Met Office

An examination of the short-range forecast error characteristics of perturbations from an ensemble of 4DEnVars when using different inflation schemes

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- Outline of inflation schemes, such as additive inflation, RTPP and RTPS.
- Present background error statistics from En-4DEnVar trials comparing against training data from ECMWF and MOGREPS ETKF.
  - Standard deviations
  - Vertical correlations
  - Horizontal length scales
- Conclusions

Multiplicative Inflation Schemes

- **RTPP** – relaxation to prior perturbations

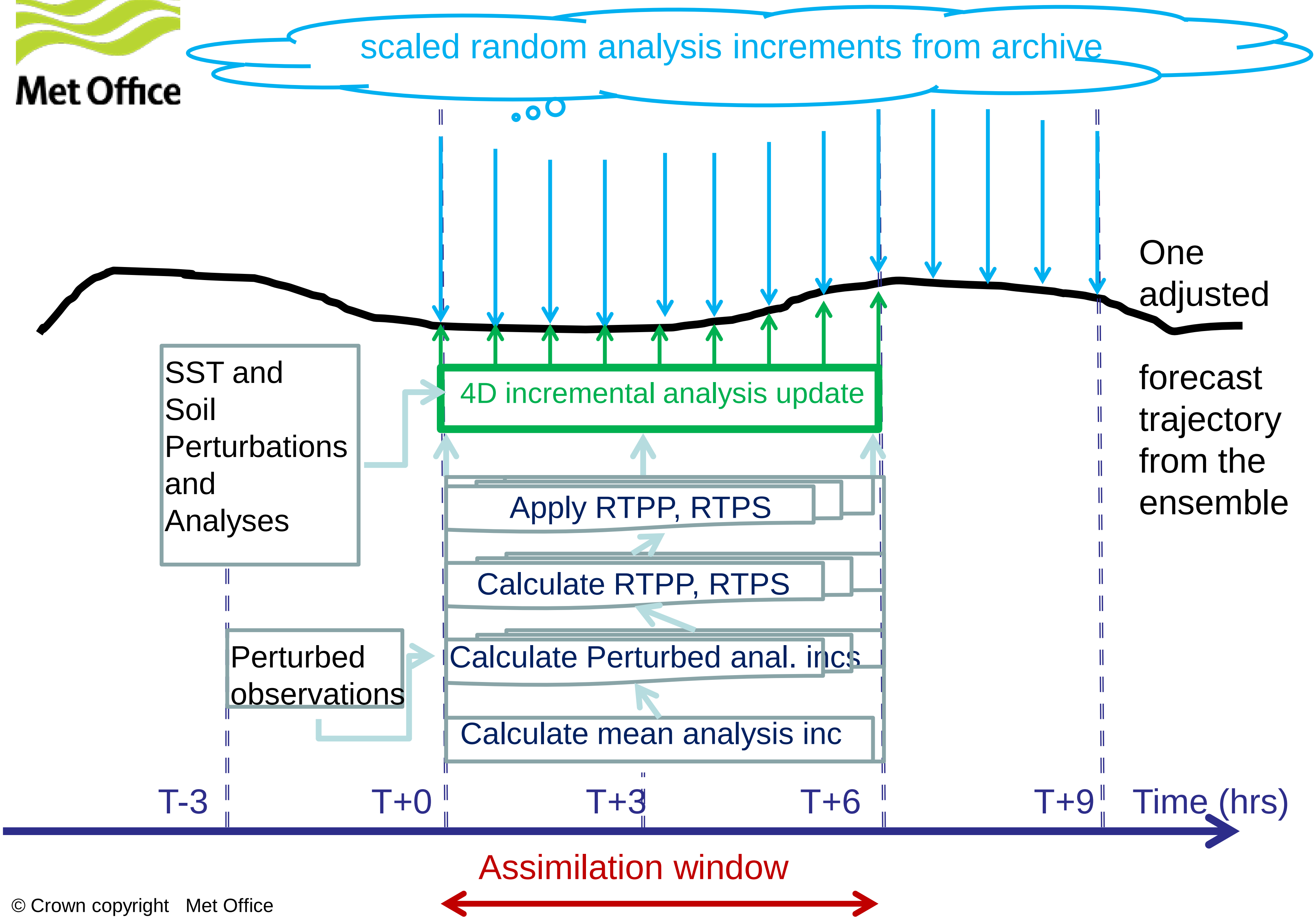
$$\mathbf{x}_i^a{}' \rightarrow \alpha \mathbf{x}_i^f{}' + (1-\alpha)\mathbf{x}_i^a{}'$$

- **RTPS** – relaxation to prior spread

$$\mathbf{x}_i^a{}' \rightarrow r\mathbf{x}_i^a{}' \qquad r = \frac{\alpha\sigma(\mathbf{x}_i^f{}') + (1-\alpha)\sigma(\mathbf{x}_i^a{}')}{\sigma(\mathbf{x}_i^a{}')}$$

