A hybrid-4DVAR system for the JMA non-hydrostatic model

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Hybrid covariance

Apart from the climatological covariance, the prior second moment used in 4DVAR is partially provided by an EnKF.

$$\mathrm{B} = \beta_C^2 B_C + \beta_E^2 (S \odot B_E)$$

- B_C: climatological covariance
- B_E: ensemble covariance
- S: localization matrix

Preconditioning by square roots of B

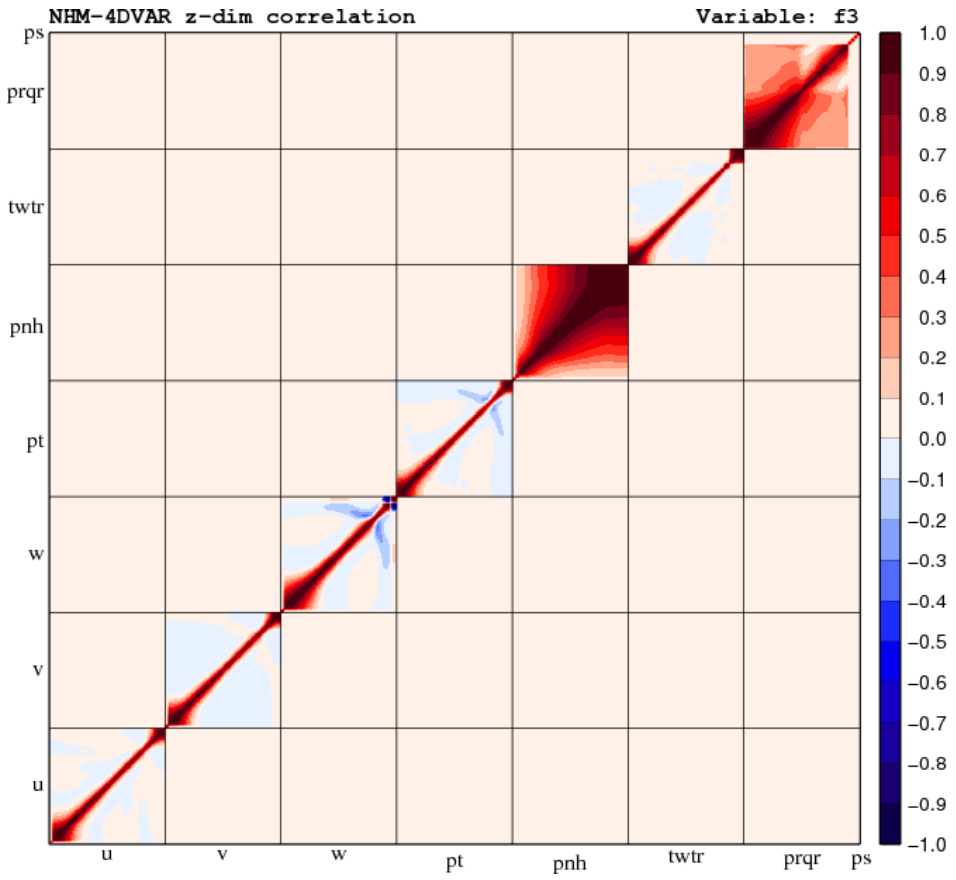
$$J(\Delta x) = \frac{1}{2}\beta_C^2 [\Delta x]^T_{B_C^{1/2}} [\Delta x]_{B_C^{1/2}} +$$
$$\frac{1}{2}\beta_E^2 [\Delta x]^T_{(S \odot B_E)^{1/2}} [\Delta x]_{(S \odot B_E)^{1/2}} +$$
$$\frac{1}{2}[y - h(x_B + \Delta x)]^T R^{-1} [y - h(x_B + \Delta x)]$$

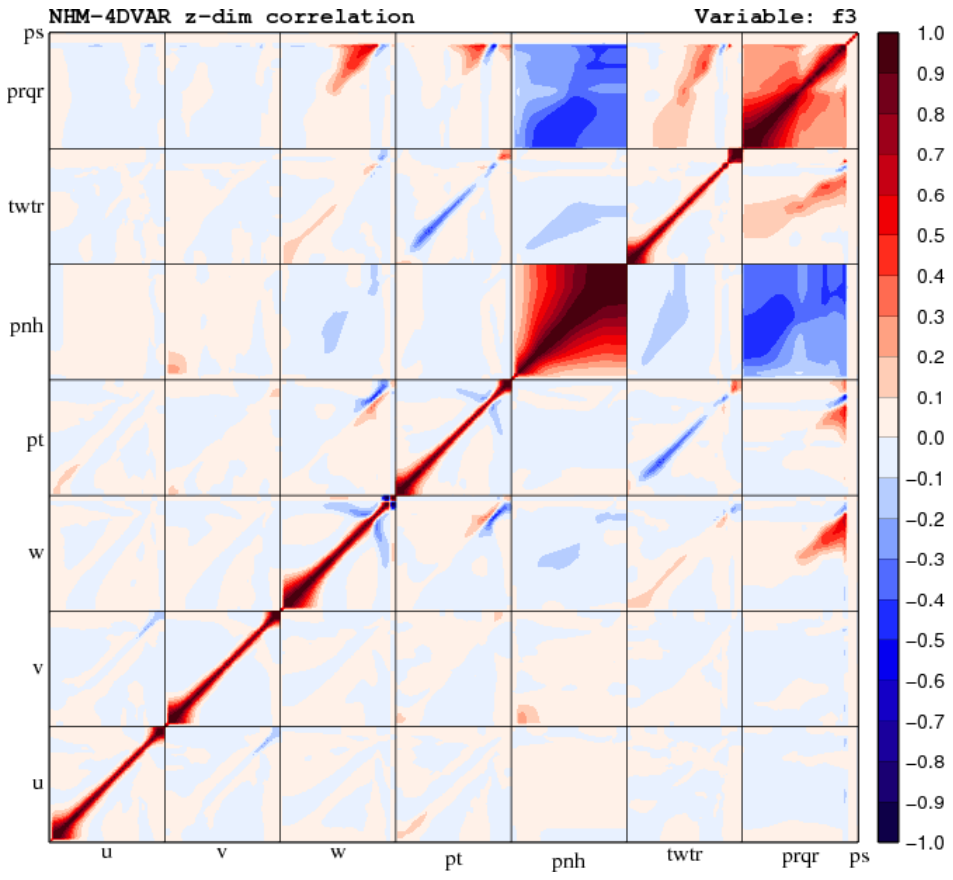
- $[\Delta x]_{B_C^{1/2}}$: coordinates of Δx in the span of the column vectors of $B_C^{1/2}$
- $[\Delta x]_{(S \odot B_E)^{1/2}}$: coordinates of Δx in the span of the column vectors of$(S \odot B_E)^{1/2}$
- Size of control variable: nx*ny*nz*nvar*nmember

