Time-Expanded Sampling (TES) For Ensemble-based Data Assimilation Applied To Conventional And Satellite Observations

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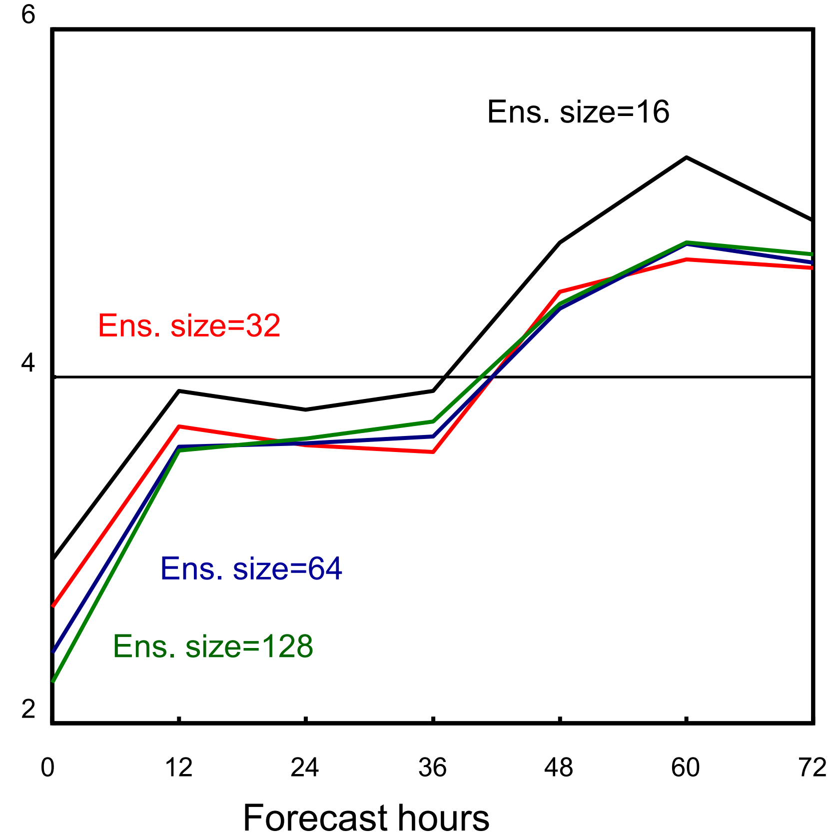
Time-Expanded Sampling (TES) For Ensemble Nowcasting

- Ensemble size plays a critical role in the performance of ensemble-based data assimilation systems and forecasts.
- For some short- or near-term applications such as nowcasting, the use of ensemble-based analyses and forecasts can present a major challenge due to the need of a sufficient ensemble size for a reasonable performance.
- TES provides an approach that can enhance the representation of the probability density function of the model state without increasing the ensemble size.

RMS Error of Wind Forecasts
(*Zhao et al. 2013*)



Zhao., Q., F. Zhang, T. Holt, C. Bishop, and Q. Xu, 2013: Development of a mesoscale ensemble data assimilation system at the Naval Research Laboratory. Wea. And Forecasting, ***28****, 1322-1336.*

Time-Expanded Sampling (TES) Method (*Xu et al. 2008*)

- The model-predicted weather systems usually develop either faster or slower than the observed.
- Hypotheses:
  1) The predicted field at a time level before or after the analysis time may better represent the true field than the one at the analysis time.
  2) By selecting more than one time levels of data from each ensemble member, one may enlarge the coverage of uncertainties in model forecast errors (especially the phase errors) in the estimation of the flow-dependent background error covariance.

