Examining the sensitivity of the accuracy of EFSO to ensemble size

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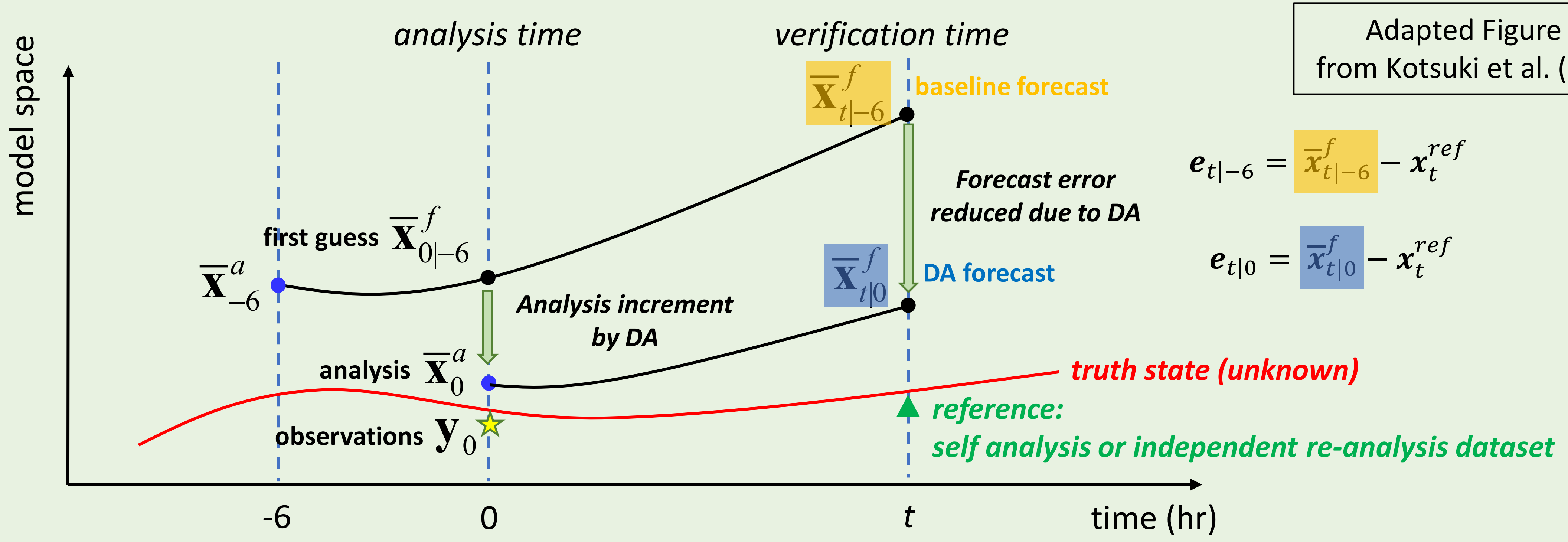
Background

- EFSO, which stands for **Ensemble Forecast Sensitivity to Observation**, is a method that quantifies the impact of assimilated observations using **ensemble of forecasts**.
- The idea originates from computing the **error reduction between two forecasts: baseline forecast vs. DA forecast**



Adapted Figure 1 from Kotsuki et al. (2019)

$$e_{t|-6} = \bar{x}^f_{t|-6} - x^{ref}_t$$

$$e_{t|0} = \bar{x}^f_{t|0} - x^{ref}_t$$

Forecast error reduction $\Delta e^2 = \left(e^2_{t|0} - e^2_{t|-6}\right) = \mathbf{e}^T_{t|0}\mathrm{C}\mathbf{e}_{t|0} - \mathbf{e}^T_{t|-6}\mathrm{C}\mathbf{e}_{t|-6} = \left(\bar{x}^f_{t|0} - \bar{x}^f_{t|-6}\right)^T C\left(\bar{x}^f_{t|0} + \bar{x}^f_{t|-6} - 2x^{ref}_t\right)$

Background (cont.)

