The development of a hybrid 4D-ensemble variational assimilation system

N.E. Bowler, A.M. Clayton, M. Jardak, P. Jermey, A.C. Lorenc, M.A. Wlasak, D.M. Barker, G.W. Inverarity and R. Swinbank

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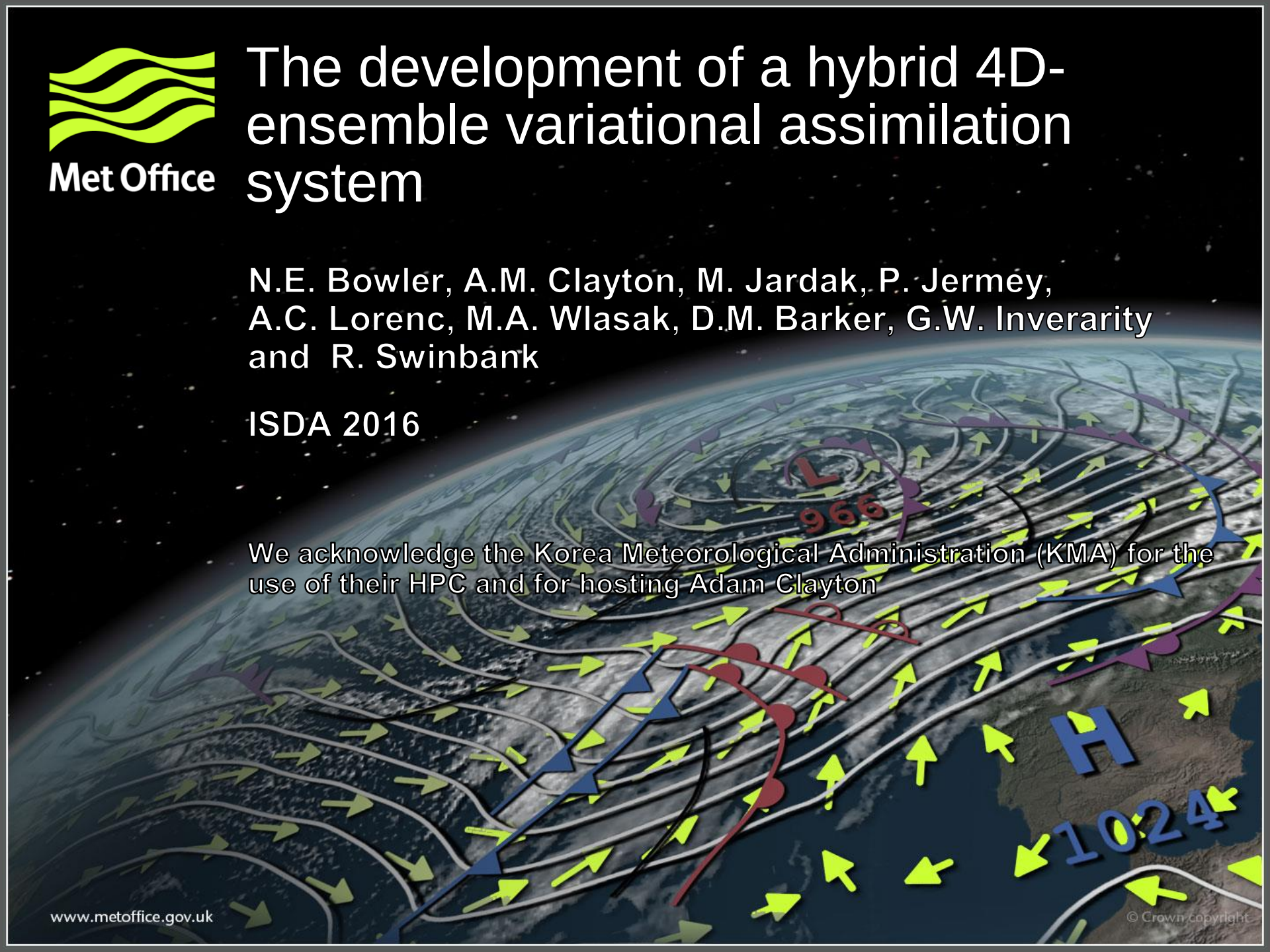