NHM Hybrid-4DVAR

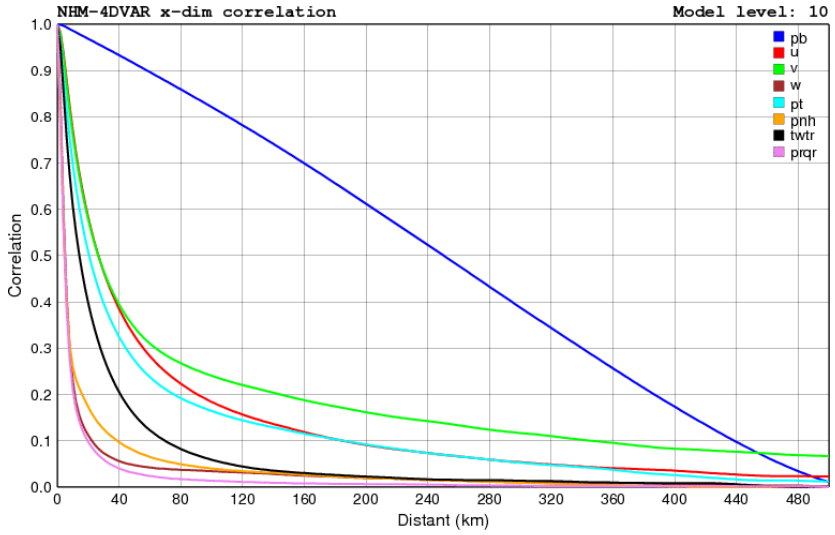
- Analysis: NHM-4DVAR developed at MRI
- Analysis covariance: NHM-LETKF developed at JMA
- Control: u, v, w, pt, non-hydrostatic pressure, pb, twtr (qv+qc), pseudo-relative qr
- The localization length scales were derived from the background correlations of NHM-4DVAR. The cross-correlations between different control variables were considered.
- Parallelization: 4D-paralelization for the operators $B^{1/2}$ and $S^{1/2}$, 1D-paralelization of LBFGS.

