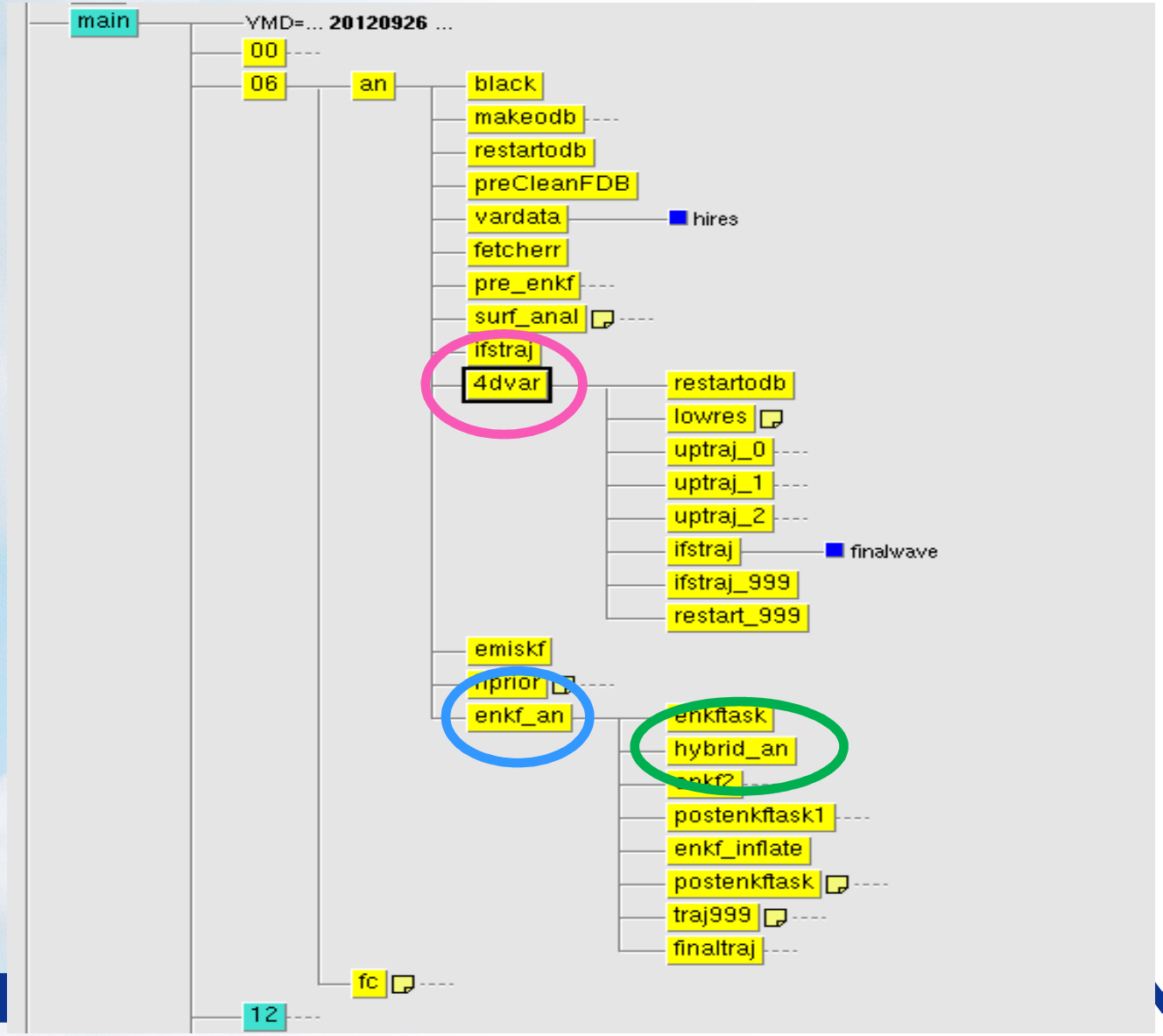
Variational and EnKF assimilation systems at ECMWF (and combinations thereof!)

6th EnKF Workshop

Massimo Bonavita and Mats Hamrud

Thanks to: Jeff Whitaker and many colleagues at ECMWF

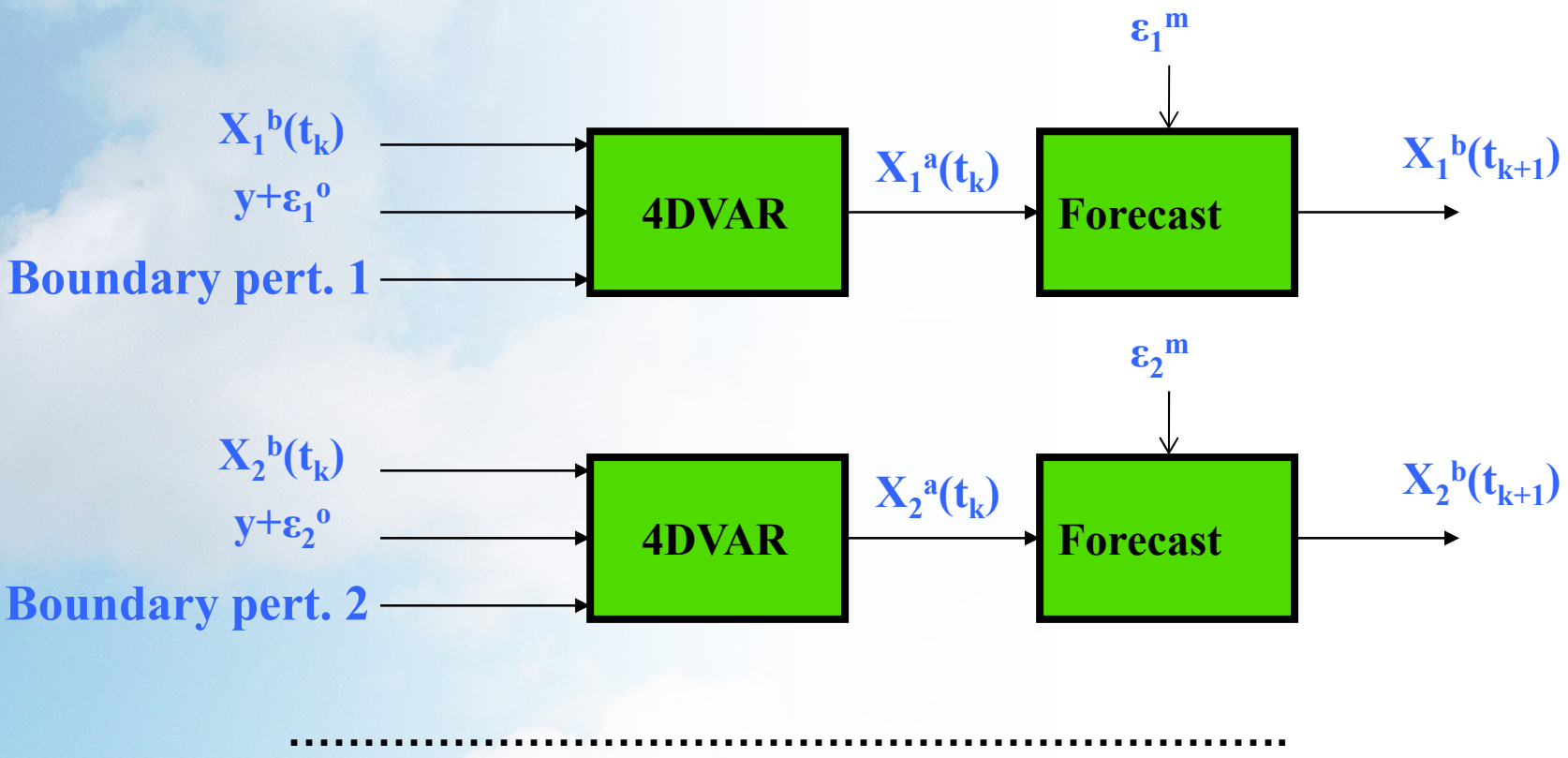
Variational and EnKF assimilation systems at ECMWF (and combinations thereof!)