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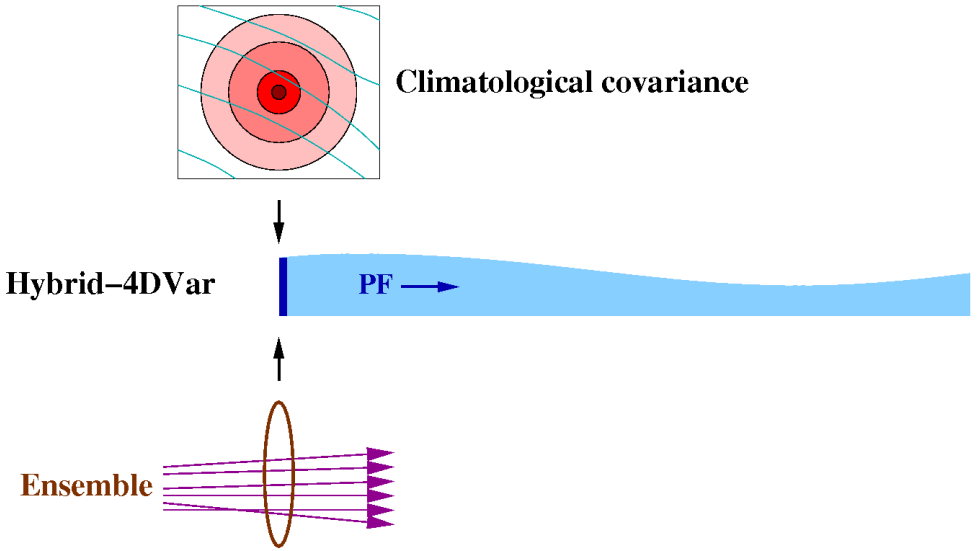
Hybrid-4DVar and hybrid-4DEnVar

Hybrid-4DVar

Clayton et al. (2013), *QJR Meteorol Soc*, **139**:1445-1461



- Background error covariance at start of window:

$$\mathbf{B} = \beta_c^2 \mathbf{B}_c + \beta_e^2 \mathbf{B}_e$$

Climatological covariance — Ensemble covariance

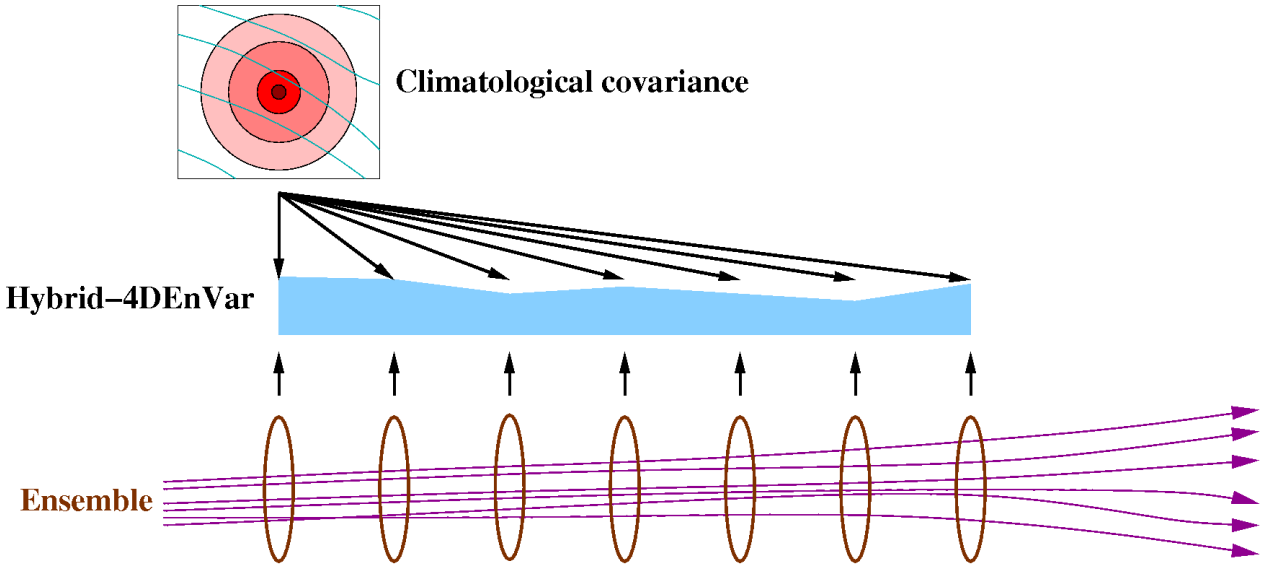
$$\mathbf{B}_e = \mathbf{C} \circ \mathbf{P}_e^f$$

Spatial localisation covariance — Raw ensemble covariance

- Localise control variables.