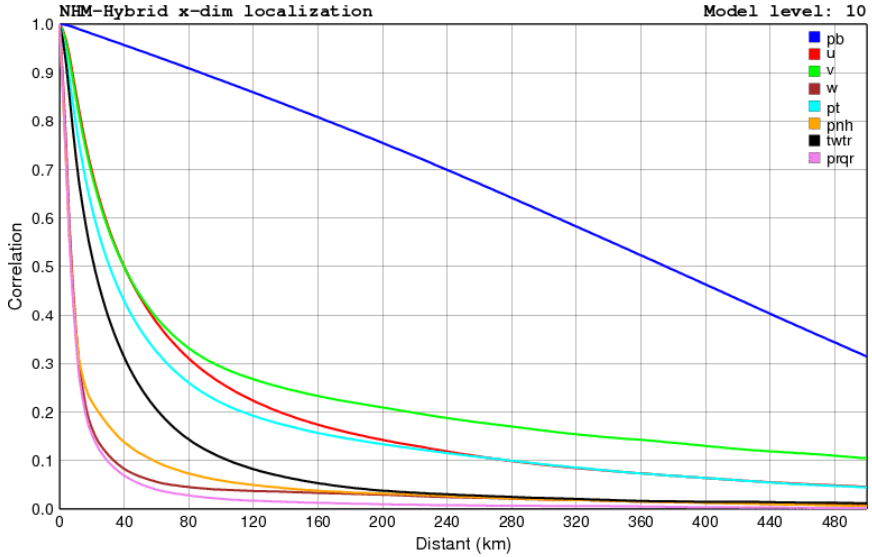
New modeling of B matrix in NHM-4DVAR





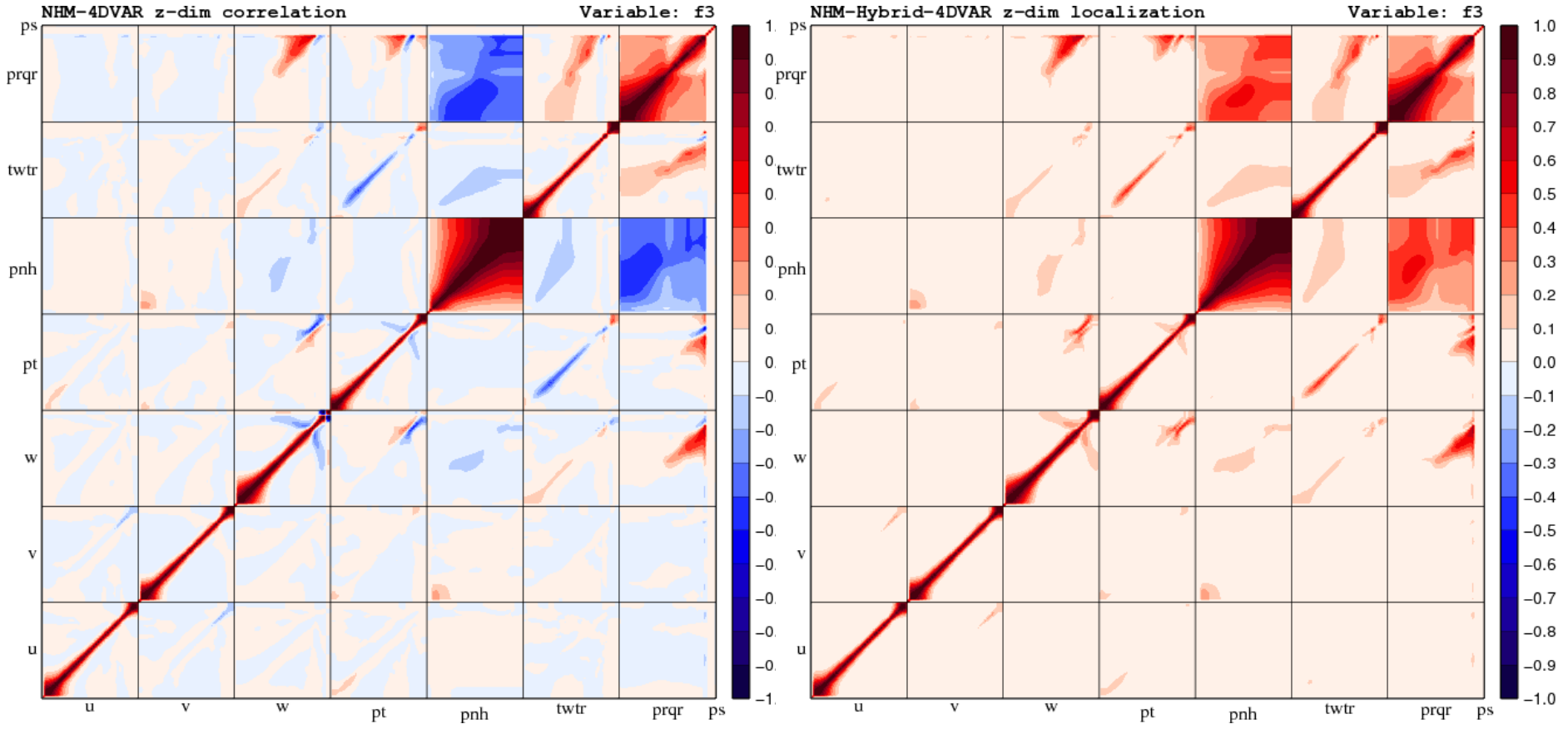
Model localization functions based on NHM-4DVAR B matrix





Localization functions were calculated from correlation functions by dilation with a factor of 1.5: loc(r) = cor(r/1.5)

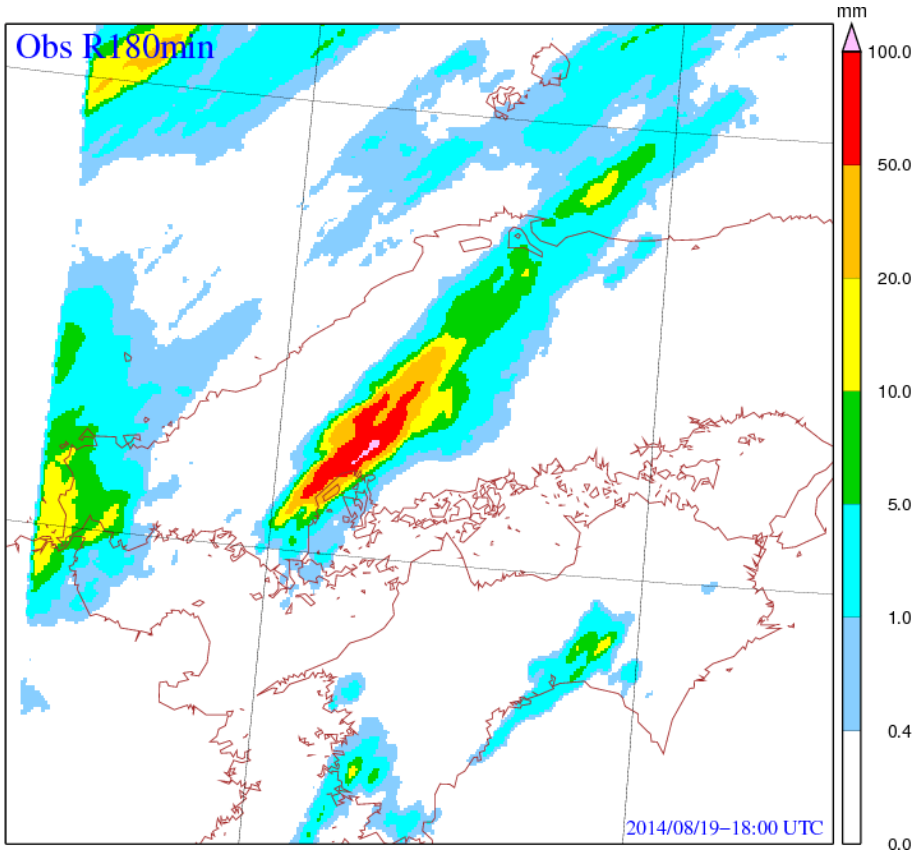
Model localization functions based on NHM-4DVAR B matrix