True forecast error reduction (**per grid point *j***): $\Delta e^2_{true,j} = \left(\overline{\boldsymbol{x}}^f_{t|0} - \overline{\boldsymbol{x}}^f_{t|-6}\right)^T_j C_{jj} \left(\overline{\boldsymbol{x}}^f_{t|0,j} + \overline{\boldsymbol{x}}^f_{t|-6,j} - 2\boldsymbol{x}^{ref}_{t,j}\right)_j$

Linear error growth assumption
Ensemble error covariance approximation

EFSO estimated forecast error reduction (**per grid point *j* per observation *l***):

$$\Delta e^2_{EFSO,j,l} = \frac{1}{m-1} (\delta \boldsymbol{y}_0)^T{}_l \cdot \boldsymbol{\rho}_{l,j} \left[(\boldsymbol{R}^{-1}\boldsymbol{Y}^a_0 \boldsymbol{X}^{f}_{t|0}{}^T)_{l,j} C_{jj} \left(\overline{\boldsymbol{x}}^f_{t|0} + \overline{\boldsymbol{x}}^f_{t|-6} - 2\boldsymbol{x}^{ref}_t\right)_j \right]$$

ensemble size | **obs - guess** | **localization matrix** | **Ensemble forecast perturbation** | **analysis perturbation in obs space**

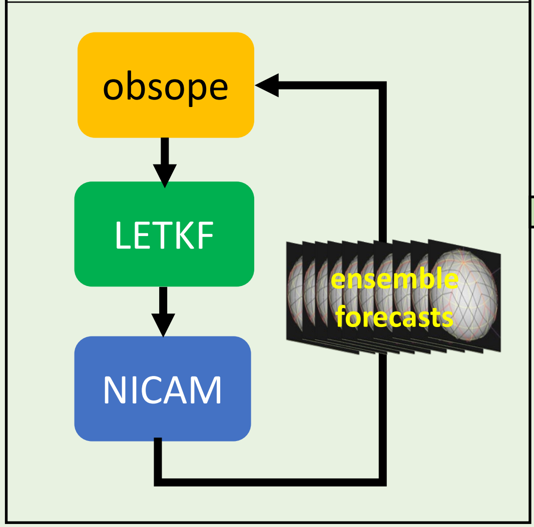
- Like any ensemble methods, EFSO also suffers from sampling error due to the use of limited-sized ensemble.
  - As such, covariance localization is used to suppress sampling error.
  - With the Fugaku supercomputating resource, we can afford to run large ensemble ($O(10^3)$) experiments and examine the sensitivity of the accuracy of EFSO to ensemble size and the localization length.

Methodology & Results

NICAM-LETKF settings:

- GL06 (Δx = 112 km) with 38 vertical levels
- Cycling interval: 6 hour
- Assimilated obs: Conventional, AMSU-A, MHS
- Localization length: H 400 km; V 0.4 ln(p)

$$\Delta e^2_{EFSO,j,l} = \frac{1}{m-1}(\delta \boldsymbol{y}_0)^T{}_l \cdot \boldsymbol{\rho}_{l,j} \left[(\boldsymbol{R}^{-1}\boldsymbol{Y}^a_0 \boldsymbol{X}^{f}_{t|0}{}^T)_{l,j} C_{jj} \left(\overline{\boldsymbol{x}}^f_{t|0} + \overline{\boldsymbol{x}}^f_{t|-6} - 2\boldsymbol{x}^{ref}_t \right)_j \right]$$



EFSO computation

Compute $\boldsymbol{Y}^a_0 \boldsymbol{X}^{f}_{t|0}{}^T$ term using ensemble data sub samples from the 1024 members:

