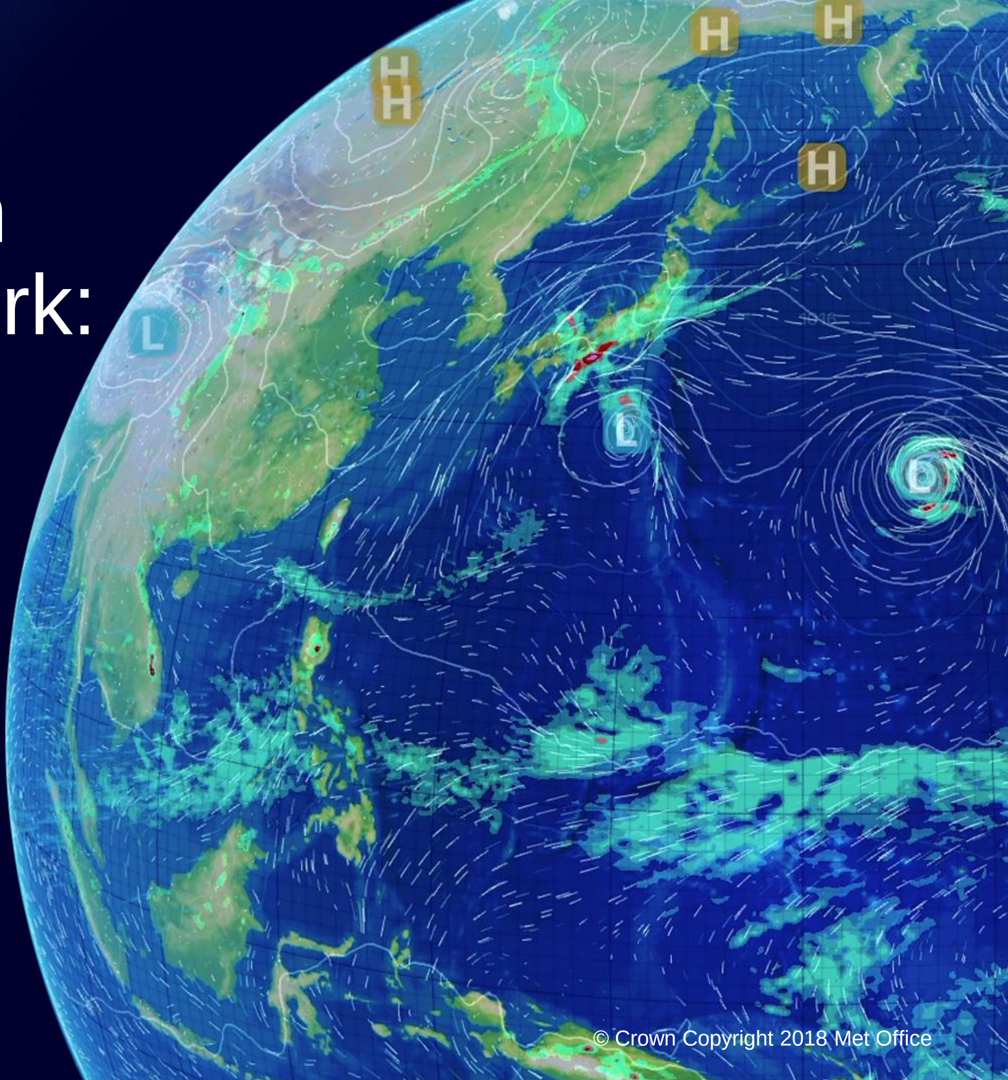
Spectral nudging in an hourly 4DVar framework: Status and Plans



42nd EWGLAM

27th SRNWP

Marco Milan, Adam Clayton, Andrew Lorenc, Gareth Dow, Robert Tubbs, Bruce Macpherson