Hybrid-4DEnVar

Lorenc et al. (2015), *Mon Weather Rev*, **143**:212-229



- No PF model and adjoint, but much more IO required to read ensemble data.
- Static B_c with B_e computed from ensemble.
- Localisation is currently in space only: same linear combination of ensemble perturbations at all times.

Operational data assimilation and ensemble generation

Operational data assimilation

- N320L70 (40 km at mid-latitudes, 80 km model top) hybrid-4DVar analysis increment
- Stationary covariance model (1.0 weight)
- Ensemble covariance with 44 members (0.3 weight)
- Evolved by perturbation forecast model
- MetUM forecast model runs on N768L70 grid (17 km at mid-latitudes)

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Operational MOGREPS-G ETKF ensemble

- 1 control and 44 perturbed members at N400L70 (32 km at mid-latitudes, 80 km model top) run to T+7 days
- Centred on hybrid-4DVar analysis reconfigured to ensemble grid

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En-4DEnVar ensemble

En-4DEnVar ensemble

- Experiments with 23, 44, 176 and 200 members
- Perturbed observations
- Additive inflation together with RTPP and RTPS multiplicative inflation
- Time-invariant localisation
- Self-exclusion

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Results

Experimental setup

- August 2012
  - N512L70 New Dynamics forecasts
  - ETKF ensemble N320L70 (23 and 176 members)
  - Hybrid-4DVar DA at N216L70
  - Hybrid-4DEnVar DA at N320L70
- February 2014
  - N320L70 ENDGAME forecasts
  - ETKF ensemble N216L70 (44 members)
  - En-4DEnVar ensemble N216L70 (44 and 200 members)
  - Hybrid-4DVar and hybrid-4DEnVar DA at N216L70

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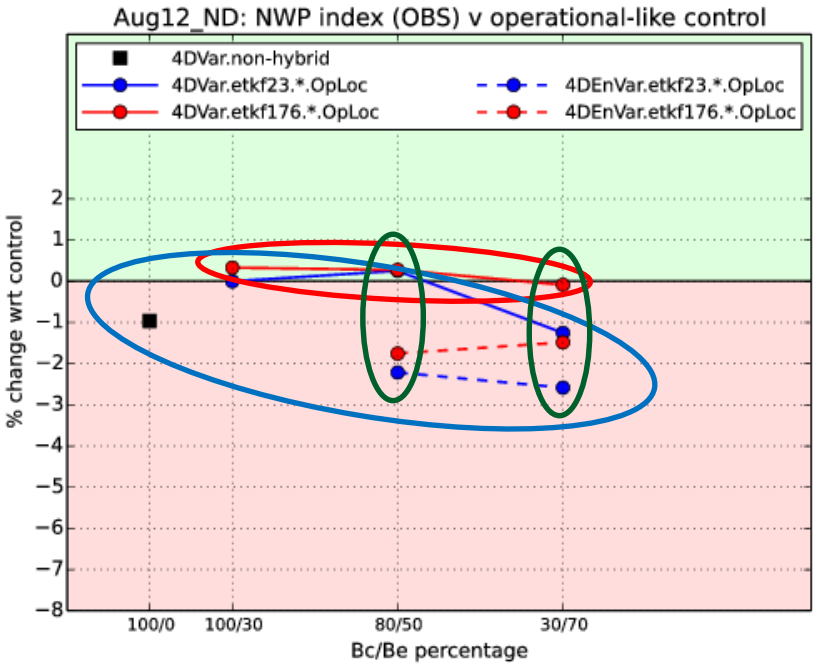
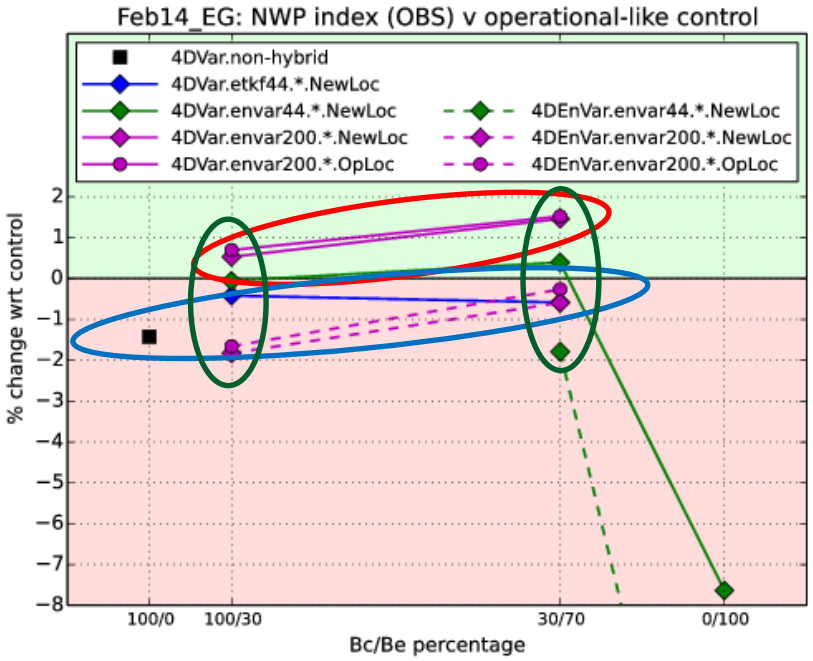
Effect of changing ensemble source on NWP index