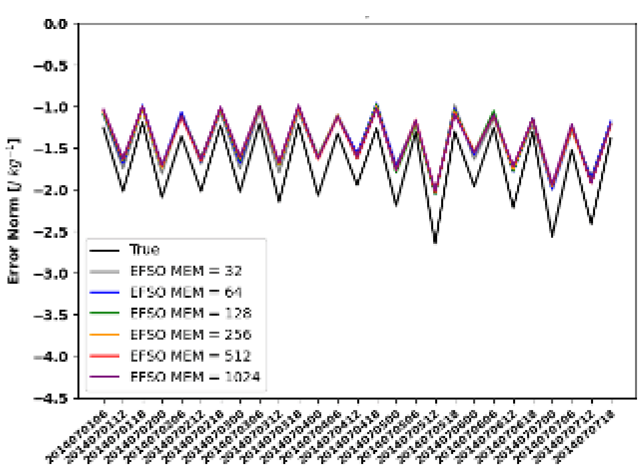
1024, 512, 256, 128, 64, 32

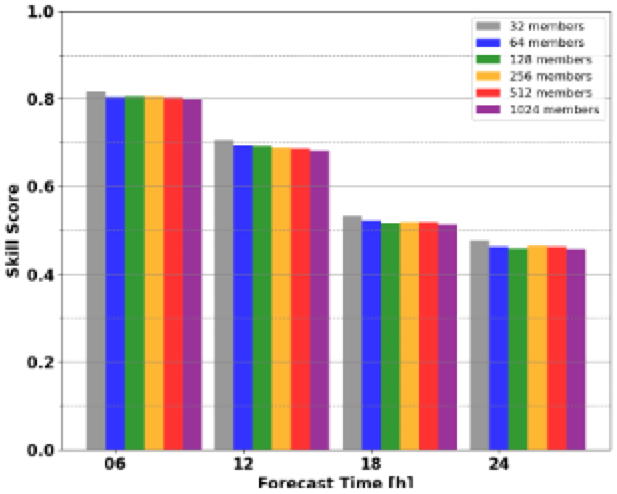
and

test different localization lengths $\boldsymbol{\rho}_{l,j}$

$$\sum_{GL}\Delta e^2_{true} = \sum_j^{Ngrid}(\Delta e^2_{true,j}) \text{ v.s. } \sum_{GL}\Delta e^2_{EFSO} = \sum_j^{Ngrid}(\Delta e^2_{EFSO,j})$$

$$skill\ score = 1 - \frac{\left[\sum_{k=1}^{Ncycle}\left(\sum_{GL}\Delta e^2_{true,k} - \sum_{GL}\Delta e^2_{EFSO,k}\right)^2\right]^{1/2}}{\left[\sum_{k=1}^{Ncycle}\left(\sum_{GL}\Delta e^2_{true,k}\right)^2\right]^{1/2}}$$

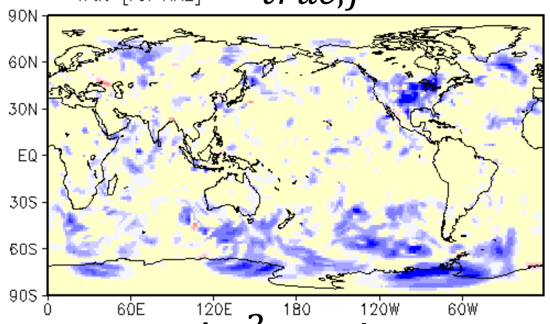




- Comparison in the form of difference between globally summed values (used in literature) suggest little sensitivity of EFSO to ensemble size.
- Counter-intuitive results were obtained where smaller ensemble is more skillfull at EFSO estimations.

More Results using new metrics

$\Delta e^2_{true,j}$

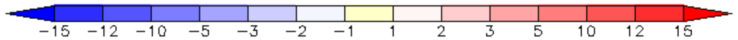


Metrics that account for spatial variation are more relevant:

$$RMSE = \left[\frac{\sum_j^{N_{grid}} (\Delta e^2_{true,j} - \Delta e^2_{EFSO,j})^2}{N_{grid}}\right]^{\frac{1}{2}}$$

