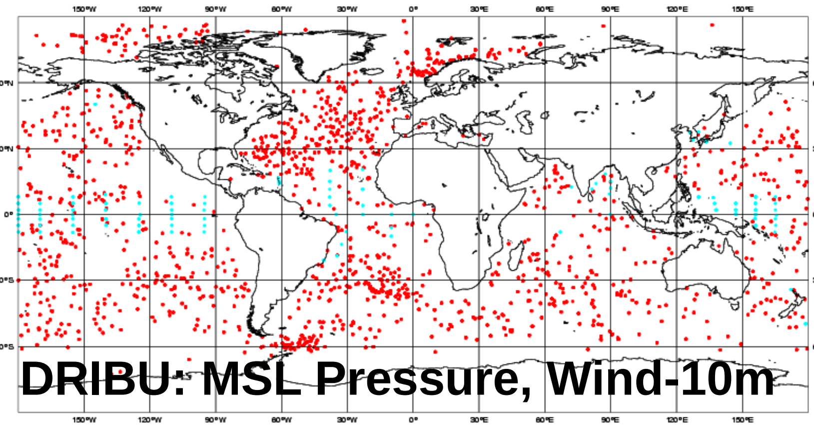


ECMWF

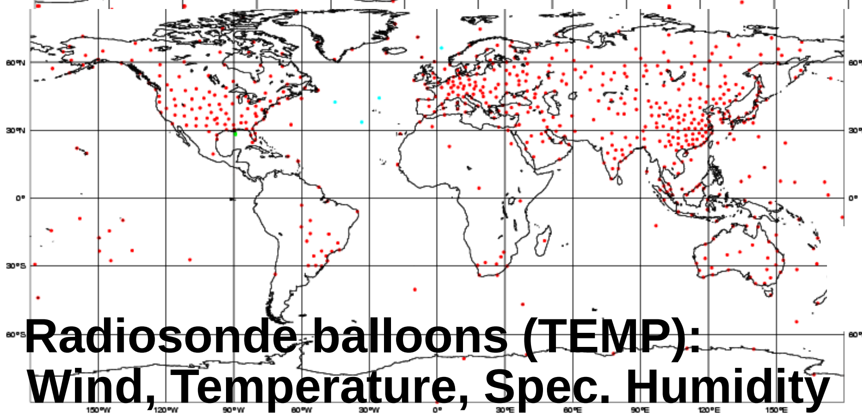
Conventional observations used by ECMWF's analysis



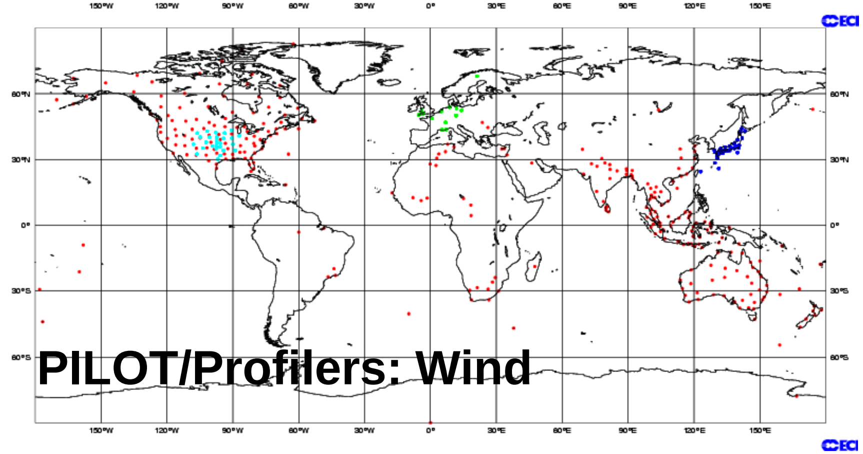
SYNOP/METAR/SHIP: MSL Pressure, 10m-wind, 2m-Rel.Hum.



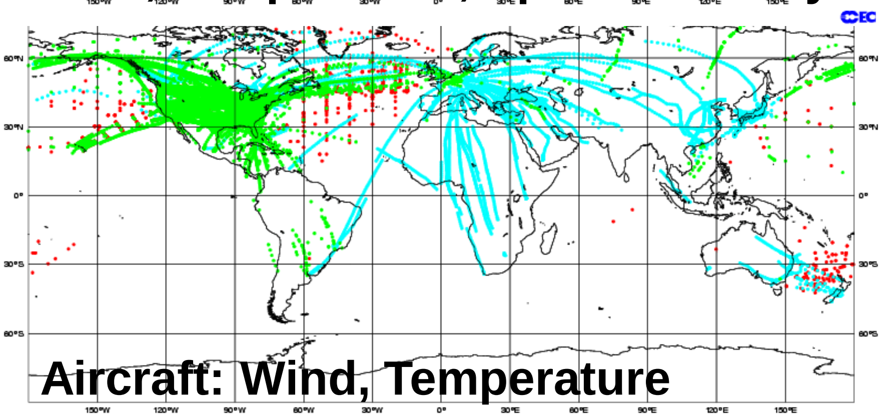
DRIBU: MSL Pressure, Wind-10m



Radiosonde balloons (TEMP): Wind, Temperature, Spec. Humidity



PILOT/Profilers: Wind

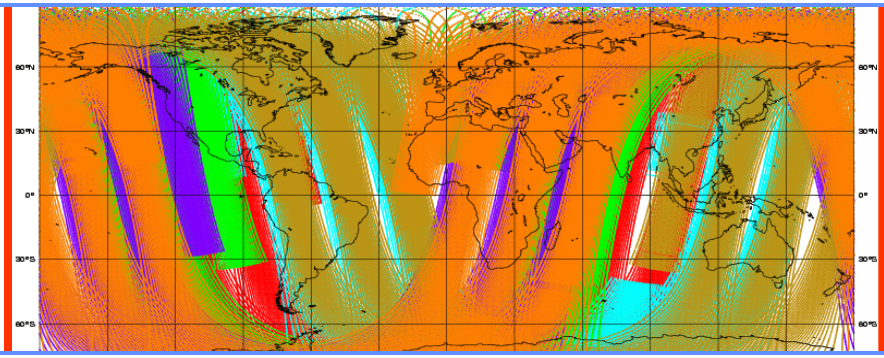


Aircraft: Wind, Temperature

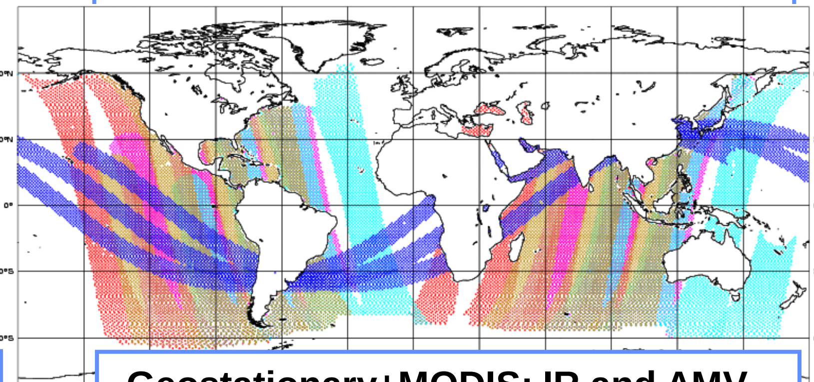
Note: We only use a limited number of the observed variables; especially over land.

Satellite data sources used by ECMWF’s analysis

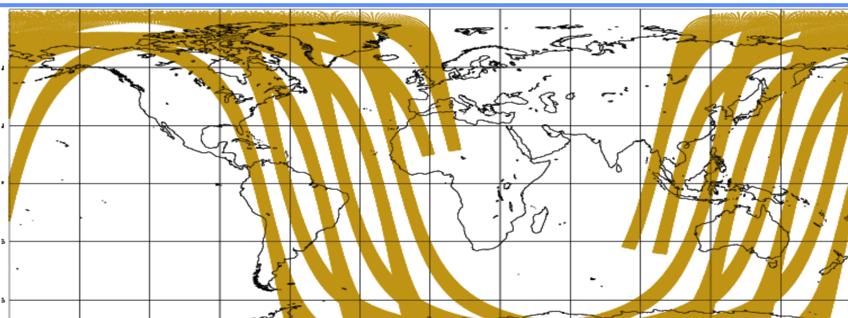
Sounders: NOAA AMSU-A/B, HIRS, AIRS, IASI, MHS



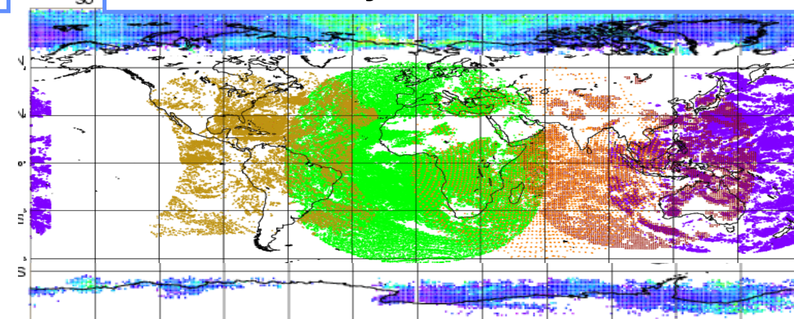
Imagers: SSMI, SSMIS, AMSR-E, TMI



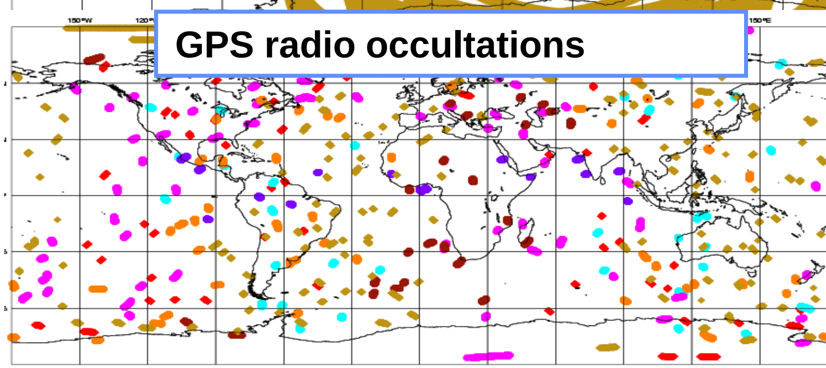
Scatterometer ocean low-level winds: ASCAT