- Hybrid-4DVar improves with increasing ensemble weight
- Hybrid-4DEnVar now beats non-hybrid-4DVar
- En-4DEnVar improves both hybrid-4DVar and -4DEnVar

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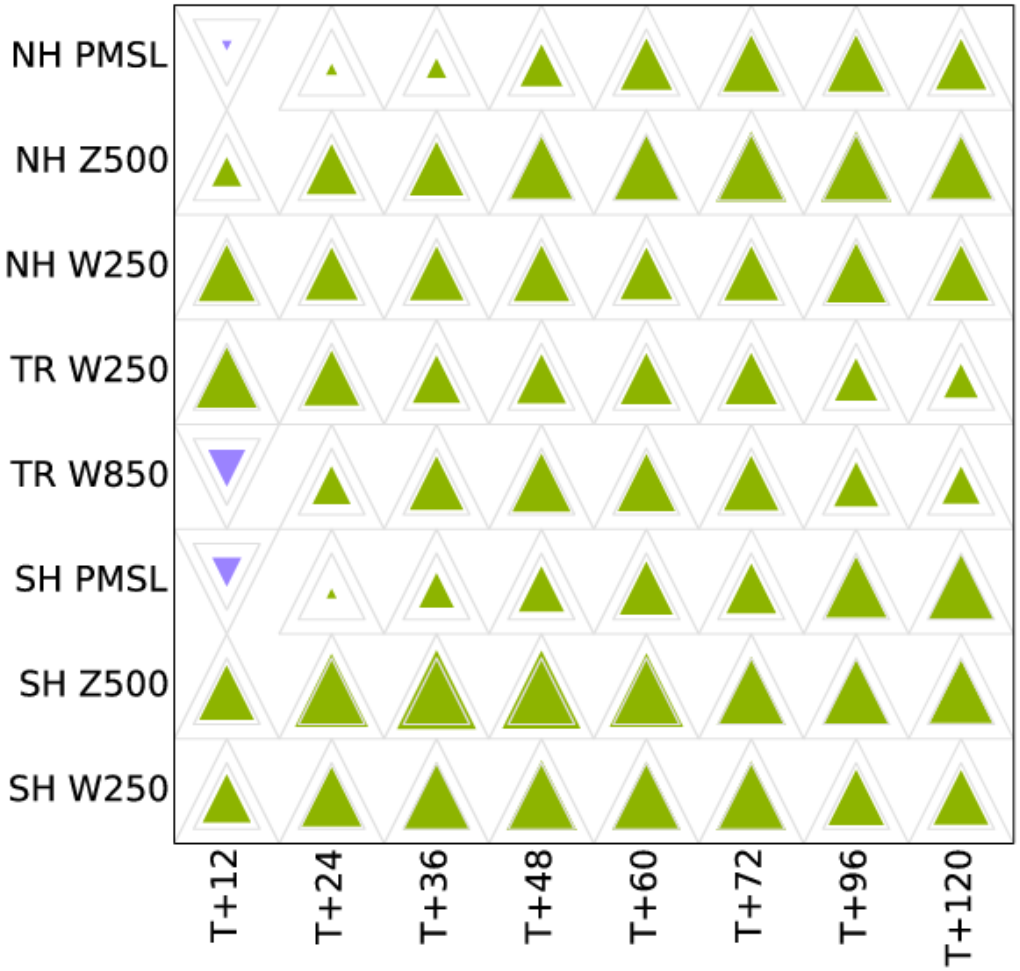
Non-hybrid-4DVar → Hybrid-4DVar