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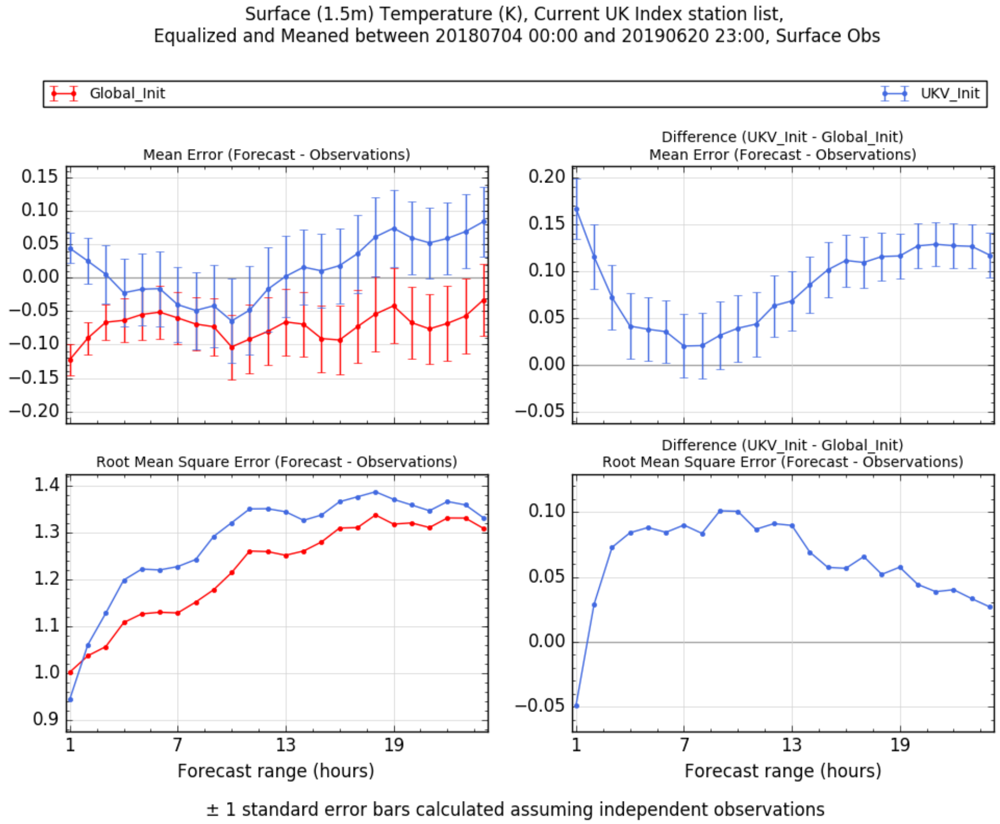
MOTIVATIONS

Impact of large scales in the analysis

UKV from UKV analysis (continuous DA)

UKV from Global analysis (downscaling)

106 forecasts
Jul '18 – Jun '19
DT's 00, 06, 12, 18 UTC



T2m

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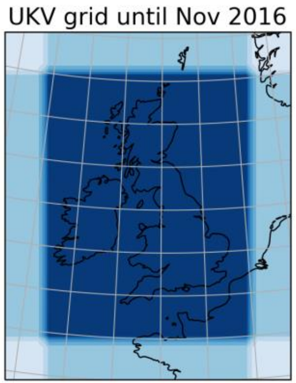
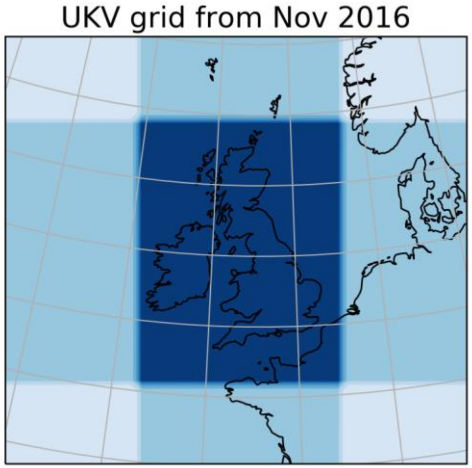
MOTIVATIONS

- Downscaler tends to be better than continuous DA for RMSE – was this a surprise?
- *Yes* – results from 2013-15 showed continuous DA was significantly better
- *Maybe no, with hindsight*:
  - ➢ Global resolution has since improved to 10km
  - ➢ Global analysis has improved
  - ➢ UKV is now on extended domain, so:
    - ❖ larger scales are more relevant
    - ❖ large scale errors in LAM analysis last longer into forecast
  - ➢ Well known problem in DA:
    - ❖ efforts to improve LAM large scales go back to 2010 in the Met Office
    - ❖ variety of operational solutions exist internationally
    - ❖ ***Testing a suitable solution is a priority issue***





