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Recent Developments in Global Ensemble Prediction at the Met Office

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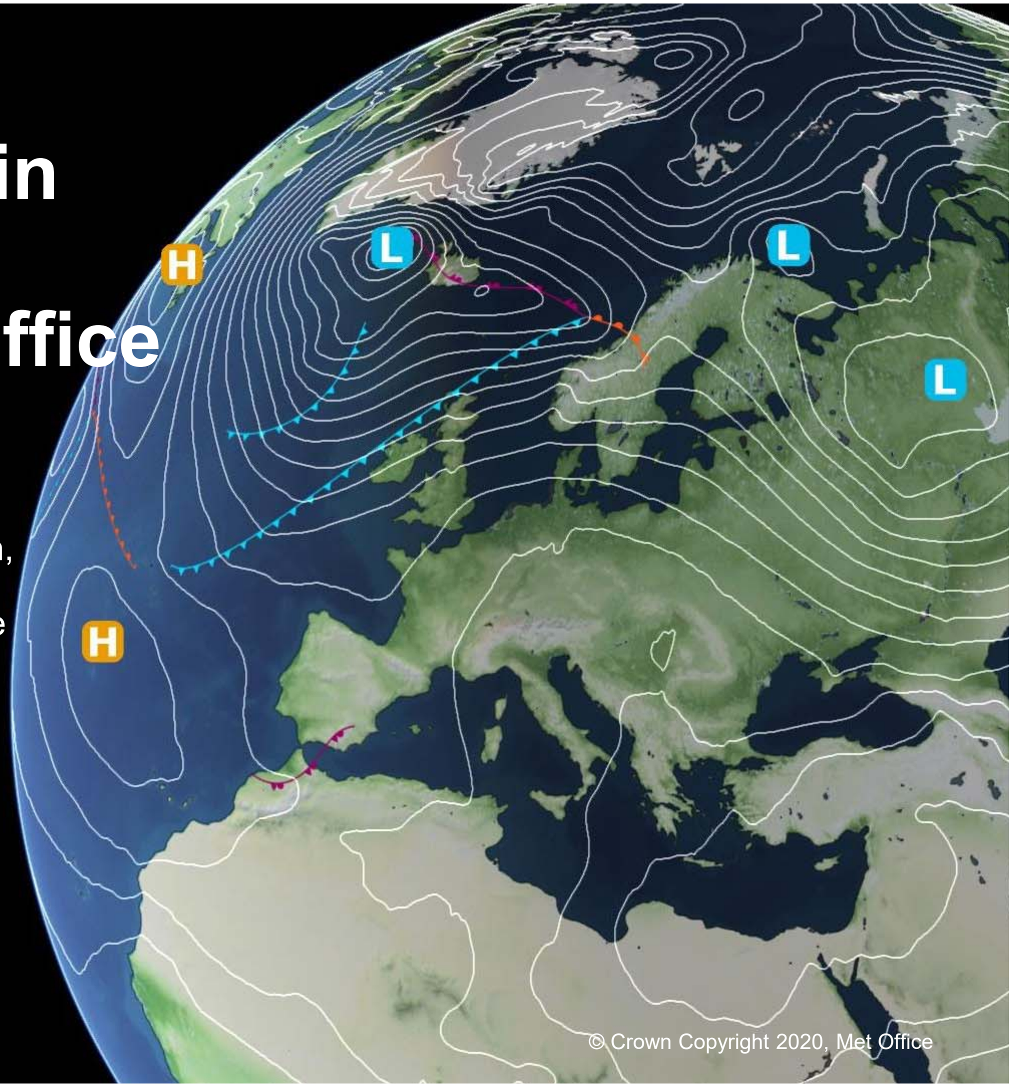
With Acknowledgements to Neill Bowler, Adam Clayton, Andrew Lorenc, Martin Willett, Helen Titley, Rachel North, Simon Thompson, Mike Thurlow, Adrian Semple

EMMDA International Conference - 24-26 February 2020

NCMRWF, India



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Talk Outline

- MOGREPS-G upgrade to En-4DEnVar
- Analysis Increment Additive Inflation scheme
- Global Atmosphere Upgrade (GA7.2)
- Verification discussion

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En-4dEnVar vs ETKF

ETKF-based ensemble: transform background ensemble perturbations using information from the latest observations

- Sophisticated adaptive inflation scheme
- Simple localisation

4DEnVar-based ensemble: Perform data assimilation for each member using VAR code

- Sophisticated localisation
- Easier to maintain and more opportunity to calibrate (may be more complex)
- Closer to operational deterministic DA system (hybrid covariances)
- Cheaper than an ensemble of 4DVar

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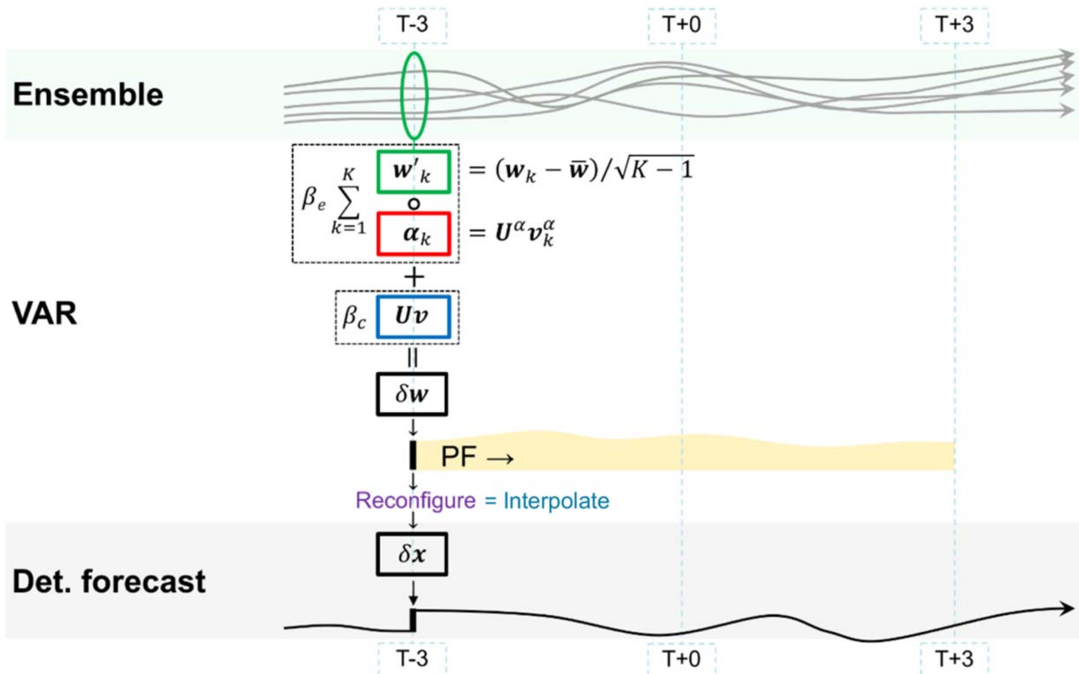
Hybrid-4DVar schematic



Details in: Clayton et al (2013) *Q.J.R. Meteorol.,Soc.*, https://doi.org/10.1002/qj.2054