ETKF 44 member ensemble; 100% Bc, 30% Be



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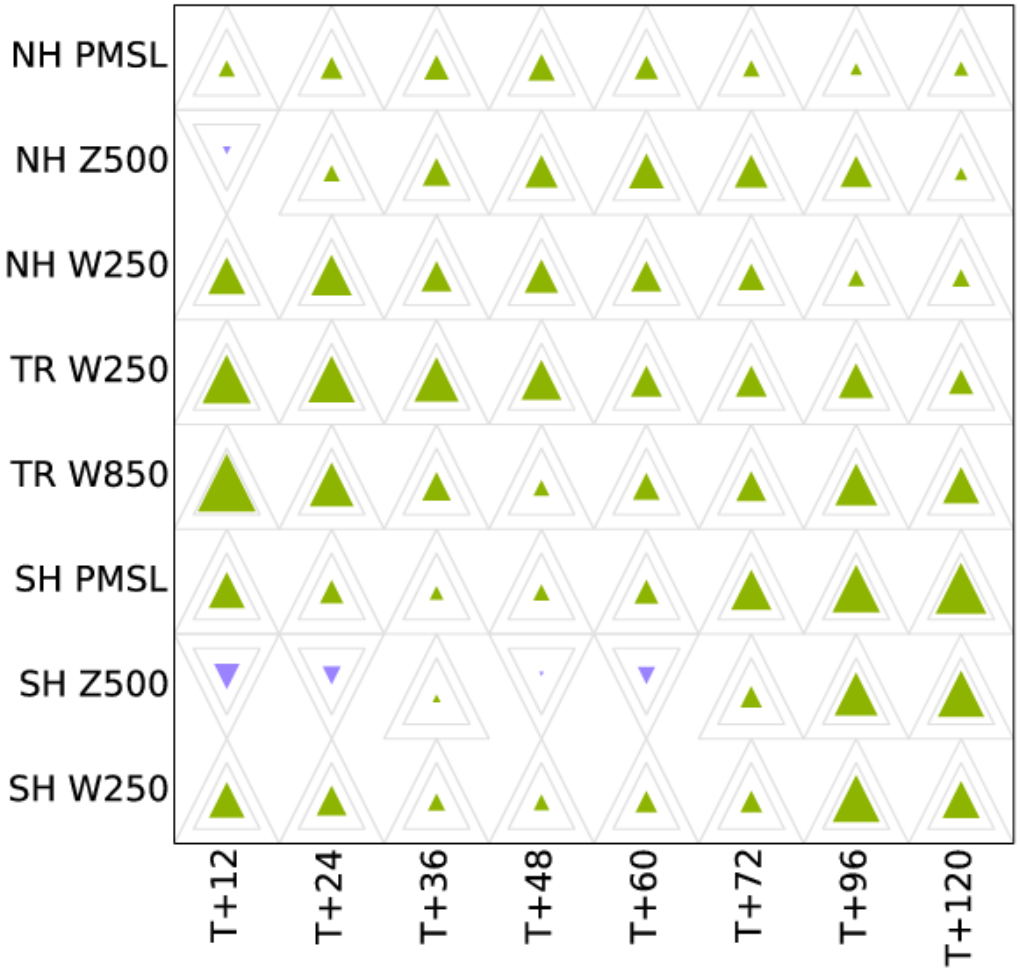
Hybrid-4DVar