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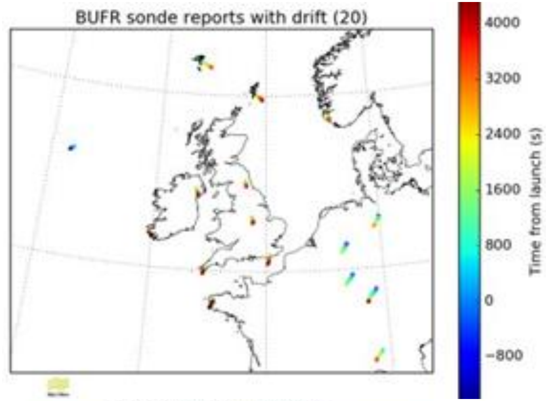
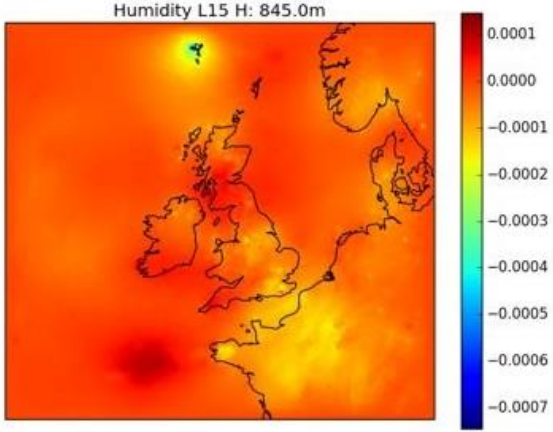
MOTIVATIONS

- We recognize the necessity of coupling large-scale dynamics with convective systems. Better estimation from global assimilation of large scales of motion.
- Technique similar to spectral nudging. Try to combine different scales without DA in the regional model.
- Our DA system lacks in ability to represent model error at large scale; the increments tend to be concentrated close to the observations.
- Nudge selected spectral scales in the regional model towards the global model. Compute background increments (BGinc) before DA.





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THEORY

- Global model (host model) state. Reconfiguration to the analysis grid:

$$\mathbf{w}^h(t) = S(\mathbf{x}^h(t))$$

- Regional model state. Reconfiguration to the analysis grid (the same):

$$\mathbf{w}^r(t) = S(\mathbf{x}^r(t))$$

- Computation of background increment (BGinc):

$$\delta\mathbf{w}^b(t) = \mathbf{w}^h(t) - \mathbf{w}^r(t)$$

- Spectral filtering BGinc.
- Use a cut-off wavelength to apply the increments only to selected scales, low pass filter.