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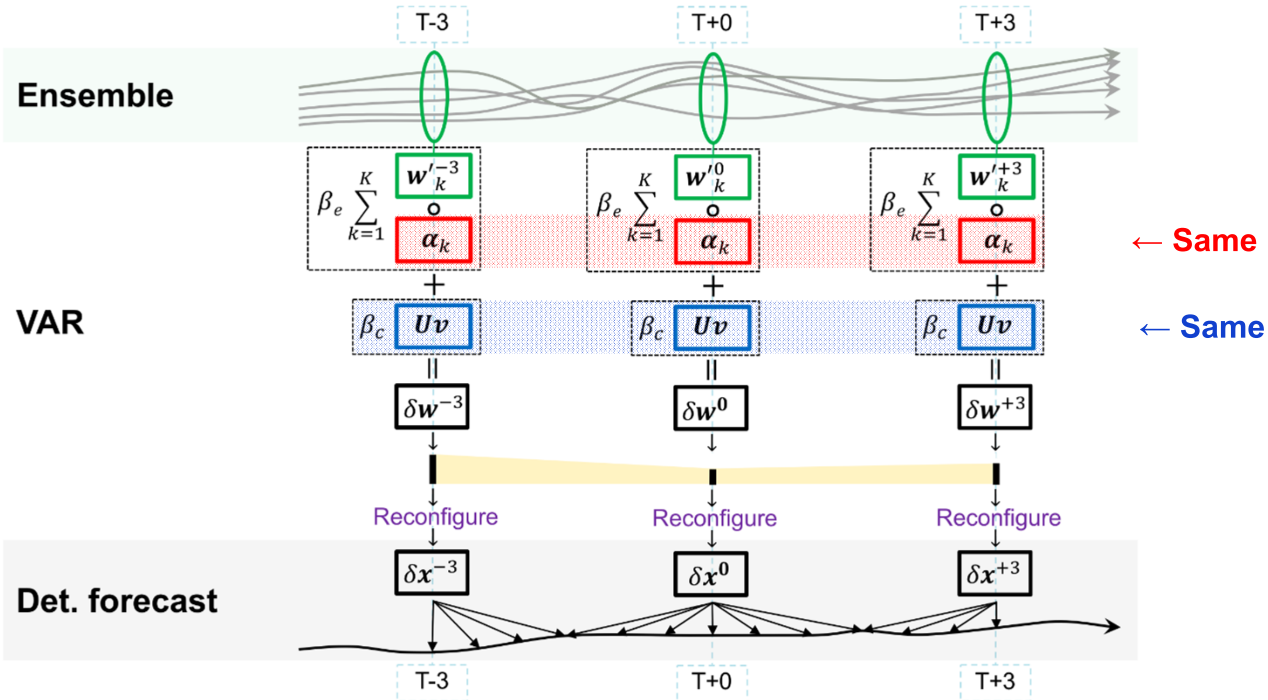
Hybrid-4DEnVar schematic



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4DEnVar-based Ensemble Design Features:
DA Configuration

Ensemble of data assimilations (En-4DEnVar step):

- “Simple self-exclusion” method to prevent inbreeding
- “Mean-pert” method to reduce computational cost

Inflation to account for data assimilation deficiencies:

- RTPP: Relaxation to Prior Perturbations
- RTPS: Relaxation to Prior Spread

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4DEnVar-based Ensemble Design Features: Model background error

- Ménétrier vertical localisation
- Waveband horizontal localisation scales (6241,919,389,256) km
- Hybrid covariance weights for the ensemble: β_c^2 = 50% and β_e^2 = 50%
- Different Hybrid covariance weights for the deterministic: β_c^2=70% and β_e^2= 30%

4DEnVar-based Ensemble Design Features: Model Uncertainties

To account for model uncertainties:

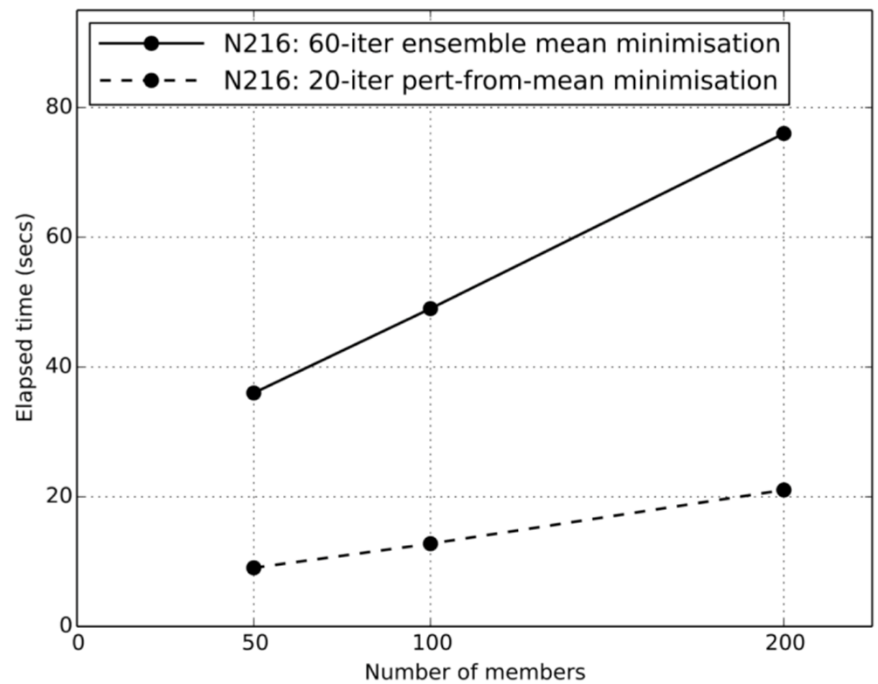
- SPT: Stochastic Perturbation of [Physics] Tendencies
- SKEB: Stochastic Kinetic Energy Backscatter
- AddInf: Additive inflation based on scaled historical analysis increments plus bias correction

To account for other uncertainties:

- Random perturbations to SST, soil moisture and soil temperature

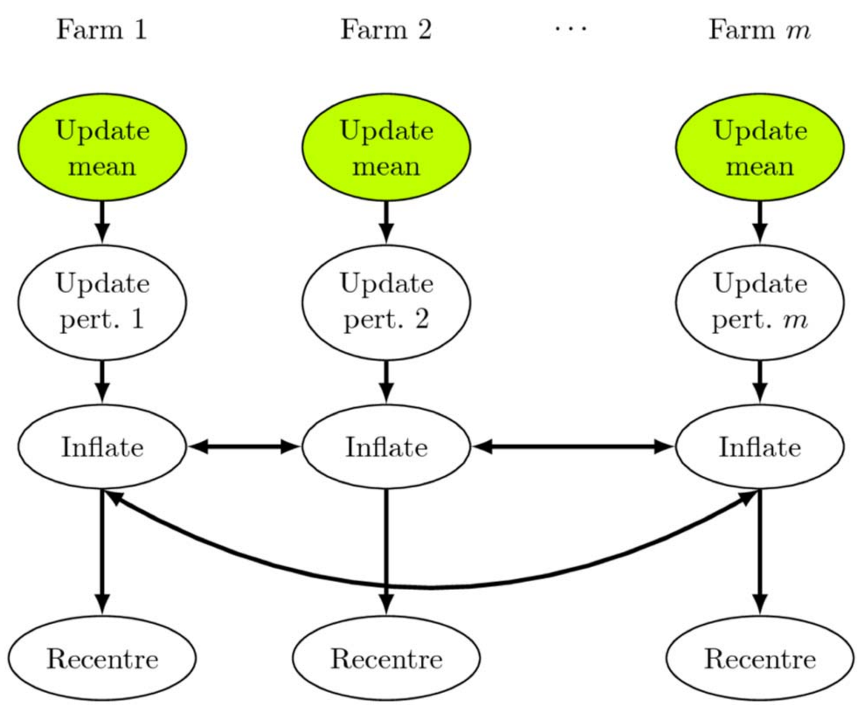
Mean-Pert Method: Reduce Computation Cost

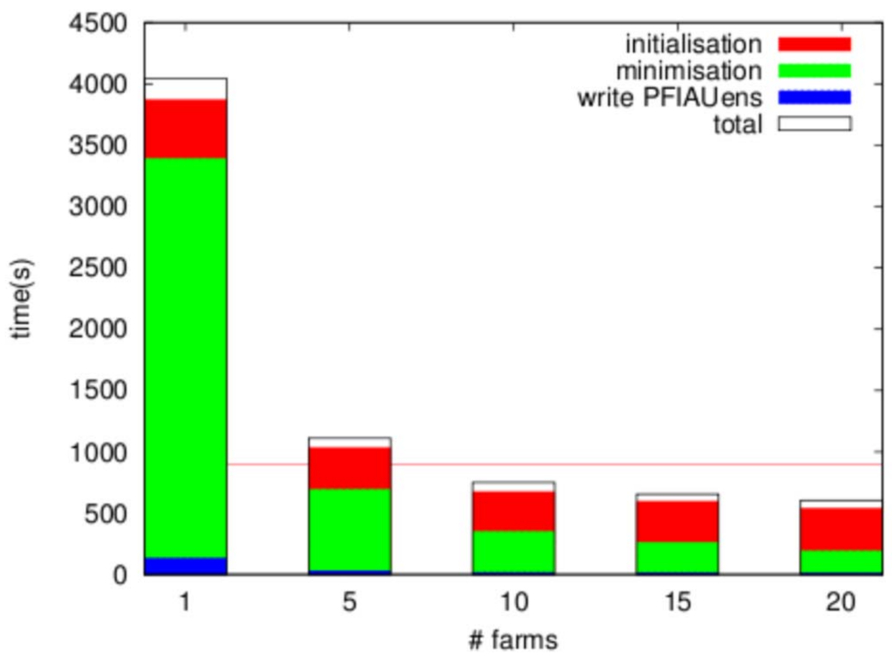
- Calculate ensemble mean analysis using fully nonlinear analysis equations
- Calculate perturbations from mean analysis for each member, using linear equations and a reduced iteration count