Var and EnKF assimilation systems at ECMWF

- Developments in current operational Hybrid 4DVar
- Development of (possible?) future operational Hybrid DA

The Ensemble of Data Assimilations (EDA)



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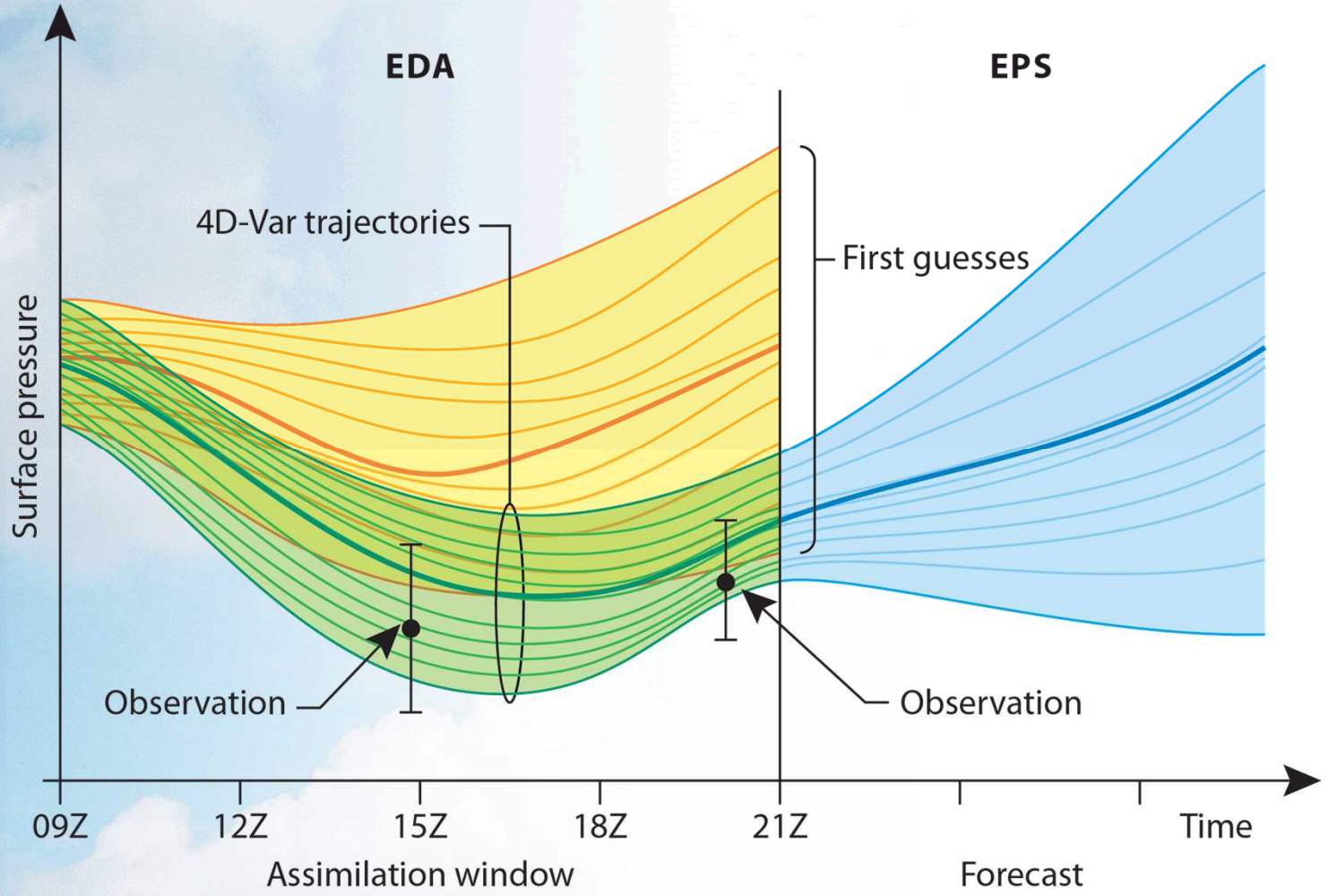
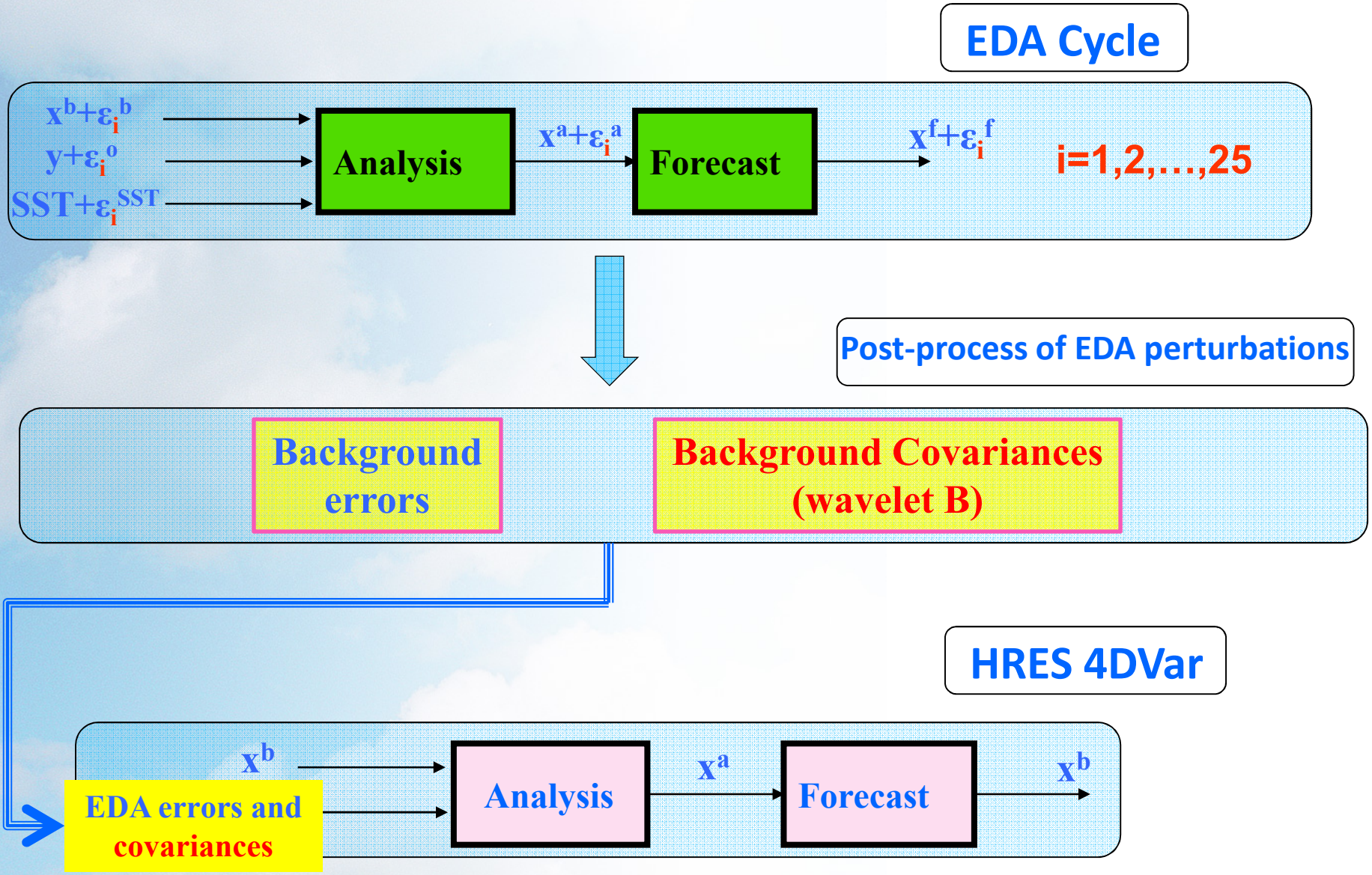
- 25 ensemble members using 4D-Var assimilations at reduced resolution
- Observations, SST and Model perturbed

Applications of the EDA



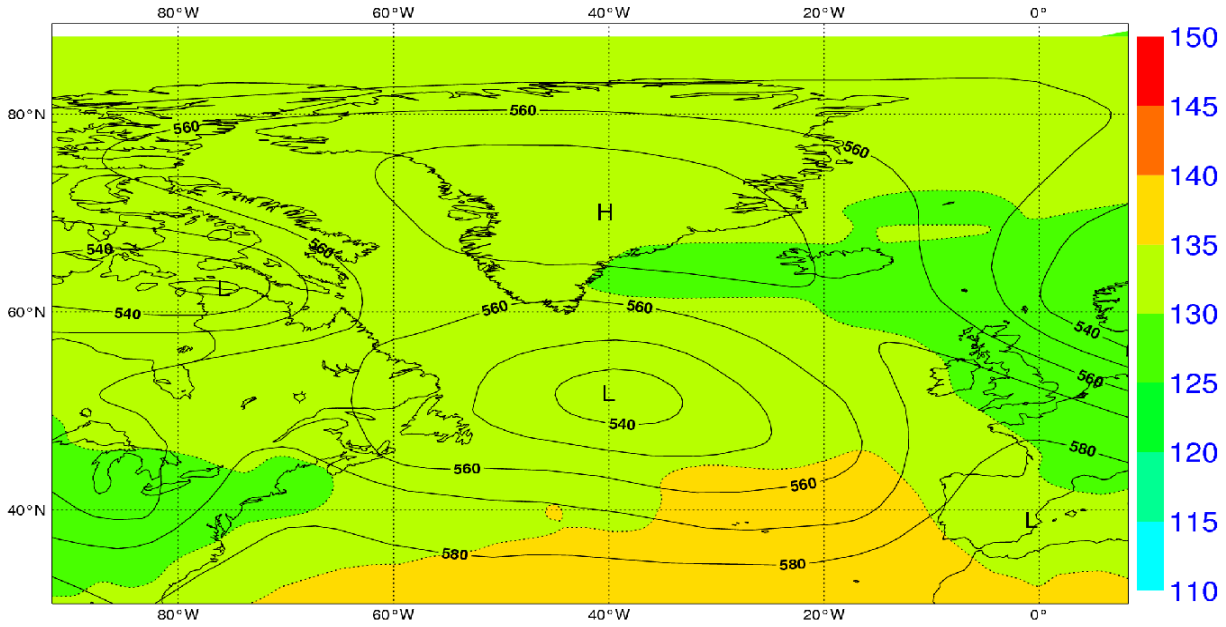

EDA Cycle
$x^b+\varepsilon_i^b$
$y+\varepsilon_i^o$
$SST+\varepsilon_i^{SST}$
Analysis
$x^a+\varepsilon_i^a$
Forecast
$x^f+\varepsilon_i^f$
i=1,2,…,25
Post-process of EDA perturbations
Background errors
Background Covariances (wavelet B)
HRES 4DVar
x^b
EDA errors and covariances
Analysis
x^a
Forecast
x^b