Additive Inflation Schemes

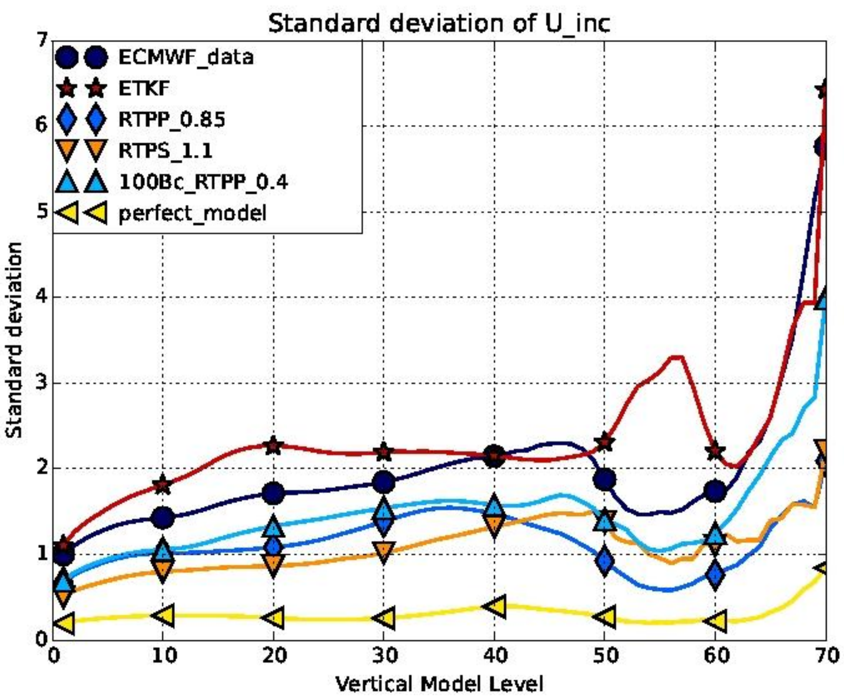
- Stochastic Physics
- The use of random scaled analysis increments. (**Additive inflation)**
  - This is a method designed by Piccolo and Cullen (2016) to take account of model error.
  - It is a statistically based scheme that is used to take account of gaps in our knowledge and taking account of bias.
  - BUT it is flow-independent and its features depend on the observing network.

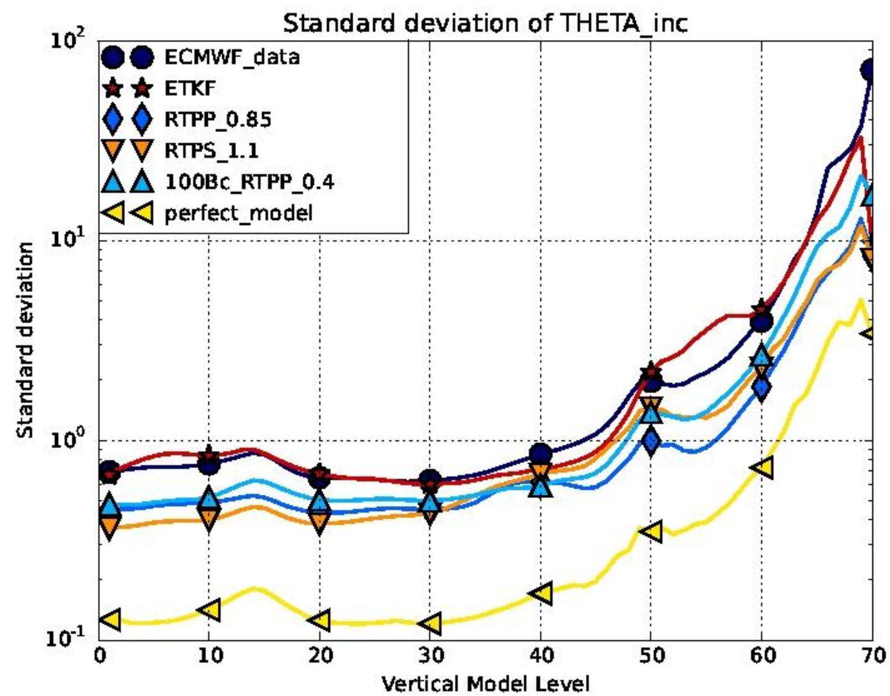

scaled random analysis increments from archive
One adjusted forecast trajectory from the ensemble
SST and Soil Perturbations and Analyses
4D incremental analysis update
Apply RTPP, RTPS
Calculate RTPP, RTPS
Calculate Perturbed anal. incs
Calculate mean analysis inc
Perturbed observations
T-3
T+0
T+3
T+6
T+9
Time (hrs)
Assimilation window

Experiments

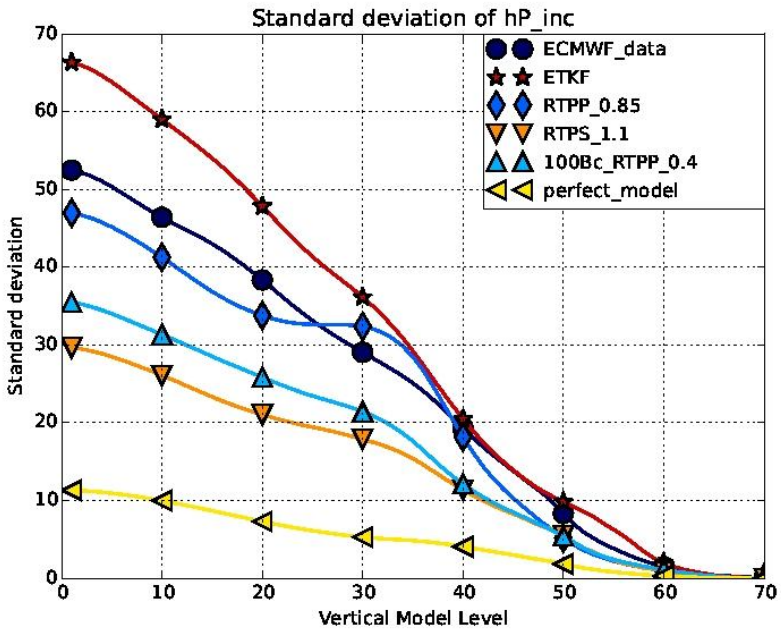
1. Use of ECMWF N320 data set (labelled ***ECMWF data***) - 300 samples -.
2. 44 members MOGREPS ***ETKF*** N400 reconfigured to N216 with stochastic physics and adaptive inflation - 880 samples -.
3. 22 members En-4DEnVar N216, Bc=50%, Be=80%, perturbed obs, additive inflation 0.5, stochastic physics, ***RTPP=0.8*** - 440 samples -.
4. 22 members En-4DEnVar N216, Bc=50%, Be=80%, perturbed obs, additive inflation 0.5, stochastic physics, ***RTPS=1.1*** - 440 samples -.
5. 22 members En-4DEnVar N216, **additive inflation 100%, Bc=100%, Be=0%,** perturbed obs,**, RTPP=0.4** (***100Bc_RTPP_0.4***) - 440 samples -.
6. 22 members En-4DEnVar N216, Bc=50%, Be=80%, **perturbed obs only**, additive inflation 0.0, no stochastic physics, RTPS=0.0, RTPP=0.0 (***perfect_model*** experiment) - 440 samples -.