Details in: Lorenc et al (2013) *Q.J.R. Meteorol., Soc.*, https://doi.org/10.1002/qj.2965

Mean-Pert Method: Farming + recentring in VAR





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Localisation and Inflation:

An ensemble can provide a sample of background-error covariance matrix. These samples are typically small

NEED TO REMOVE THE NOISE

- Tight localisation implies imbalance in perturbations, slow growth.
- Broad localisation implies over-estimation of observation impact, small spread.

NEED FOR INFLATION TO INCREASE THE SPREAD

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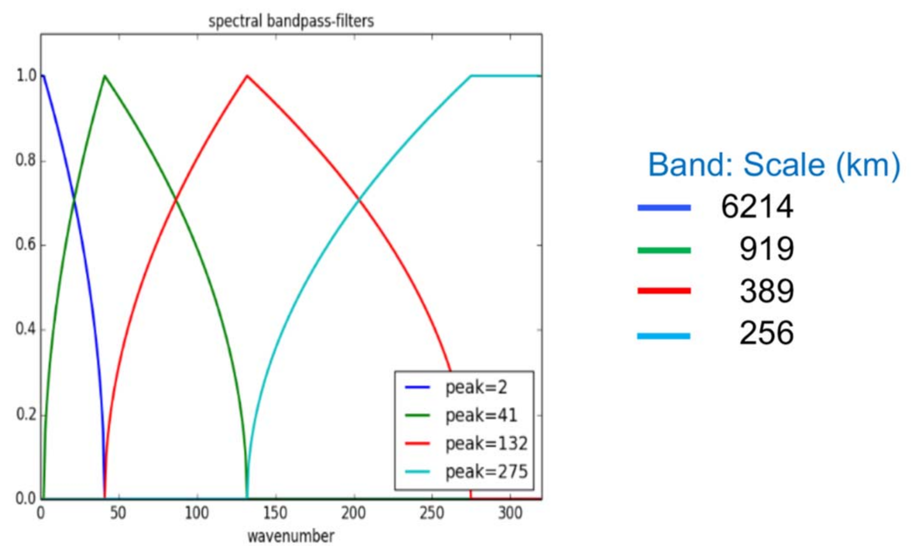
Improved Processing of Ensemble Data:
Horizontal Waveband Localisation

- Correlations decrease with distance between horizontal wavenumbers, therefore split ensemble error modes into wavebands and assume they are uncorrelated
- Apply shorter localisation scales to shorter scale bands



Details in: Buehner (2012). *Mon. Weather Rev.* https://doi.org/10.1175/MWR-D-10-05052.1

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4DEnVar-based Ensemble Design Features: Inflation

Inflation to account for DA deficiencies:

- RTPP: Relaxation to Prior Perturbations - factor 0.5 mimic EnSRF/DEnKF $\mathbf{x}_i'^a \leftarrow (1-\alpha)\mathbf{x}_i'^a + \alpha\mathbf{x}_i'^b$
    - RTPP good at maintaining ensemble spread
    - Makes perturbations too large-scale and too balanced

- RTPS: Relaxation to Prior Spread $\sigma^a \leftarrow (1-\alpha)\sigma^a + \alpha\sigma^b$
    - More realistic effect on scale and balance of perturbations
    - Relatively poor at maintaining ensemble spread

Details in: Zhang et al. (2004) *Mon. Weather Rev.* https://doi.org/10.1175/15200493(2004)132%3C1238:IOIEAO$3E2.0.CO;2 and Whitaker and Hamill (2012), *Mon. Weather Rev.* https:/doi.org/10.1175/MWR-D-11-00276.1

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Additive Inflation

Archive of analysis increments: $\delta\mathbf{x}_a^k$ for $k=1 \ldots N_a$

Average analysis increment: $\overline{\delta\mathbf{x}_a} = \frac{1}{N_a}\sum_{k=1}^{N_a} \delta\mathbf{x}_a^k$

Randomly select N_e increments from the archive: $\boldsymbol{i}_j$ for $j=1 \ldots N_e$

For each 6-hour window, add these increments to the analysis mean, removing the sample average:

$$\delta\mathbf{x}_e^j = \alpha\left(\delta\mathbf{x}_a^{i_j} - \frac{1}{N_e}\sum_{m=1}^{N_e}\delta\mathbf{x}_a^{i_m}\right) + \overline{\delta\mathbf{x}_a}$$

Details in: Bowler et al. (2017). *Q. J. R. Meteorol. Soc.*, https://doi.org/10.1002/qj.3004

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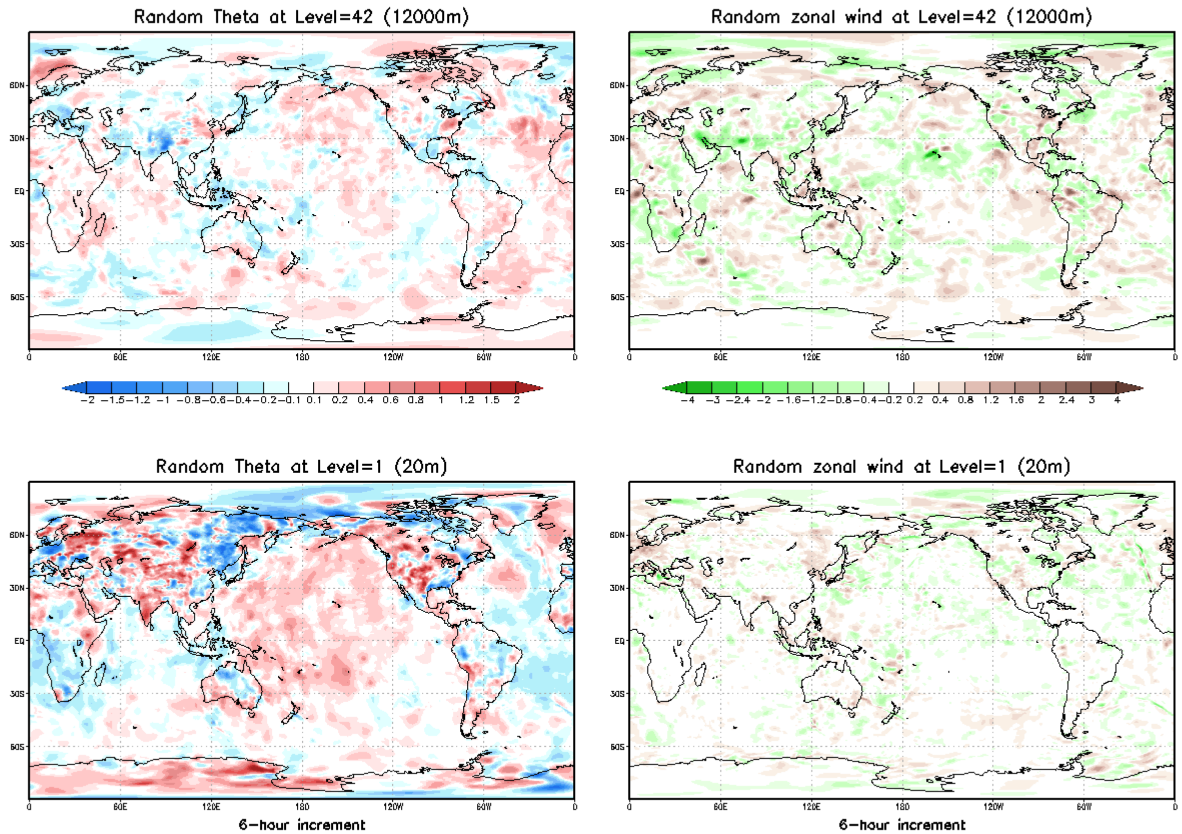