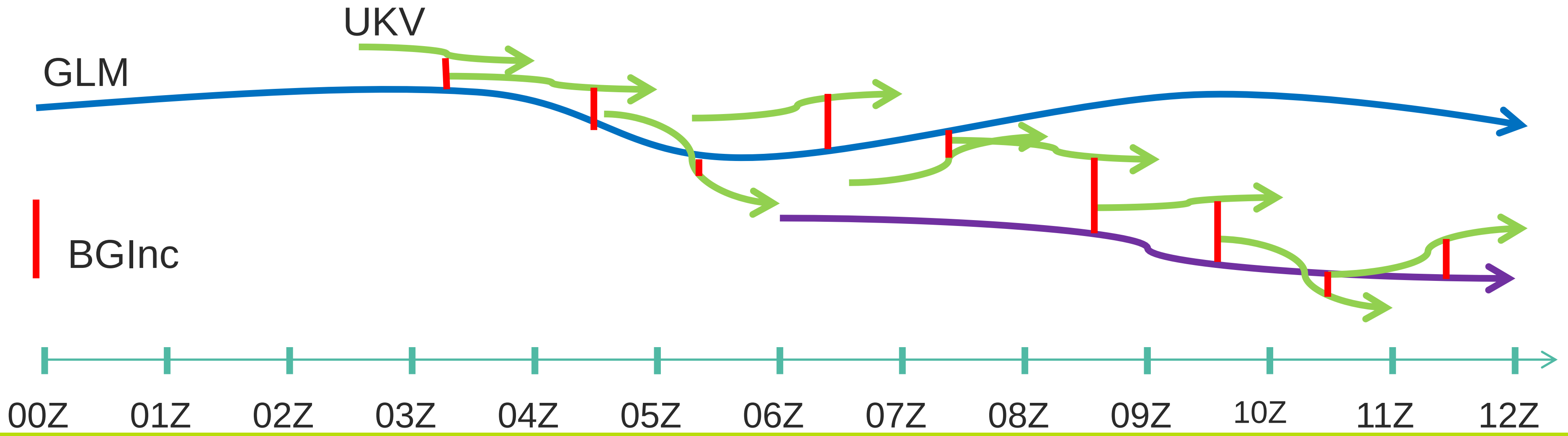
USE OF LARGE-SCALE “BGIncs” IN VAR

Basic idea

Update the UKV background with large-scale differences (on the VAR grid) between:

a. The GLM (global) forecast (6 hourly cycles) that provides the LBCs for the subsequent UKV forecast.

b. The UKV (LAM) background (hourly 4D-Var).



SPECTRAL DIAGNOSTIC FOR CUT-OFF

- NMC method (Parrish and Derber, 1992); forecast differences as proxy of model error.
- LAM, use of forecast differences with same LBCs (eqLBC); to avoid error from LBC (global model).
- In VAR high error values leads to trusting the observations more than the background, leading to higher increments.
- Forecast differences with different LBCs (diffLBC) should contain errors from large scales, derived from the different global model LBCs.
- Compare the power spectra of diffLBC and eqLBC to understand at which wavelength we can set the cut-off.
- To see the differences, use: diffLBC/eqLBC. A value equal to one means the two spectra are giving the same information for the specific wavelength.

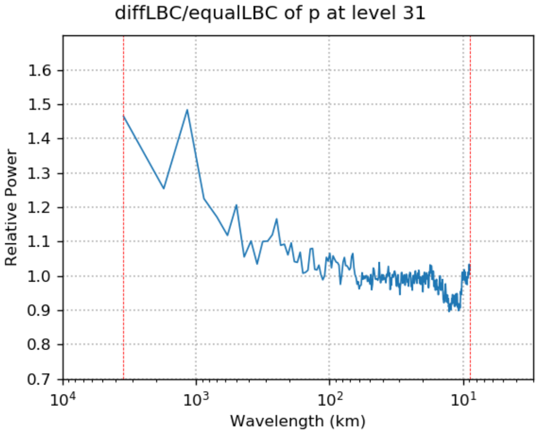
SPECTRAL DIAGNOSTIC FOR CUT-OFF

Preliminary diagnostic:

- Test if different levels need different cut-offs. Vertical weight.
- Test of different variables.
- Mean of 100 random power spectra from two seasons. Avoid correlation between forecasts and undesirable effect due to situations like “blocking”.
- diffLBC higher power spectra for larger scales (as expected).
- For every vertical level quite the same behaviour, for p and u. However, we believe that smaller scales have higher impact near the surface.
- Theta (not shown), different behaviour. Under investigation.
- Suggested cut-off at around 700km.

Around 1450 m

Around 3470 m



Preliminary short trials

Animations of UKV-GLM differences

- Concatenate T-0.5 (time of adding increments) to T+0.5 (end of assimilation window) forecasts, and extract GLM-matching times.
- Subtract GLM forecast providing the LBCs, after reconfiguring it onto the UKV grid.
- Use the low pass filter. Actual cut-off linear, use a wave band between 1000km and 250km.
- Apply the increments at the beginning of the assimilation window.
- Animations are from 02UTC to 9UTC. New LBC at 3UTC and 9 UTC, applied at T-30'.
- First time is 2 mins after an LBC update.