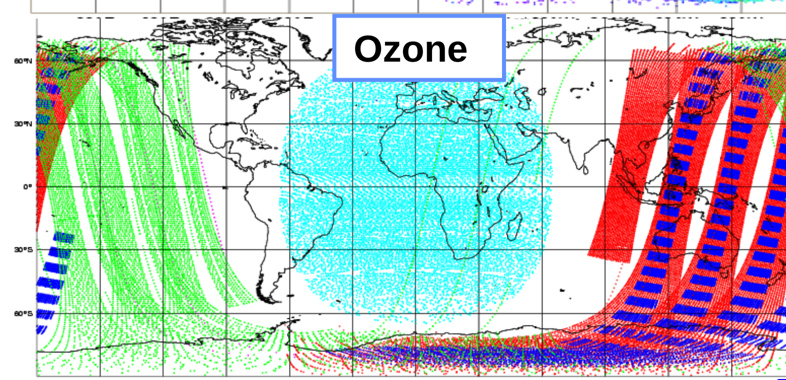
Geostationary+MODIS: IR and AMV



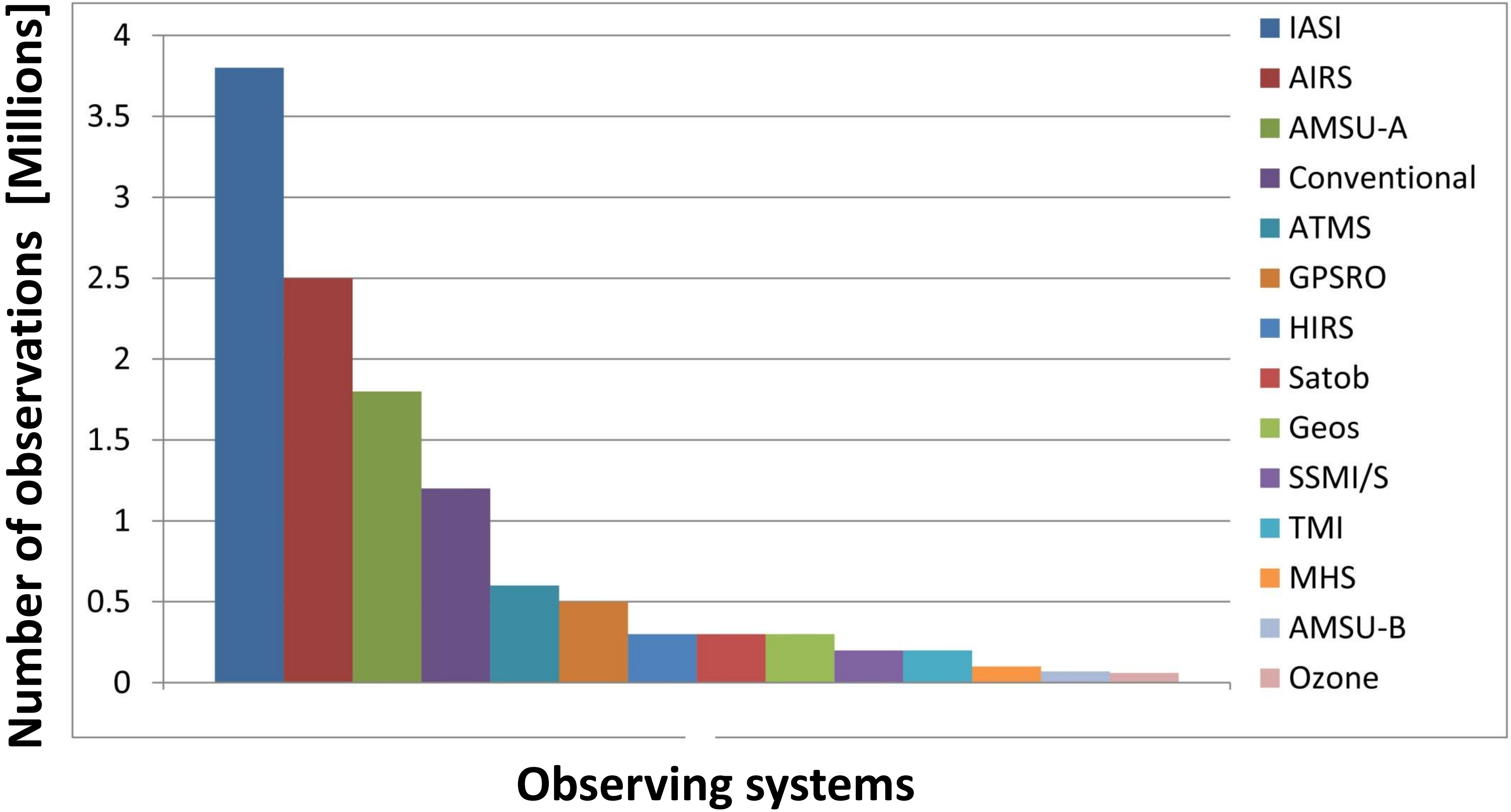
GPS radio occultations



Ozone



Number of observations used for a 12-hour 4D-Var analysis: Total approx. 12M (conventional data approx. 1.2M)



ECMWF

Quality control of observations is very important

Data extraction

- Check out duplicate reports
- Ship tracks check
- Hydrostatic check

Thinning

- Some data is not used to avoid over-sampling and correlated errors
- Departures and flags are still calculated for further assessment

Blacklisting

- Data skipped due to systematic bad performance or due to different considerations (e.g. data being assessed in passive mode)
- Departures and flags available for all data for further assessment

Model/4D-Var dependent QC

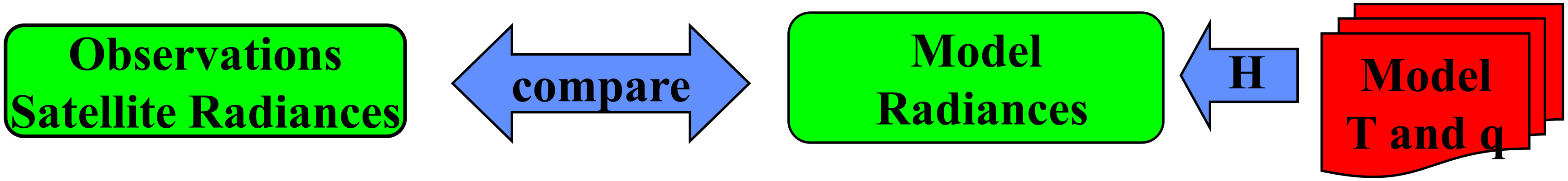
- First guess based rejections
- VarQC rejections

Used data → **Increments**

Analysis

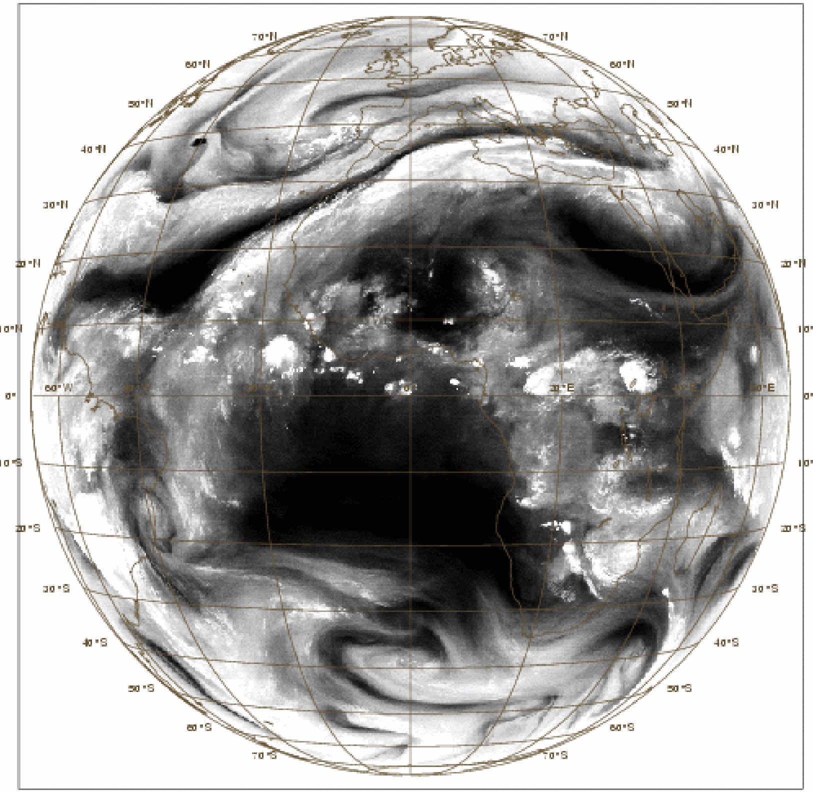
How we use satellite data in the analysis

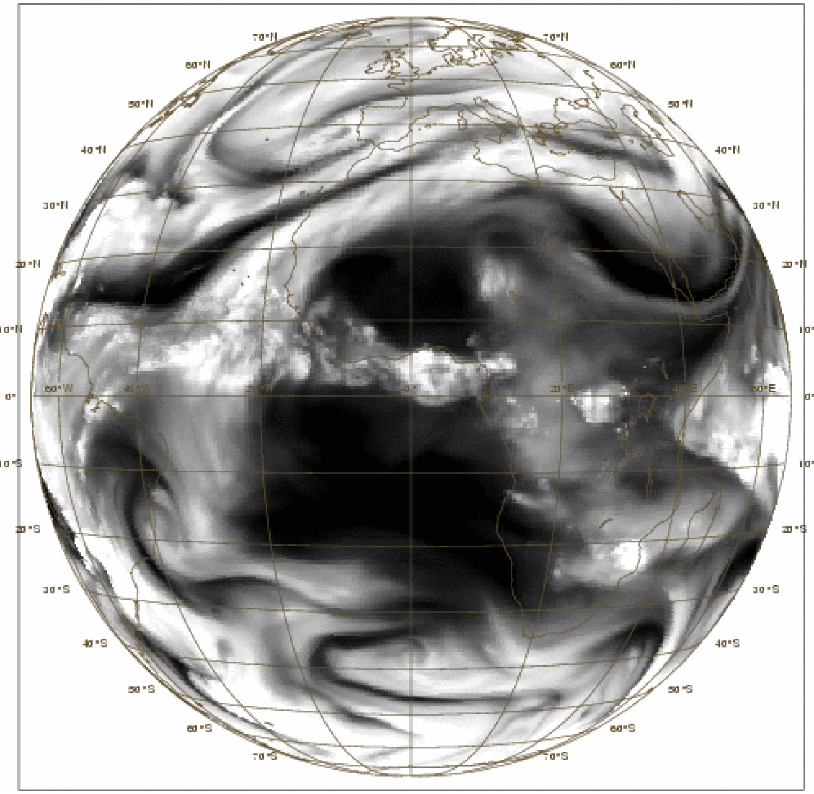
- Observations are not made at model grid points.
- Satellites measure radiances, NOT temperature and humidity .
- We calculate a model radiance estimate of the radiance measurement, using a so-called ‘observation operator’ H.
- H performs a complex transformations of model variables (T,q) to radiances.
- The model estimate is compared with the observed radiance.
- This methods works really well in variational data-assimilation.



The variational method allows model radiances to be compared directly to observed radiances

Observations Satellite Radiances ⟷ **compare** ⟷ **Model Radiances** ← **H** ← **Model T and q**

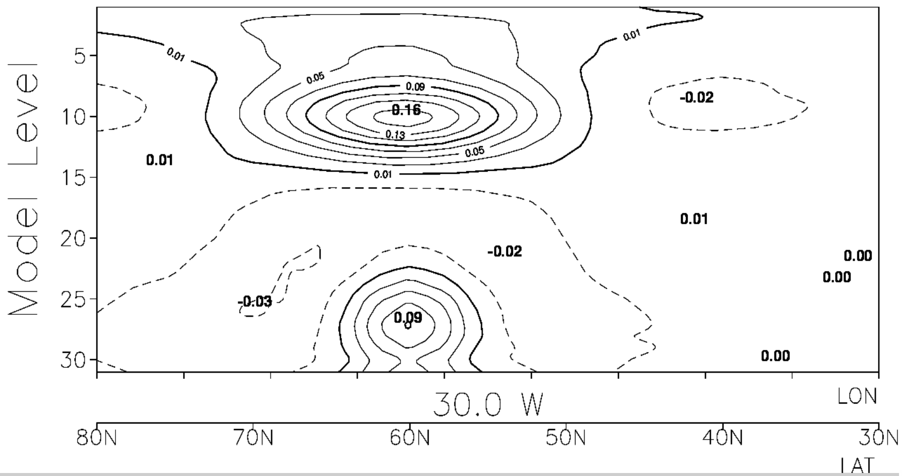




ECMWF

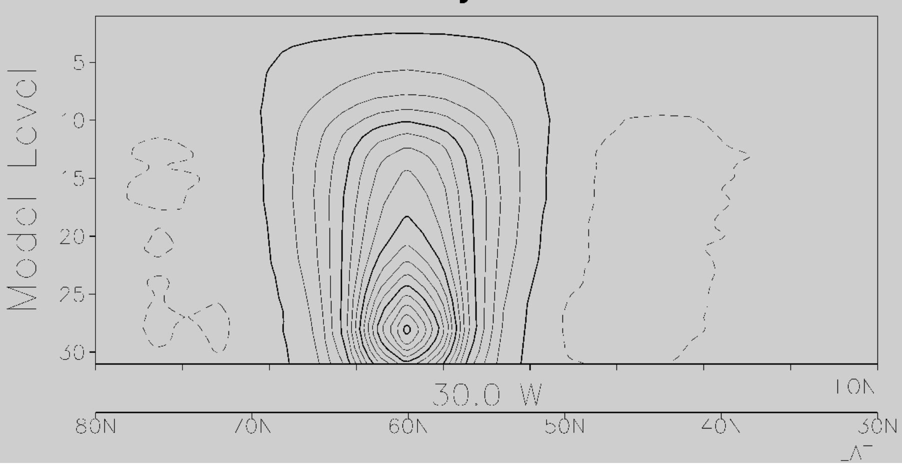
J_b: Ensures that the model fields are adjusted meteorologically consistently in the region close to the observation location