Online wavelet B update

1. From November 2013 (CY40R1) background error covariances (wavelet B) are computed online, i.e. they are updated at every assimilation time (00, 12 UTC)

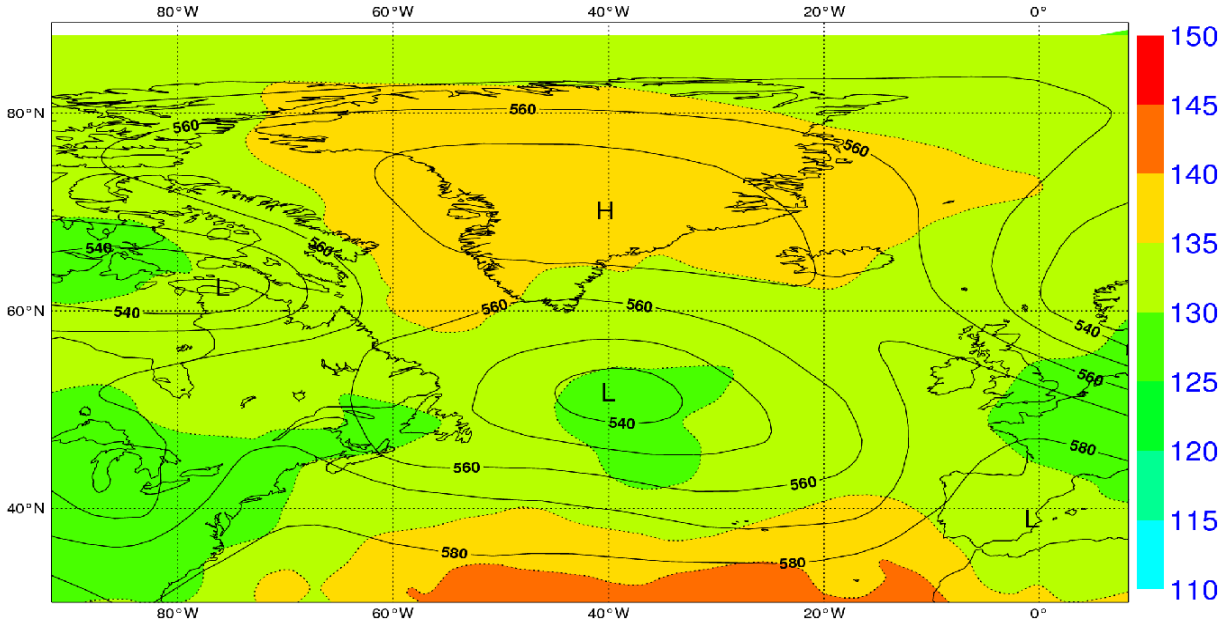
2. EDA perturbations from the past 12 days are used, with an exponential decay factor (i.e., reduce noise at the cost of losing some flow-dependent detail)