Ensemble of state vectors of N members

$$\boldsymbol{E}_t^N = [\boldsymbol{w}_t^1, \boldsymbol{w}_t^2, ..., \boldsymbol{w}_t^N]$$

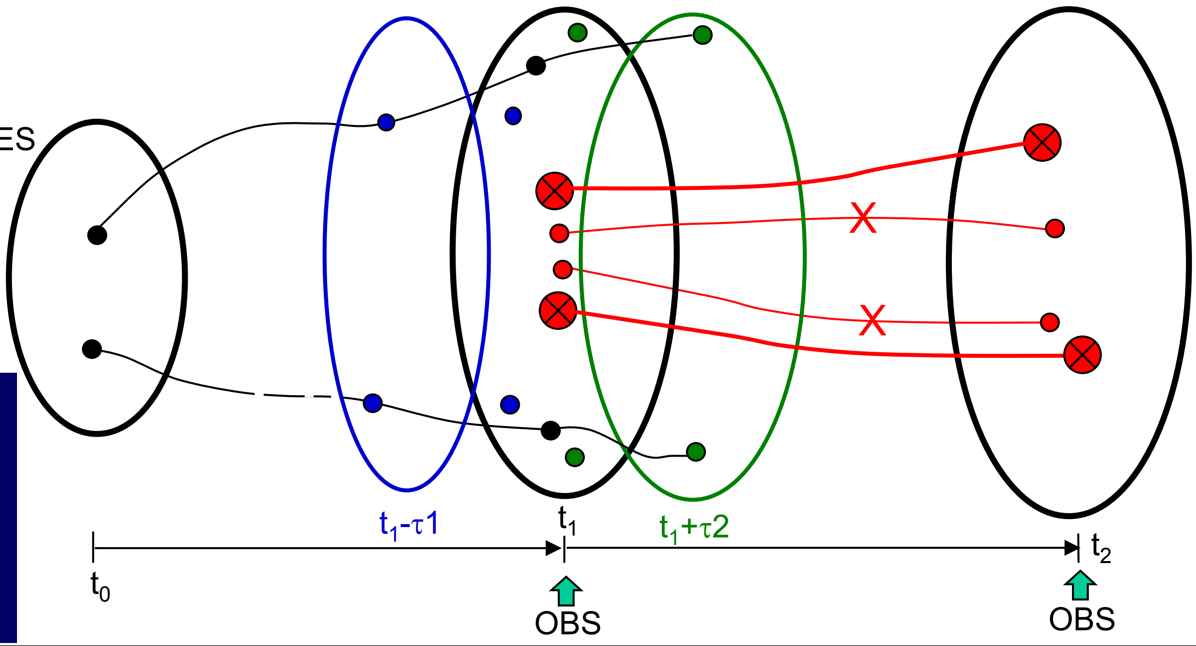
Ensemble of state vectors of N members with TES

$$\boldsymbol{E}_t^{TES} = [\boldsymbol{w}_{t-\tau}^1, \boldsymbol{w}_t^1, \boldsymbol{w}_{t+\tau}^1, ..., \boldsymbol{w}_{t-\tau}^N, \boldsymbol{w}_t^N, \boldsymbol{w}_{t+\tau}^N]$$

Ensemble of state vectors of 3N members

$$\boldsymbol{E}_t^{3N} = [\boldsymbol{w}_t^1, \boldsymbol{w}_t^2, ..., \boldsymbol{w}_t^{3N}]$$