z1000 obs - temperature increments

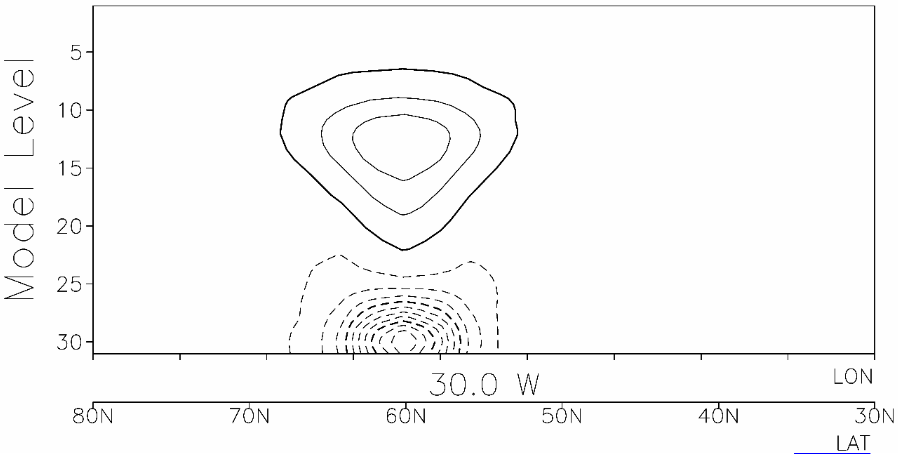


Increments due to a single observation of geopotential height at 1000hPa at 60N with value 10m below the background.

z1000 obs - vorticity increments

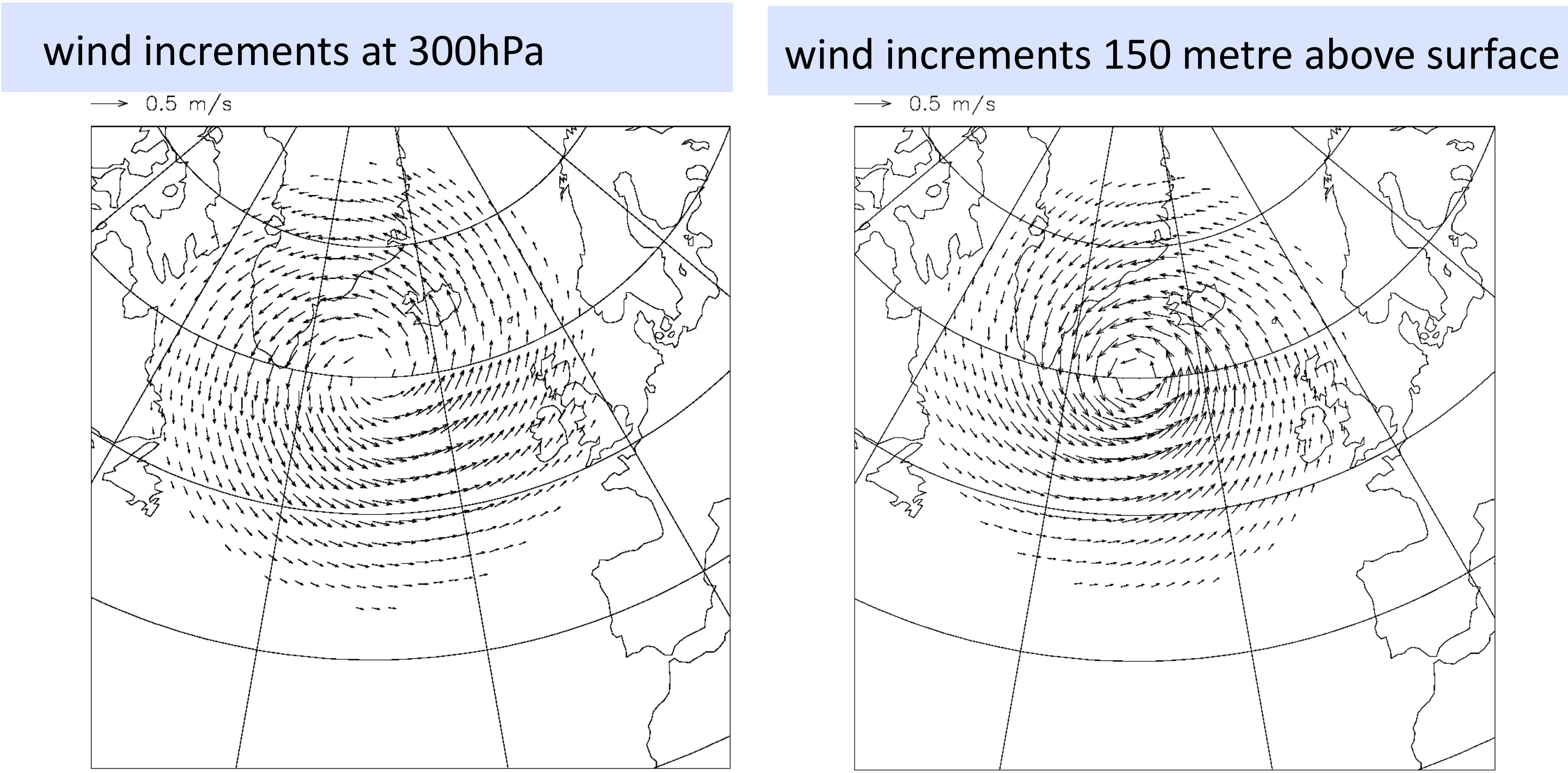


z1000 obs - divergence increments



ECMWF

J_b: The Balance Operator ensures the height and wind field balance is retained in the extra-tropics

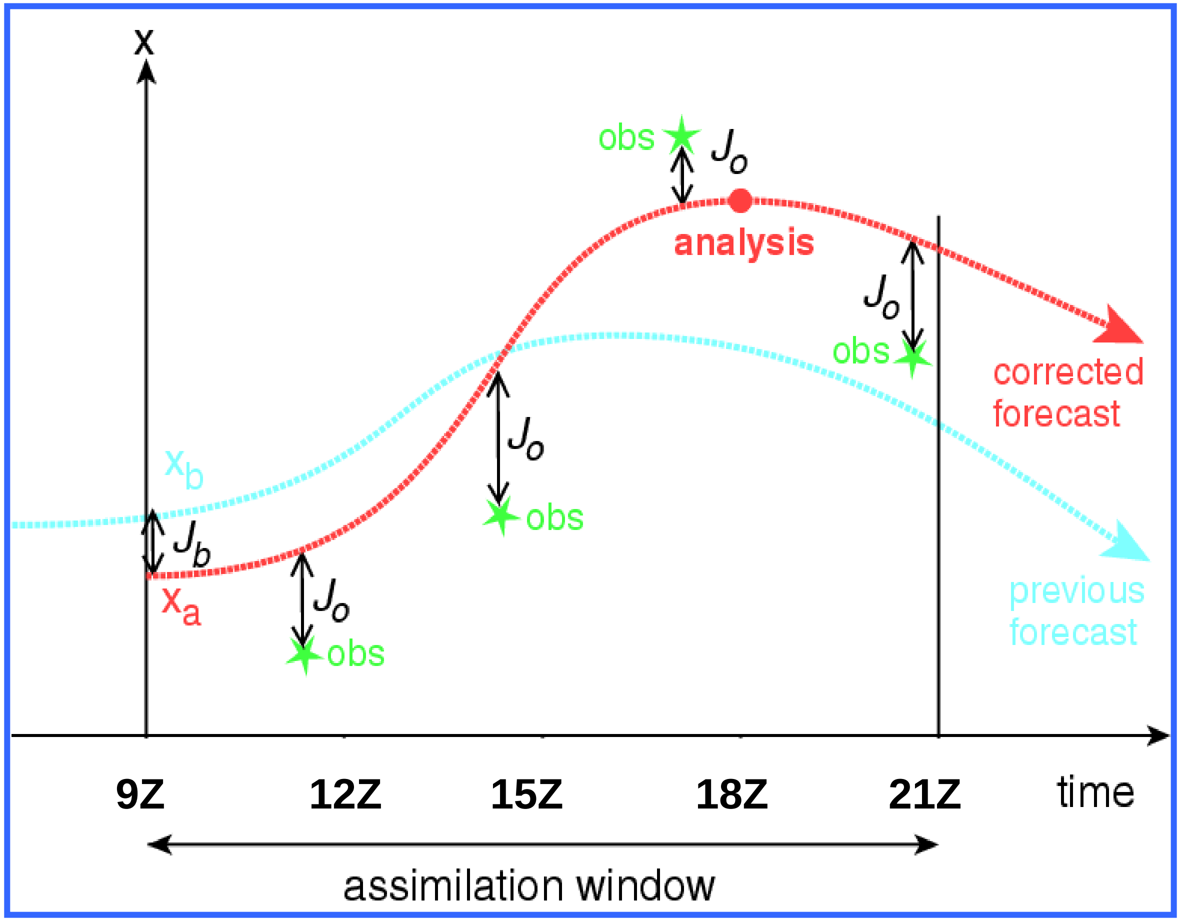


Increments for a single observation of geopotential height at 1000hPa.