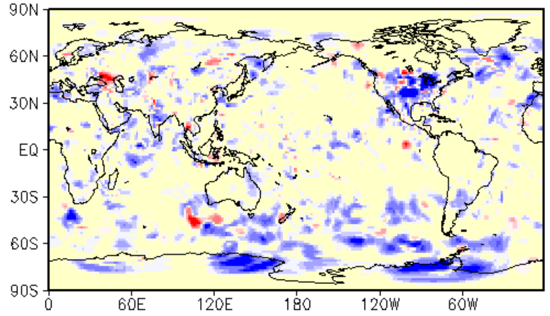
$$Relative\ Skill\ Score = 1 - \frac{RMSE_m - RMSE_{1024}}{RMSE_{1024}}$$

Corr = Pearson's correlation coefficient between $\Delta e^2_{true,j}$ and $\Delta e^2_{EFSO,j}$

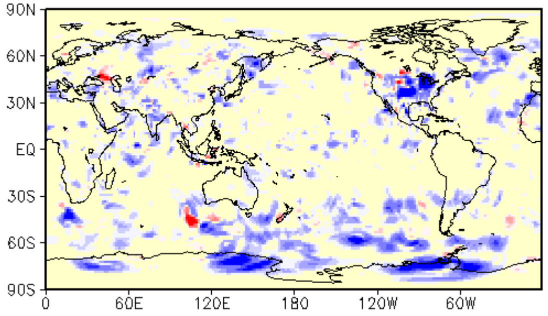


$\Delta e^2_{EFSO}, j$

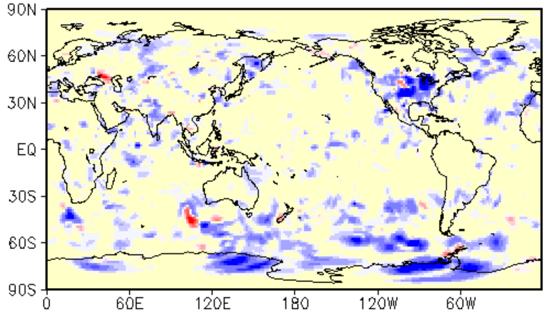
32 mem



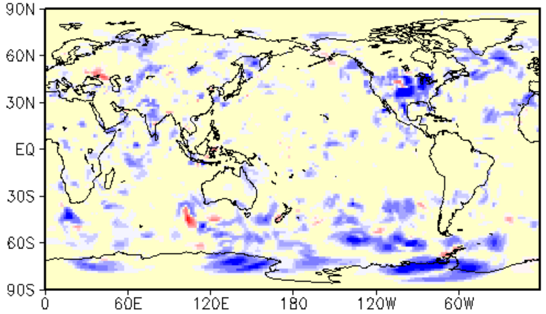
64 mem



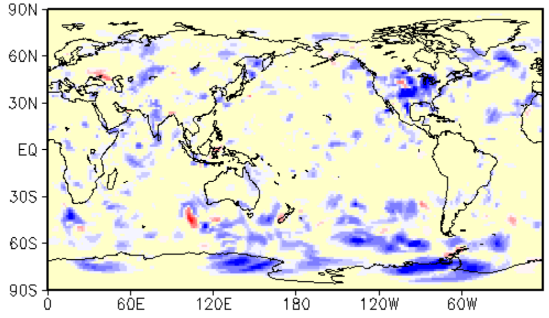
128 mem



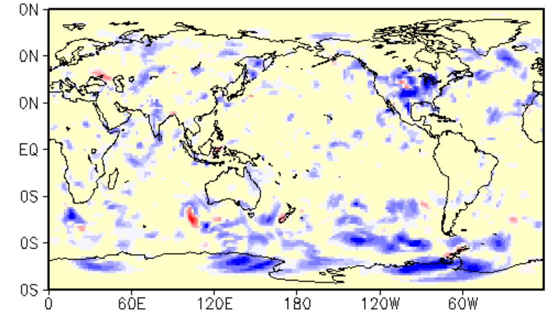