Error Correlation L-scales for Vorticity, 500 hPa

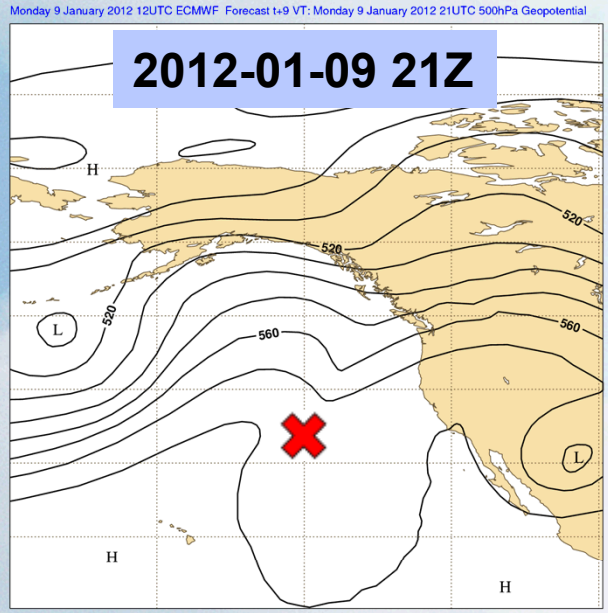


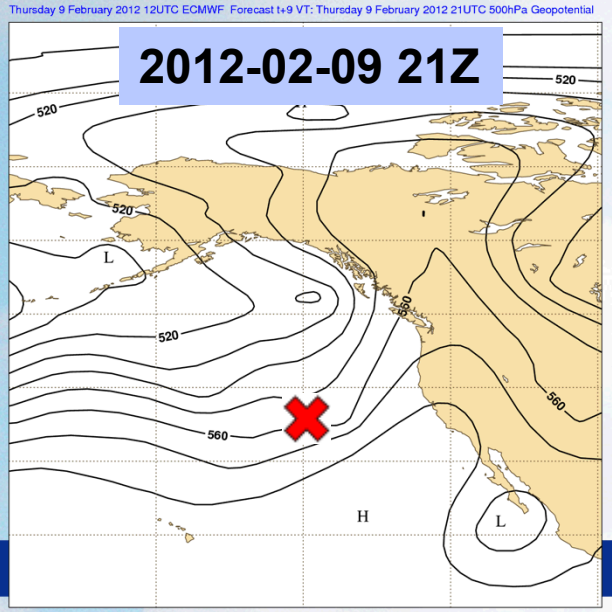
Static wavelet B

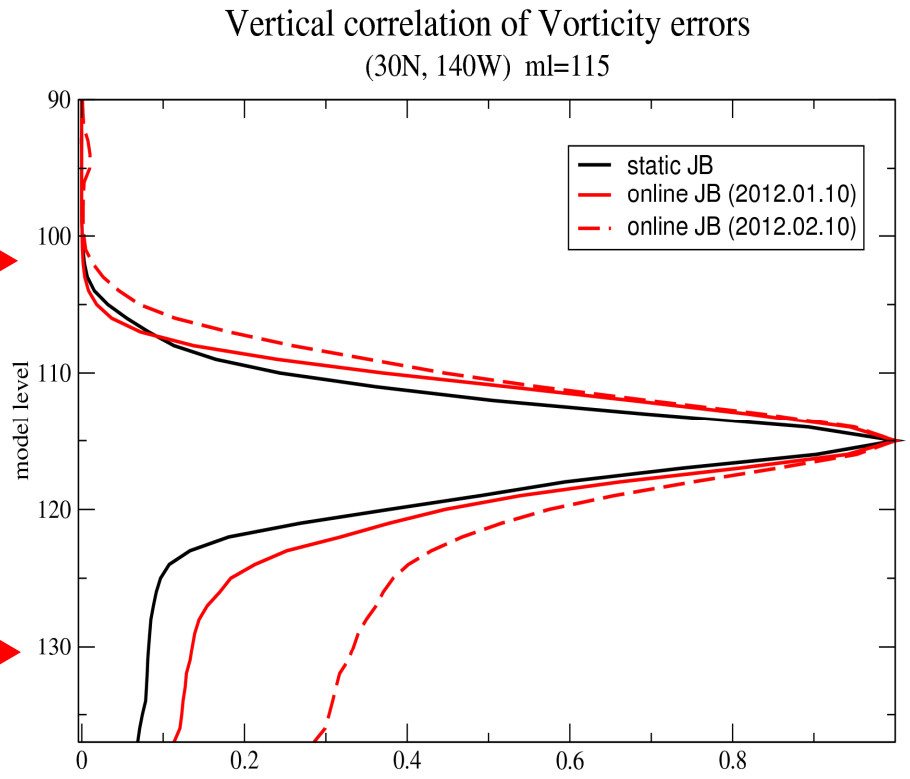
Online wavelet B



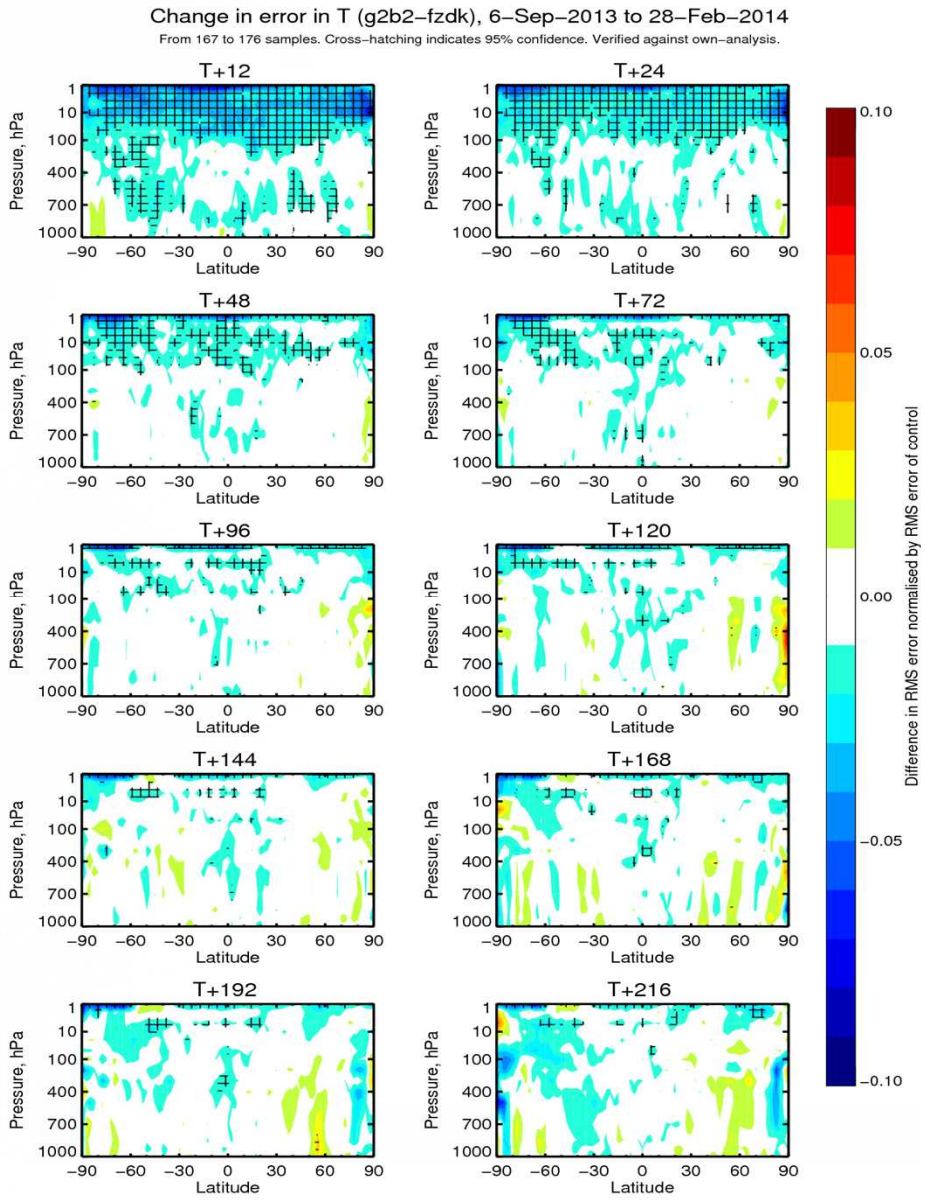
Vertical Error Correlation - Vorticity, 850 hPa

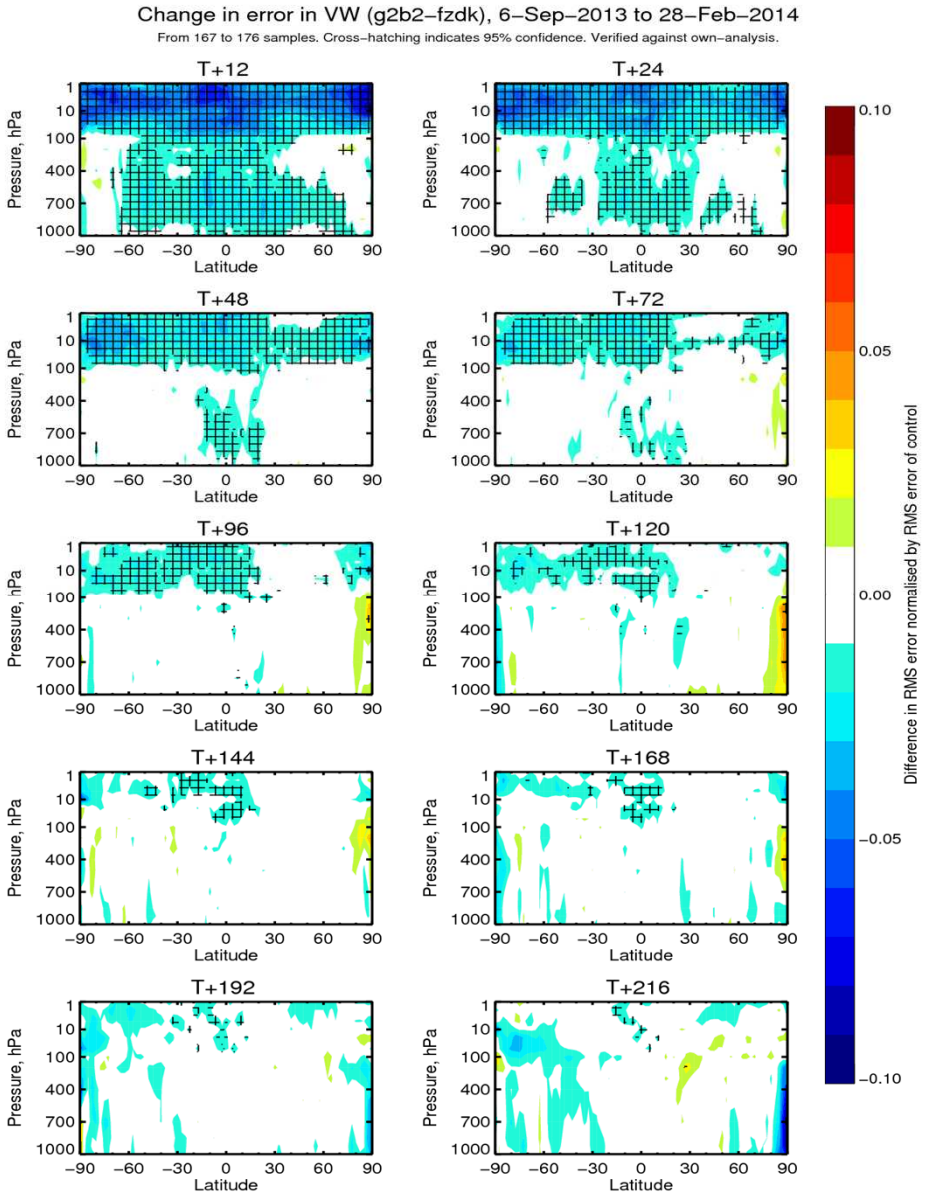






From November 2014 (CY40R3) online wavelet B will not be computed from a running average of EDA perturbations but from latest EDA perturbations + sample of climatological perturbations



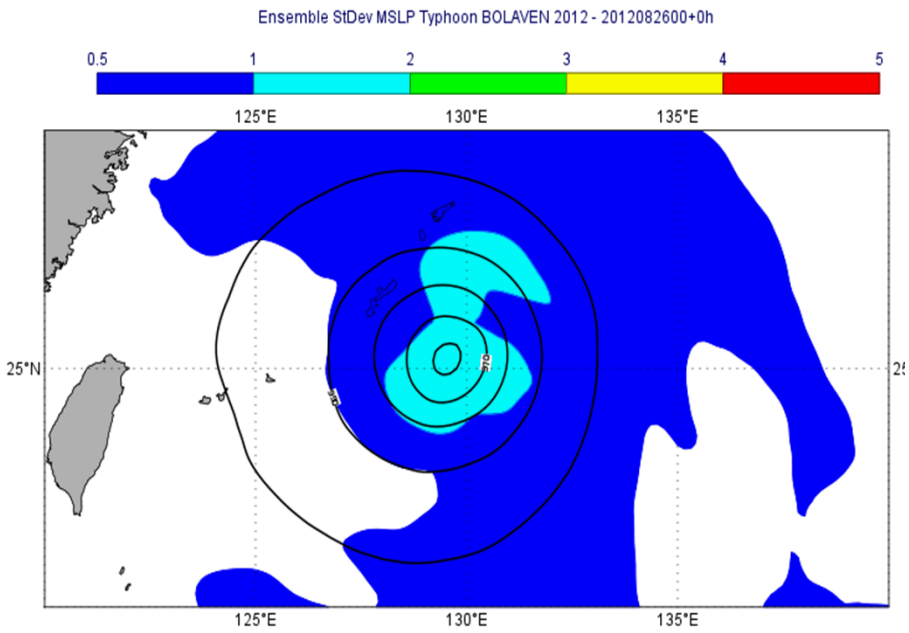


1. The EDA is an effective and theoretically well grounded system for the error cycling of the High Resolution 4DVar, but is very expensive for current (and future!) resources

