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.

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

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

Preconditioning by square roots of B

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

- $[\Delta x]_{B_C^{1/2}}$: 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











0.4

0.0

2014/08/19-18:00 UTC

Valid: 2014/08/19 18:00UTC

Results



Verification: 4DVAR Bens vs. 4DVAR

	Ctl 4DVAR Bens-4DVAR 0^3 05 01				Temporal Scale (hour)							01	RR01H 0				Chubu		
	01	03	03	01	03	03	01	03	05	01	05	03	01	03	03	01	03	03	
50) 99%	98%	99%	33%	33%	78%	77%	77%	83%	37%	81%	87%	89%	79%	57%	84%	66%	65%	0.50 0.45 0.40
40) 97 %	97%	99%	34%	36%	74%	84%	81%	82%	47%	29%	79%	91%	86%	71%	92%	78%	74%	0.35 0.30 0.25 0.20
cale (Km) 05) 95 %	95%	99%	36%	62%	72%	87%	82%	81%	54%	40%	28%	94%	92%	86%	98%	90%	83%	0.15 0.10 0.05 0.00
Spatial So 05) 94%	95%	99%	61%	66%	76%	83%	82%	82%	51%	49%	40%	96%	96%	94%	99%	98%	92%	-0.05 Ierence -0.10 ce
10) 91%	95%	99%	59%	70%	80%	78%	82%	84%	47%	60%	57%	95%	99%	97%	99%	99%	99%	-0.20 -0.25 -0.30 -0.35
06	5 91 %	95%	99%	60%	73%	81%	72%	81%	84%	49%	65%	61%	94%	99%	97%	99%	99%	99%	-0.40 -0.45 -0.50
	Start	0.1 2014	081906	00	01	05 10 Threshold (mm)								20 50 End: 201408191200					

Verification : Hybrid-4DVAR vs. 4DVAR

	Ctl Hy	vbrid H	3 5080 -7	4DVAR 01	Temporal Scale (hour) 03 05 01 03 05 01									03	RR01H 03-10h 05 01 03			Chubu 05	
50) 86%	61%	46%	73%	33%	77%	87%	42%	22%	56%	18%	2%	87%	64%	33%	81%	93%	94%	0.50 0.45 0.40
40) 85%	58%	44%	75%	36%	77%	91%	49%	28%	60%	23%	5%	87%	62%	36%	81%	93%	94%	0.35 0.30 0.25 0.20
cale (Km)) 83%	56%	40%	73%	39%	78%	91%	52%	29%	57%	26%	7%	86%	59%	34%	80%	90%	94%	0.15 0.10 FSS 0.05 Dif
Spatial So) 80 %	53%	66%	67%	39%	19%	84%	48%	79%	46%	16%	6%	76%	33%	17%	75%	89%	93%	-0.05 ference -0.10 ce
10) 75 %	48%	71%	42%	37%	16%	64%	36%	87%	26%	93%	99%	40%	6%	97%	75%	88%	90%	-0.20 -0.25 -0.30 -0.35
00	5 73 %	48%	72%	34%	35%	15%	50%	68%	91%	21%	94%	99%	26%	94%	97%	73%	83%	89%	-0.40 -0.45 -0.50
	Start:	0,1 20140	081906	00	01	01 05 10 Threshold (mm)							20	50 End: 201408191200					

Hybrid gain

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

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

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



Hybrid K5050



Hybrid B5080



1.0

0.4

0.0

2014/08/19-18:00 UTC

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.