256 mem



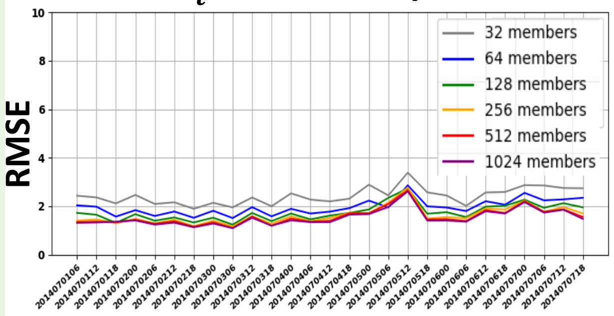
512 mem

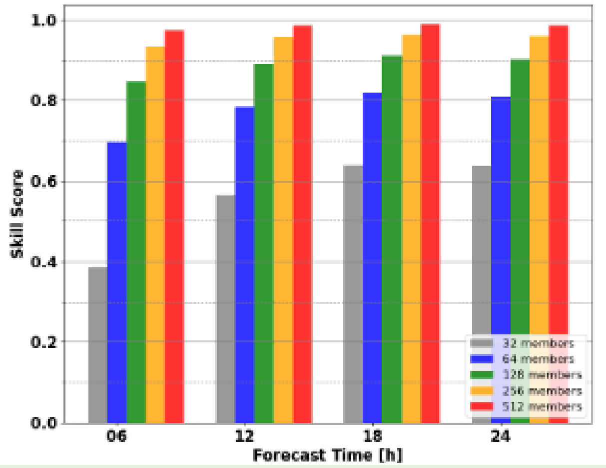


1024 mem



x_t^{ref} = **Self-Analysis**





Correlation Coefficient		
0.7552	0.8030	0.8432
0.8744	0.8769	0.8831

More Results on Fraction of Beneficial Observations (FBO)

FBO = # beneficial / (# beneficial + # detrimental)

(this definition excludes neutral obs)

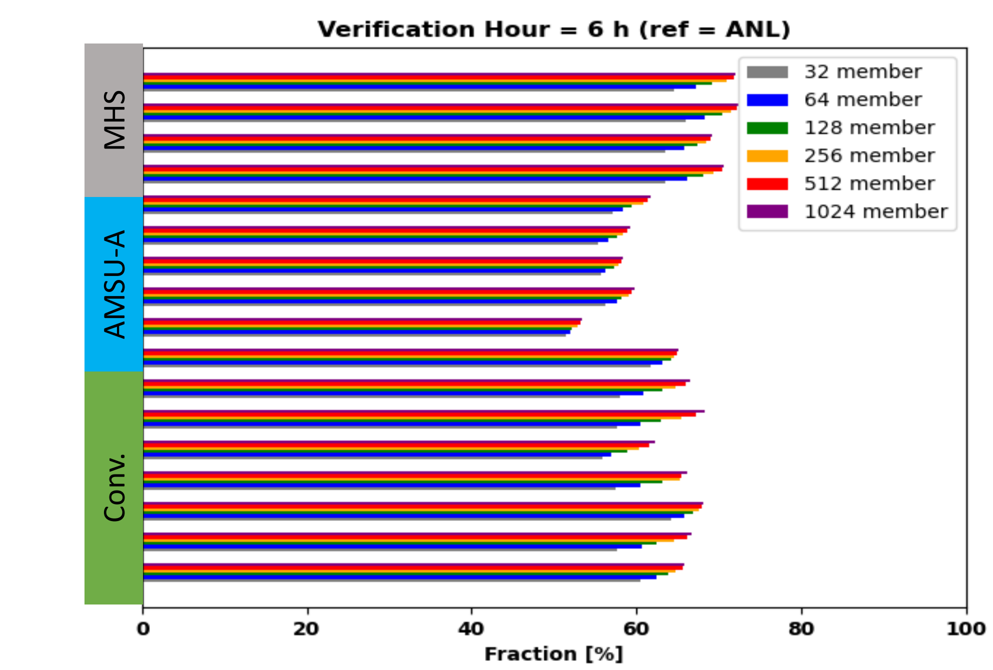
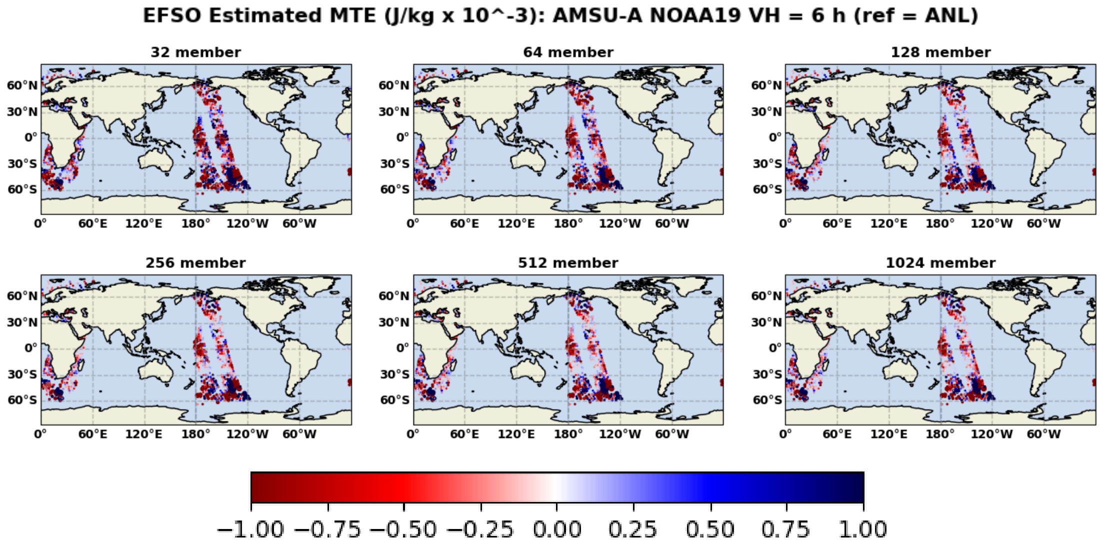