Standard Deviations - longitude component of wind (u) and potential temperature (theta)





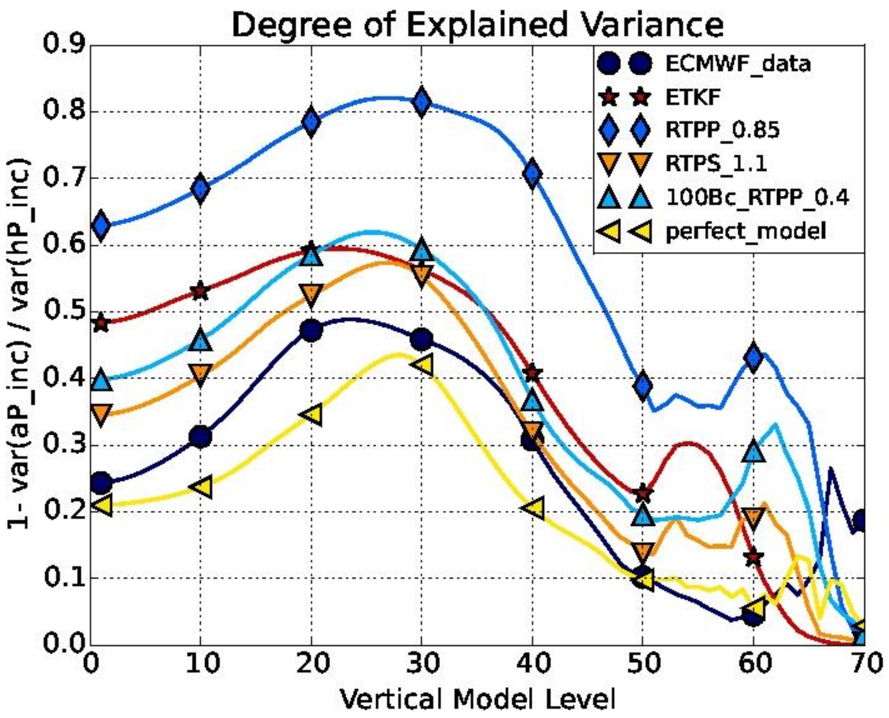
Standard Deviations – hydrostatic pressure and comments



- The perfect model experiment shows the clear need for inflation (though a large drop in the standard deviation is partly due to high Be weight/lack of ensemble members).
- Even with an RTPS greater than 1, the standard deviations are low.
- Except for pressure, the expt with **additive 1.0, 100% Bc weight, RTPP= 0.4** produces a decent amount of spread. For ensemble purposes this has not been pursued as we were after a more flow-dependent background error covariance that provides CRPS values comparable to the ETKF.
- There is a notable “kink” in the pressure profile when using a **large** value of **RTPP**.

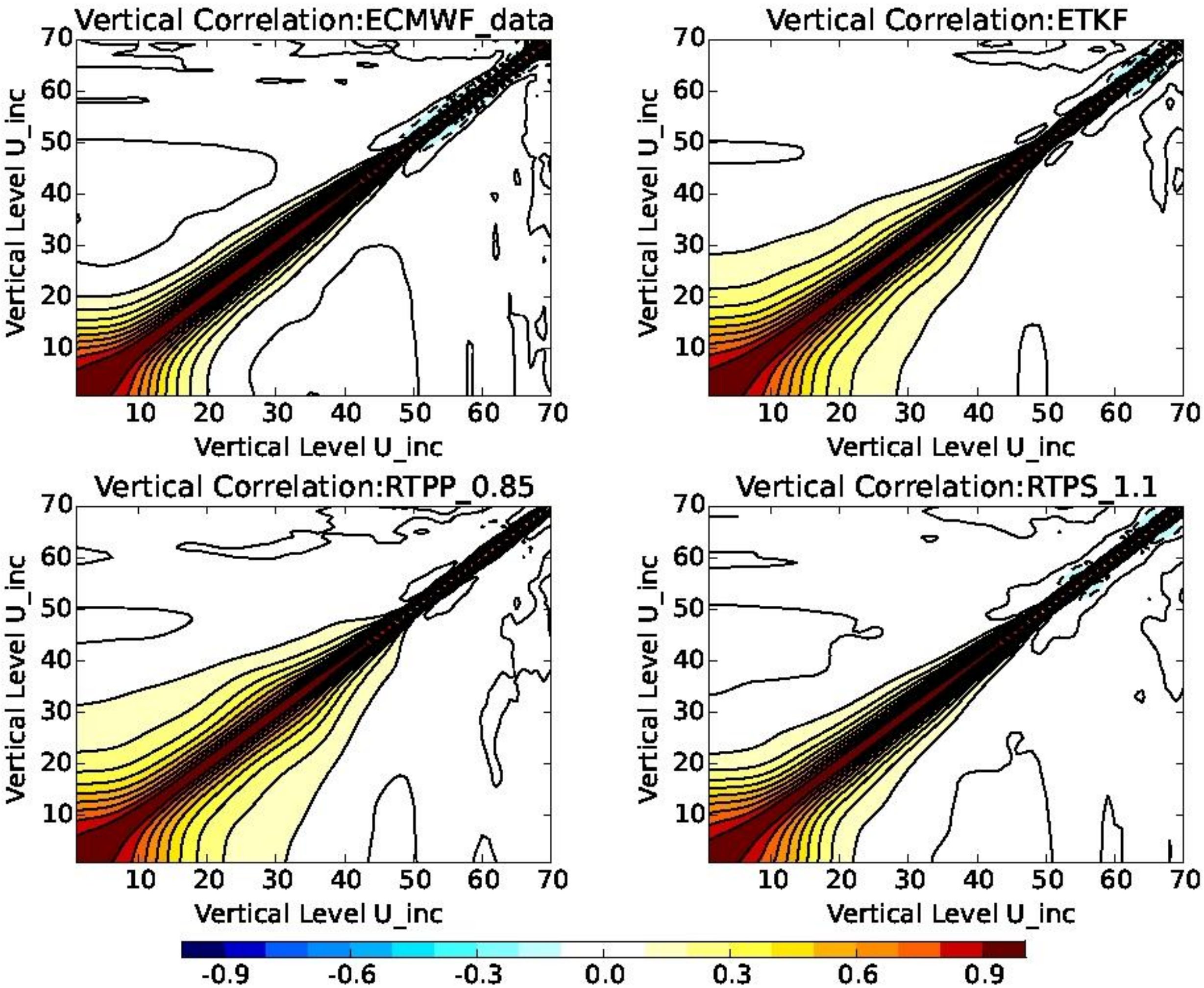
Multivariate coupling through vertical regression and linear balance.