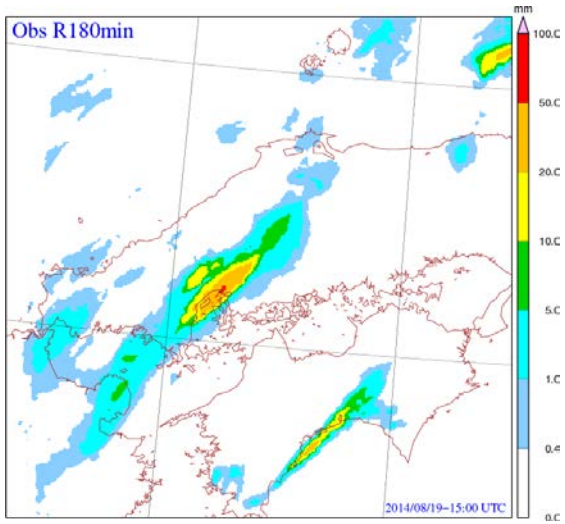
Note that vertical localization functions were calculated from the absolute values of correlation functions

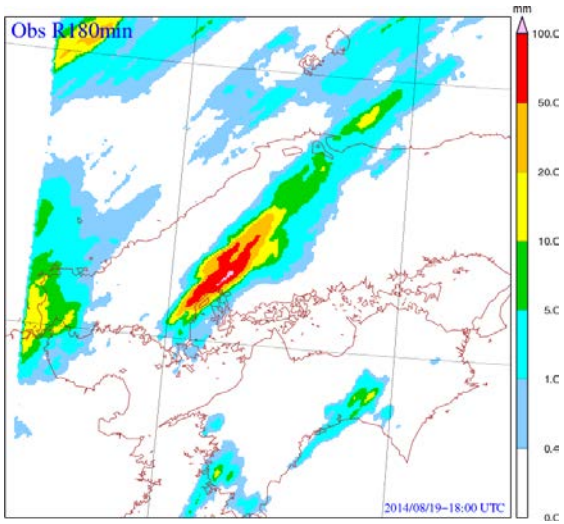
Experimental settings: Hiroshima heavy rain event

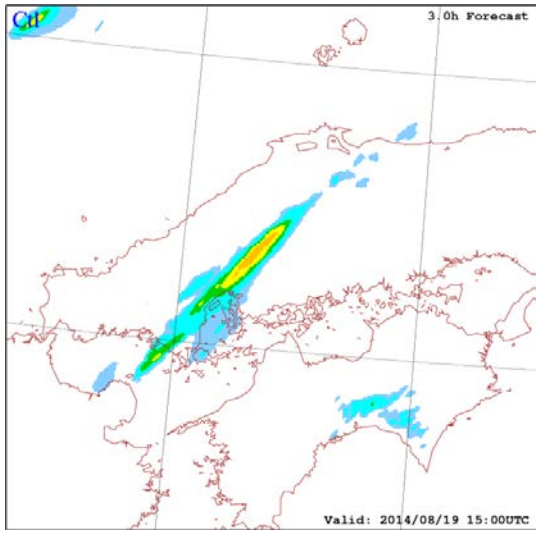
- Methods: 4DVAR, 4DVAR Bens, and Hybrid-4DVAR (climatological weight = 80%, ensemble weight = 50%)
- Assimilation cycle: 30 minutes
- Domain: 200x200 horizontal grid points, 40 levels
- Resolutions: inner 2 km, outer 1 km
- Ensemble: 50 members
- Observations: every 5-min, conventional, GPS, Doppler radial winds