A few 4D-Var Characteristics

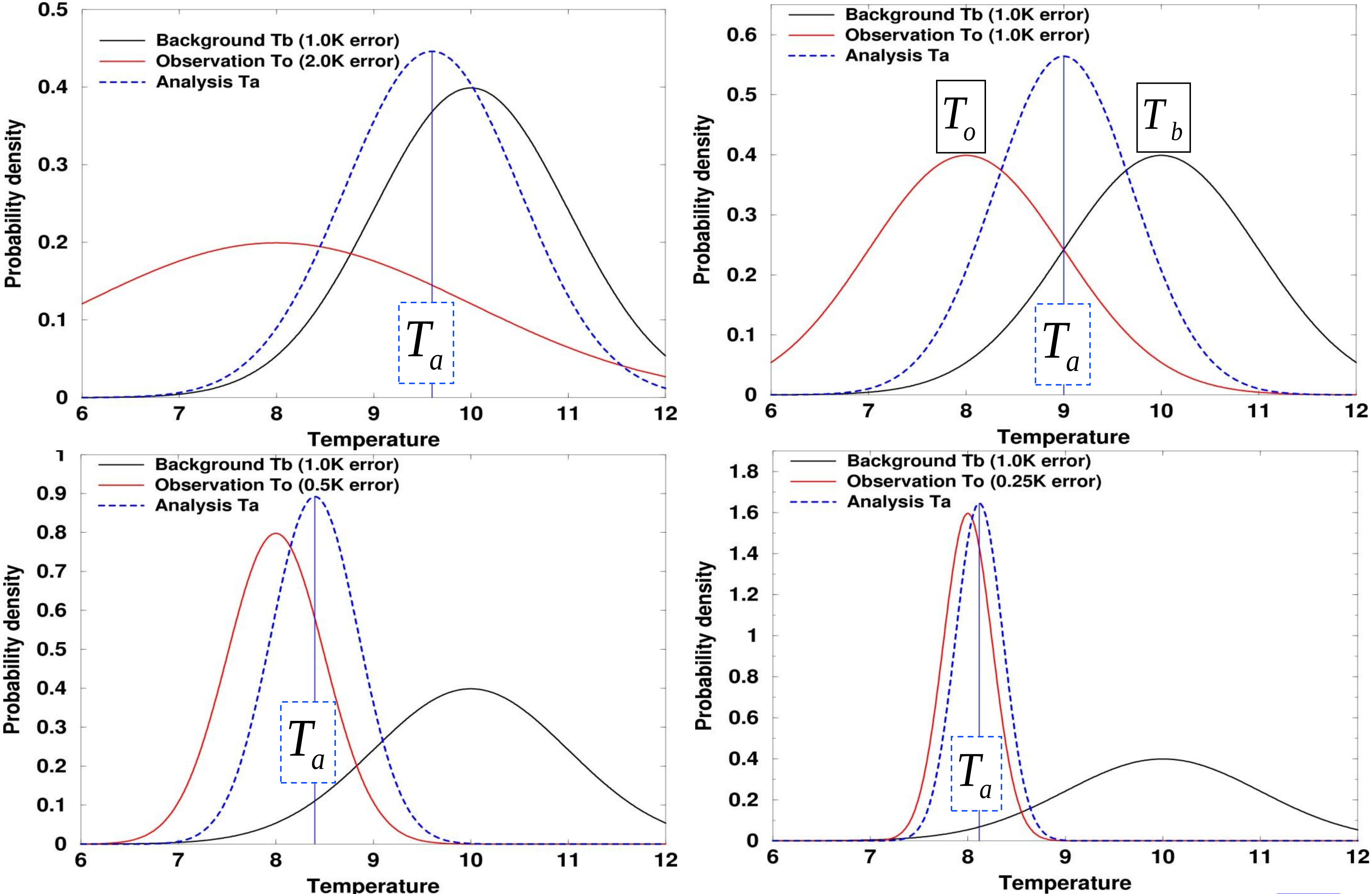
- All observations within a 12-hour period (~12,000,000) are used simultaneously in one global (iterative) estimation problem

- "Observation – model" values are computed at the observation time at high resolution: **16 km**
- 4D-Var finds the 12-hour forecast that take account of the observations in a dynamically consistent way.
- Based on a tangent linear and adjoint forecast models, used in the minimization process.
- 80,000,000 model variables (surface pressure, temperature, wind, specific humidity and ozone) are adjusted



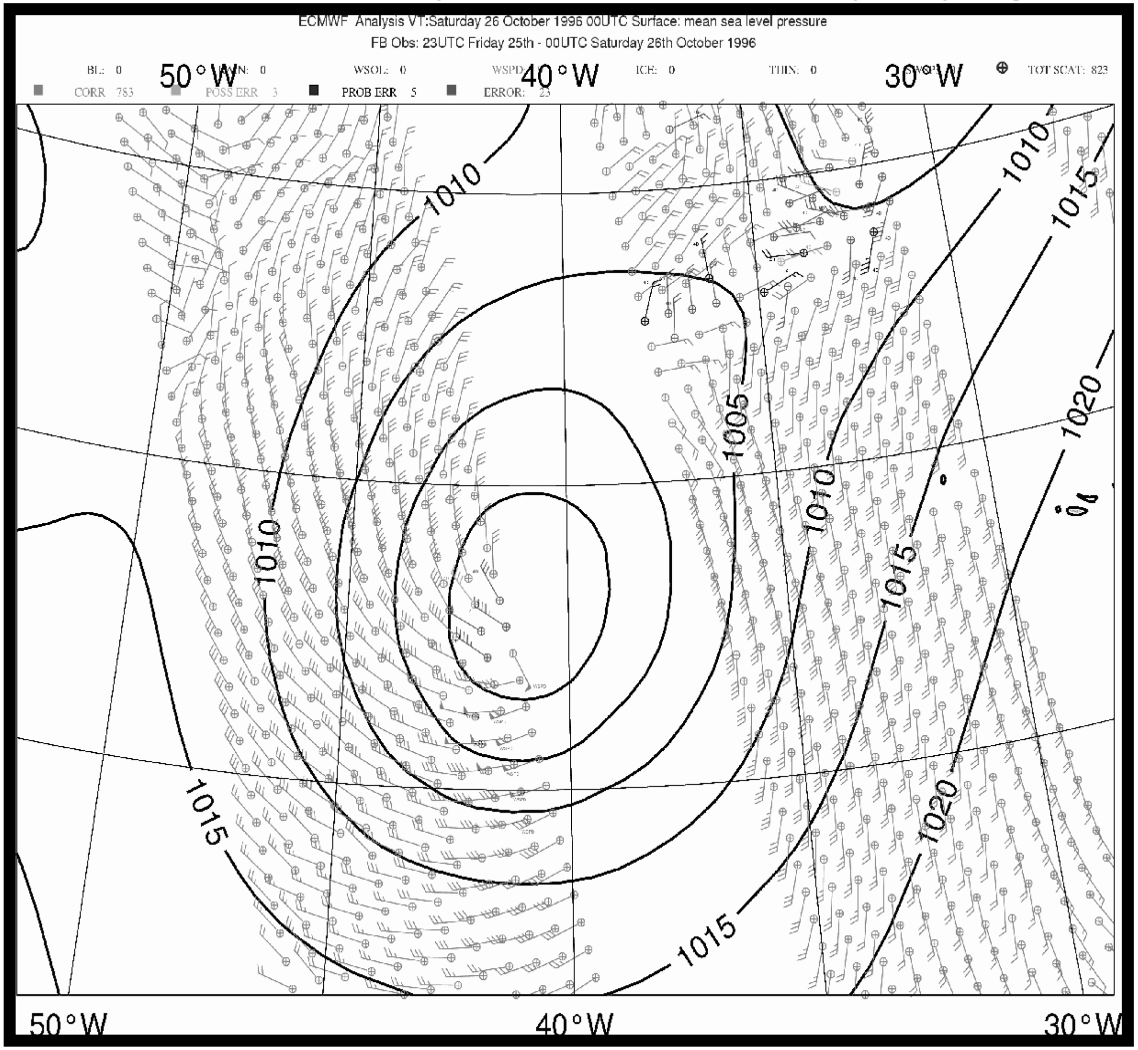
ECMWF

Observation and background error specification is very important



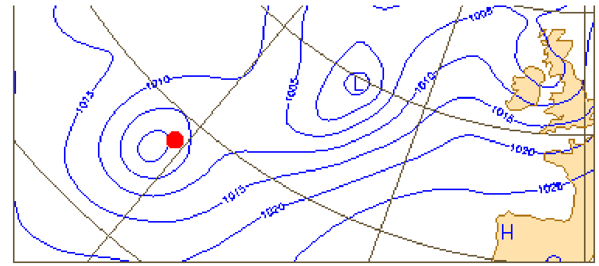
Hurricane Lili. Surface scatterometer winds.

An example how 4D-Var propagates information vertically

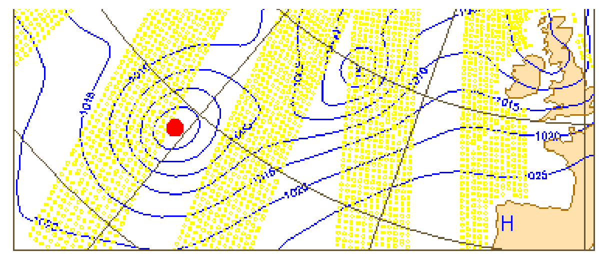


No SCAT analysis

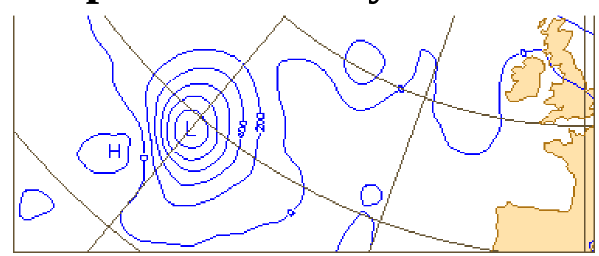
First guess MSL pressure



Analysis MSL pressure



MSL pressure Analysis increments



NSCAT analysis

S.M. Leidner, L. Isaksen and R.S. Hoffman 'Impact of NSCAT Winds on Tropical Cyclones in the ECMWF 4DVAR assimilation system' Mon. Wea. Rev. 131,1,3-26 (2003)

Hurricane Lili. Surface scatterometer winds.

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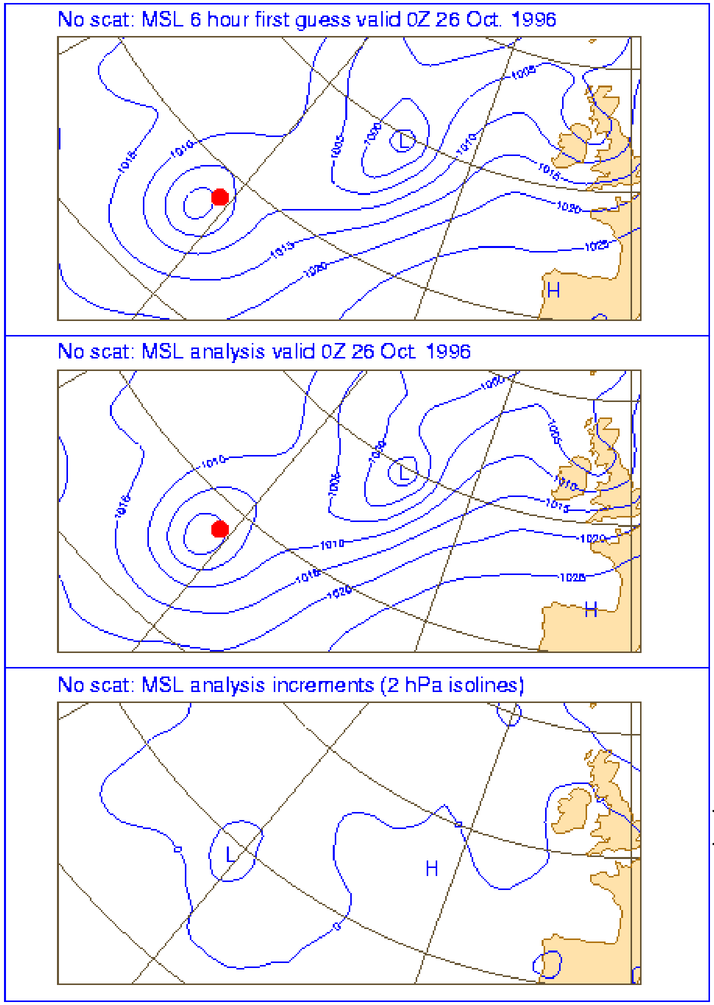
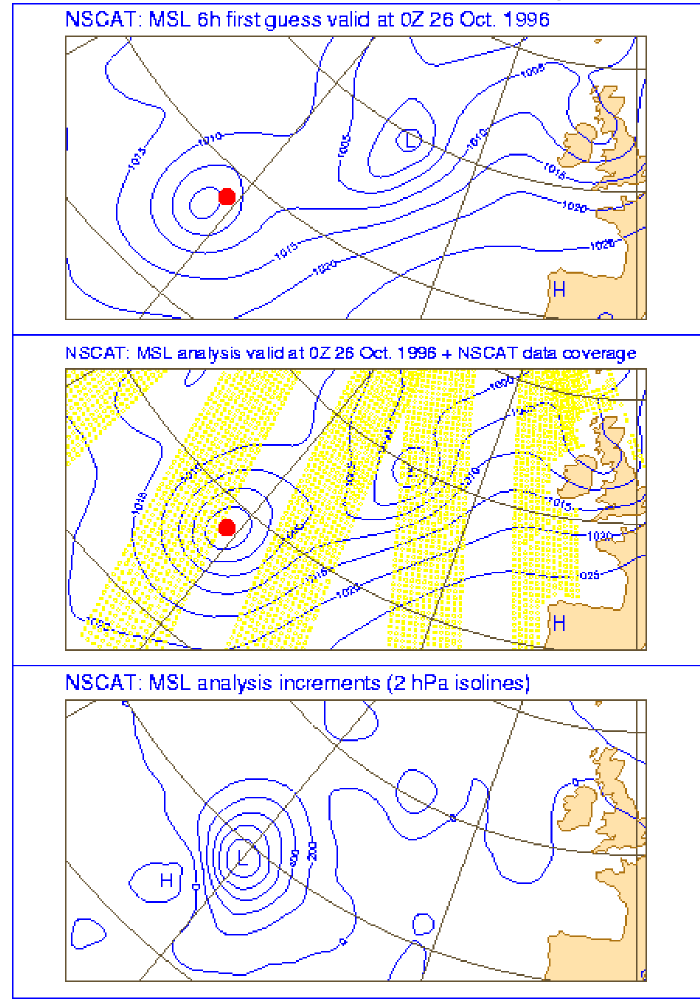