- A value of 1.0 means that the hydrostatic pressure is purely determined by the rotational wind.
- A value of 0.0 means that there is no such coupling.
- We see **excessive multivariate coupling** when using **large RTPP**.



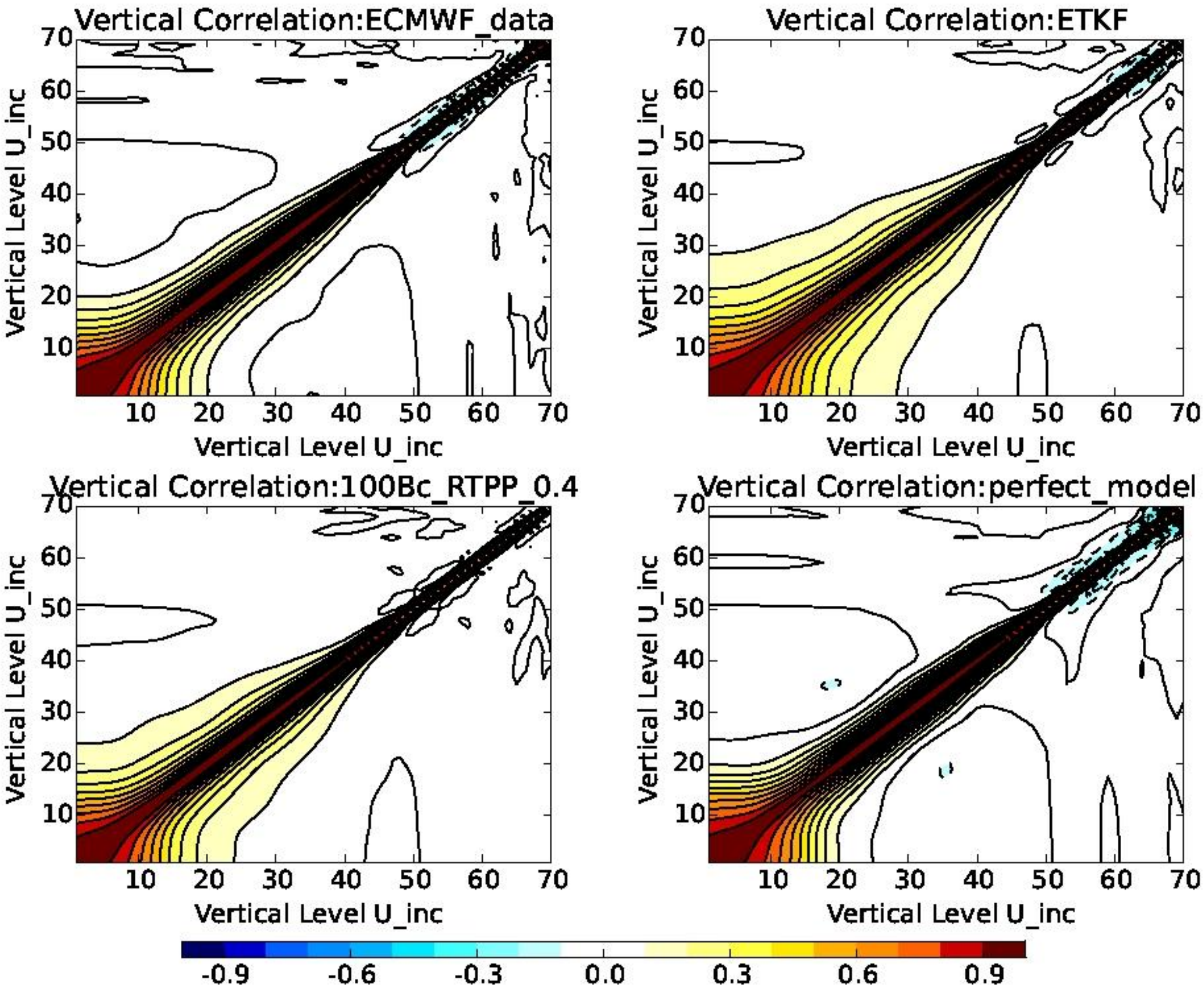
Vertical correlations - longitude component of wind (u)

- Broadest vertical correlations are seen with **large RTPP** (consistent with the excessive multivariate coupling).
- Too broad correlations in static B will increase the condition number of the Hessian in the VAR minimisation as the minimisation becomes more constrained by obs at distance.