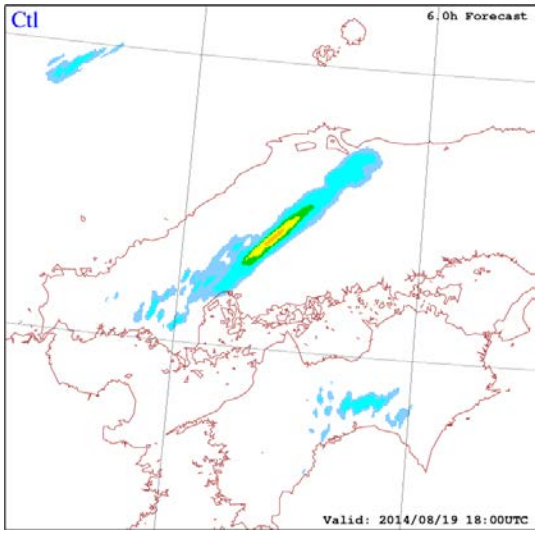


Downscaling forecast



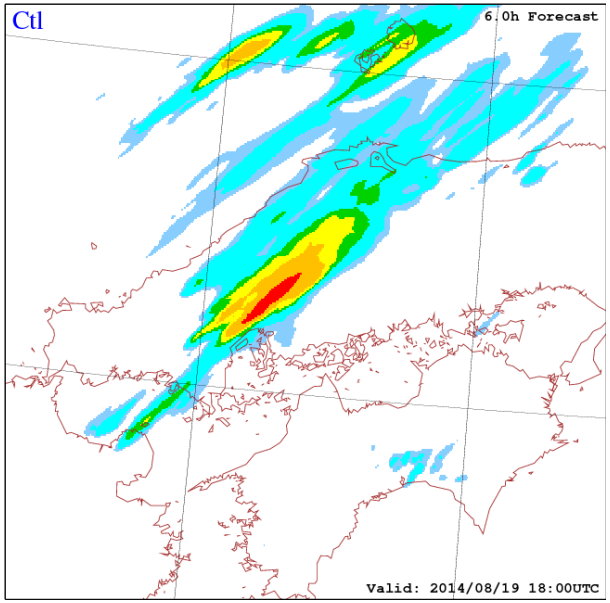




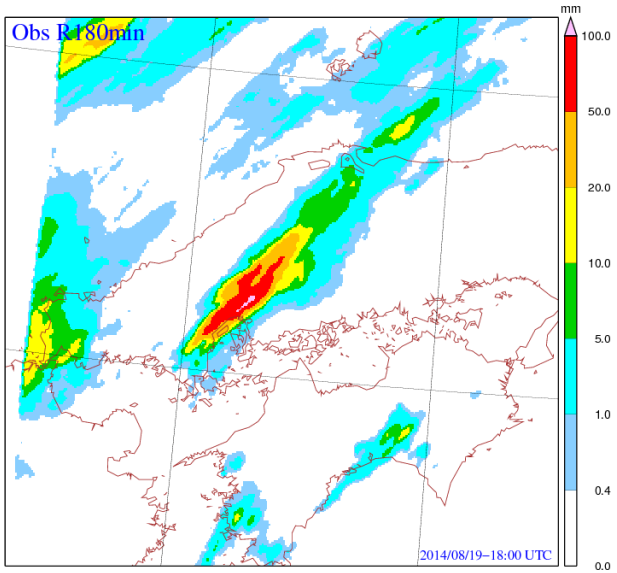


Results

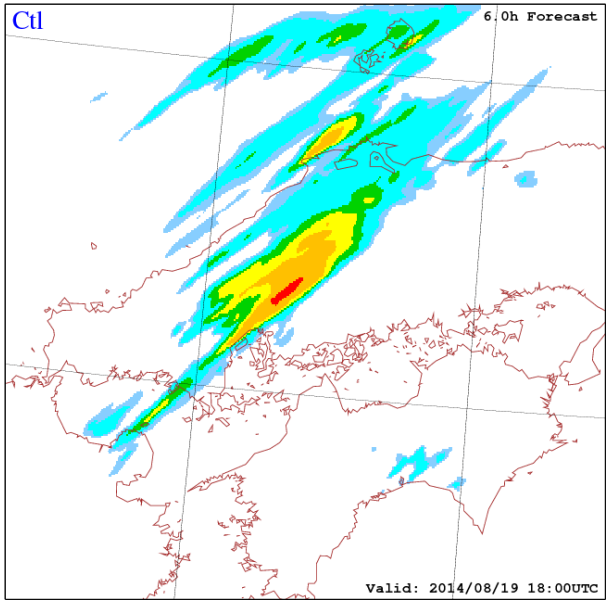
4DVAR



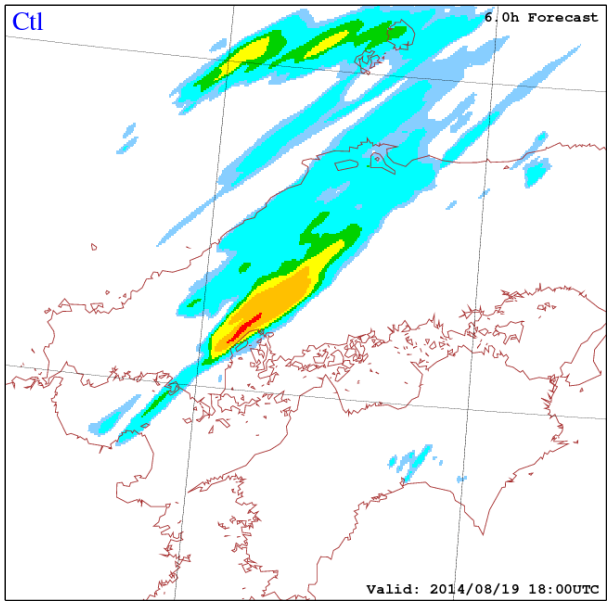
Obs



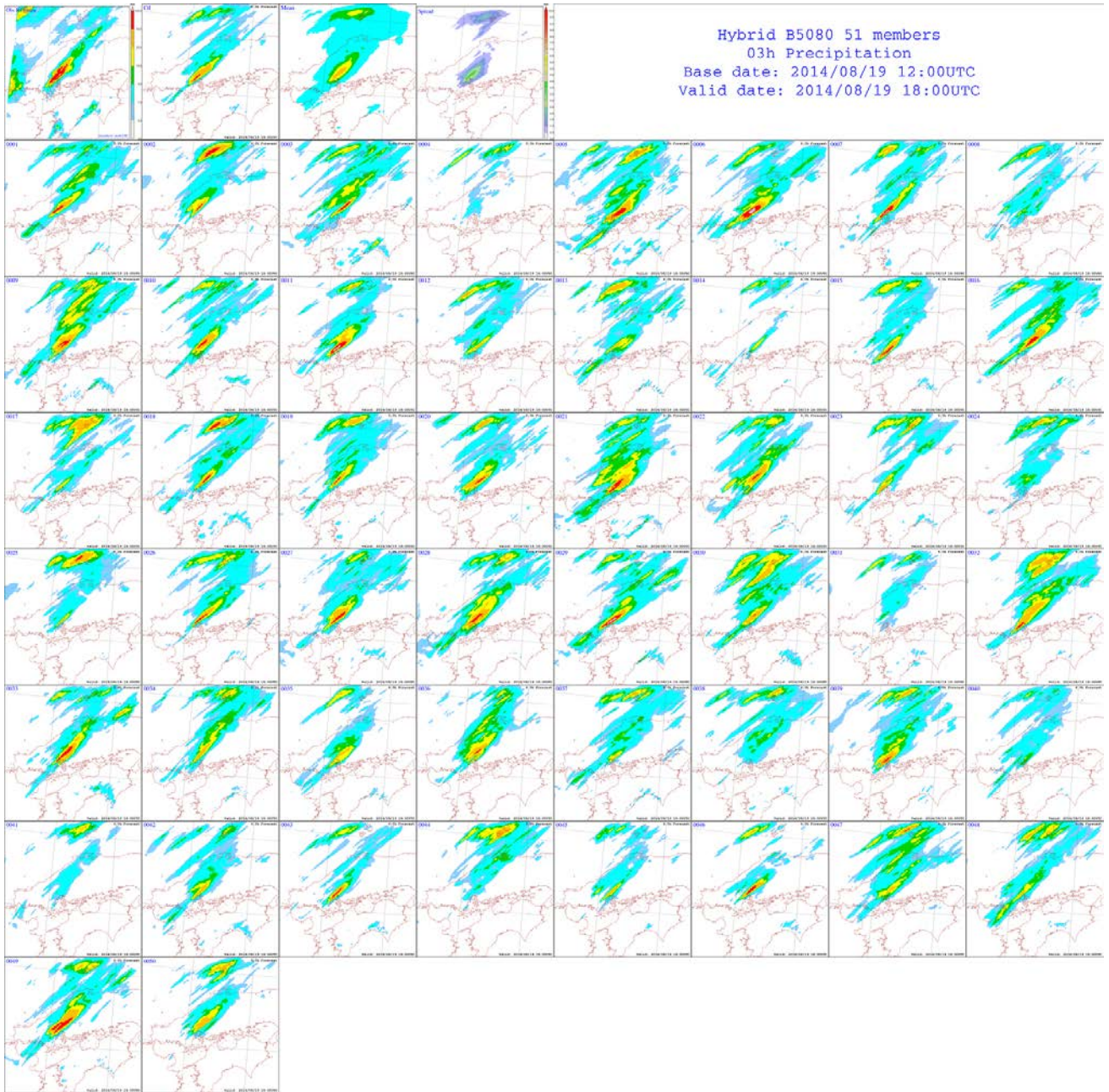