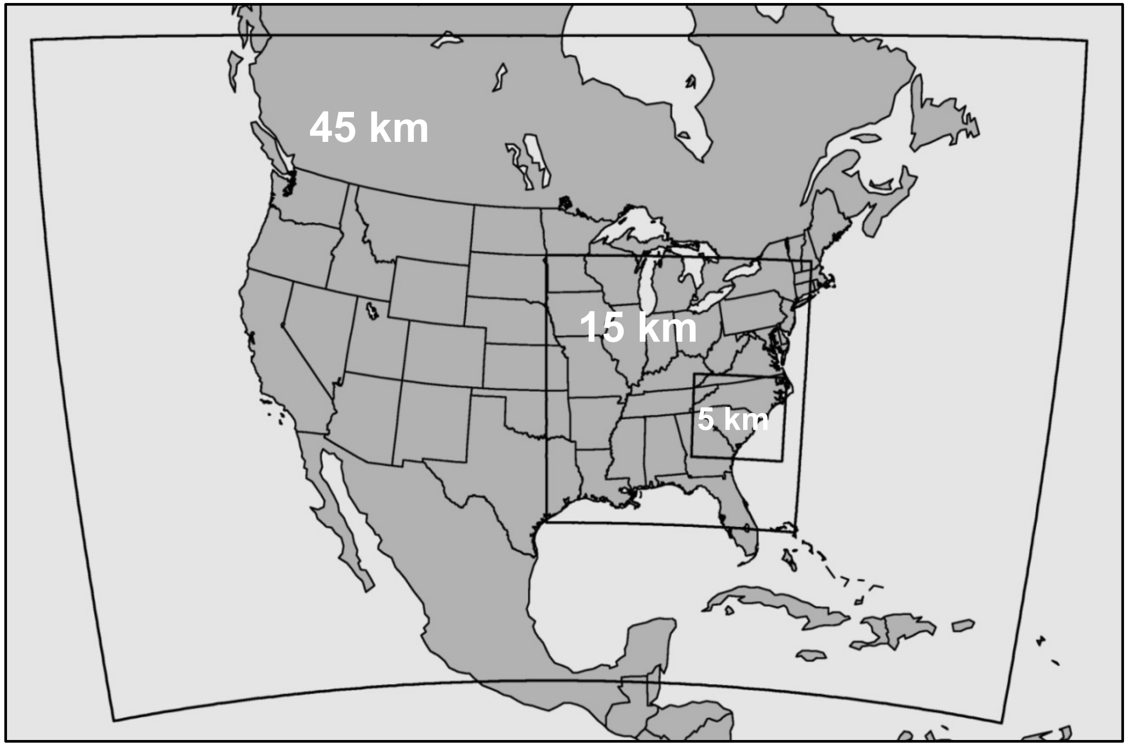
- E^{TES} has large uncertainty coverage than E^N since $w_{t-\tau}$ and $w_{t+\tau}$ have extra information about the model fcst errors
- E^{3N} is better than E^{TES} due to the independence between $w_{t-\tau}$ & w_t and also between $w_{t+\tau}$ & w_t in E^{TES}



Xu., Q., L. Wei, H. Lu, C. Qiu, and Q. Zhao, 2008: Time-expanded sampling for ensemble-based filters: Assimilation experiments with a shallow-water equation model. J. Geophys. Res., ***113****, D02114, doi:10.1029/2007JD008624.*

Test of TES with COAMPS® and EnKF

- Three nested grids were used to test the TES with different grid resolutions.
- The test was conducted for a period of five days (00Z June 23 – 12Z June 27, 2005)
- Conventional and satellite data were assimilated every 12 hours using EnKF followed by 72-hour ensemble forecasts
- Three experiments were conducted:
  - Ens10 and Ens10-TES continued for the 5-day period
  - Ens30 was run for the 12Z 23 June case only
  - In Ens10-TES, τ =3 hours



Three experiments:

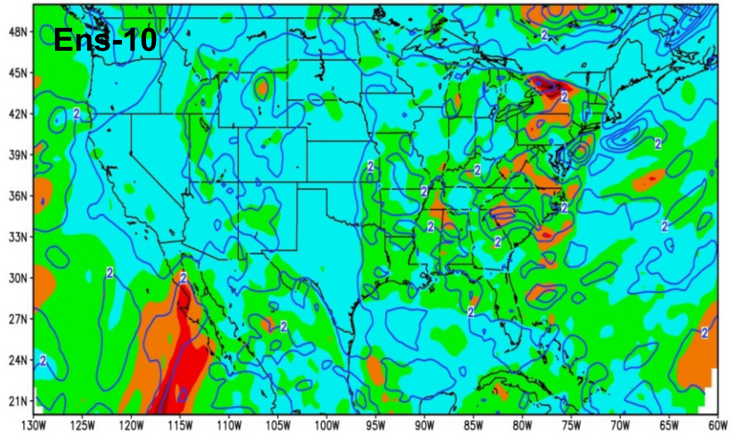
Ens10 : 10 ensemble members

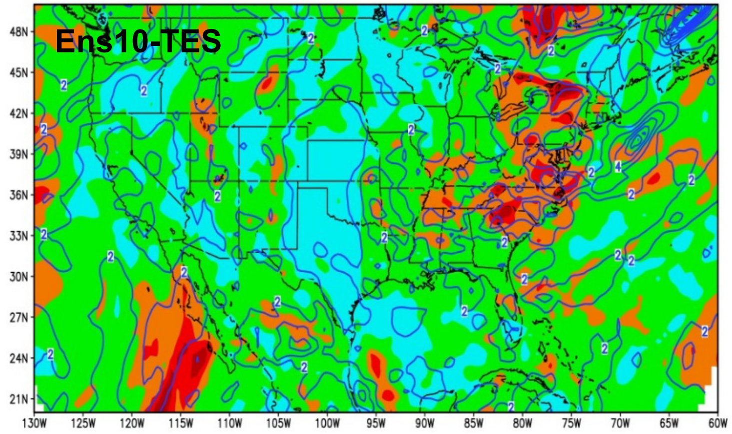
Ens10-TES: 10 ensemble members with TES technique

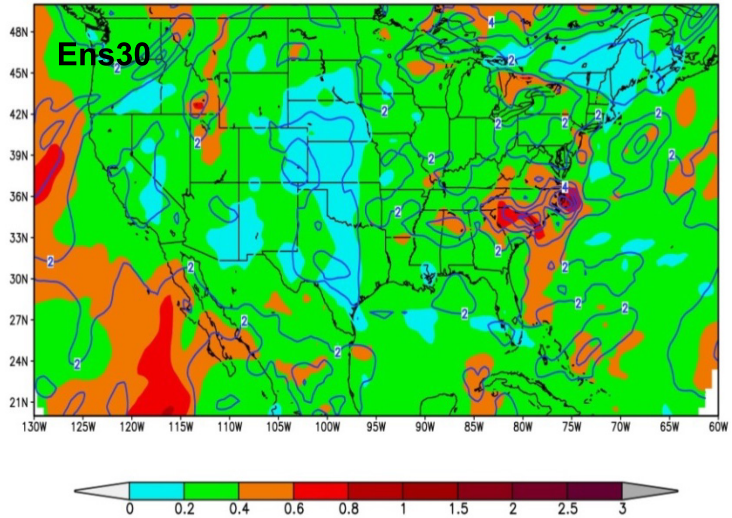
Ens30: 30 ensemble members

Ensemble Spreads at Z=7800 m

(Colored areas: θ, degree; Contours: wind speed, ms^{-1})