First guess MSL pressure

Analysis MSL pressure

MSL pressure Analysis increments



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NSCAT analysis

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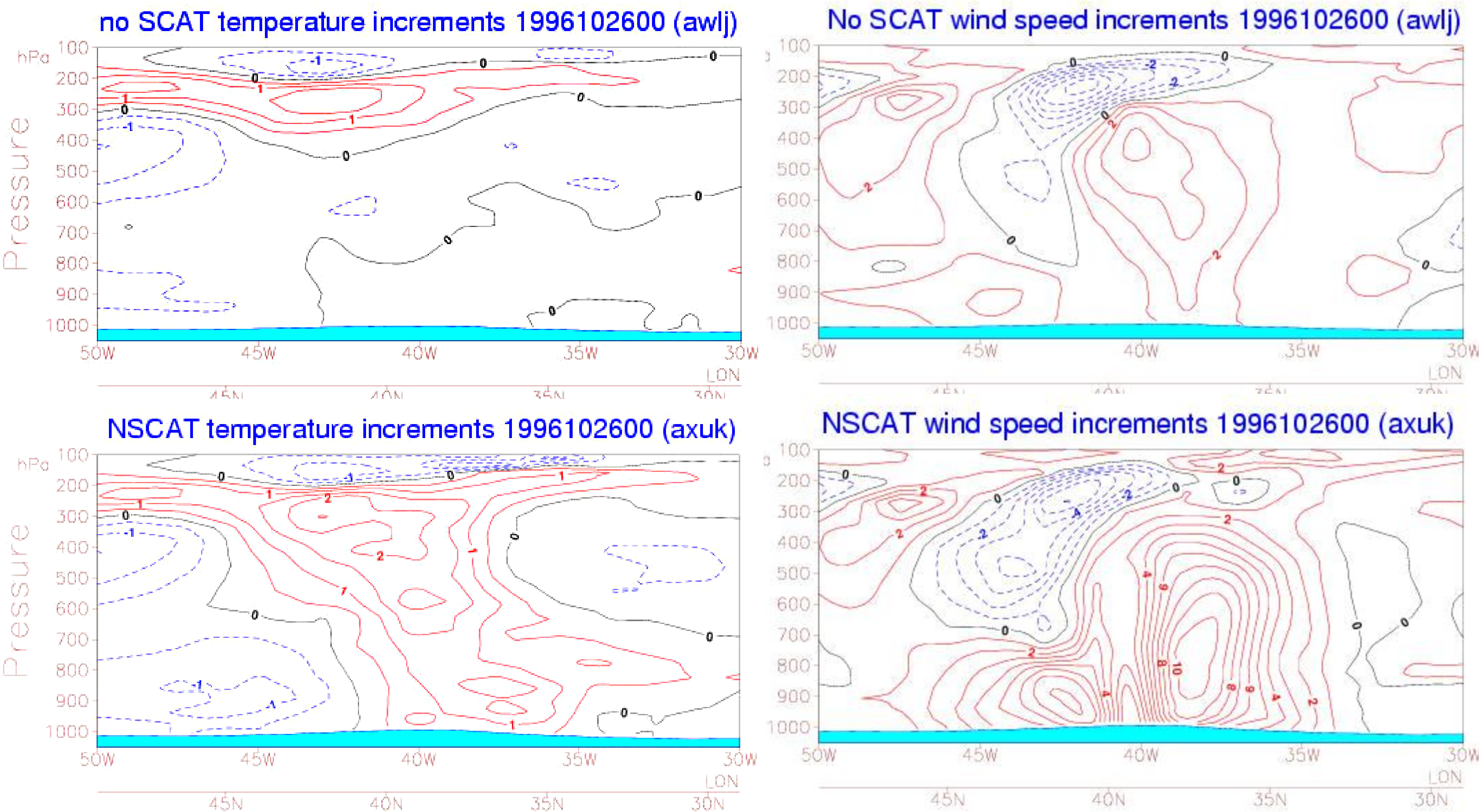
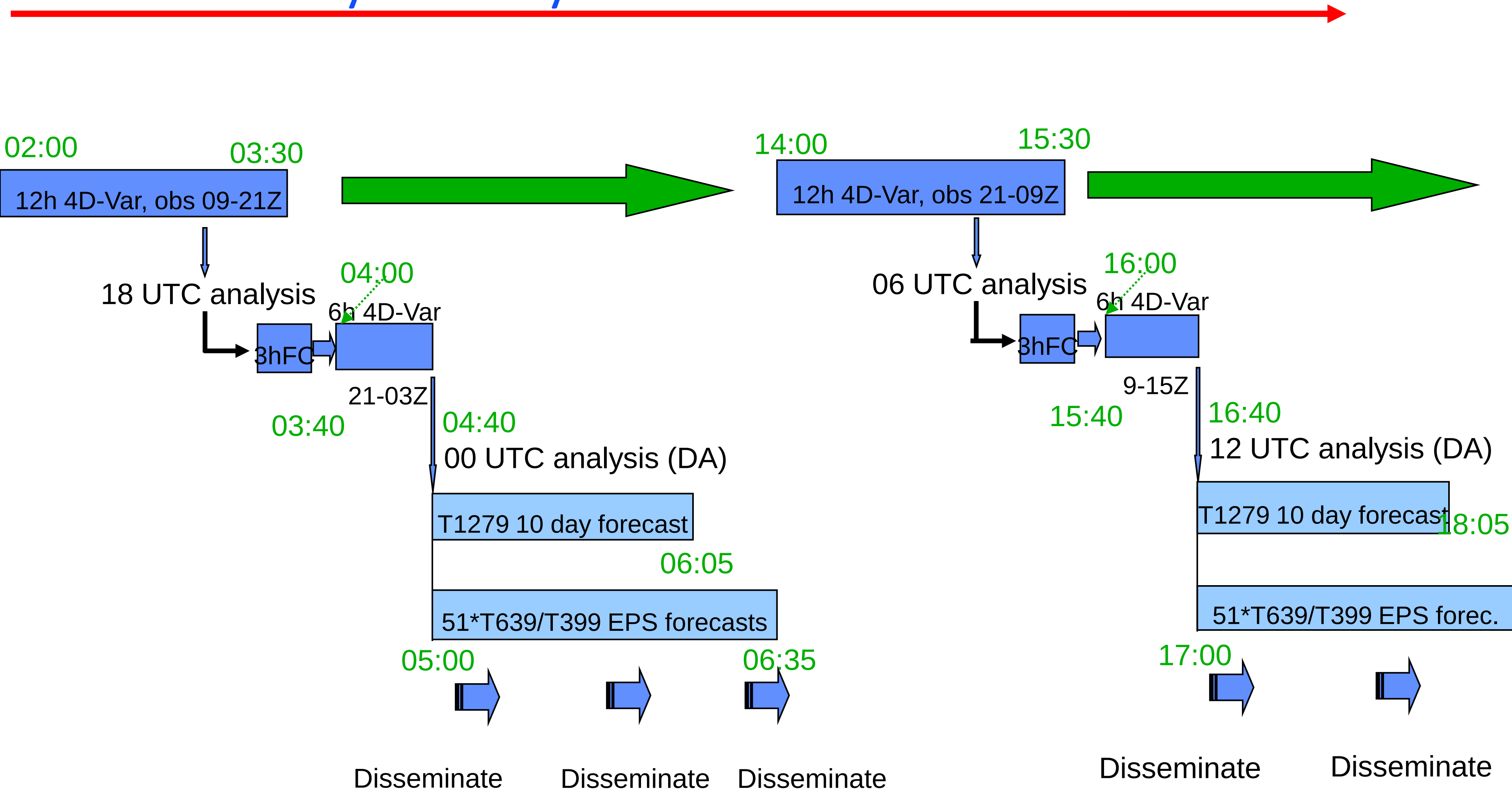
Surface scatterometer wind information is propagated vertically and improve the analysis. Due to implicit flow-dependency in 4D-Var



ECMWF

Operational schedule
Early delivery suite introduced June 2004



Recent operational data assimilation changes at ECMWF

- Improved humidity analysis, accounting better for super saturation effects
- Improved scalability – but still more to be done
- Cycling model error bias in weak-constraint 4D-Var
- Reduced observation error for AMSU-A radiances
- Bias correction of aircraft temperature observations
- Using the data assimilation system for ERA-20C (1900-2010)

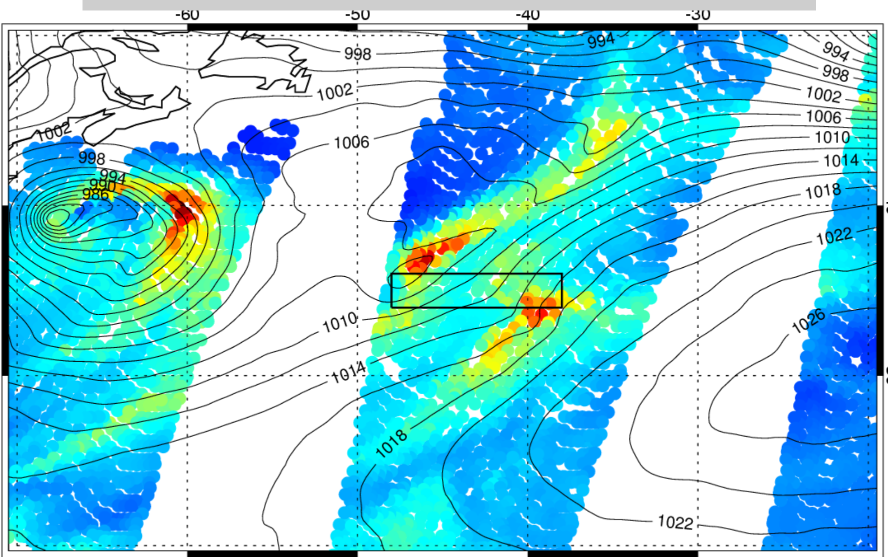
- Assimilation of rain-affected microwave satellite data
- Use EDA to provide flow-dependent background error variance in 4D-Var
- Extended Kalman Filter (EKF) for soil moisture analysis
- New snow analysis and higher resolution snow satellite data

Improved assimilation of satellite moisture data

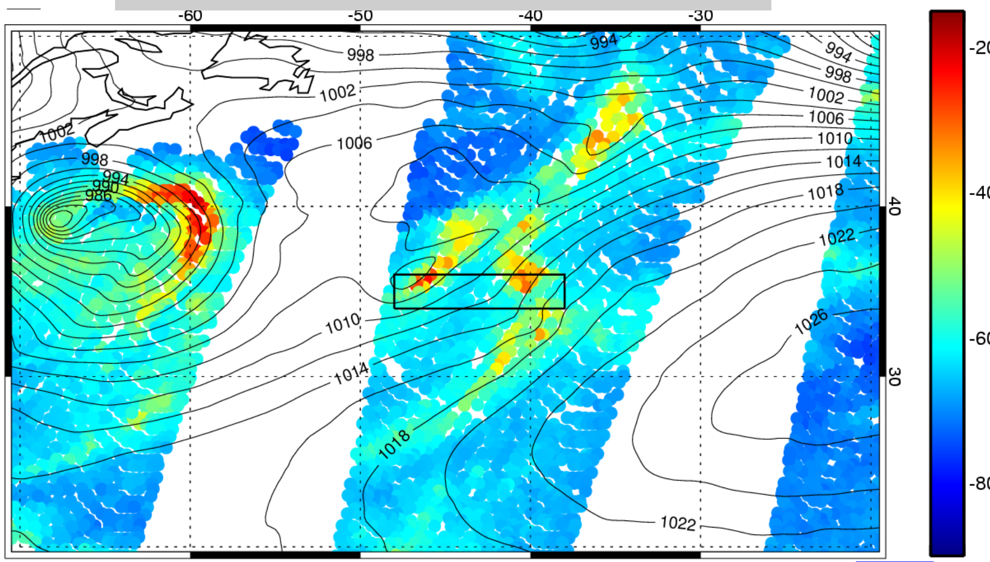
Assimilation of rain-affected microwave

- First version (SSM/I radiances) 2005; extended to SSMIS, TMI, AMSR-E in 2007
- Direct 4D-Var radiance assimilation from March 2009; improved 2010; improved 2011
- Main difficulties: inaccurate moist physics parameterizations (location/intensity), formulation of observation errors, bias correction, linearity.