4DVAR Bens



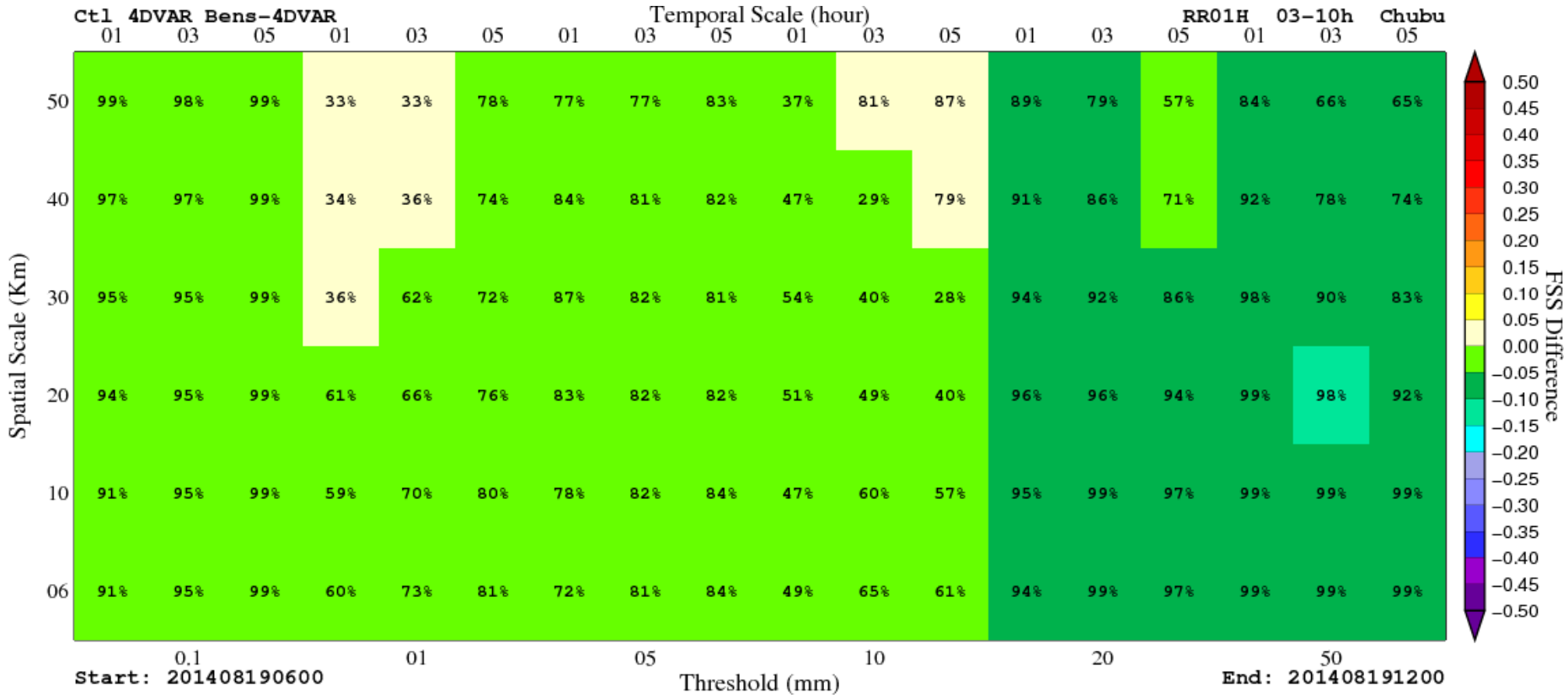
Hybrid



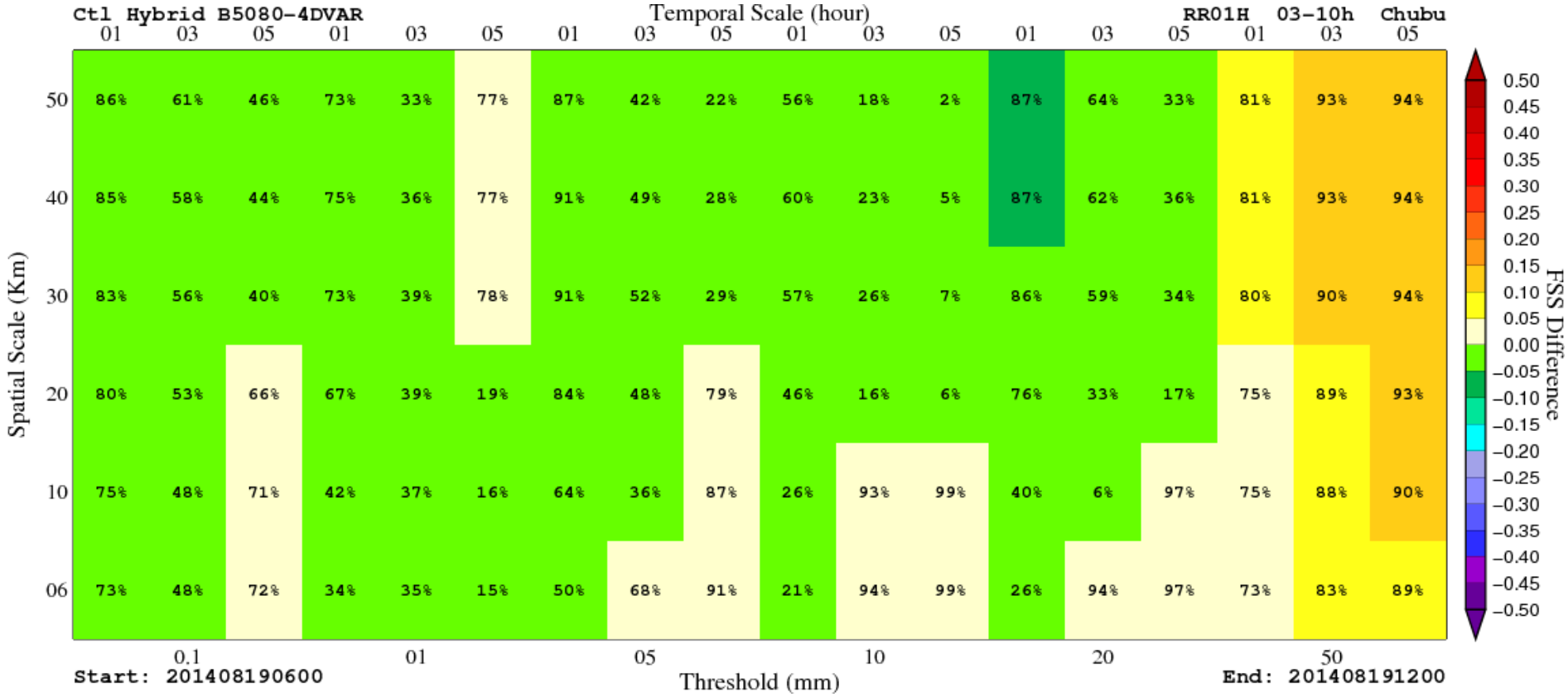
Results


Hybrid B5080 51 members
03h Precipitation
Base date: 2014/08/19 12:00UTC
Valid date: 2014/08/19 18:00UTC

Verification: 4DVAR Bens vs. 4DVAR



Verification : Hybrid-4DVAR vs. 4DVAR