AddInf – random increments

- Increments are small
- Interesting spatial structures
- Reflect the model error as diagnosed by the data assimilation scheme

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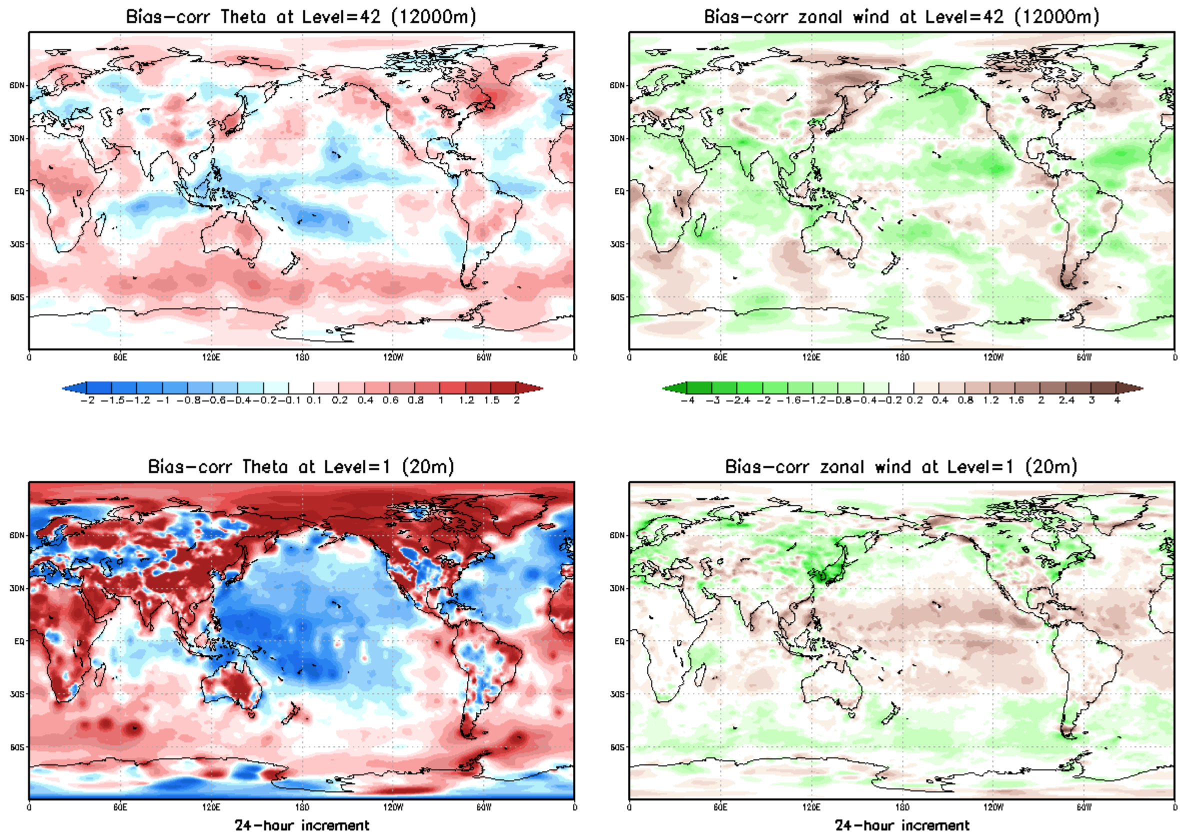

AddInf – "bias-correction"

- Interesting spatial structures which are probably related to real model biases
- Does show imprint of observing system, so needs more careful interpretation

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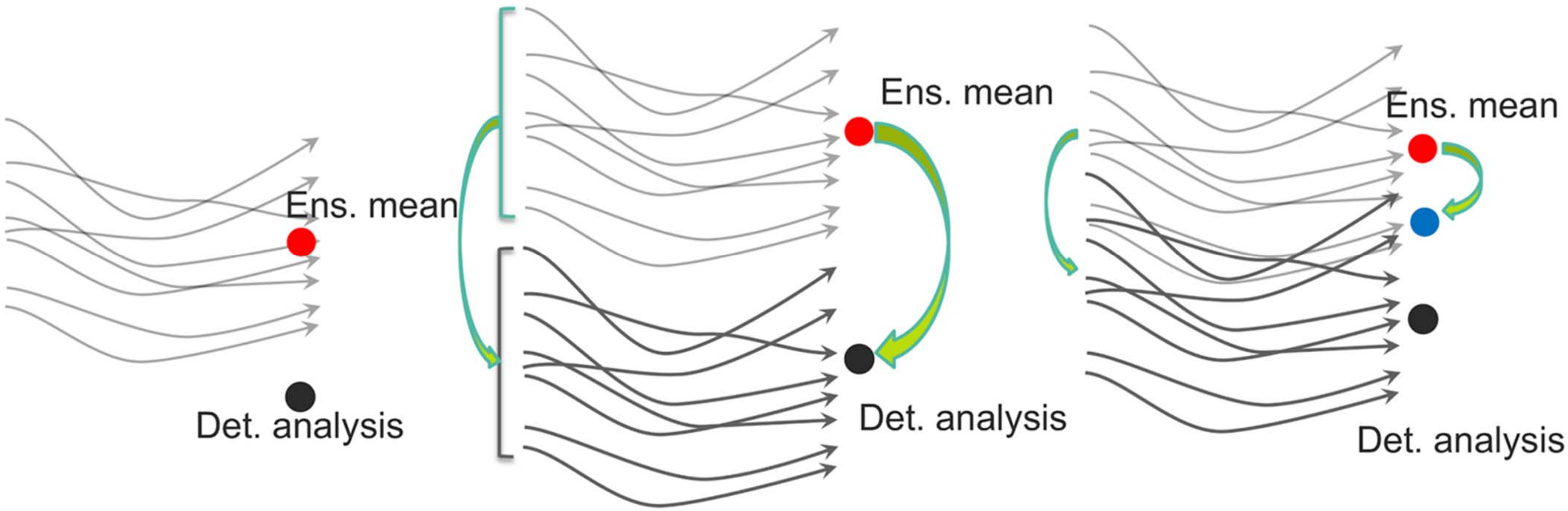
Recentering versus No Recentering:



No recentering

full recentering

Partial recentering

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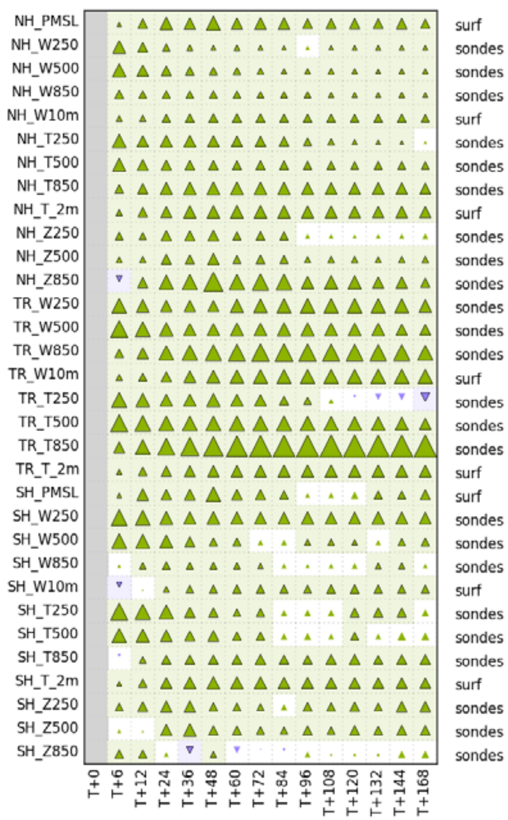
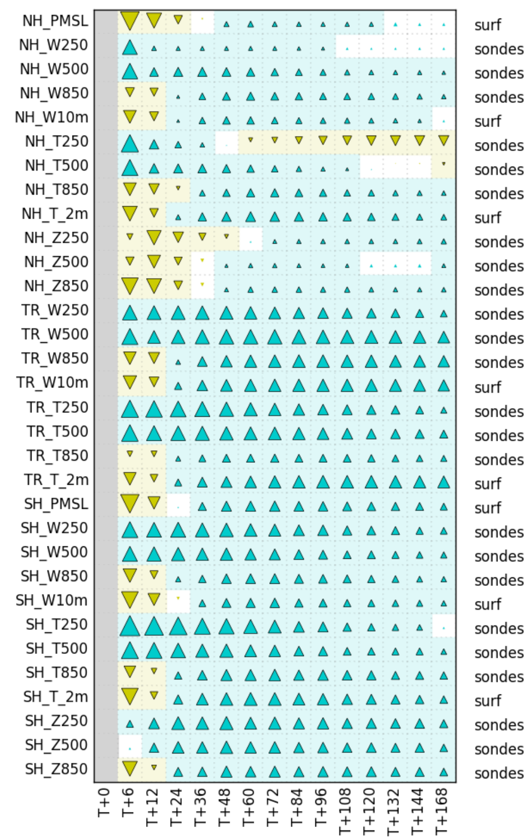
En-4DEnVar Summary

- En-4DEnVar performs much better than ETKF
  - Improved RMSE and CRPS against obs, own analysis, ECWMF analysis
  - Impact on deterministic performance via hybrid 4DVar not as positive
- Partially recentring around deterministic analysis gives small benefits
- Additive inflation very effective in controlling ensemble spread
- Horizontal localisation using wavebands gives big benefits
- Ménétrier vertical localisation gives little to no benefits

Scorecards 3-month trial of En-4DEnVar Jul-Oct 2018





- Ensemble verification shown here is against observations
- Change in CRPS and Spread very positive
- At early lead-times the ETKF over-inflated spread to improve dispersion later

CRPS (max=20%) Spread (max=50%)

Ensemble vs Obs

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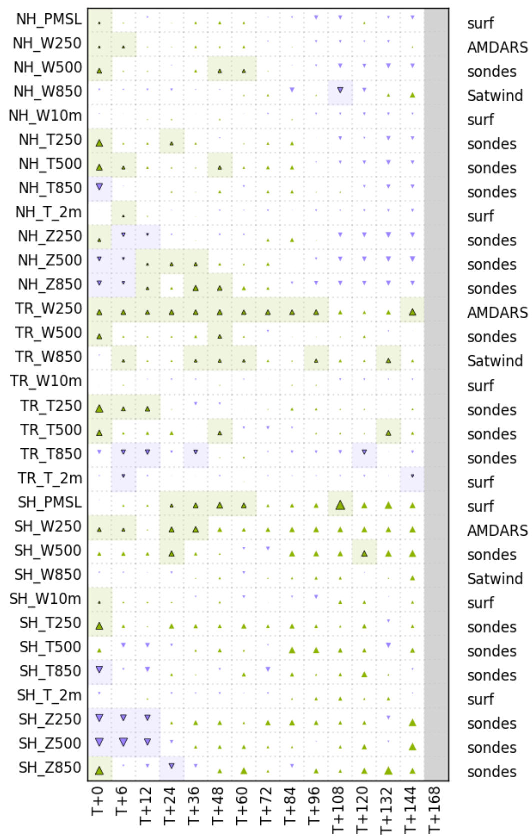
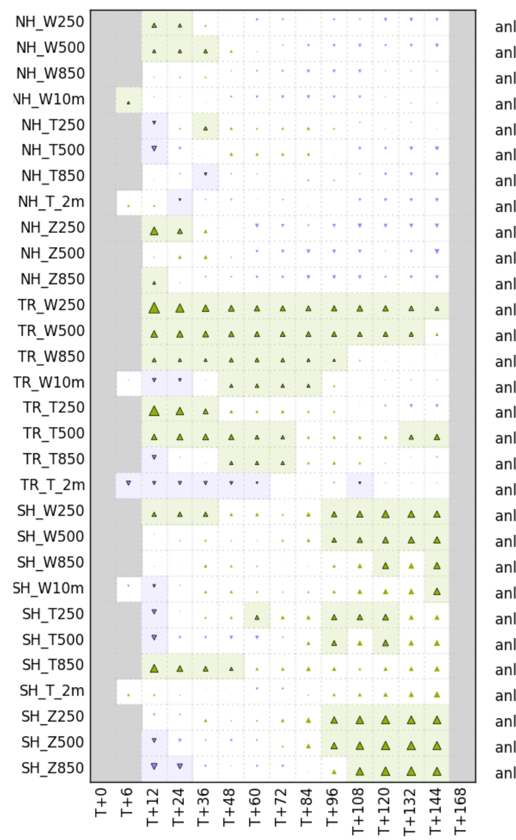
Scorecards 3-month trial of En-4DEnVar Jul-Oct 2018





- Modest improvement to deterministic performance from new ensemble
- Biggest gains in tropics
- No specific concerns about consistent degradation

Obs (max=20%)

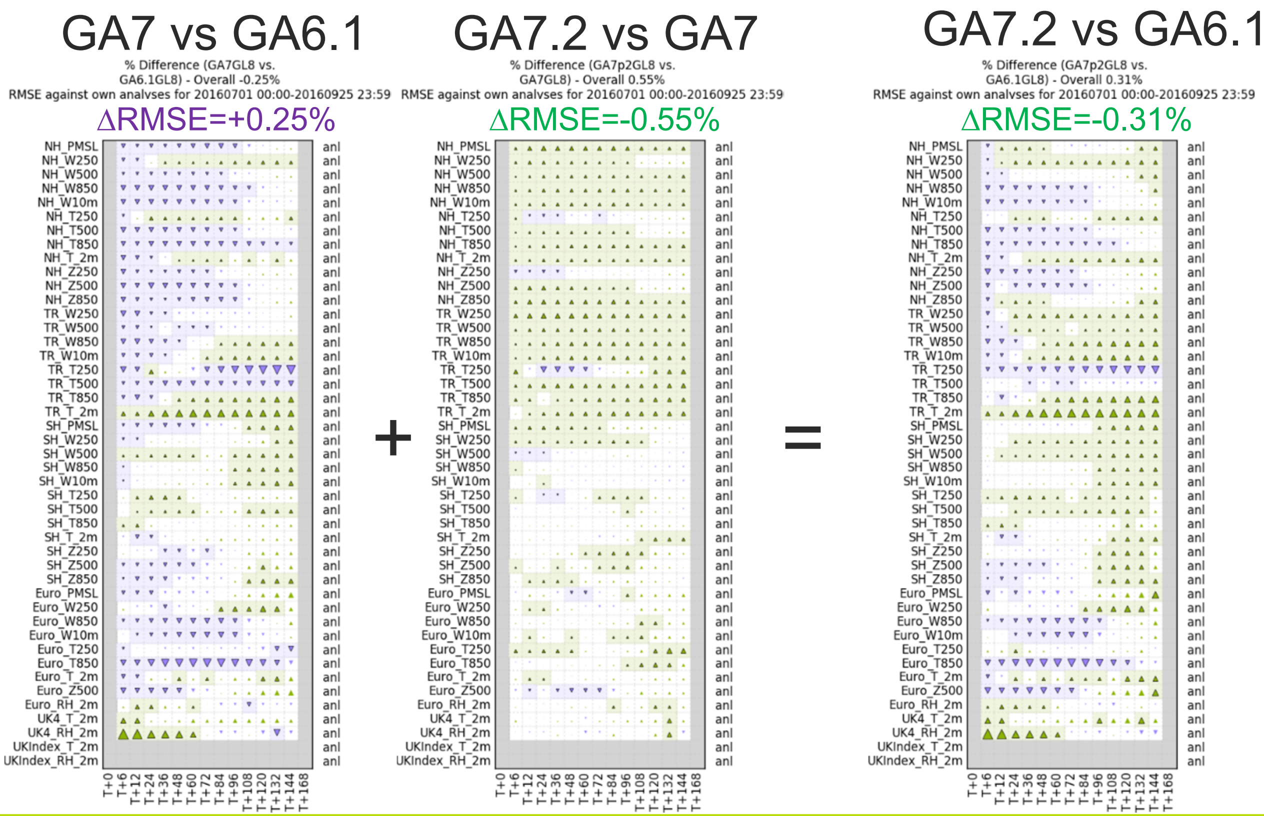
ECMWF Anl (max=20%)