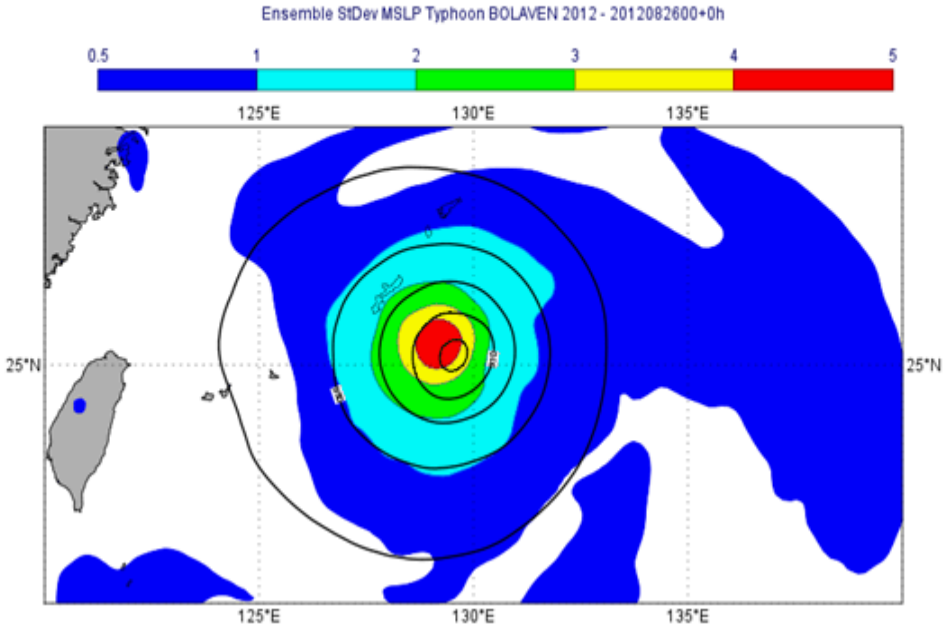
2. There are obvious advantages from running a larger ensemble at higher resolution

Typhoon BOLAVEN 2012 – MSLP ENS StDev

T399 EDA



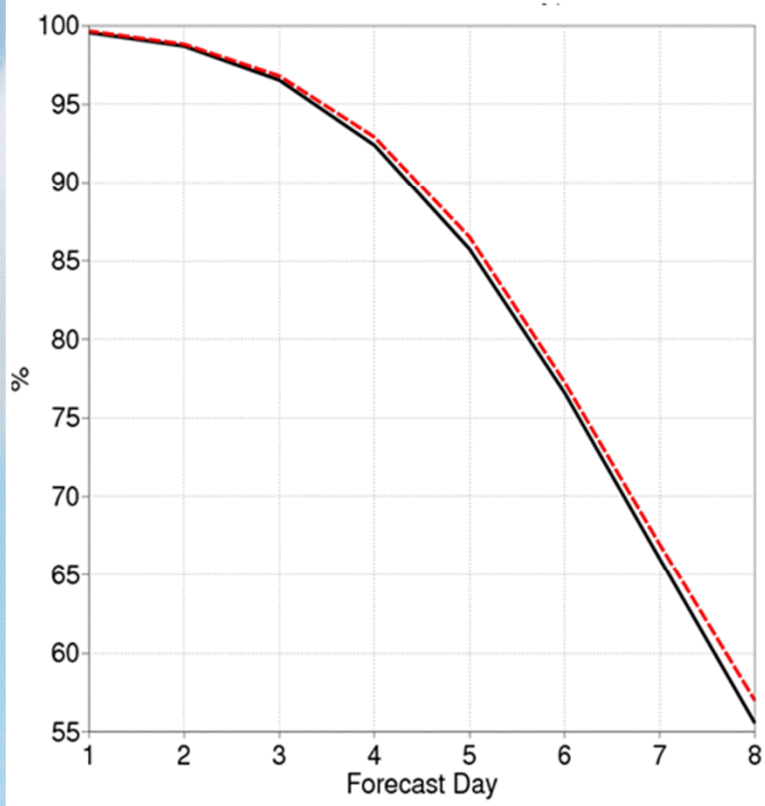
T639 EDA



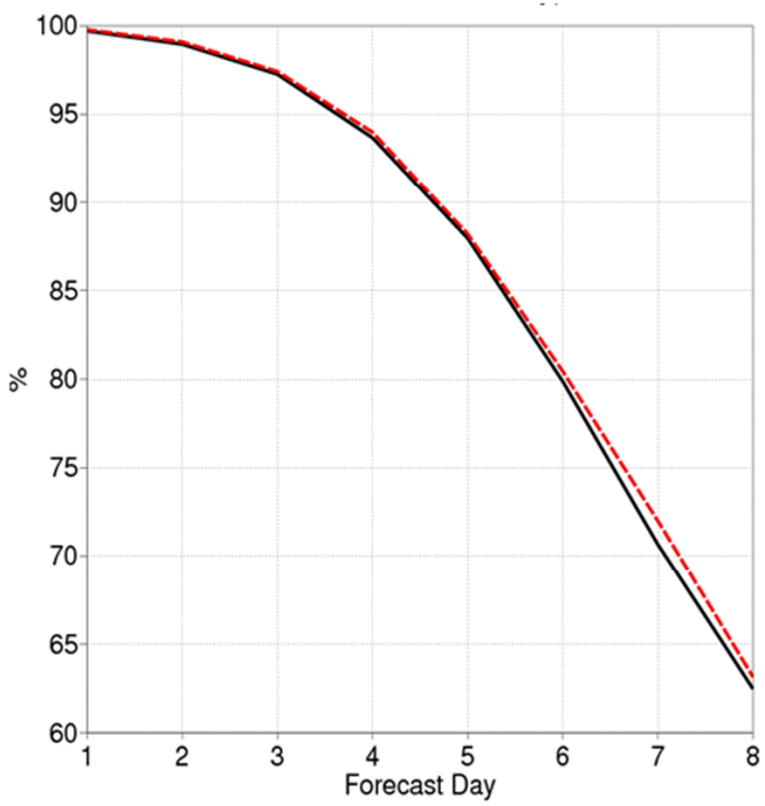
EnKF developments

T399 100 member EnKF

T399 4DVar – static B



Z500 hPa AC - NHem



Z500 hPa AC - SHem

ECMWF

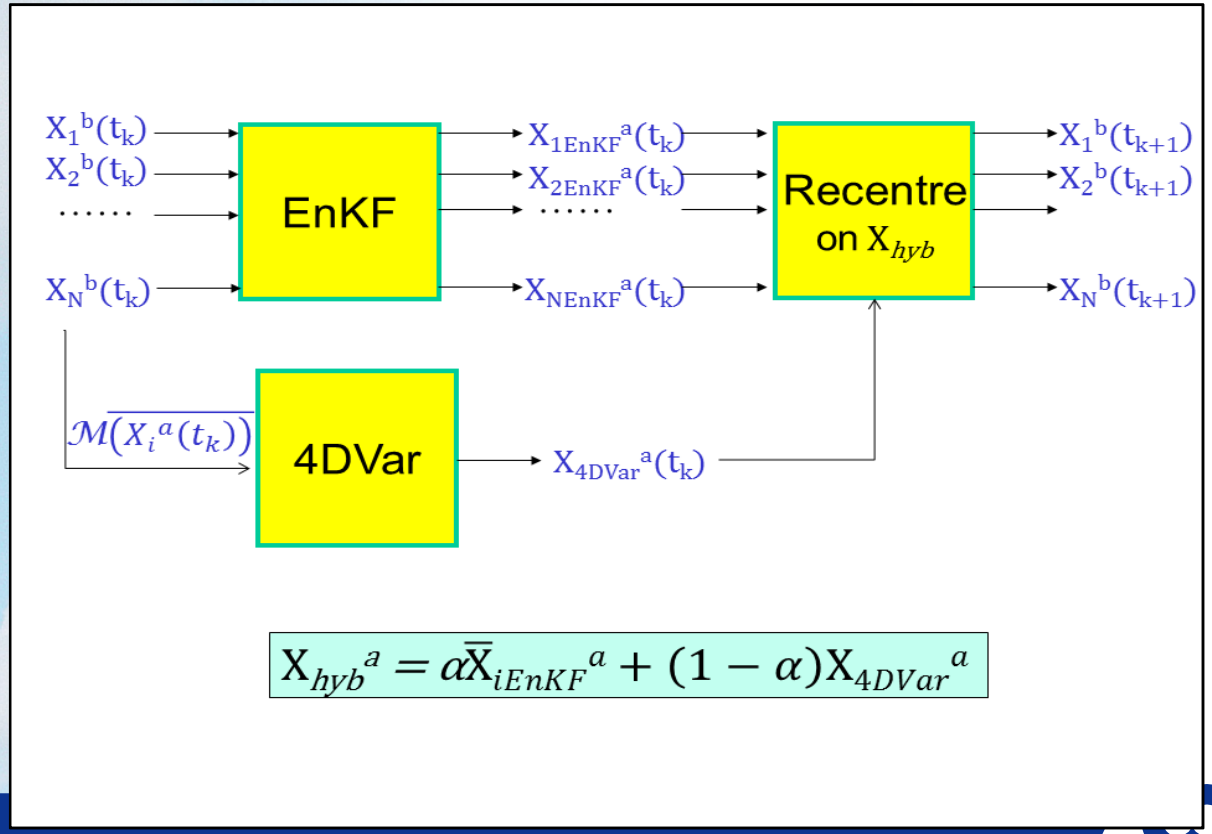
Hybrid Gain EnKF

- Can we improve by blending two analysis system of similar quality?
- Penny, 2013, shows this performs comparably to hybrid B methods