Hybrid gain

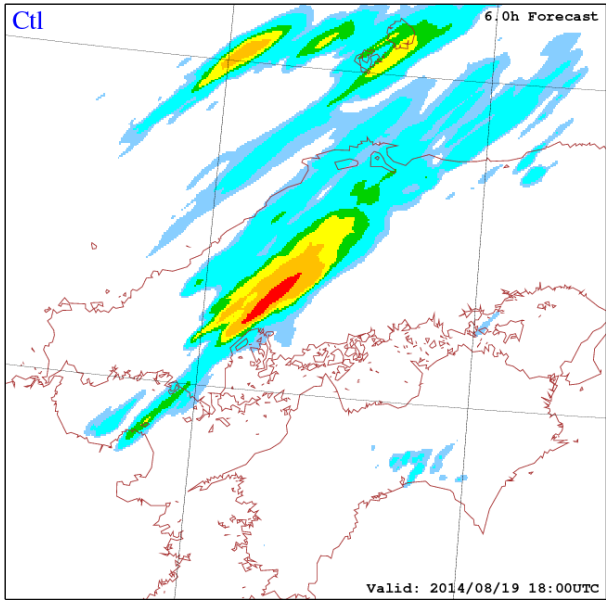
Instead of covariance, now Kalman gain is the linear combination between the gains of 4DVAR and EnKF.

$$\mathrm{K} = \alpha K_C + (1-\alpha) K_E$$

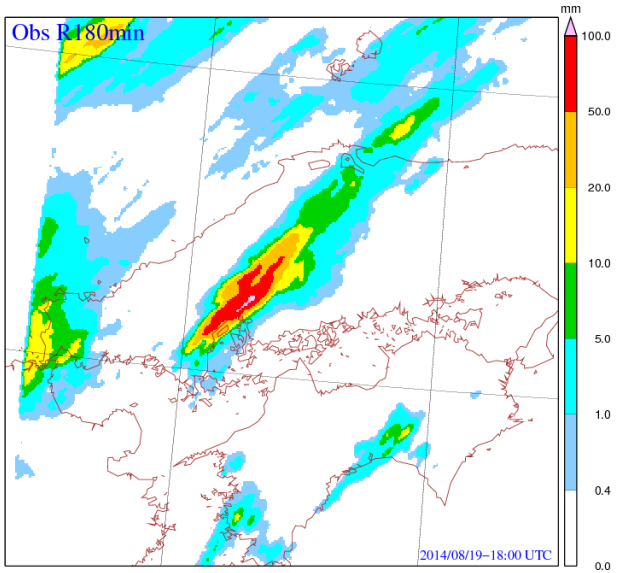
$$\mathrm{x}^a = \alpha x_C^a + (1-\alpha) x_E^a$$