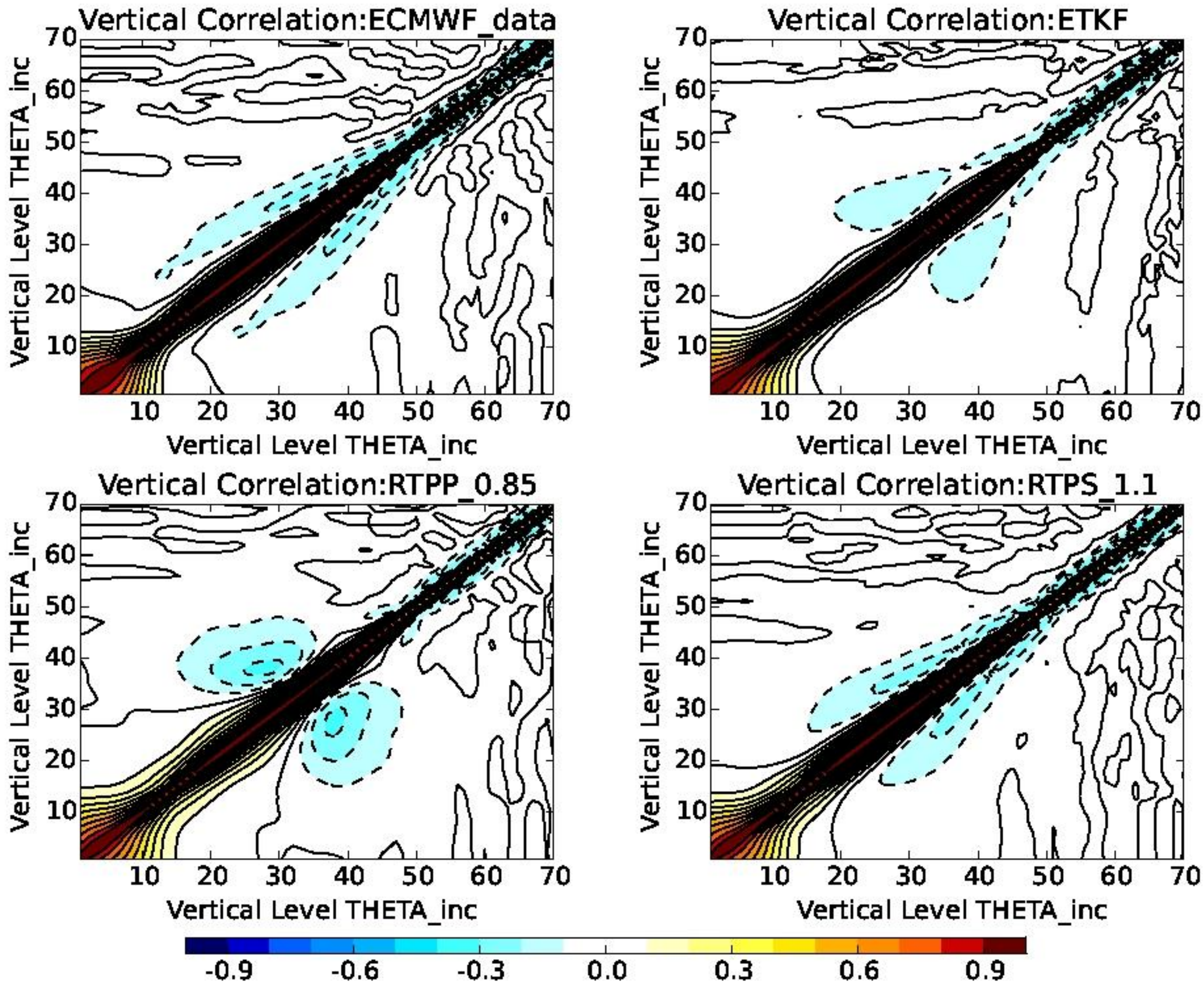
Vertical correlations - longitude component of wind (u)

- **ECMWF data** tends to have tight vertical correlations – almost as tight as the perfect model experiment.
- ECMWF data is what we use to define our static B matrix in VAR and is what we believe to be true.



Vertical correlations – potential temperature (theta)

- **Large RTPP** has strongest anti-correlations between levels 30 and 37 and are quite broad.



Vertical correlations – potential temperature (theta)

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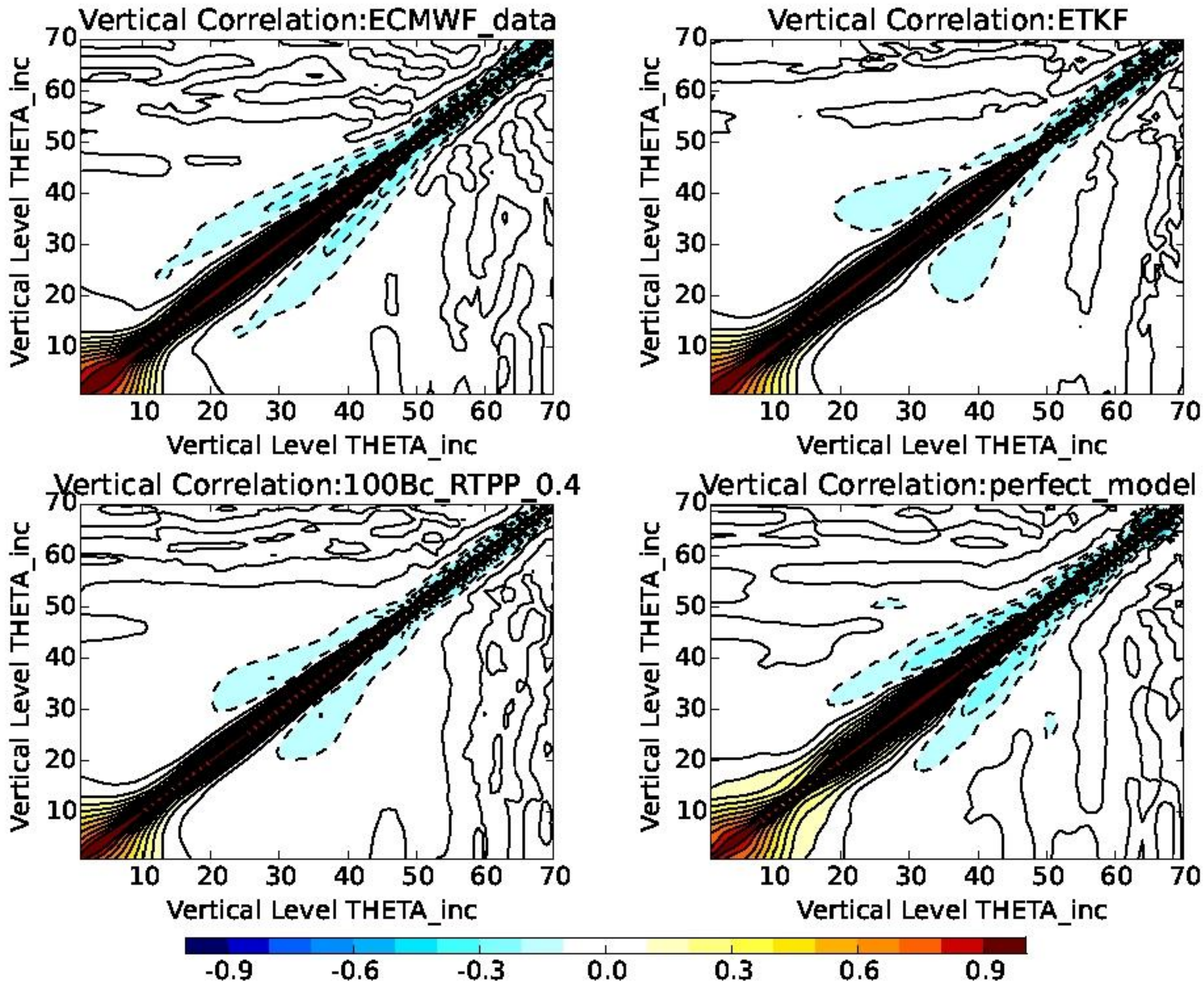
- The **100% Bc expt** with **full additive inflation** has the tightest vertical correlations for theta.