ETKF → En-4DEnVar 44 member ensemble;
100% Bc, 30% Be



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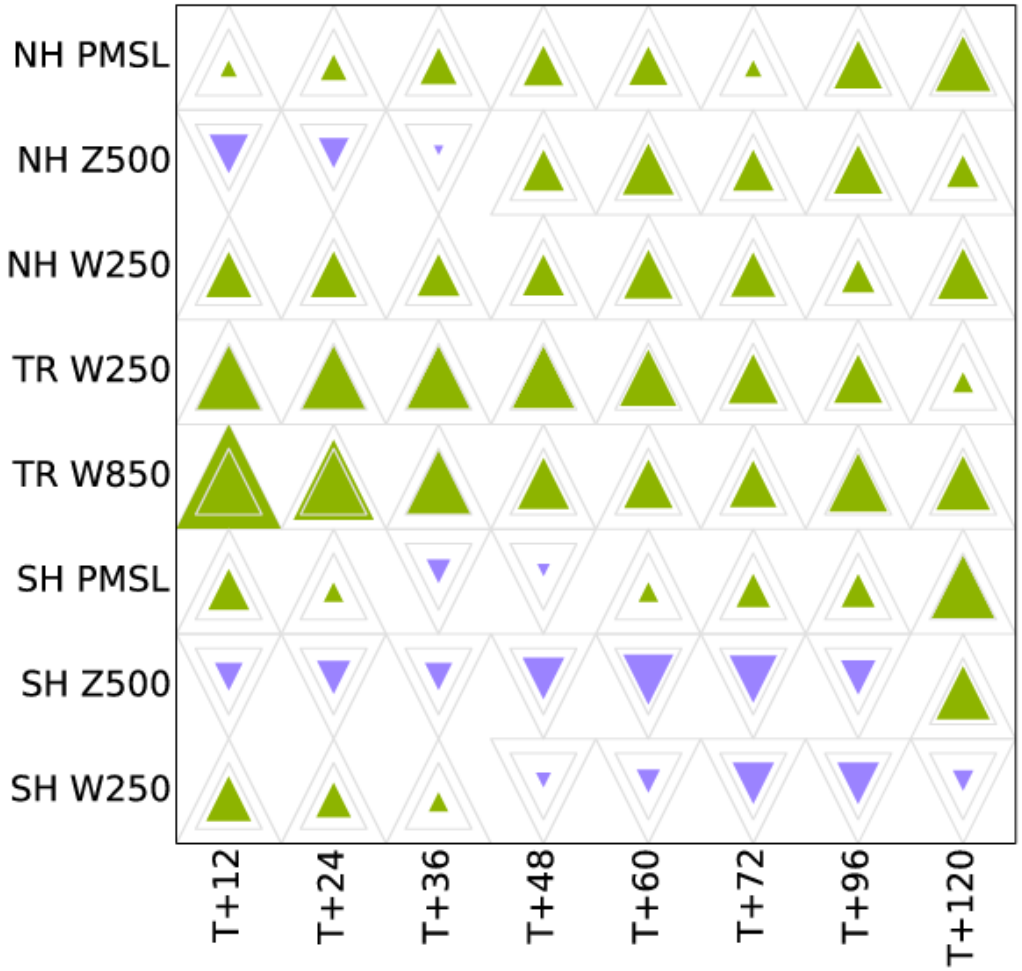
Hybrid-4DVar

ETKF → En-4DEnVar 44 member ensemble;
30% Bc, 70% Be



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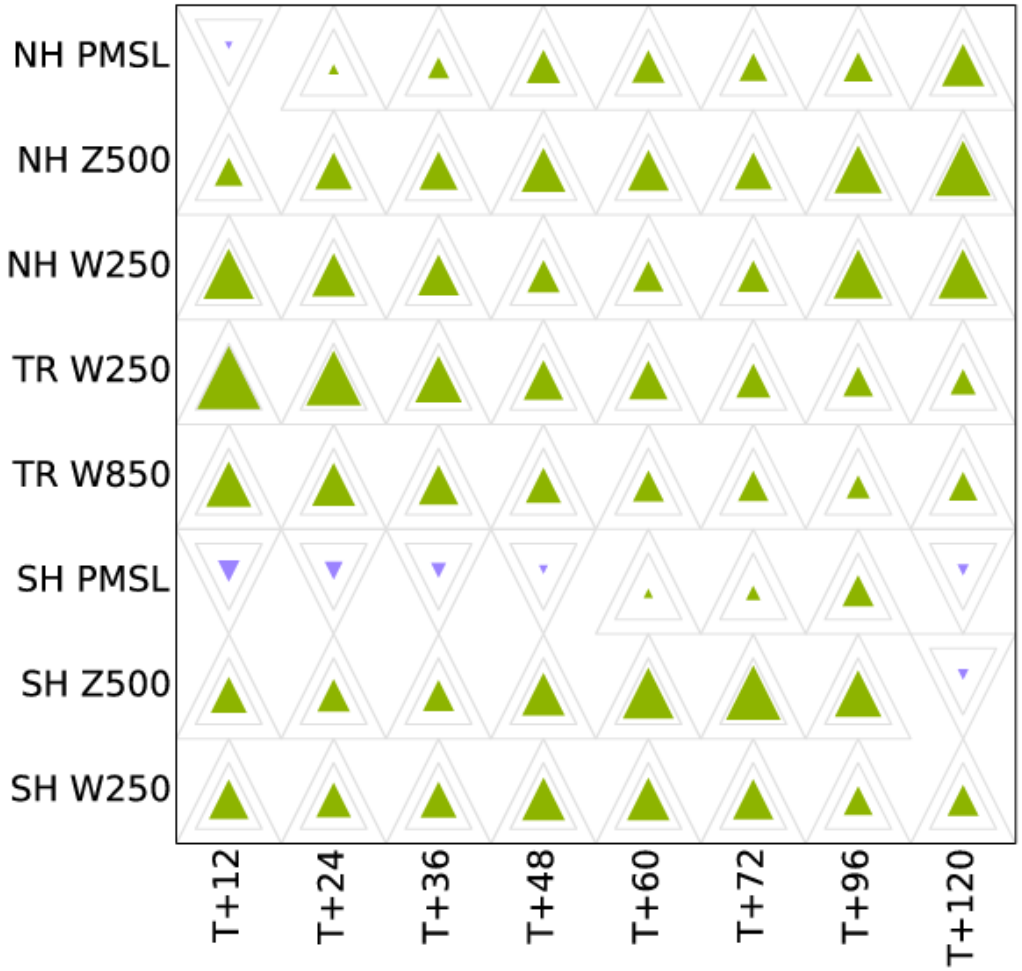
Hybrid-4DVar