EnKF developments

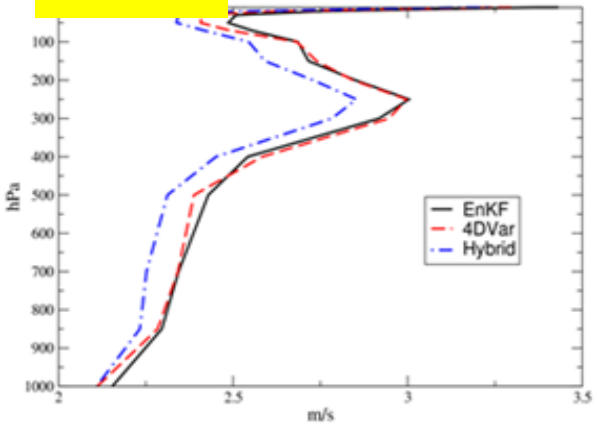
- Can we improve by blending two analysis system of similar quality inside the EnKF framework?
- Penny, 2013, shows this performs comparably to hybrid B methods

Hybrid Gain EnKF

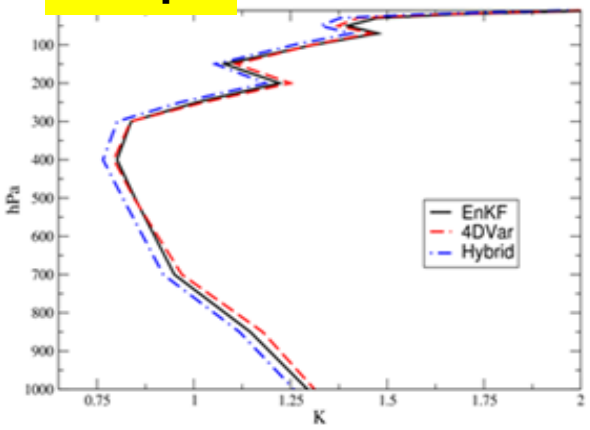


$$X_{hyb}^{\ a} = \alpha \bar{X}_{iEnKF}^{\ a} + (1-\alpha) X_{4DVar}^{\ a}$$

u wind

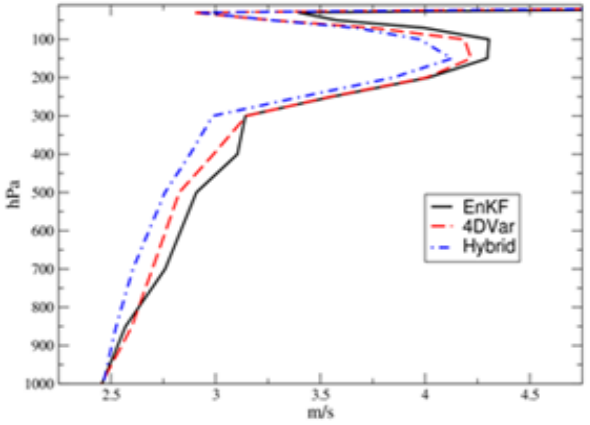


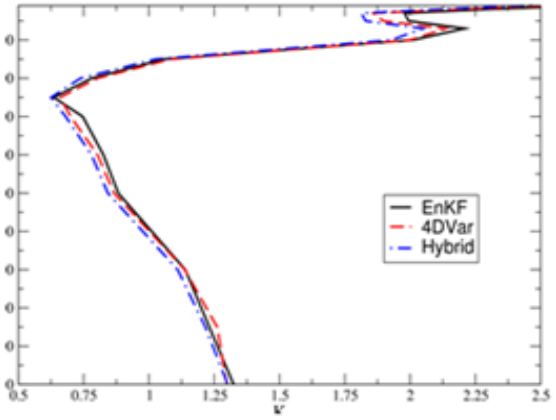
Temp.