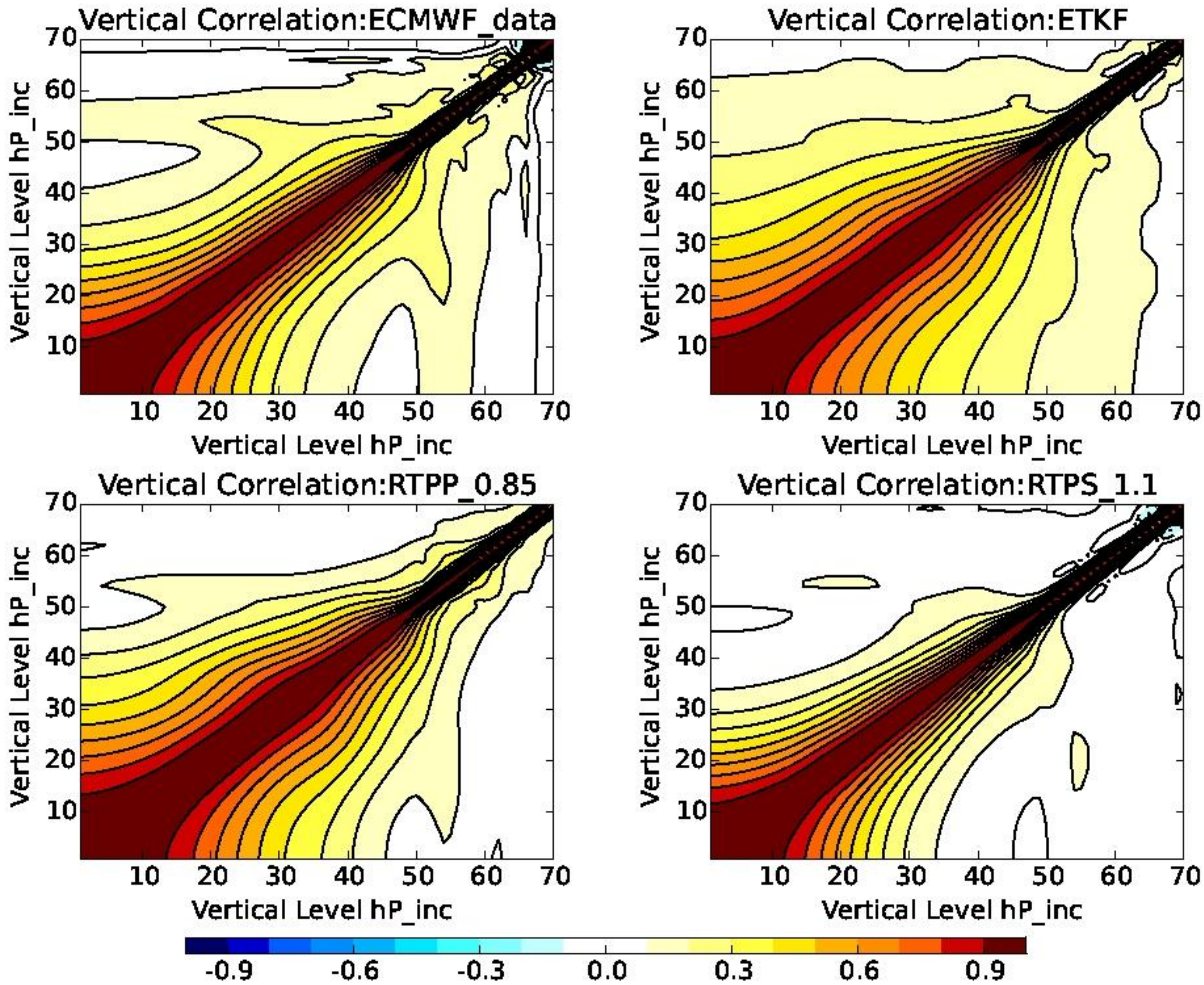
- What is surprising is that the **perfect model** experiment has relatively broad vertical correlations, presumably due to the noisy effect of perturbed observations.