En-4DEnVar 44 → 200 members;
100% Bc, 30% Be



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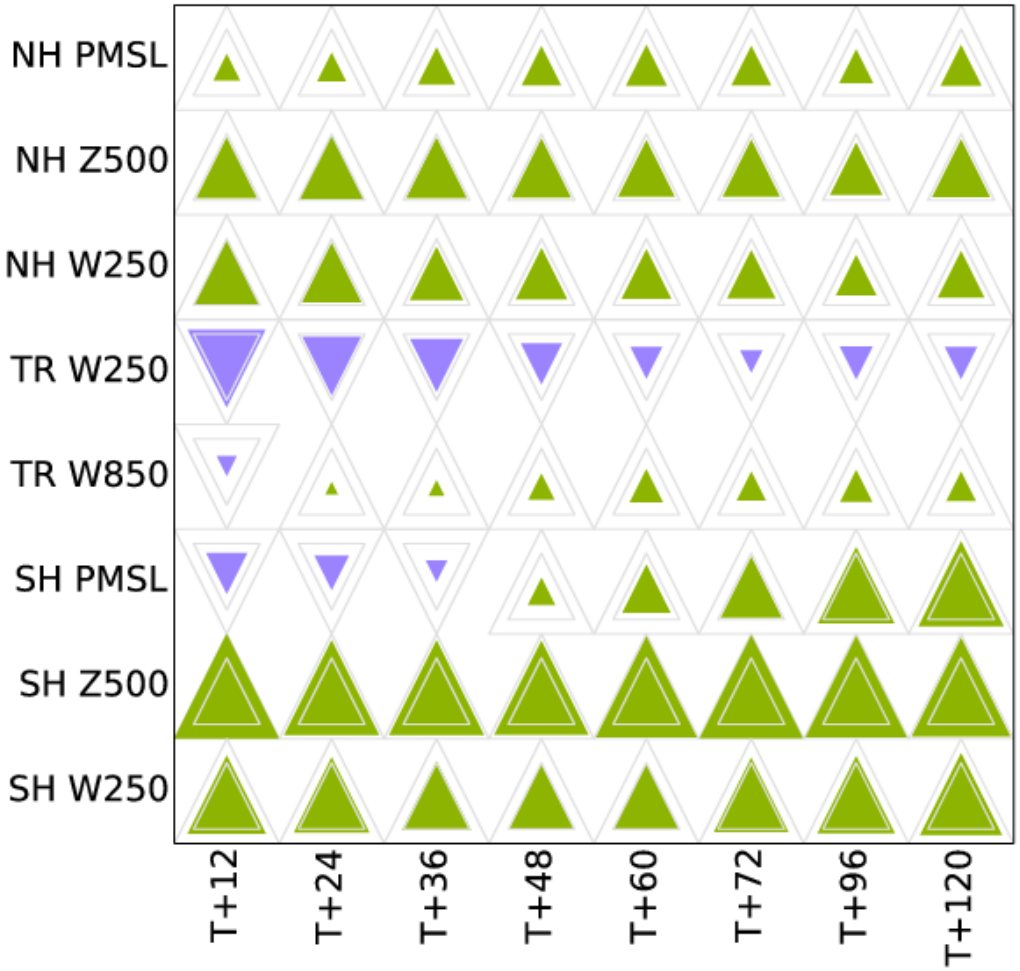
Hybrid-4DVar