Results

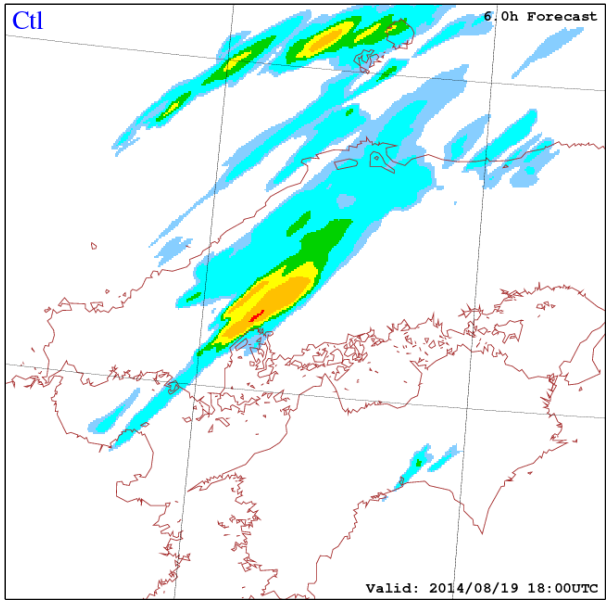
4DVAR



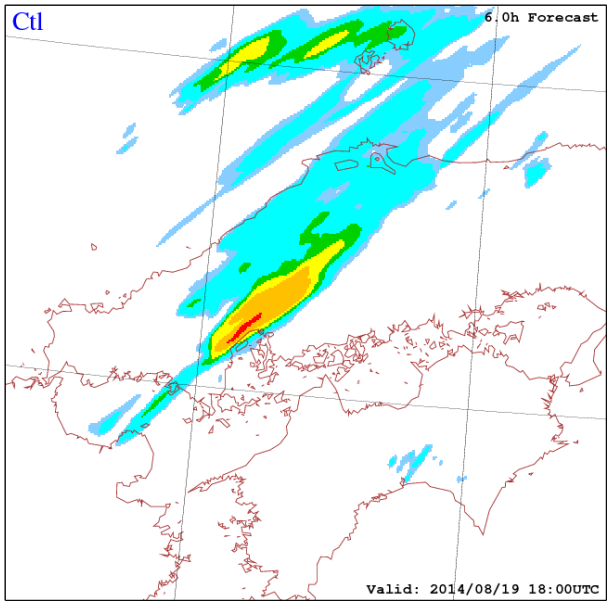
Obs



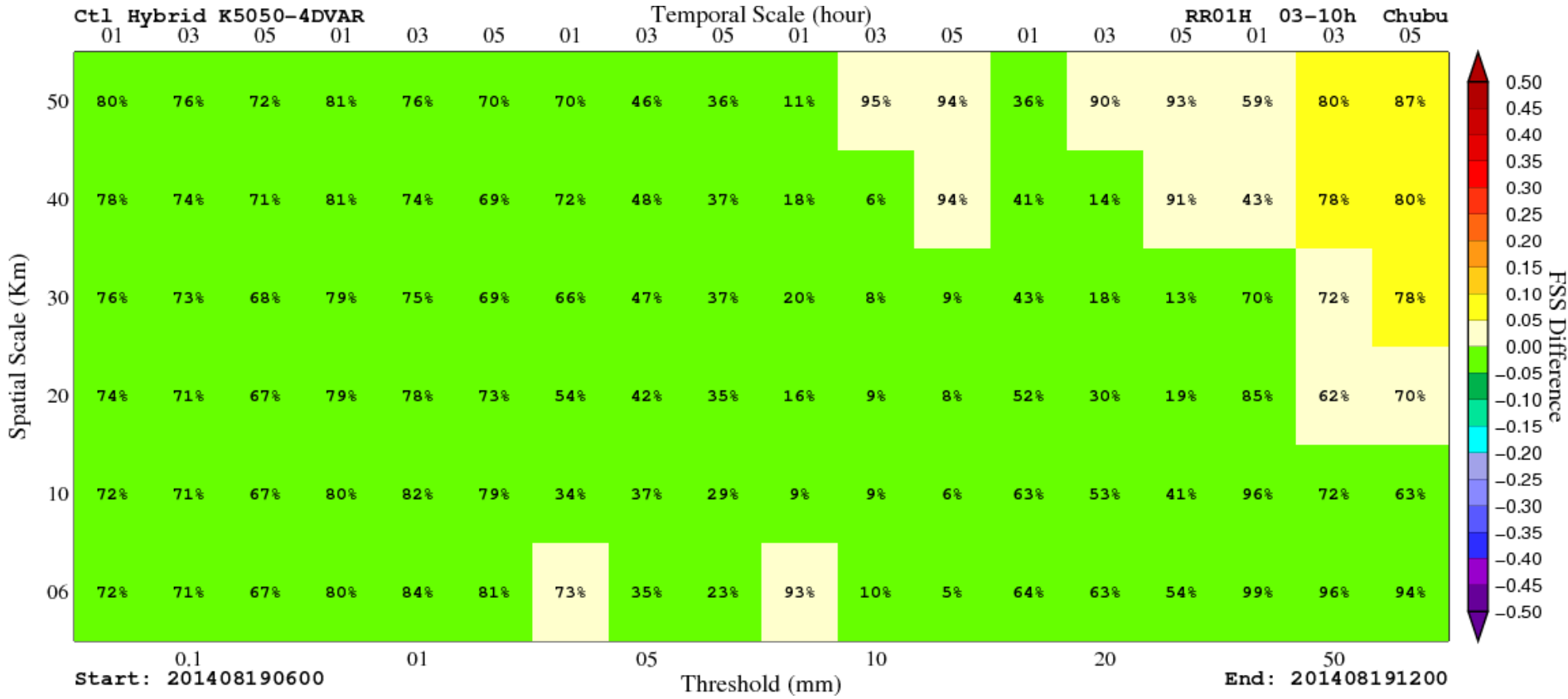
Hybrid K5050



Hybrid B5080



Verification: Hybrid gain vs. 4DVAR



Summary

- Two hybrid systems were developed in the SPIRE3 project: hybrid B and hybrid K.
- Two hybrid systems work well but it's not clear whether they beat 4DVAR or not in rainfall forecast except at high rainfall thresholds.
- Hybrid K consumes less computational resource than hybrid B but its analyses are comparable to the analyses of hybrid B.
- The size of the control variable in the current hybrid-4DVAR is proportional to the number of ensemble members. This causes the running time to increase considerably. The preconditioning with B instead of square roots of B should be considered.