TABLE 3 The time-mean fraction of beneficial observations (%) in CTRL averaged from 4 to 31 July 2014

Kotsuki et al. (2019)

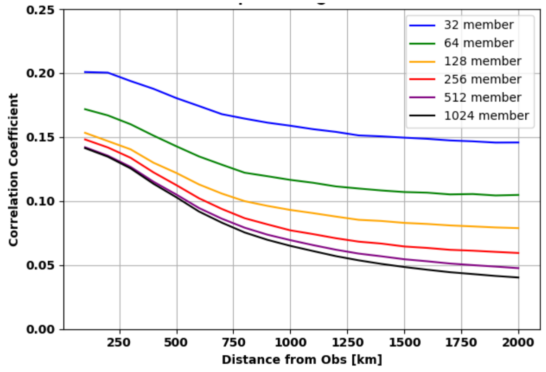
	FT (h)	Verification reference			
		CTRL	TWIN-EXP	ERA-Interim	AMSU-A
Fraction of beneficial observations (%)	06	58.9	54.4	55.4	51.9
	12	56.1	54.0	54.3	52.2

- Larger ensemble size leads to increased FBO



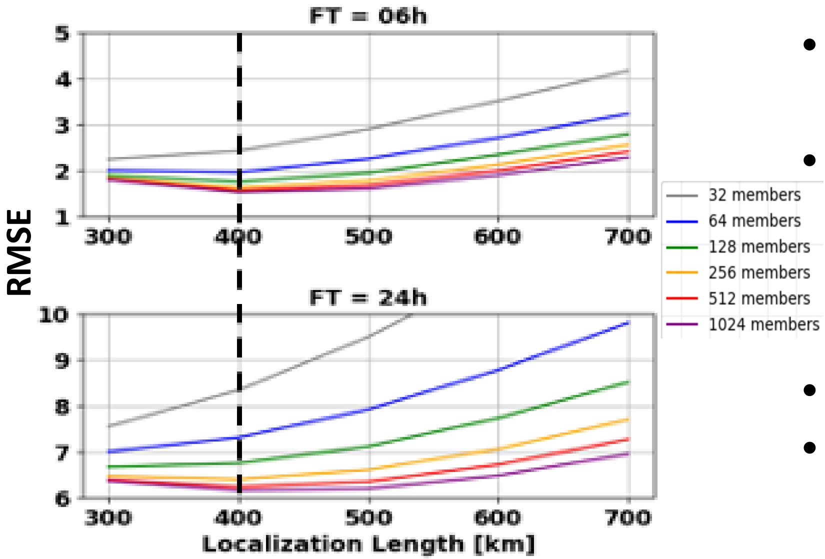
beneficial <--- no impact ---> detrimental