En-4DEnVar 200 member ensemble; 100% Bc, 30% Be → 30% Bc, 70% Be



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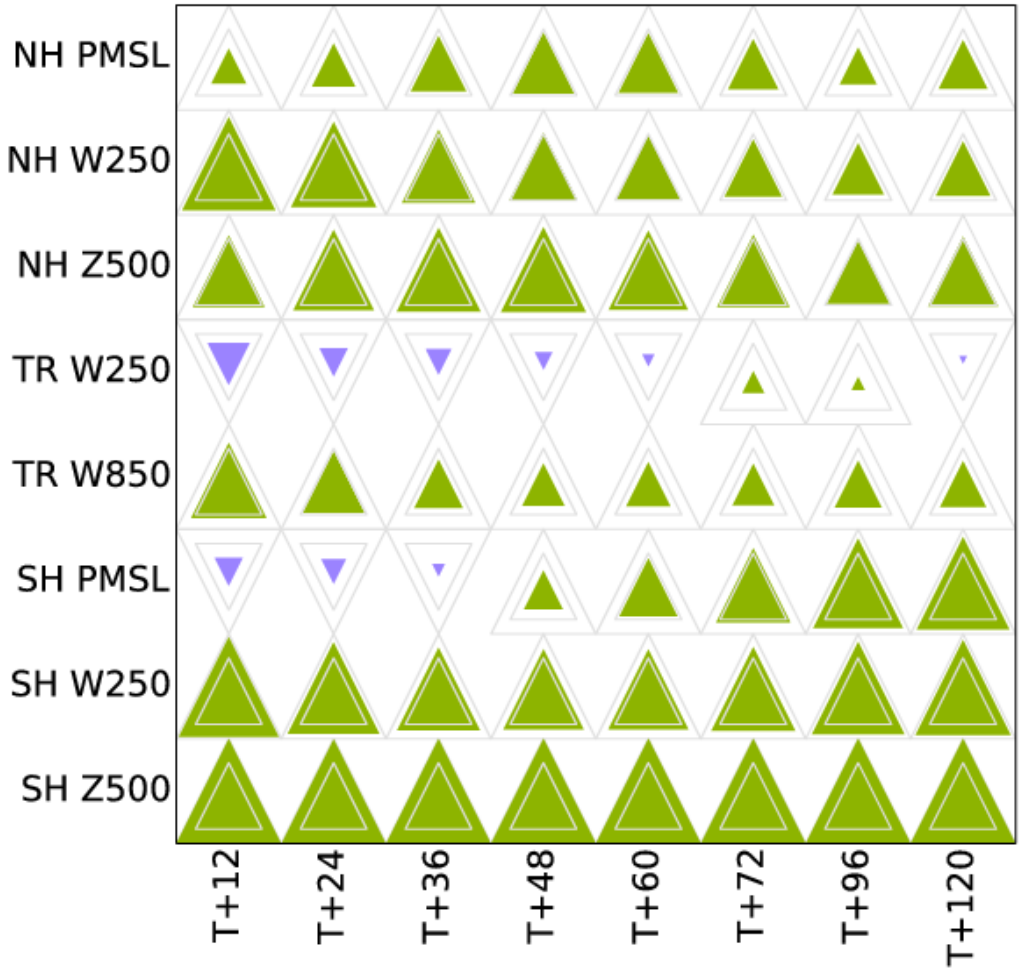
Hybrid-4DVar

ETKF → En-4DEnVar; 44 → 200 members;
100% Bc, 30% Be → 30% Bc, 70% Be



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Summary and future work

- Hybrid-4DEnVar now outperforms non-hybrid-4DVar with an En-4DEnVar ensemble
- Both hybrid-4DVar and hybrid-4DEnVar improve when going from the operational ETKF ensemble to an En-4DEnVar ensemble
- Hybrid-4DVar still outperforms hybrid-4DEnVar
- Continue using hybrid-4DVar for the life of our Cray XC40, aspiring to change the ETKF ensemble to an En-4DEnVar ensemble

Questions and answers