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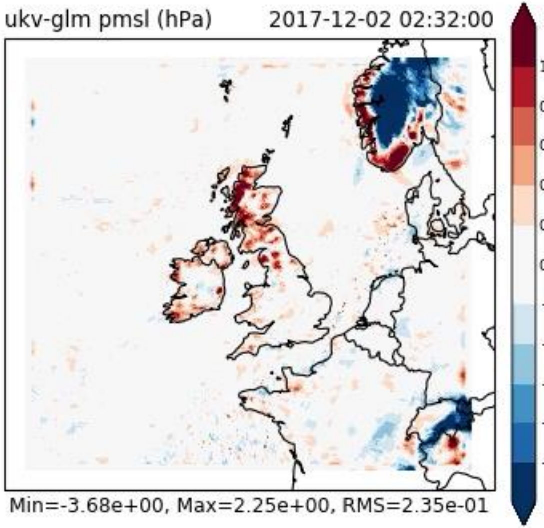
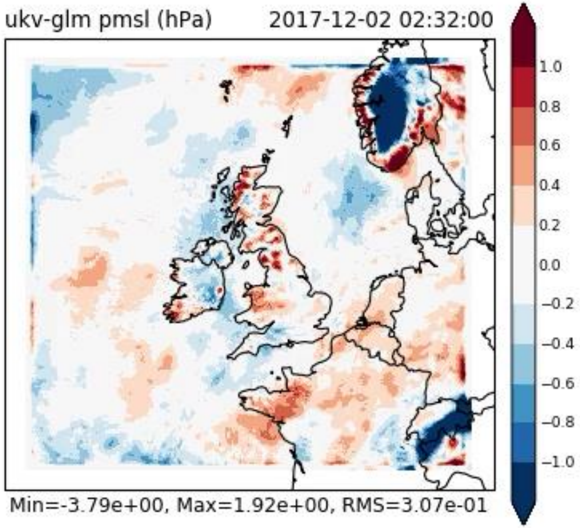
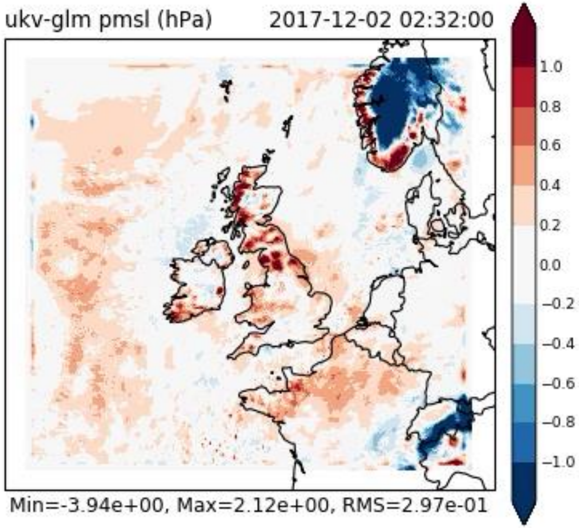
BGIncs but no DA



4DVar without BGIncs

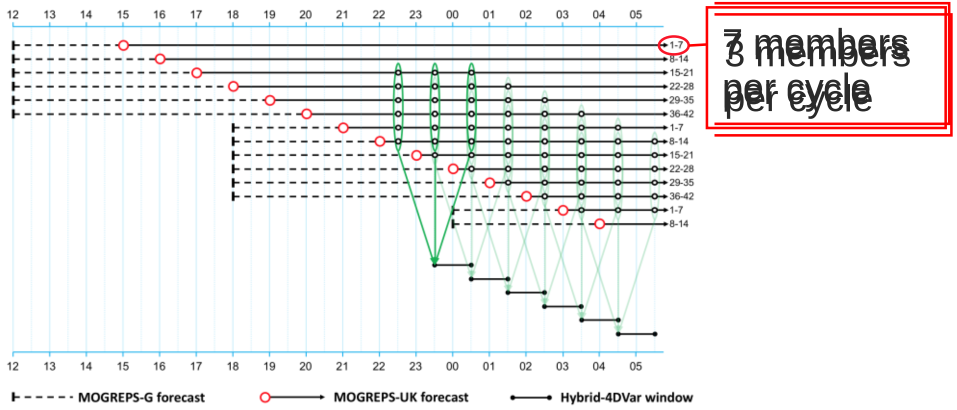


4DVar with BGIncs



Long term plan: Hybrid 4D-Var

- Operational in the global model, since 2011.
- Introduces the "error of the day" in the covariances.
- Actual local ensemble 18 members.
- Different approaches for the ensemble; 42, 42x3 (time lagging and time shifting) members.
- Even using ensembles with large number of members. We need localisation to reduce sampling noise.