Vertical correlations – hydrostatic pressure

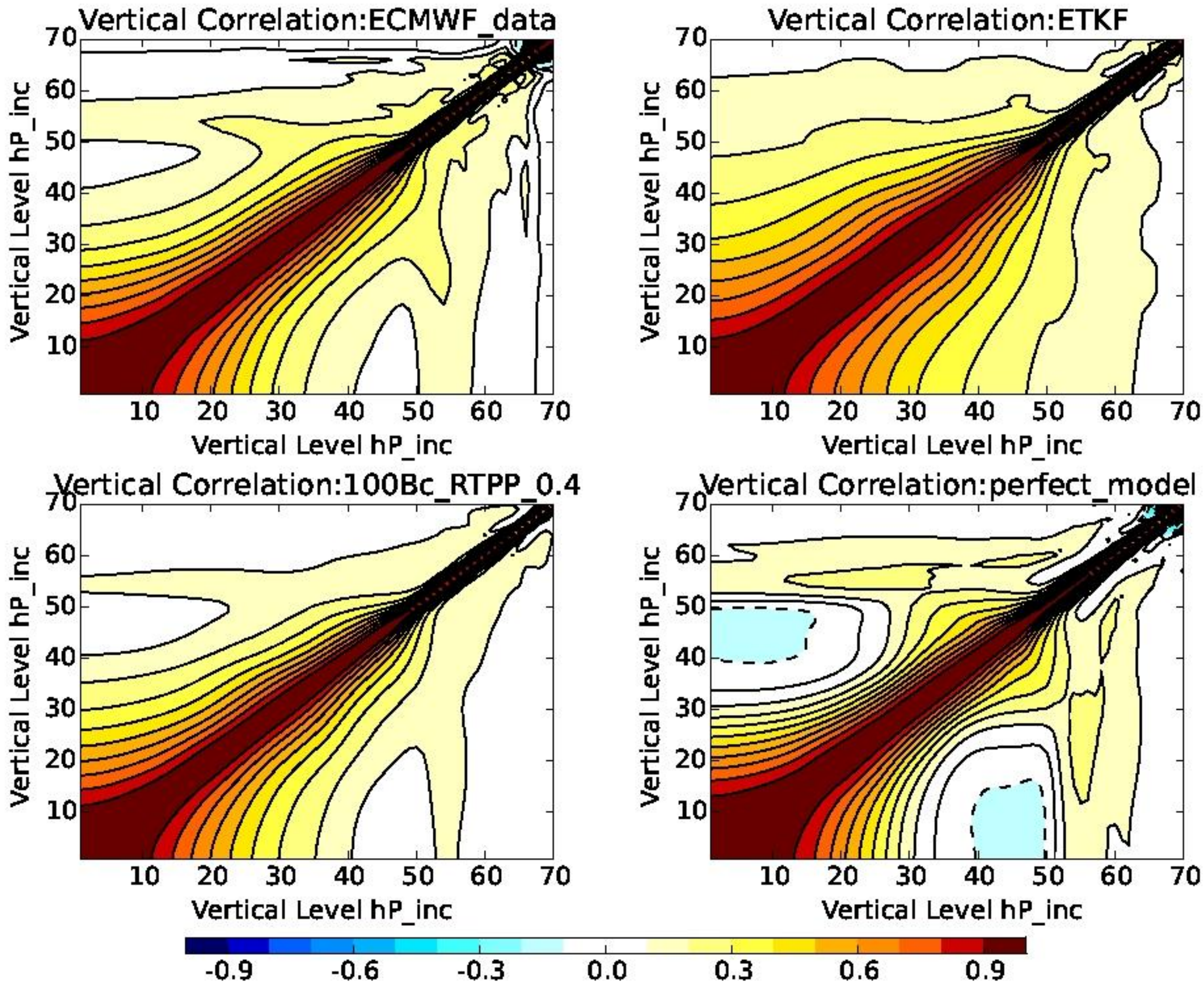
- The **ETKF** data was unviable for generating static B due to poor Hessian conditioning, due to strong multivariate coupling and broad vertical correlations.

- The experiment with **RTPP=0.85** has large vertical correlations that are comparable to the ETKF. Both expts have excessive multivariate coupling (too balanced).