4D-Var first guess SSM/I ΔTb 19v-19h [K]



SSM/I observational ΔTb 19v-19h [K]

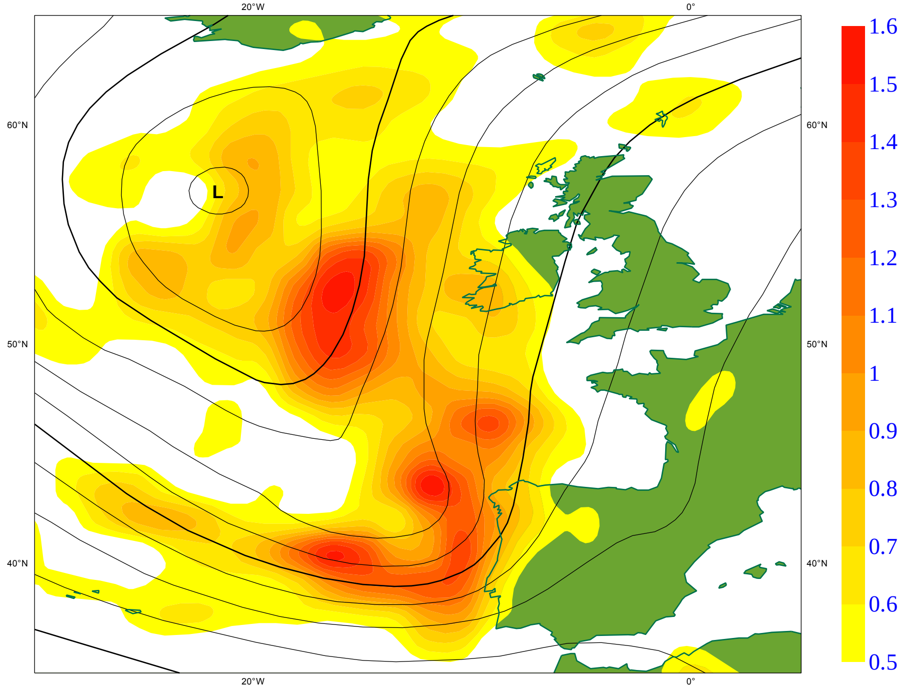


ECMWF

Ensemble of Data Assimilations (EDA)

- Run an ensemble of analyses with perturbed observations, model physics and Sea Surface Temperature fields.
- 10 EDA members plus a control at lower resolution.
- Form differences between pairs of analyses (and short-range forecast) fields.
- These differences will have the statistical characteristics of analysis (and short-range forecast) error.

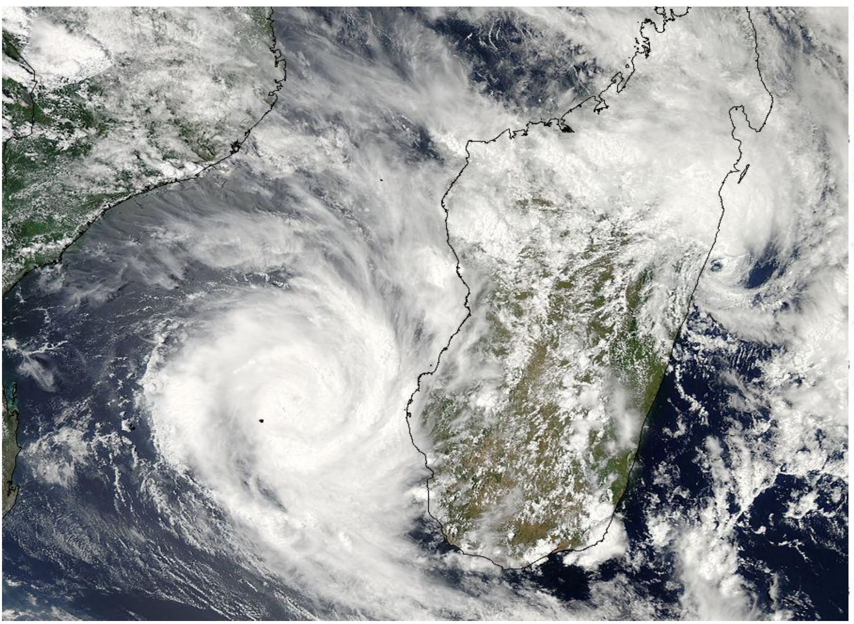
Yellow shading where the short-range forecast is uncertain: give observations more weight in these regions.



ECMWF

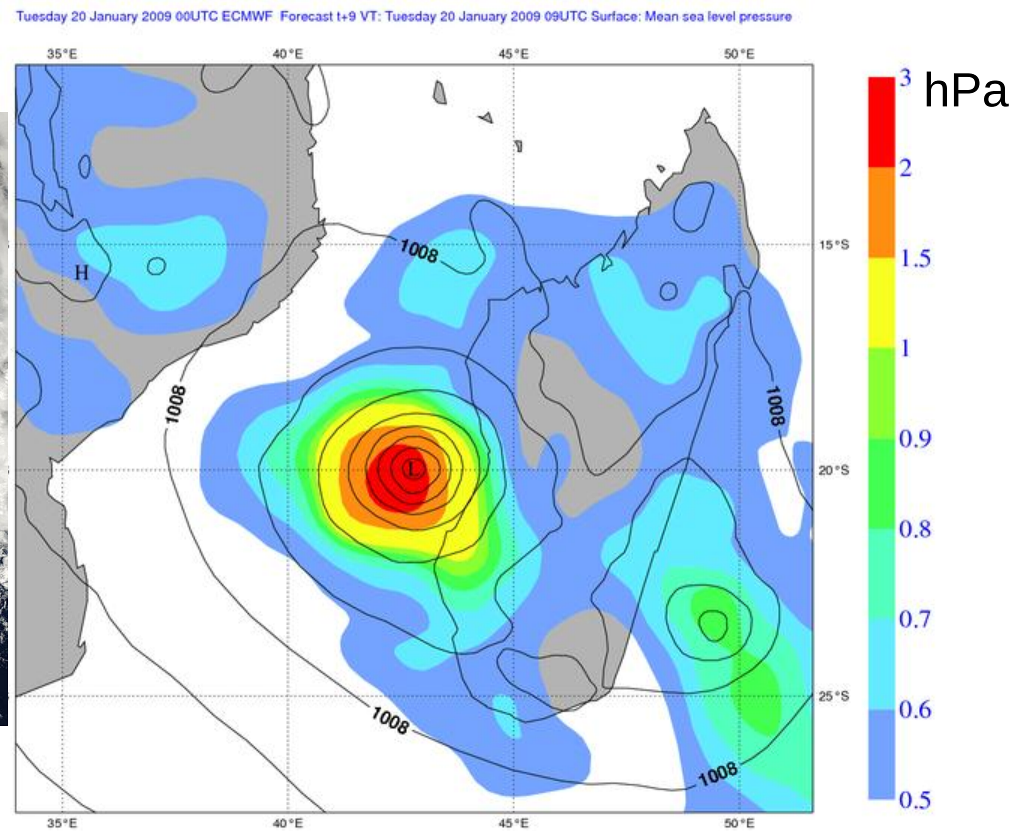
In May 2011 ECMWF implemented EDA based flow-dependent background error variance in 4D-Var

The 10-member EDA has been used to estimate the background error variance in the deterministic 4D-Var.



Hurricane Fanele, 20 January 2009

EDA based background error variance for Surface pressure



ECMWF

Why implementing Ensemble of Data Assimilations?

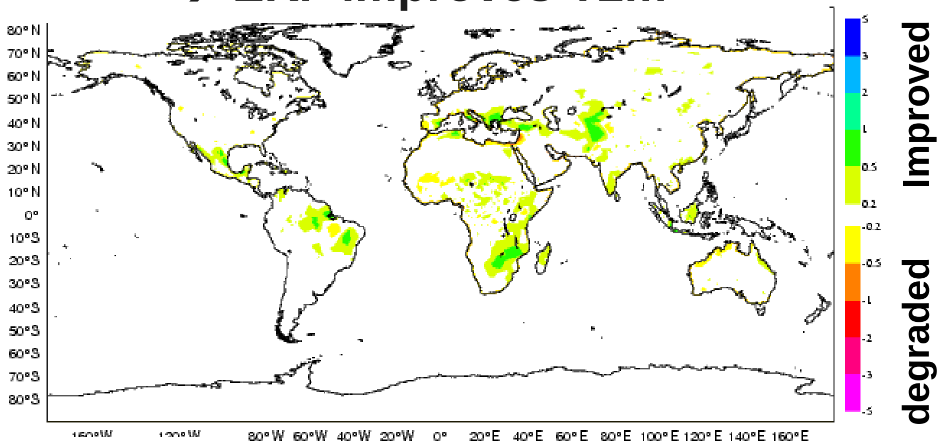
- **In general to estimate analysis uncertainty**
- To improve the initial perturbations in the Ensemble Prediction (implemented June 2010)
- To calculate static and seasonal background error statistics
- To estimate flow-dependent background error in 4D-Var - "errors-of-the-day" (implemented May 2011)
- To improve QC decisions and improve the use of observations in 4D-Var (implemented May 2011)

Soil moisture assimilation using Extended Kalman Filter Implemented in November 2010