Deterministic RMSE

GA7 Description

- Latest Global Atmosphere configuration (frozen in January 2016)
- GA7.1 (climate config) atmospheric component of GC3/GC3.1 used in CMIP6
- >30 developments relative to GA6 including:
  - Convection: 6a convection, w-based CAPE timescale, etc.
  - Cloud/microphysics: warm-rain microphysics, forced shallow Cu, turbulent production of liquid cloud, etc.
  - Radiation: improved gaseous absorption, McICA upgrades, ice optical and microphysical properties, etc.
  - Dynamics: improvements to moisture advection, θ conservation, etc.
- See Walters, 2017 or GA7.0 Documentation for full details

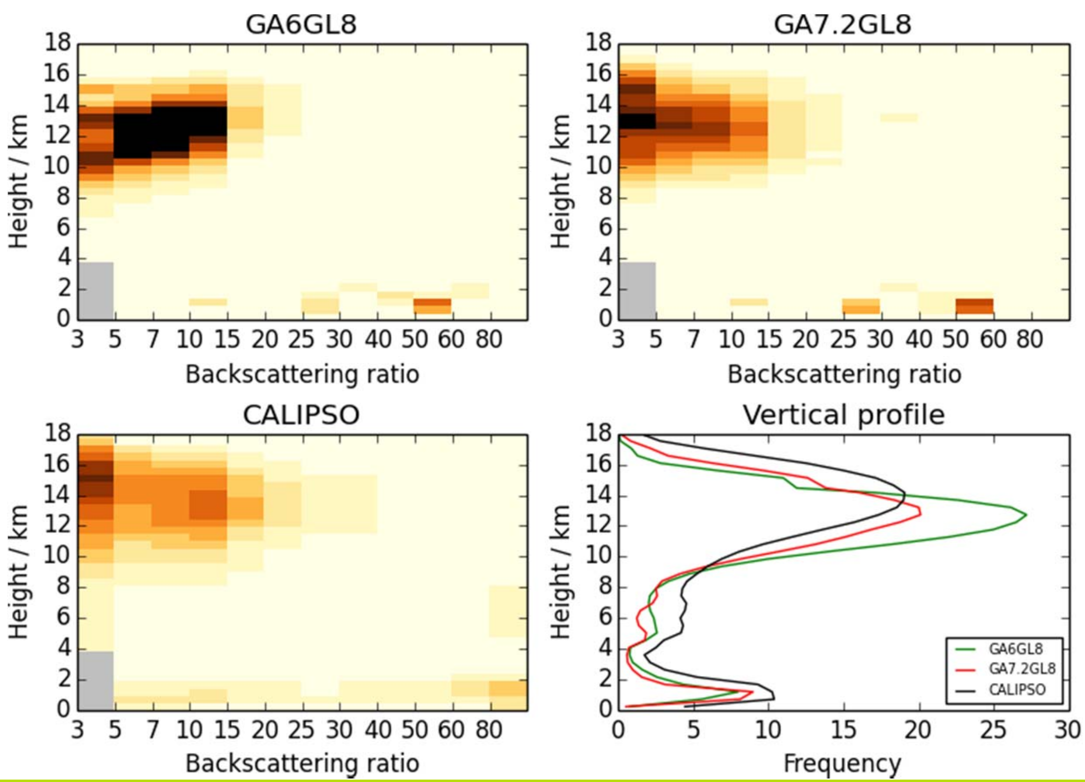
Low-res (40km) Trial JAS 2016 Verification against own analyses



- GA7.2 changes consistently beneficial
- GA7.2 slightly positive or neutral relative to GA6.1
- Convection change improves tropical lower troposphere temperatures, but degrades upper troposphere temperatures
- More positive against obs and ECMWF analyses

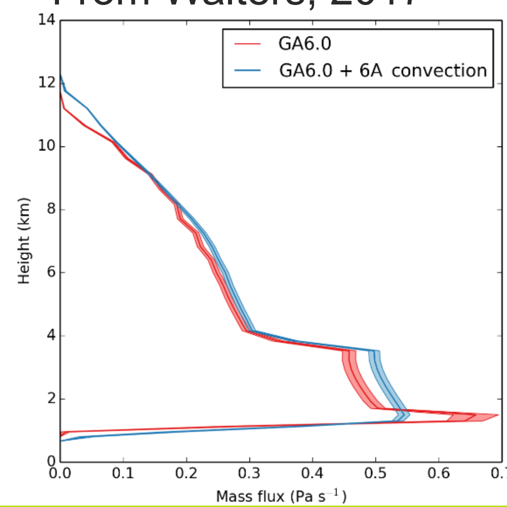
Physical Improvements

Cloud climatology for the Tropics



- Tropical convection is deeper and hence cloud tops higher

Mass flux profile:
6A vs 5A convection.
From Walters, 2017



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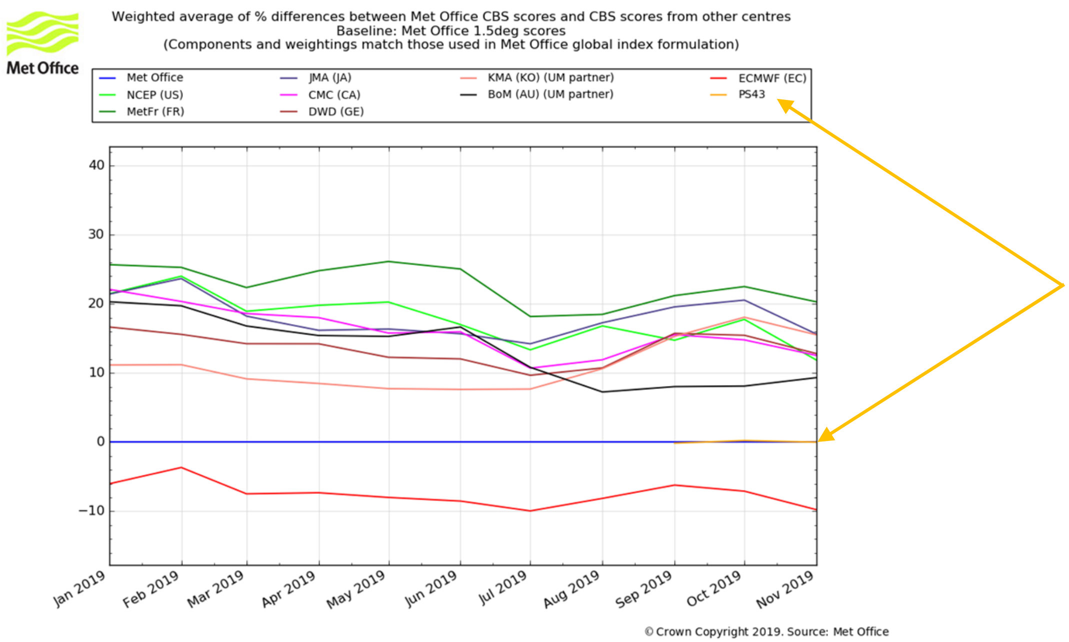
Deterministic model comparison “index”



- As expected, no direct impact of **PS43** on deterministic Sep-Nov forecast performance vs own analysis for the basket of scores used in this index
- **OS42** is reference, so **ECMWF** which performs better than us is below the line