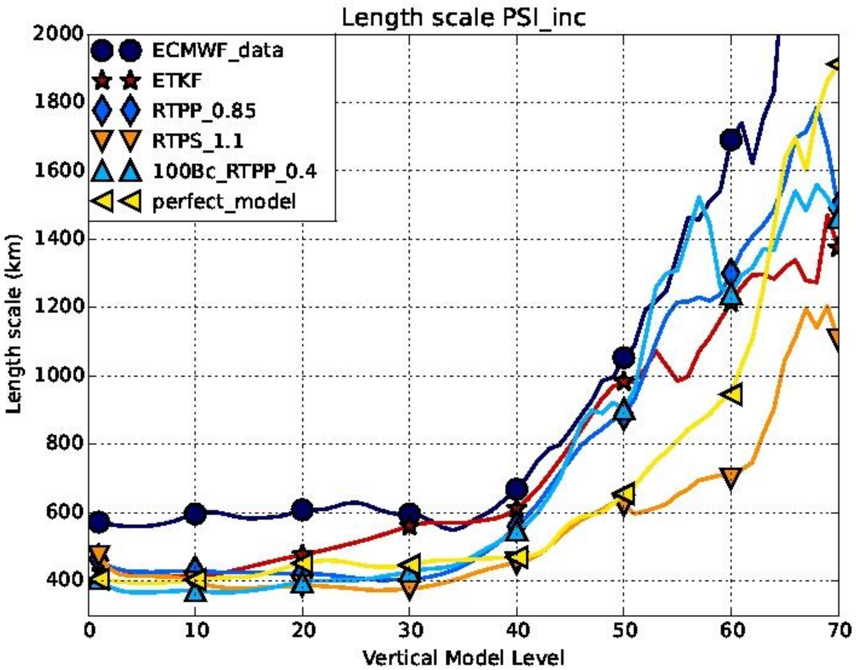


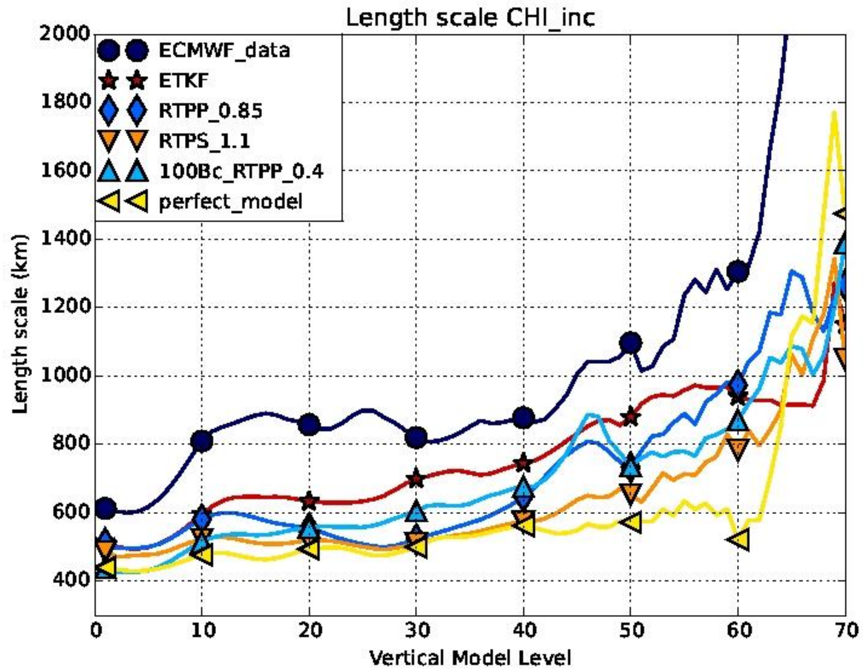
Vertical correlations – hydrostatic pressure

- The **full additive inflation, 100Bc expt with RTPP=0.4** has vertical correlations very similar to the ECMWF training data.



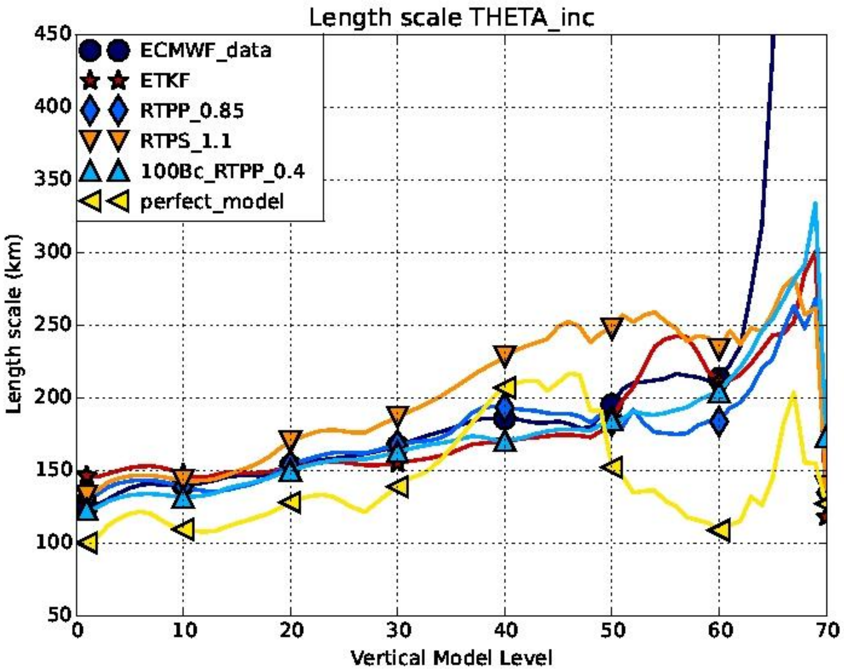
Horizontal length scales - streamfunction and velocity potential

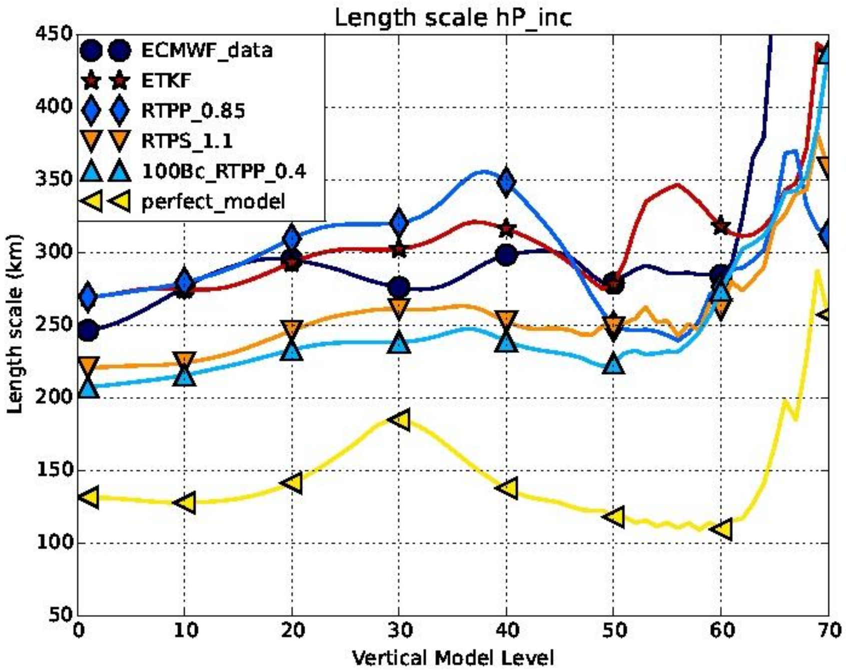




- PSI – is the inverse Laplacian of the horizontal 2D vorticity.
- CHI – is the inverse Laplacian of the horizontal 2D divergence.
- **ECMWF training data** has a lot of power at low horizontal wavenumbers.
- **RTPS** and **perfect model** have particularly short length scales.

Horizontal length scales – potential temperature and pressure.





- Again perfect model gives short horizontal length scales.
- We don't quite understand why **RTPS** produces excessively broad horizontal length scales in potential temperature.

Conclusions

The choice of inflation scheme has a large impact on the characteristics of the background error.

- Using **scaled random analysis increments** produce fields that are quite unbalanced and are quite dependent on observation coverage.
- A large **RTPP value** has the effect of increased balance in terms of more multivariate coupling, broader vertical correlations and a “kink” in the vertical profile of the standard deviations.
- **RTPS** has unusually long theta horizontal length scales and needs an inflated analysis error variance to be greater than the background error variance to give sufficient spread!!!

None of the inflation schemes are ideal and so we have gone with a mixture of the above.