Impact on 2-metre Temperature

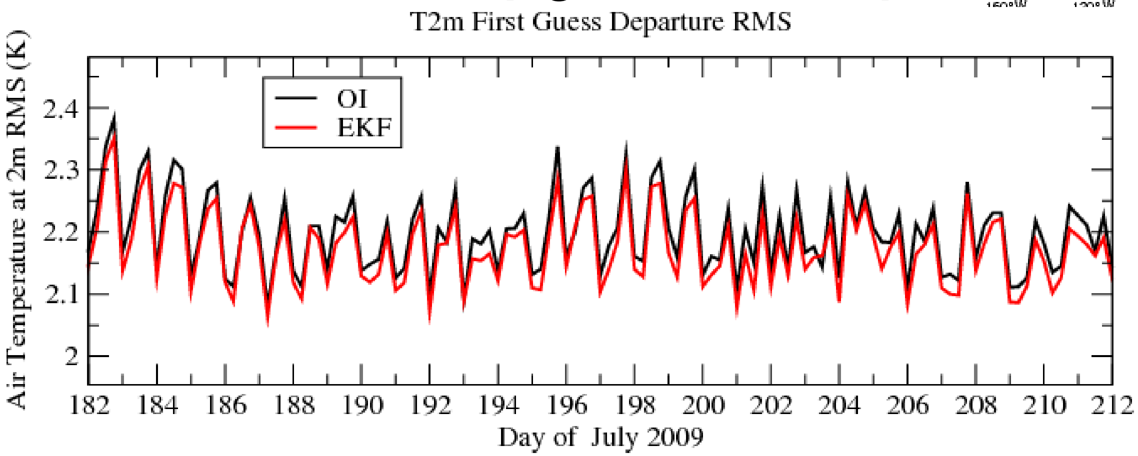
T2m error (OI-SEKF) 48h fc

→ EKF improves T2m



Compared to the old OI analysis, the simplified Extended Kalman Filter consistently improves T2m

Global mean RMS (against SYNOP)



ECMWF

November 2010: new Optimum Interpolation snow analysis

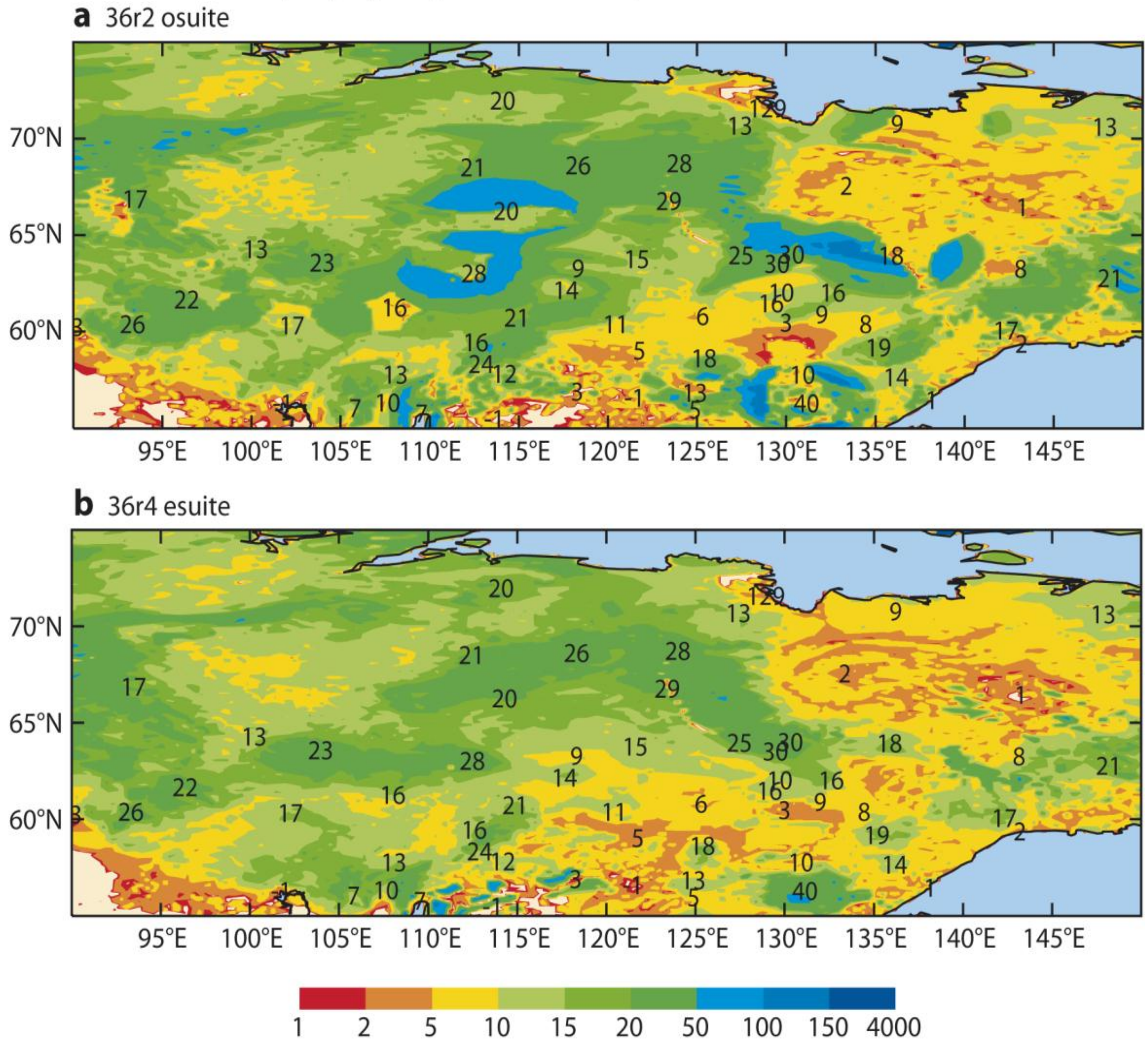
The change improves the snow analysis significantly.

Spurious patterns and serious shortcomings of previous scheme resolved.

Better agreement with SYNOP snow observations.

- Top: Old Cressman using 24km NESDIS data
- Bottom: New OI (Brasnett 1999) approach using 4km NESDIS data

Snow depth (cm) analysis and SYNOP reports on 30 October 2010 at 00 UTC



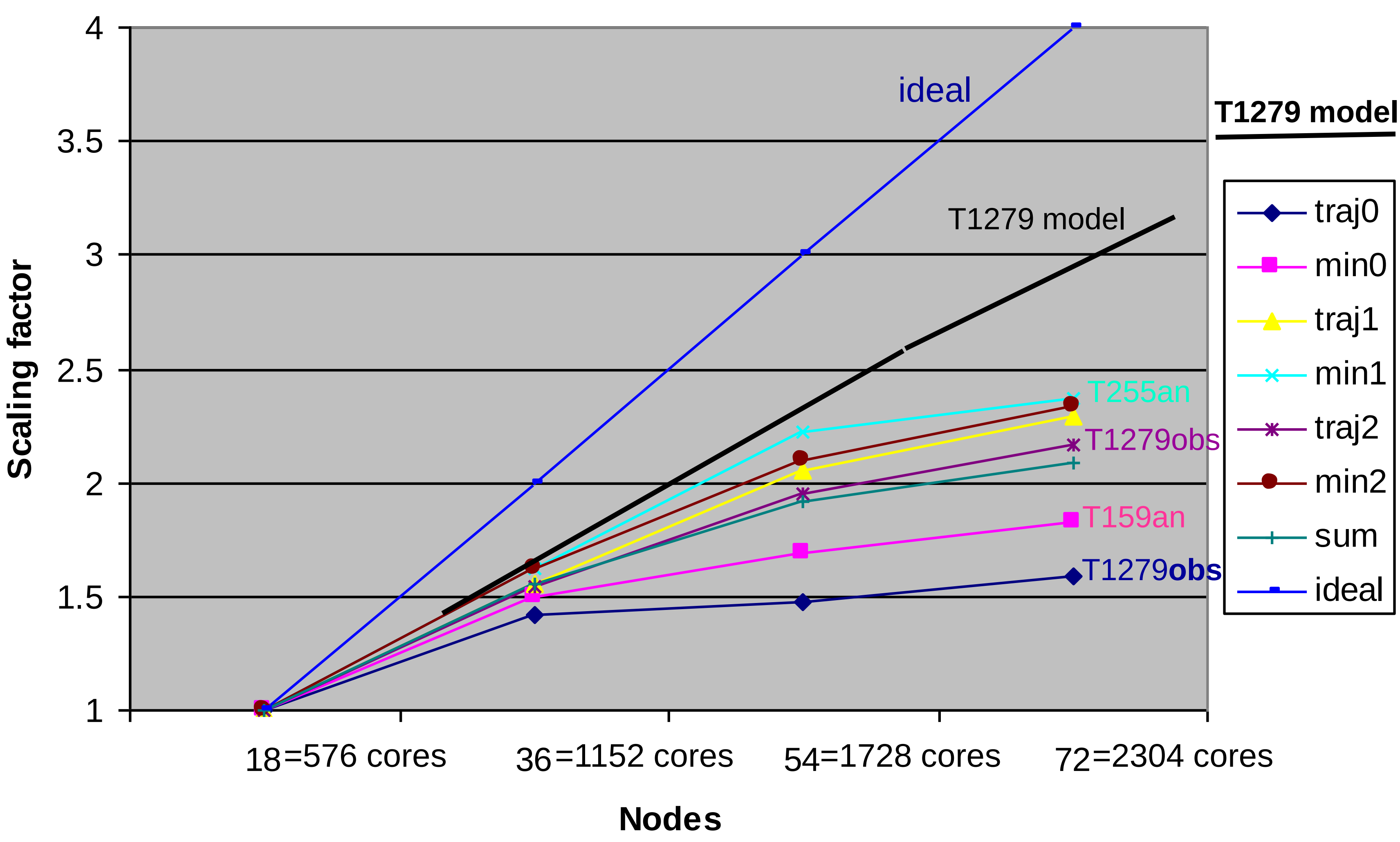
ECMWF

Coming soon in the data assimilation system at ECMWF

- Vertical resolution increase planned for May 2013 (~137 levels)
- Use of ASCAT data in EKF soil moisture analysis
- Introduction of cloud condensate in the data assimilation
- Retune observation errors for all data types
- A move to an Object Oriented Prediction System

- Improved scalability of 4D-Var
- COPE – Continuous observation processing environment
- Use EDA based flow-dependent covariance in 4D-Var
- Long window 4D-Var: extend to 24 hour window - and later 48-72 hours

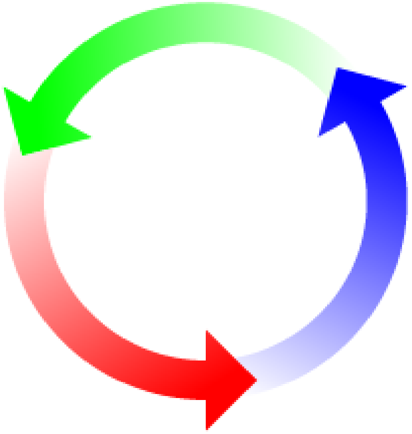
Improve scalability of 4D-Var for next generation HPC



ECMWF

Continuous Observation Processing Environment (COPE)

- Implement a hub Observation Data Base (ODB) interface
- Shortens the time critical path by performing observation pre-processing and screening as data arrive
- Improve scalability by removing most observation related tasks from time critical path
- Reduce risk of failures in the analysis during the time critical path
- Enables near real-time quality control and monitoring of observations
- More modular software

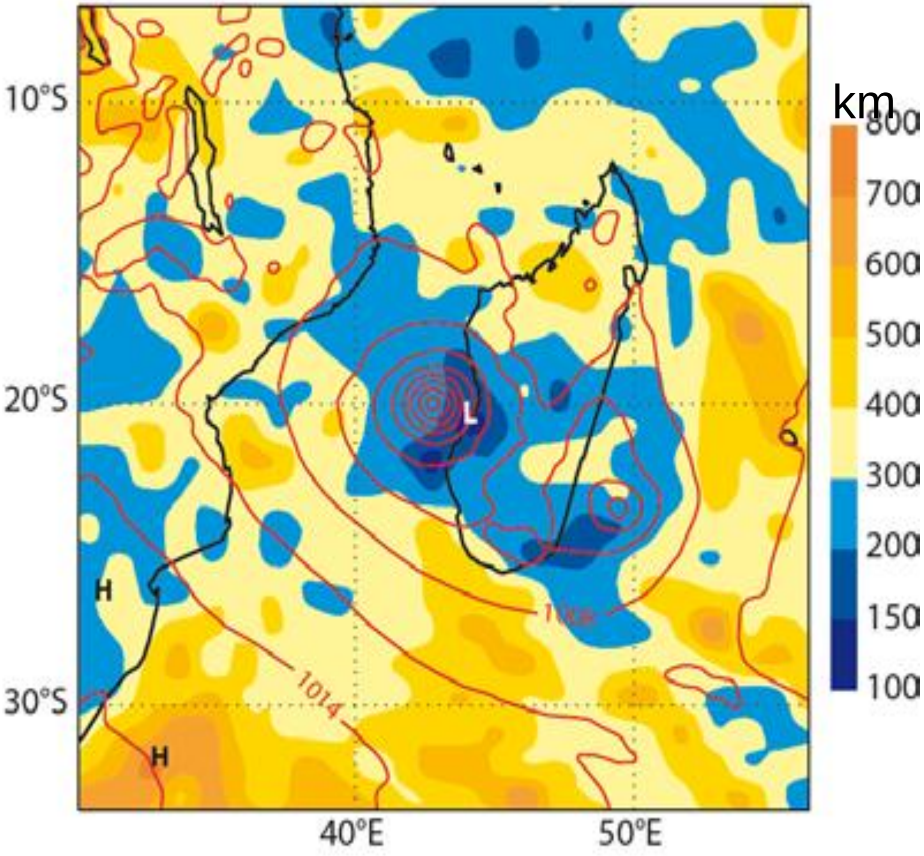


EDA flow dependent covariances planned for 2013

Next upgrade in June 2013:

First implementation of flow-dependent background error covariances.