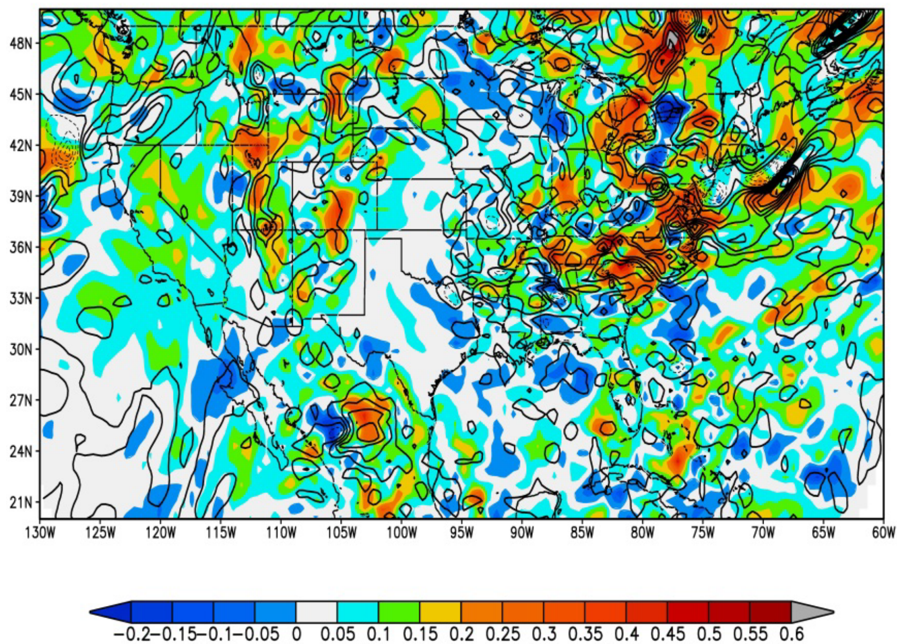




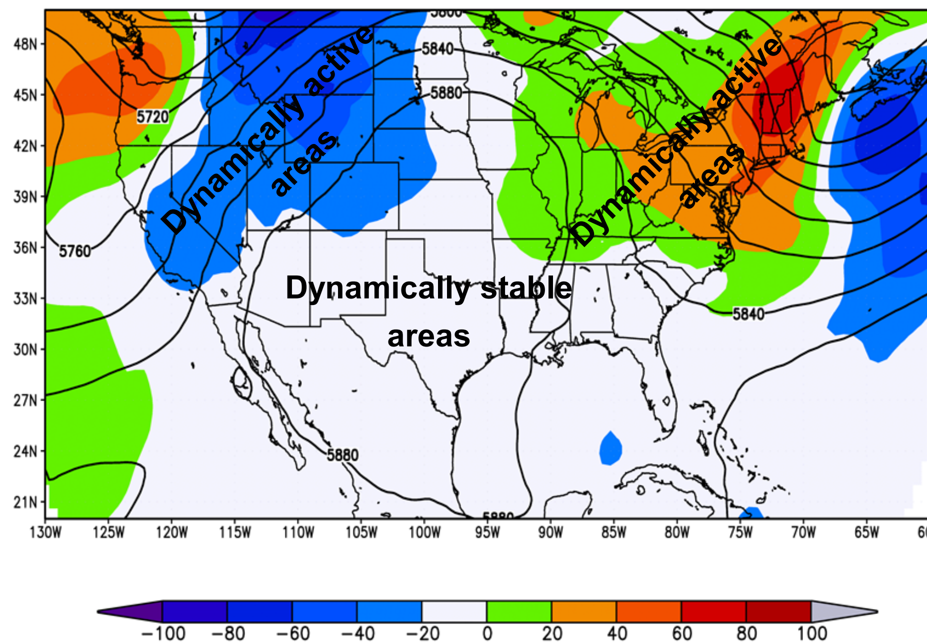


- The major areas of large ensemble spread are located over the eastern US and the coastal areas for all three experiments.
- Compared to Ens30, the ensemble spreads from Ens10 are smaller.
- Small ensemble spread caused by the small ensemble size in Ens10 has been substantially increased by Ens10-TES.

Ensemble Spread Differences (Ens10-TES – Ens10)
(Colored areas: θ, degree; Contours: wind speed, ms^{-1})



500 hPa Geopotential Height (Φ_{500})
Analysis (contours, meter) **&**
12-hour changes in Φ_{500} (colored areas, meter)