- As # of ensemble members increases, more obs changes from positive (detrimental) to neutral (no impact): Less detrimental observations, larger FBO.

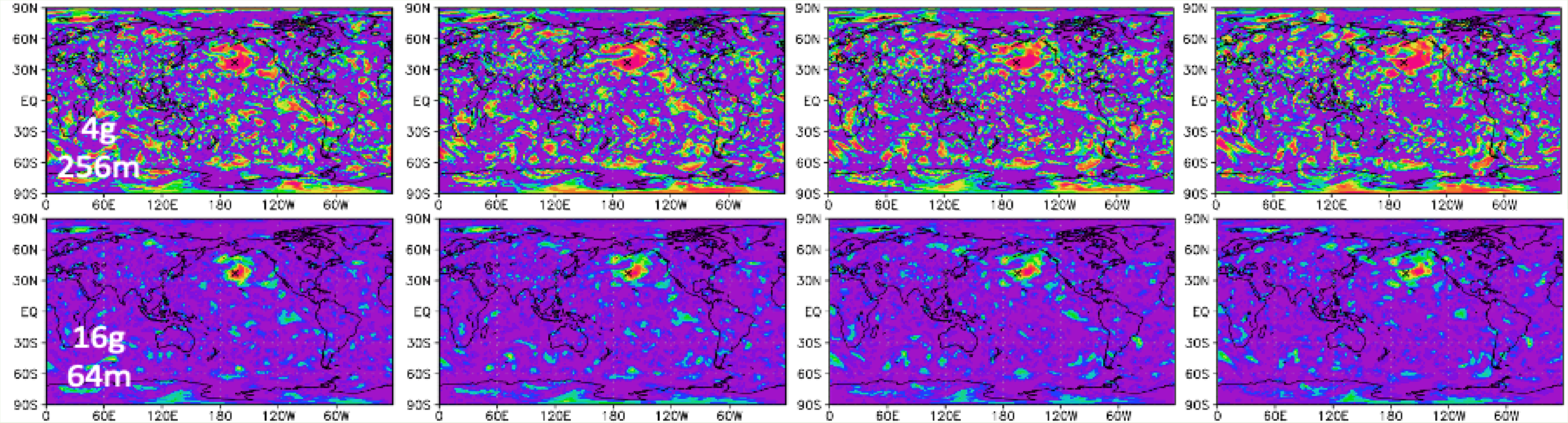


Averaged absolute corr. coef (normalied $\boldsymbol{Y}_0^a \boldsymbol{X}_{t|0}^{f\ T}$) between AMSU-A NOAA19 and Temperature @ 500 hPa

More Results on Localization & Summary



- When estimating EFSO accuracy in the form of difference between globally summed values, it suggests little sensitivity and leads to counter-intuitive result.
- Considering spatial variation of Δe^2, three metrics are used: RMSE, Correlation coefficient, and Relative skill score:
  - Confirm sensitivity: **larger ensemble has smaller RMSE and higher correlation**
  - Ensemble of **128 or more can capture >80 % of 1024 ensemble performance**
- We also found that **using larger ensemble size in EFSO leads to larger FBO**
- To address the evolution of localization, **simplying increasing localization length does not lead improved EFSO**



Applying a dynamical localization function based on Regression Confidence Factor (RCF) to EFSO is currently under investigation.

Thanks for your attention!