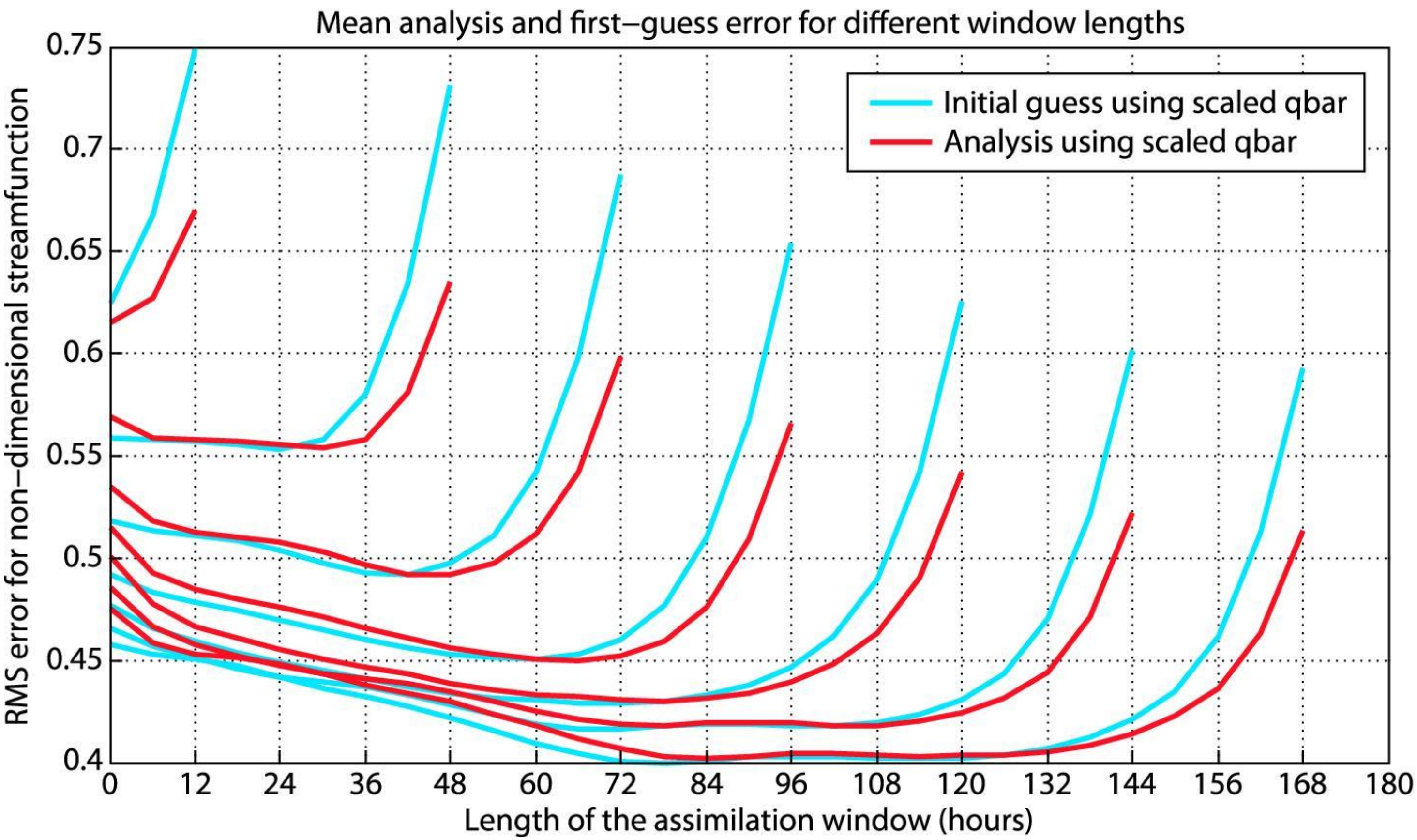
EDA-based background error correlation length scales for surface pressure



ECMWF

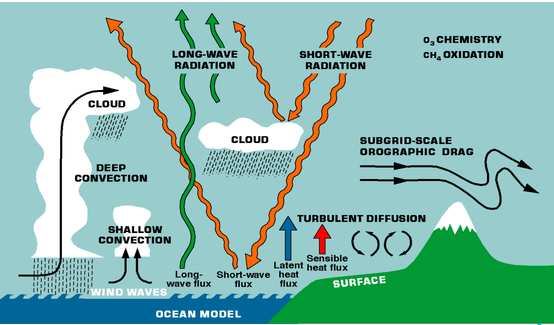
Long-window, weak-constraint 4D-Var - a longer-term project

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

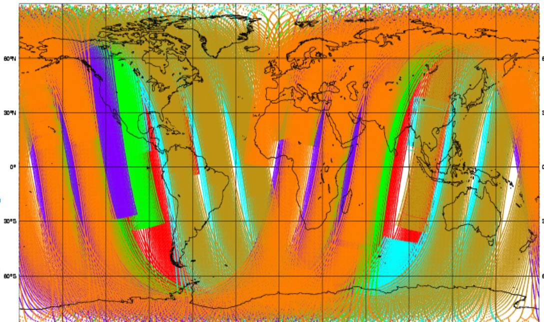


ECMWF

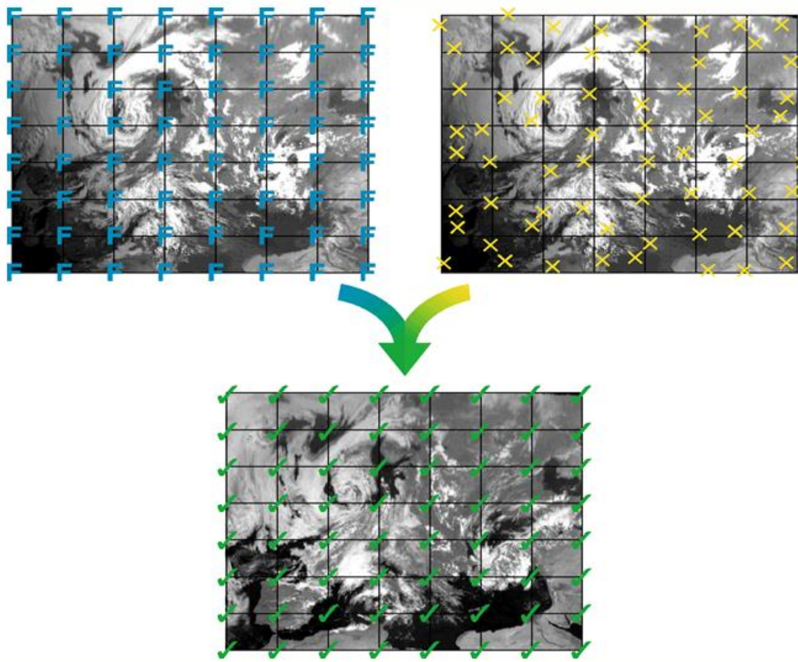
Data assimilation at ECMWF

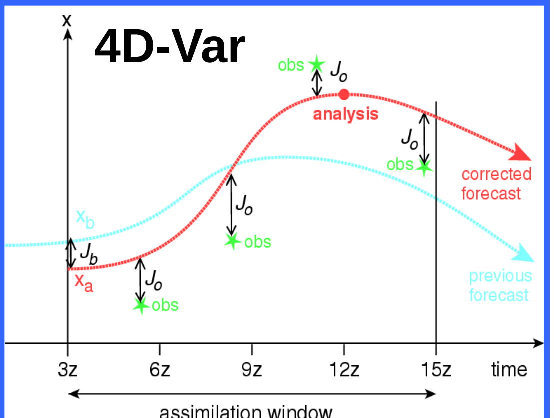


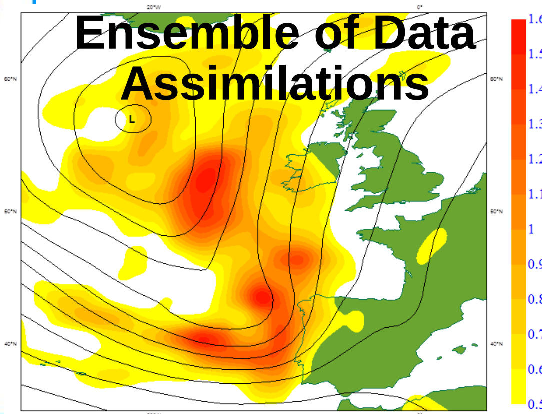
Forecast model

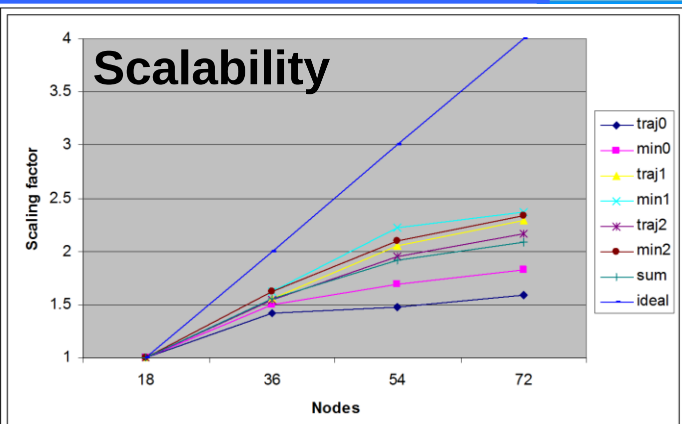


Observations



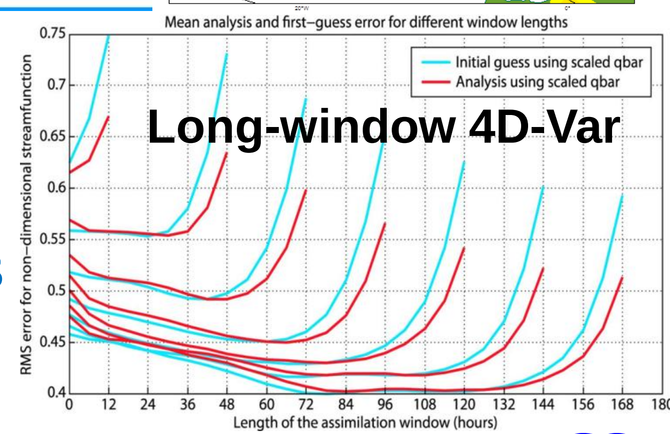






Methods

Progress and plans



ECMWF