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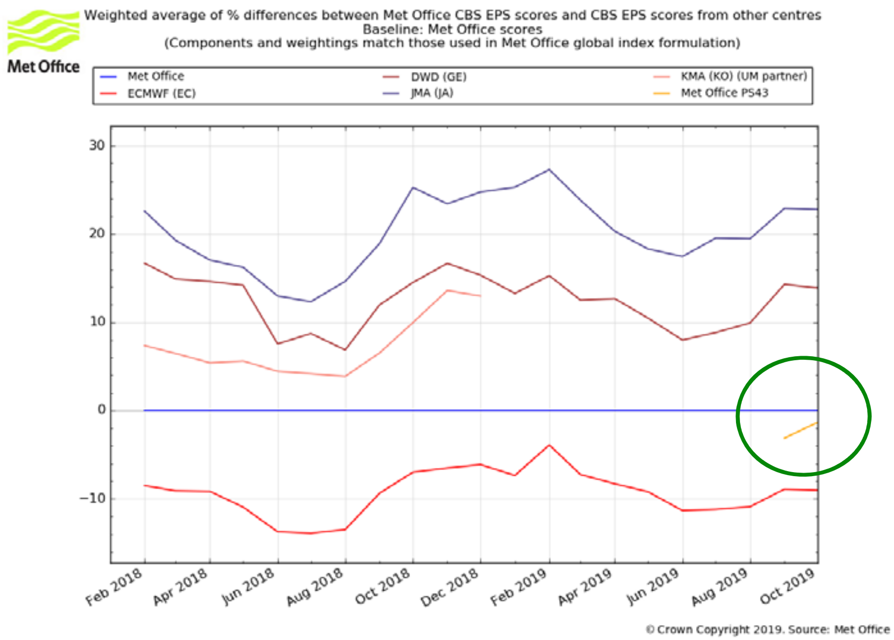
Ensemble model comparison “index”



- A similar index is used for ensemble CRPS performance
- Here a clear improvement in **PS43** is shown

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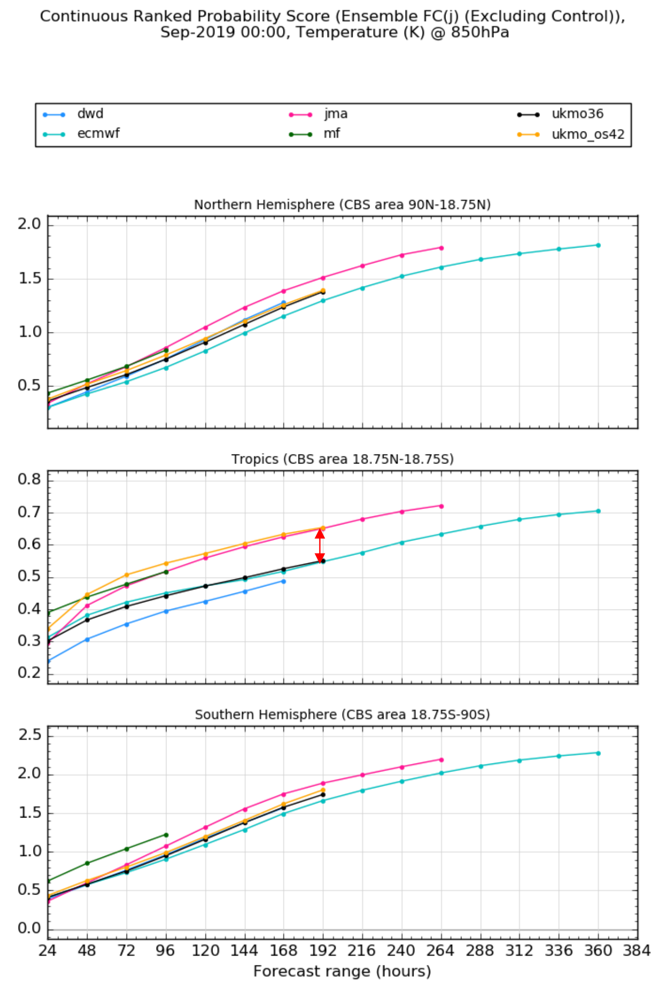
Ensemble model comparison

- Typically we do rather poorly at 850hPa temperature forecasts, especially in the tropics
- The combined GA7 and ensemble change make a dramatic change to this score!
- Note how well the DWD ensemble does in this score…



Data Source: Japan Meteorological Agency website http://epsv.kishou.go.jp/EPSv/

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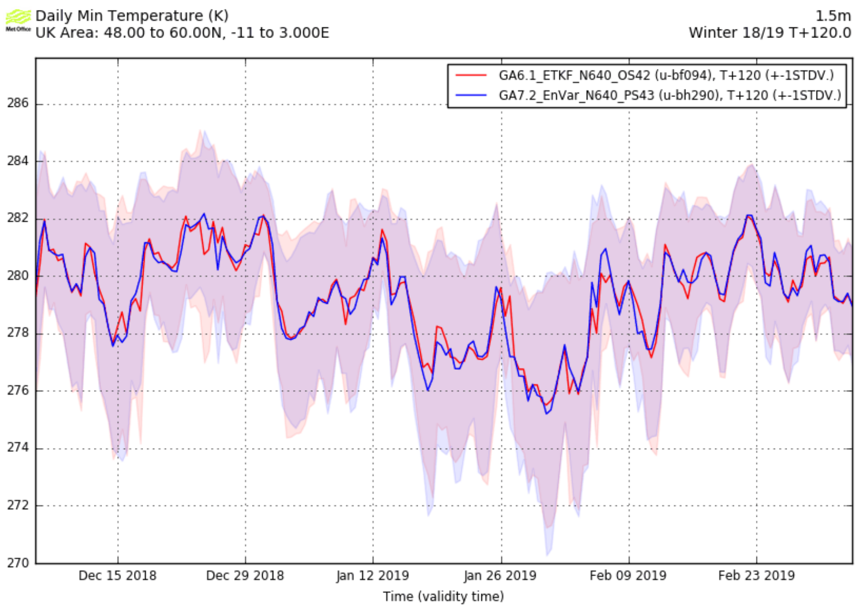
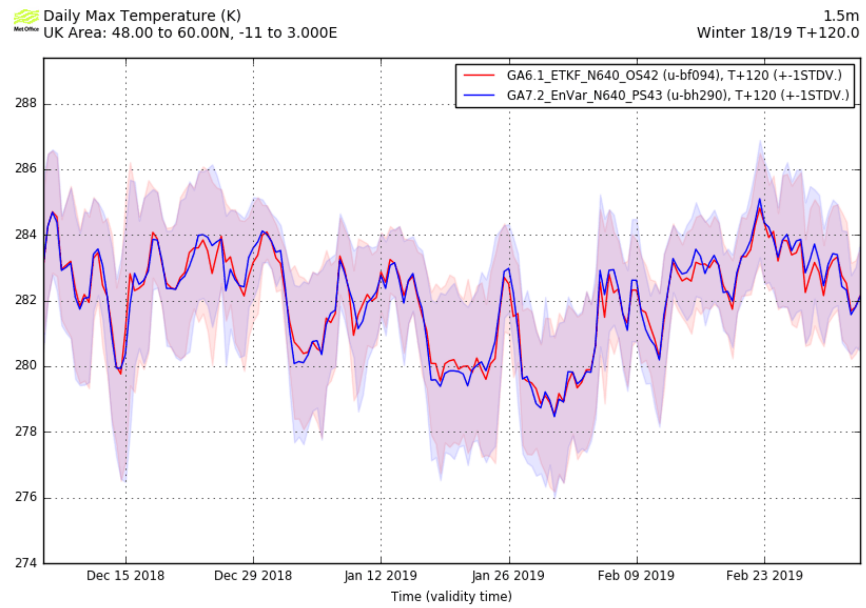
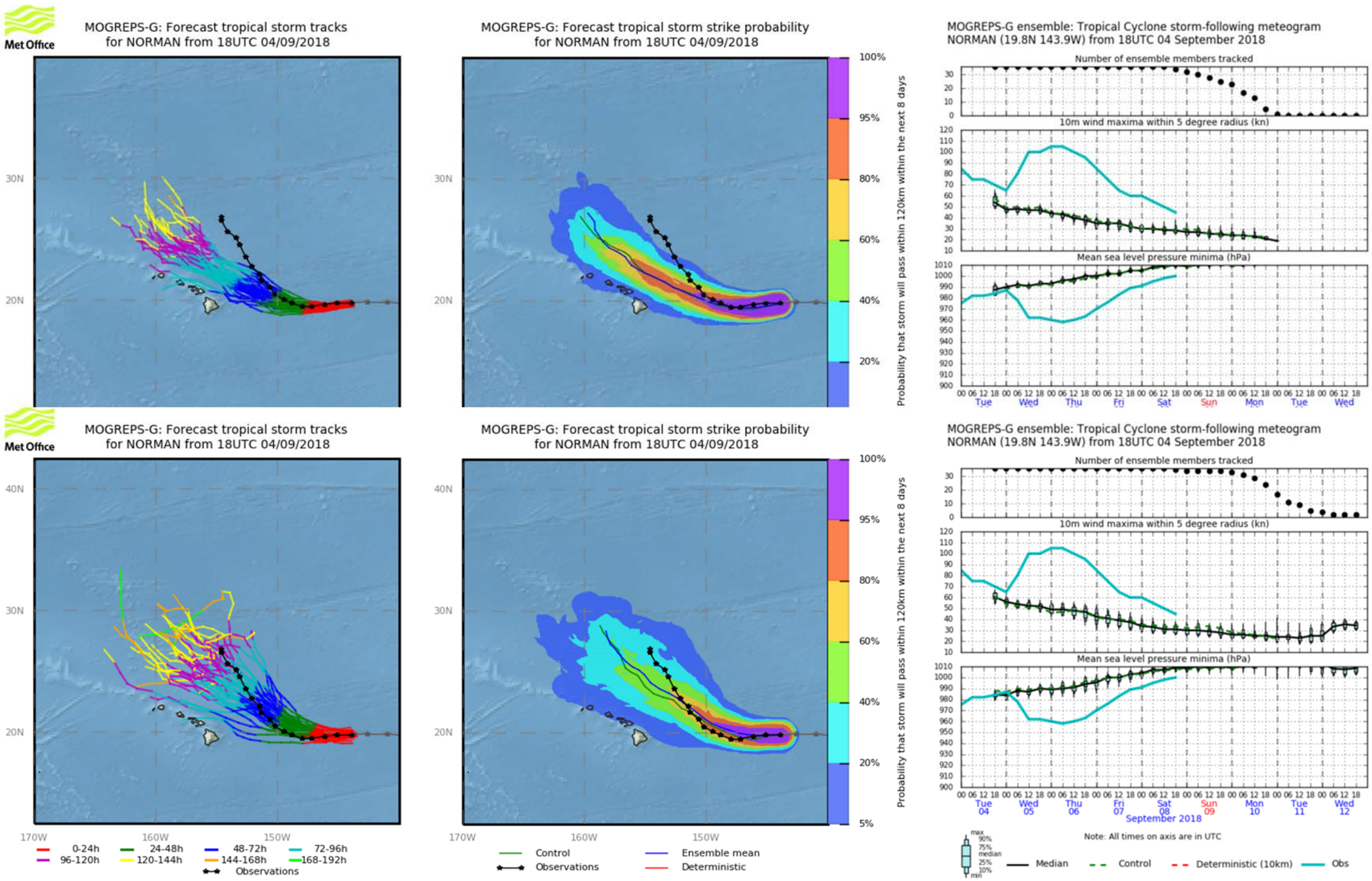
PS43 = lower min's when it's cold and higher max's when it's hot