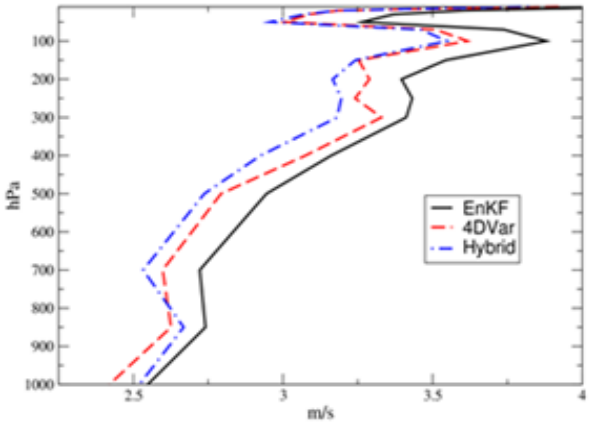
EnKF
4DVar
Hybrid

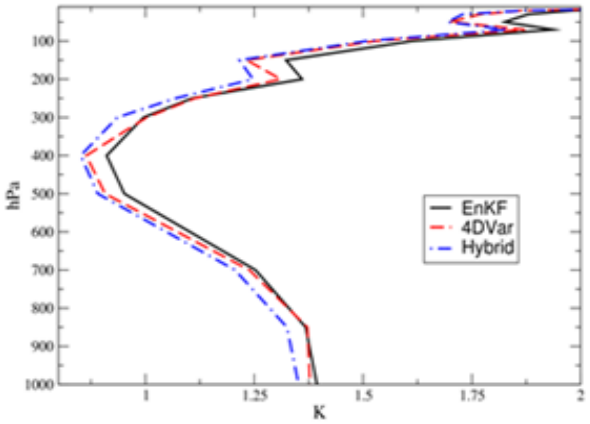
NHem





Trop





SHem

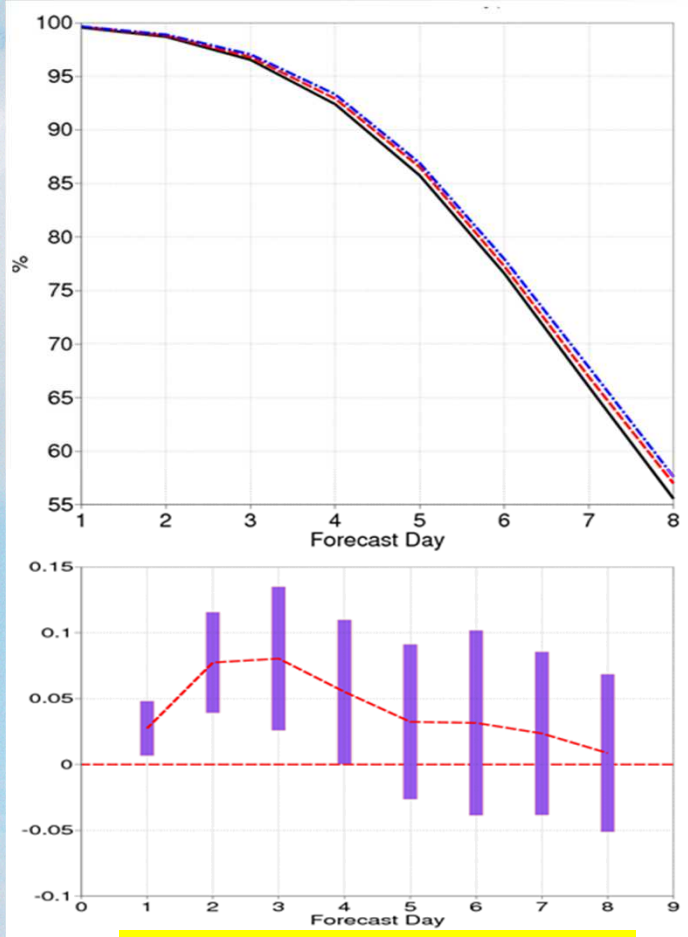
ECMWF

Hybrid Gain EnKF

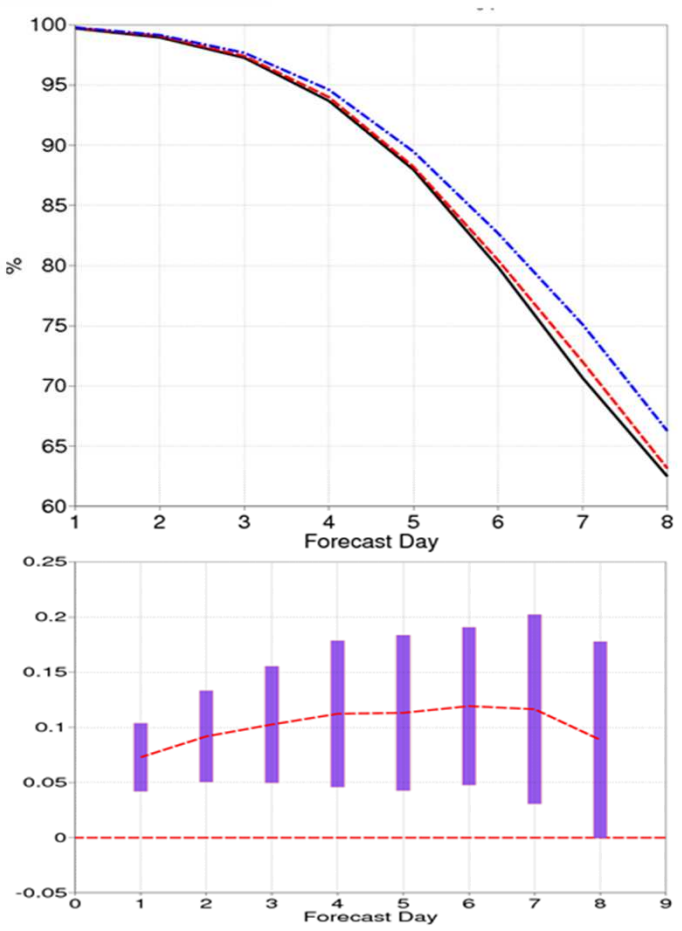
T399 100 member EnKF

T399 4DVar – static B

T399 100 member Hybrid EnKF



Z500 hPa AC - NHem

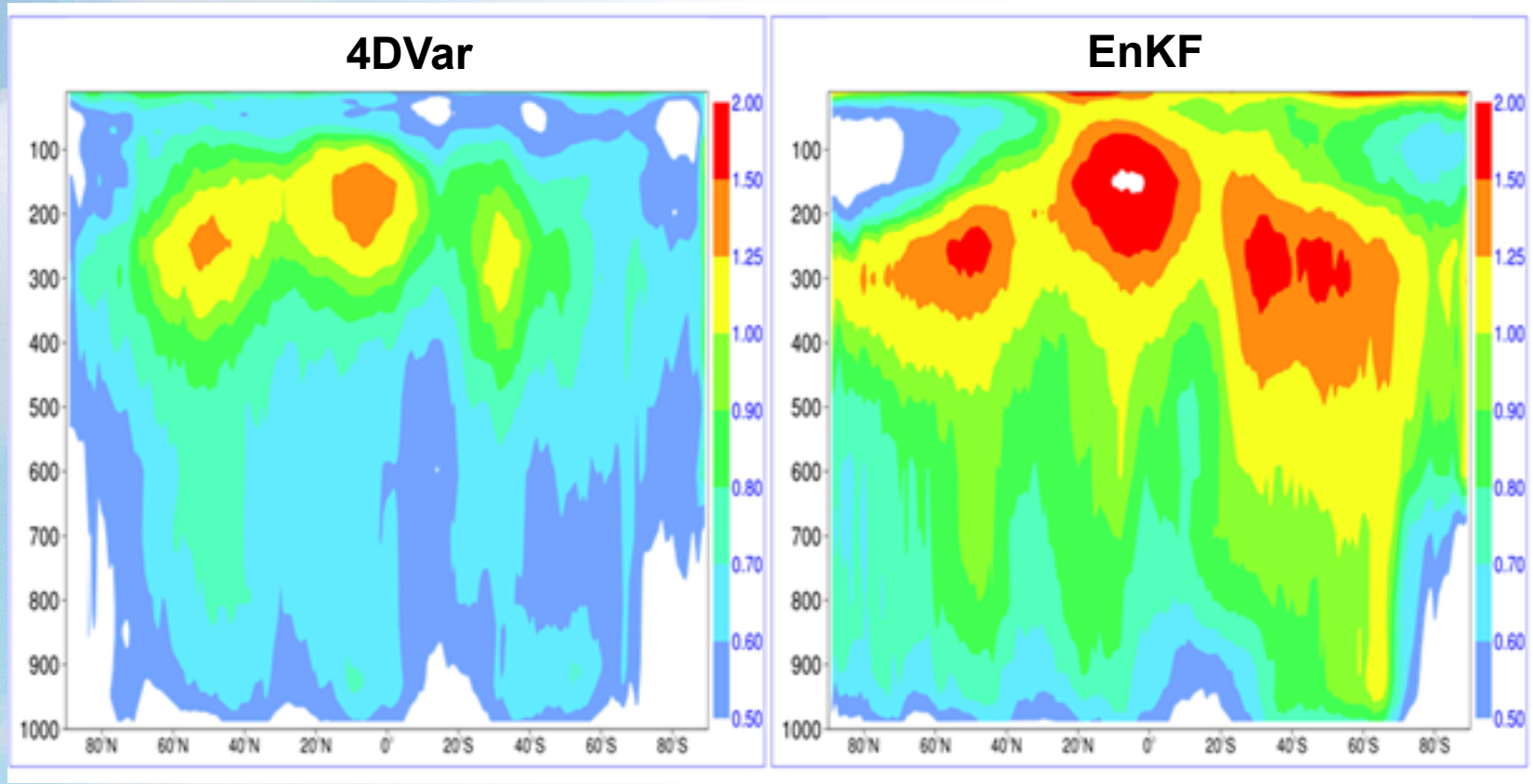


Z500 hPa AC - SHem

ECMWF

Hybrid Gain EnKF

- What do 4DVar and EnKF do differently?

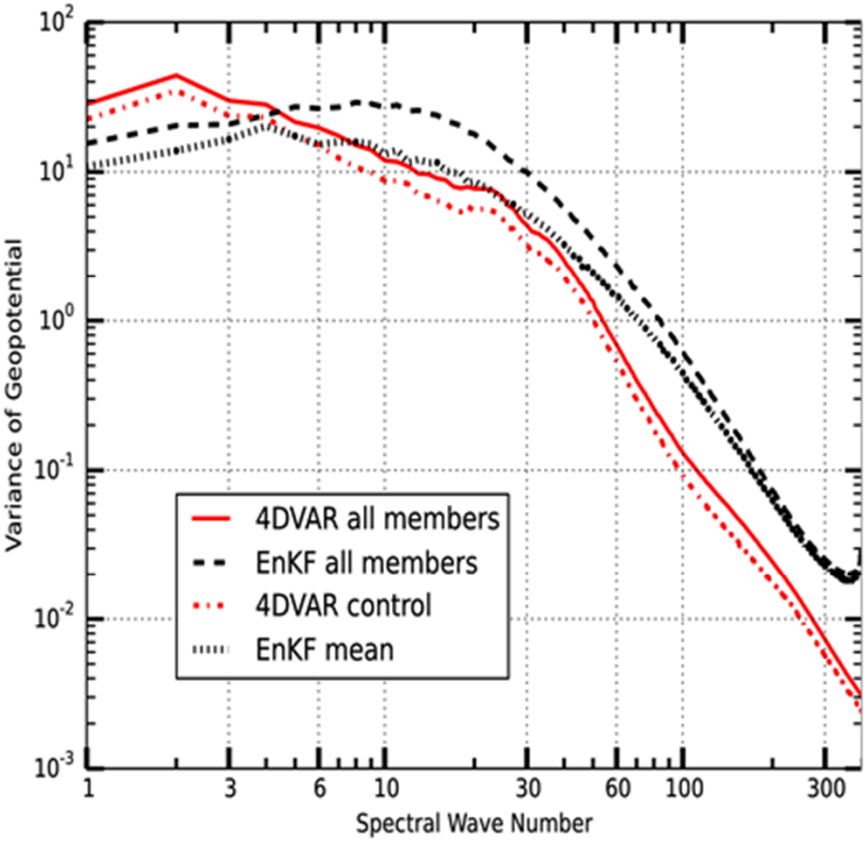


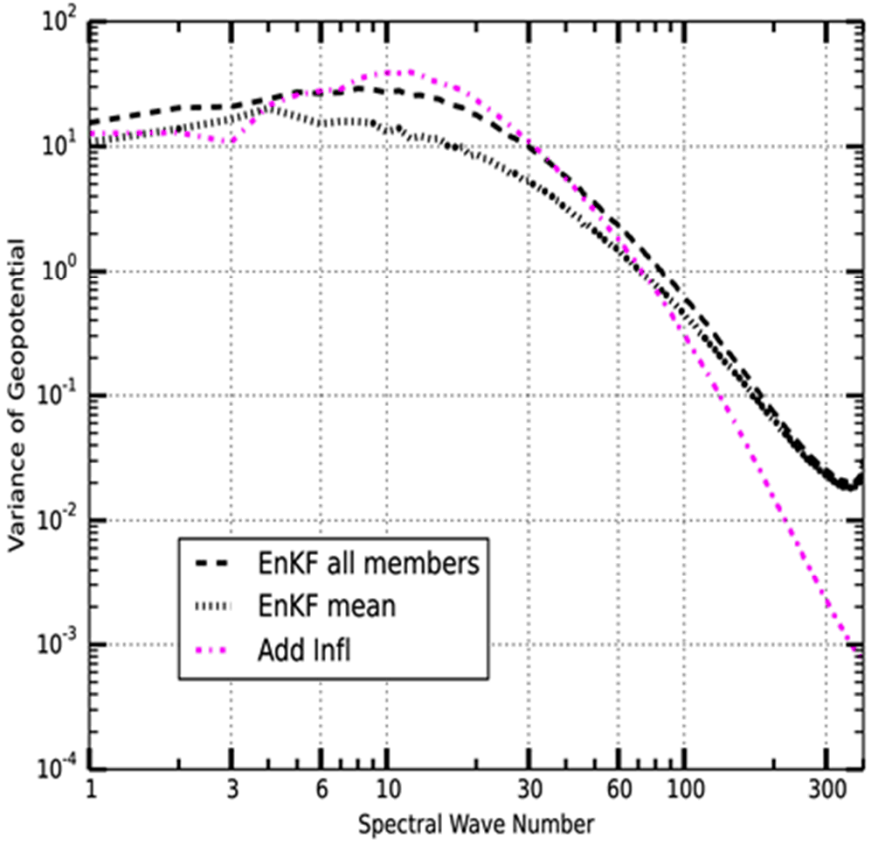
Zonal averages of the standard deviation of the zonal wind analysis increm.