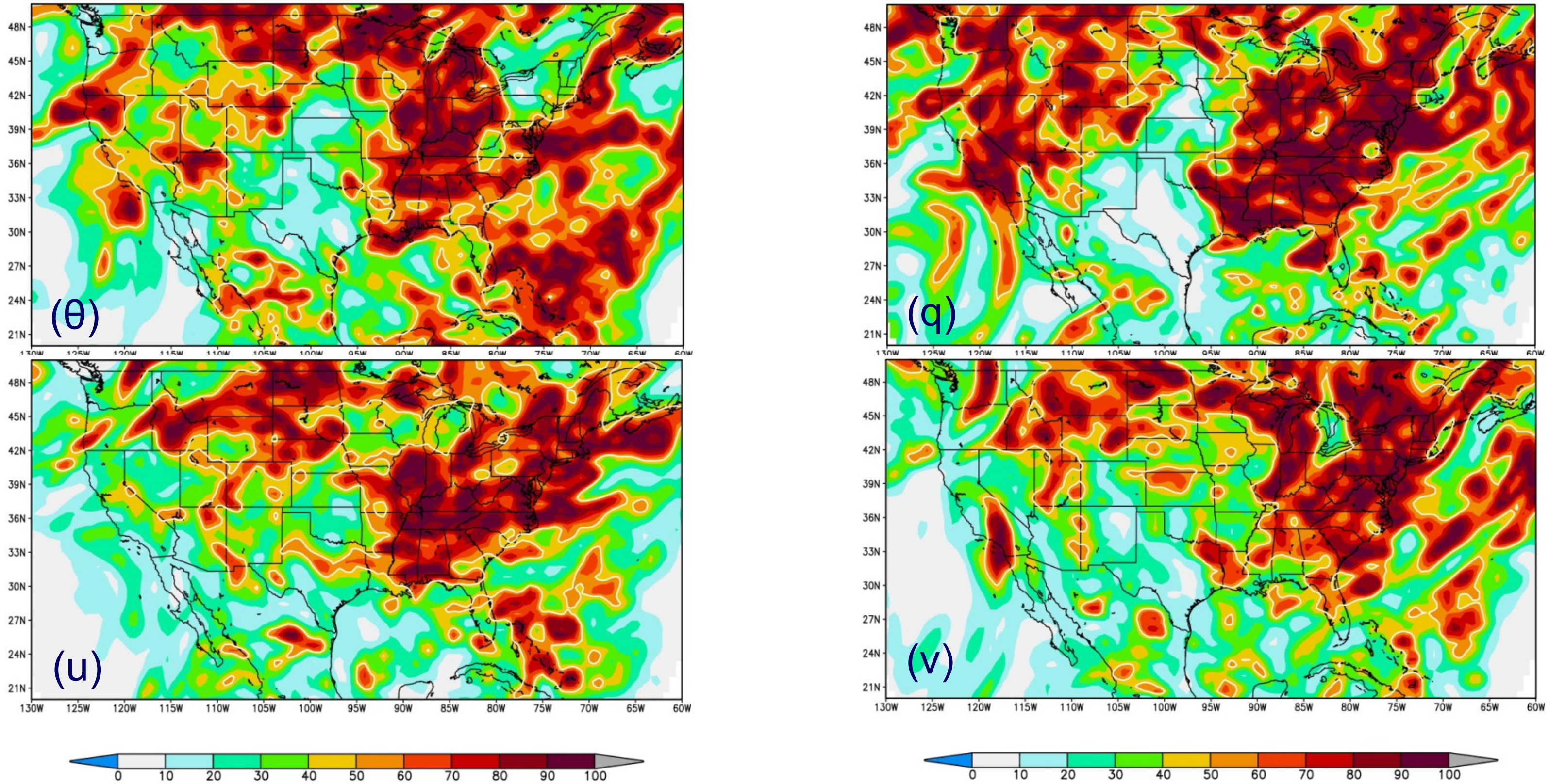
- The ensemble spread increases by TES are mainly located in dynamically active areas.
- The increased ensemble spread by TES is helpful in improving the representation of background error variance used in the data assimilation in storm-active areas especially when the actual ensemble size is small.