Examples for named storms: Hurricane Norman



OS42

Nice example of the increased spread and improved track forecasts, with observations now inside the spread

PS43 package trial

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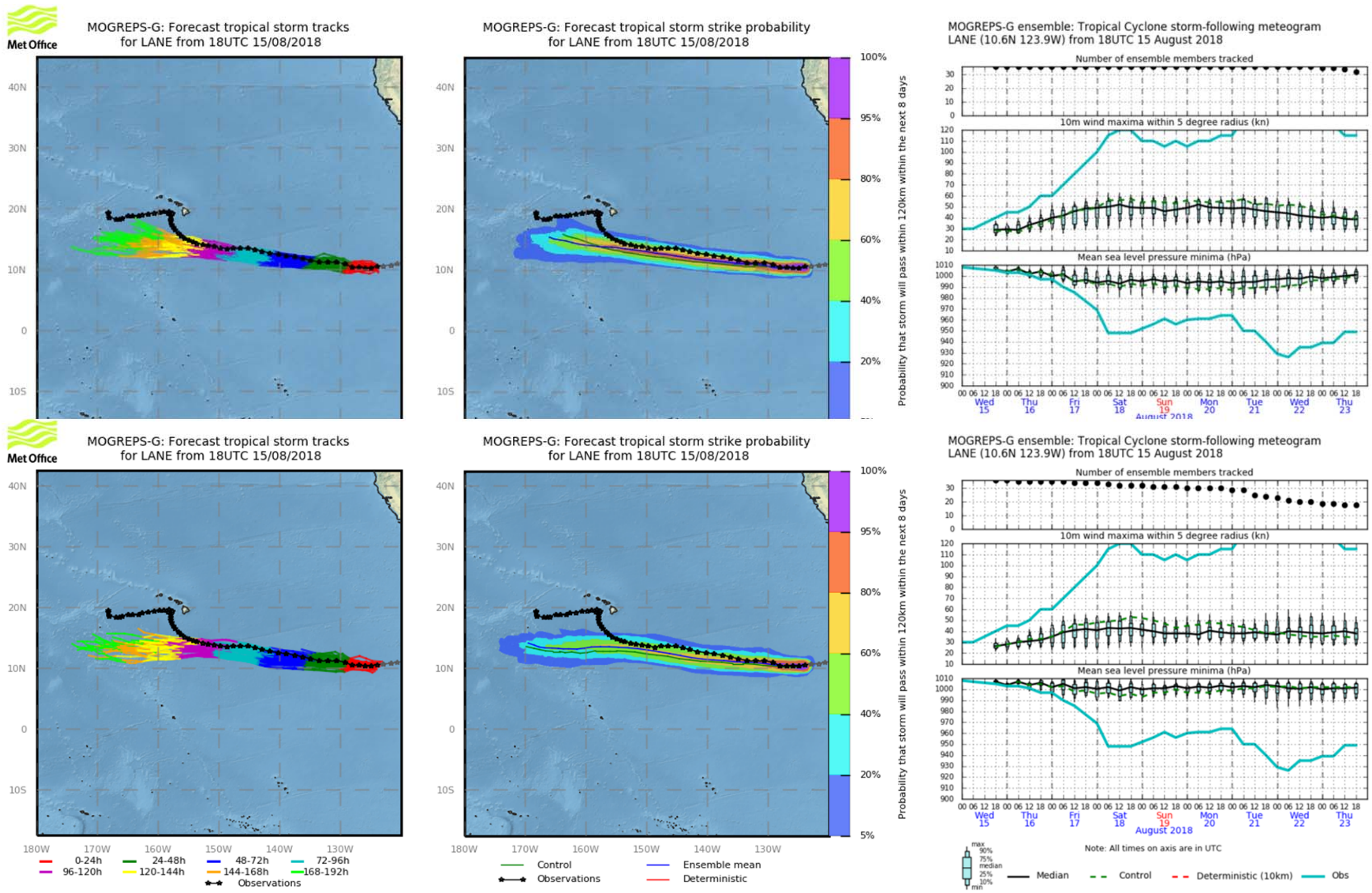
Examples for named storms: Hurricane Lane



OS42

Example of one of the cases where the obs are still outside of the spread, and longer track errors are worse in the trial

PS43 package trial

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Summary and what is next?

- PS43 – implemented on 4 Dec 2019
  - Culmination of many years of development
  - Break-through in global atmosphere (GA) development cycle
  - Some of the benefits include better global cloud cover, temperature at 850hPa, more realistic precipitation, better convection and reduced biases
  - Great advance in our global ensemble capability, with more reliable forecasts
- PS44 – start in May 2020, implementation in Oct 2020
  - Further tuning of the EDA aiming to improve deterministic scores (lagging-and-shifting)
- PS45 – start in Feb 2021, implementation Jul 2021
  - Coupled Ocean-Atmosphere NWP, with weakly-coupled data assimilation
  - GA8GL9 (GC4)

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En-4DEnVar References

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