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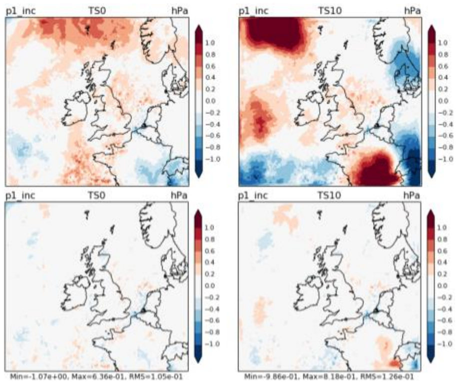
- First tests suggest to apply localisation in PF space (u, v, theta, qT and p).
- BGinc could remove large scales from EOTD and use the large scales provided from global model. UKV assumes zero values at the boundaries, but different members have different boundary values.
- Static covariances computed using trials based on BGinc have potentially a better error representativity of the large scales.

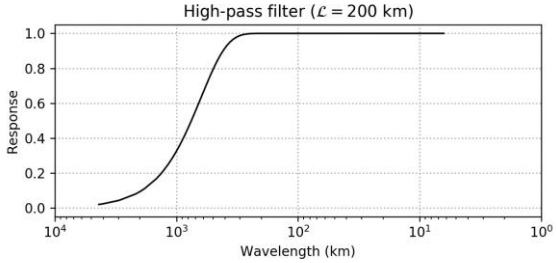
Full perturbation

Large scales removed



T+0 mins **T+20 mins**

Evolution of p_{surf} for typical ensemble perturbations



Filtering performed with cosine transforms

CONCLUSIONS

- Recognise importance of large scale signal in LAMs.
- Blend large scale signal from global model in LAMs.
- Our static covariances lead to low increments at large scales, problem in representing large scale error in our system.
- New static covariances with a better representation of large scale error.
- BGinc can support Hybrid 4D-Var for boundary definition.

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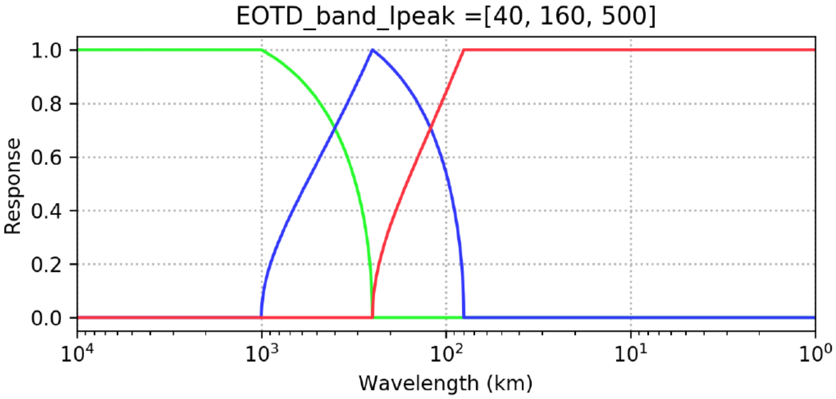
THANK YOU

Questions

- Cut-off used
- It is not possible to add Bginc within the current 4D-Var.
  - Zero boundary values (Bginc different from zero at the boundary).

CUT-OFF

- Spectral transform already present in our code. 2D spectral transform on each single full field.
- Hybrid: horizontal localisation needs to be approximately homogeneous across the domain, despite the presence of the lateral boundaries.
- Cut-off wavenumber (for low-pass filter), the one at which the power spectrum of error variances of the global model (GM) and regional model (RM) started to diverge from each other (Guidard and Fischer, 2008).
- Hybrid 4DVar (not yet completed), we tested waveband filters (similar to Caron et al. 2019).
- Use the large-scale waveband (green line) for BGinc.
- Useful for weighting in Hybrid 4DVar.



Boundary conditions

- UKV uses zero lateral boundary conditions to the increments (or zero normal gradient for the velocity potential).
- Use double sine and cosine transforms to represent the fields in spectral space. Thus, periodicity within the domain is not required.
- E.g. We represent the streamfunction on a Nx×Ny grid for wavenumbers

$0 \leq k \leq Nx-1$ and $0 \leq l \leq Ny$. Using i, j point in grid space:

$$w_{i,j} = \sum_{k=1}^{N_x-2} \sum_{l=1}^{N_y-2} \sin\left(\frac{\pi(i-1)k}{N_x-1}\right) \sin\left(\frac{\pi(j-1)l}{N_y-1}\right) v_{k,l}$$

- The increments on one side of the domain are not repeated on the other side of the domain (Milan et al., 2019)