ECMWF

Hybrid Gain EnKF

- What do 4DVar and EnKF do differently?





Power spectra of Z500 hPa analysis increments

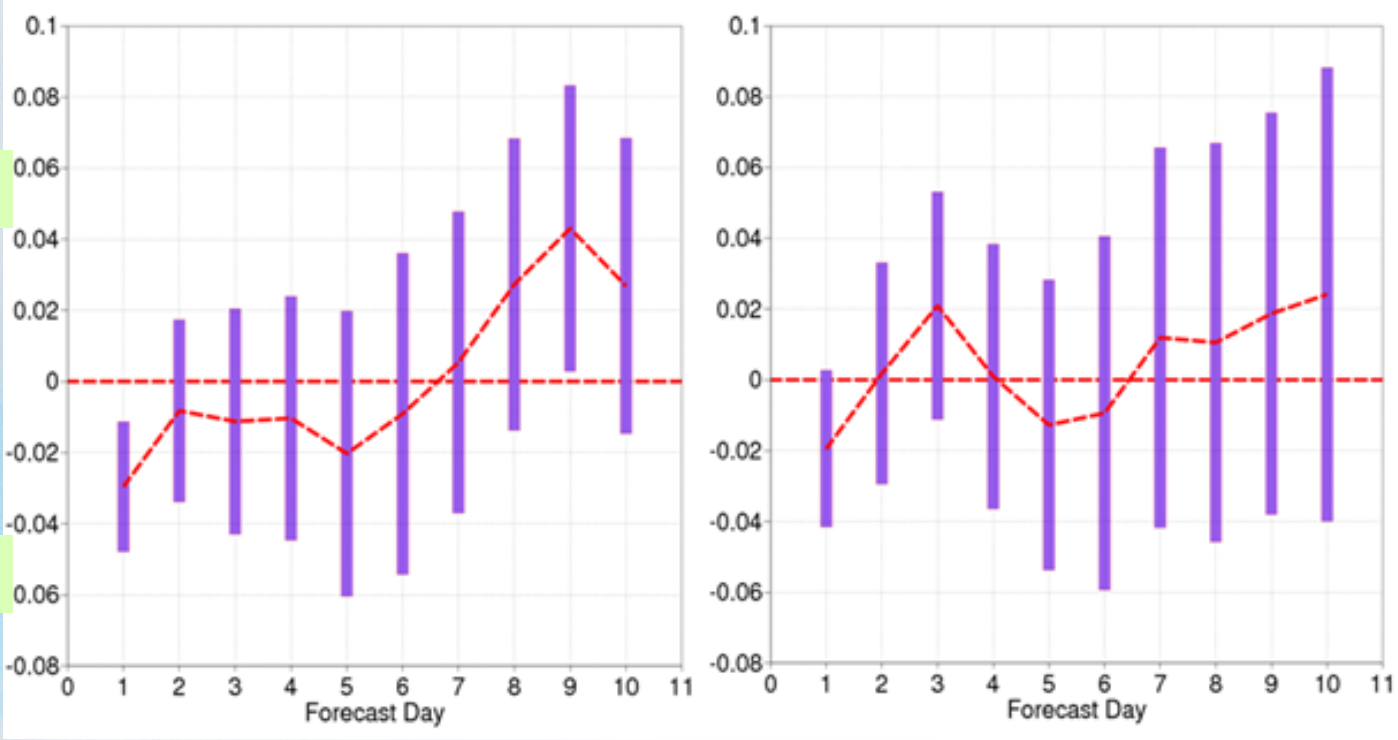
Hybrid Gain EnKF

- The Hybrid Gain EnKF compares well with EnKF and static 4DVar, how does it stack up against hybrid 4DVar (i.e., current operational system)?

T511 experiment, 100 days, verified against oper. analysis

Hyb. EnKF

Hyb. 4DVar



Z500 hPa AC - NHem

Z500 hPa AC - SHem

ECMWF

Final thoughts

- The Hybrid 4DVar development proceeds with good results. Next we are going to take a closer look at balance operators and methods to introduce anisotropy in the wavelet formulation
- The EDA has desirable properties, but it is very expensive: running an EnKF would allow us to run a 100 member T639 ensemble at the same cost of a 25 member T399 EDA!
- A pure EnKF DA system has roughly similar skill to a standard 4DVar

Final thoughts

- A way to increase the skill of an EnKF system is through the hybrid gain EnKF approach: this is functionally equivalent to hybrid B covariance systems, but it offers additional practical advantages.
- In preliminary experimentation, hybrid gain EnKF performs comparably to the current operational hybrid 4DVar.
- A system with a hybrid gain EnKF for error cycling and hybrid 4DVar for the high resolution analysis would have two main advantages:

1. Allow running a larger ensemble at higher resolution;
2. Provide two competitive analysis estimates

Final thoughts

"Online covariances are a good thing, but everything in Moderation!"

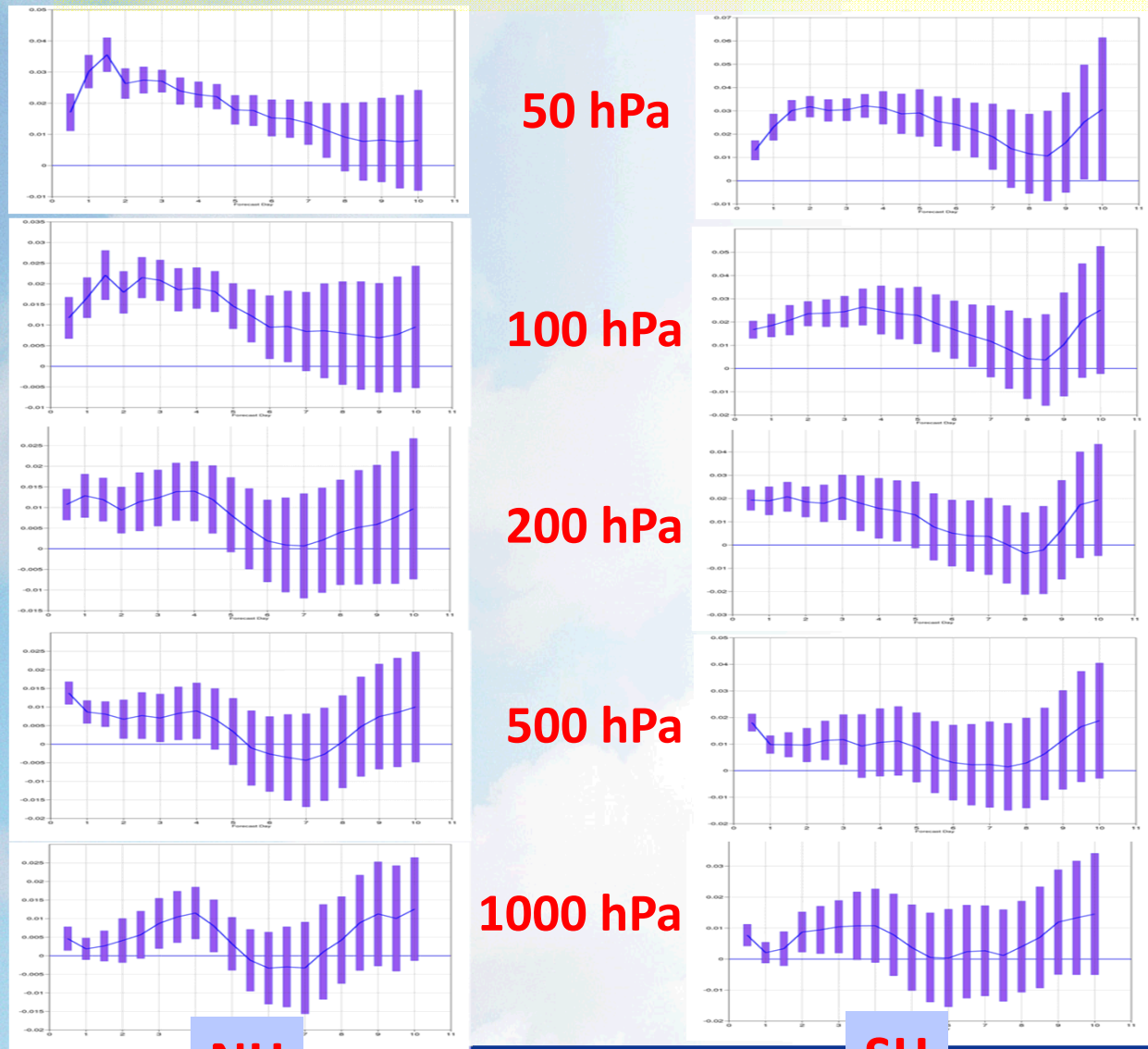
More details in:

Hamrud, Bonavita and Isaksen, 2014: "EnKF and Hybrid Gain Data Assimilation", ECMWF Tech. Memo., in preparation.

Additional Slides

Impact of online wavelet B

Reduction in Geopotential RMSE - 95% confidence



Period: Feb - June 2012

T511L91, 3 Outer Loops (T159/T255/T255)

Verified against operational analysis

ECMWF