Non-correlation (percent) between the forecast hours t=9 & t=12 (the analysis time) of the previous ensemble forecasts

(The white contour outlines the areas with non-correlation larger than 50 percent)

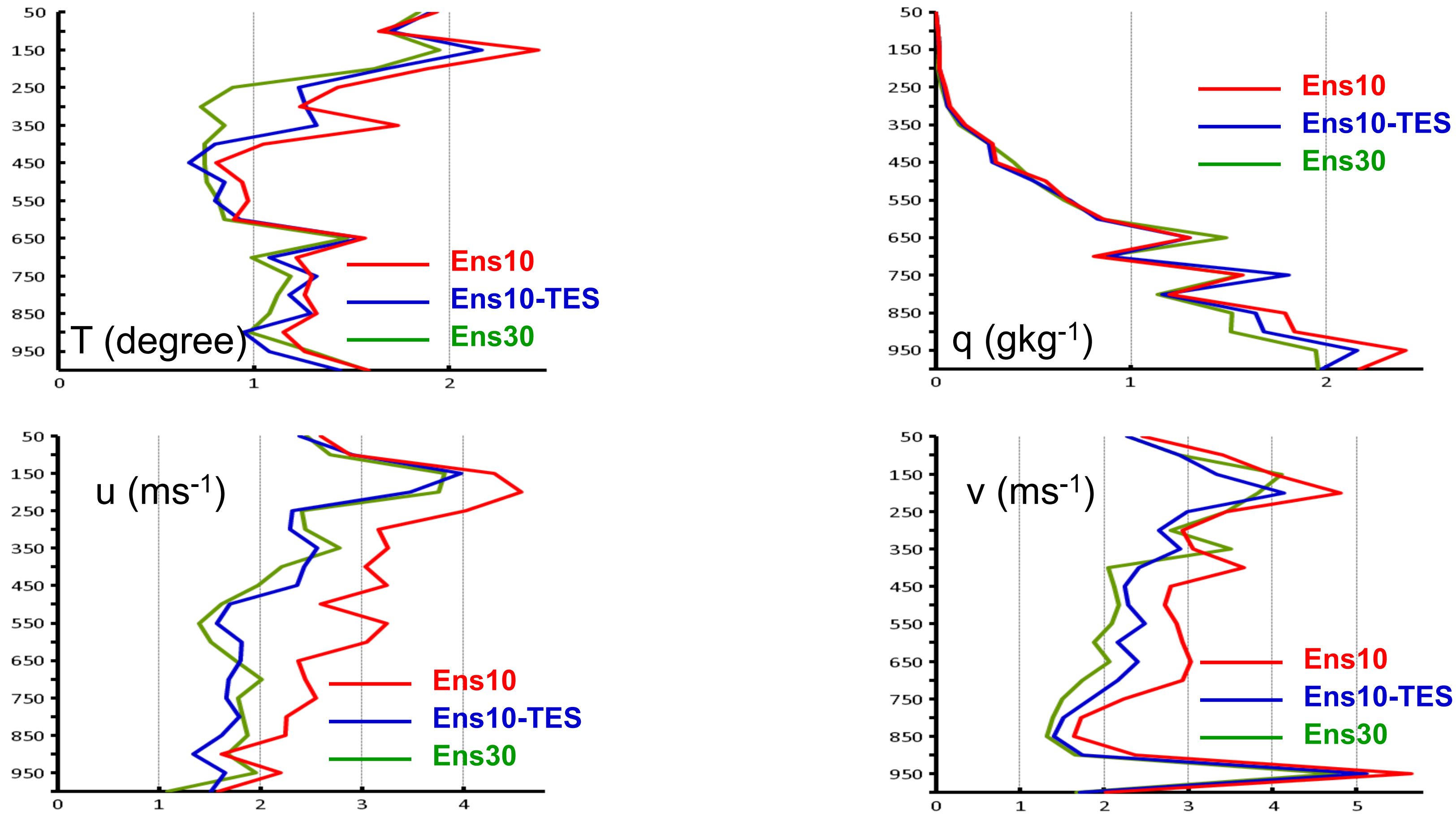
Non-correlation: $\rho_k' = 1.0 - |\rho_k|$

$$\rho_k = \frac{\frac{1}{N-1}\sum_{i=1}^{N}(x_{1ik}-\overline{x_{1k}})(x_{2ik}-\overline{x_{2k}})}{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_{1ik}-\overline{x_{1k}})^2}\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_{2ik}-\overline{x_{2k}})^2}}$$



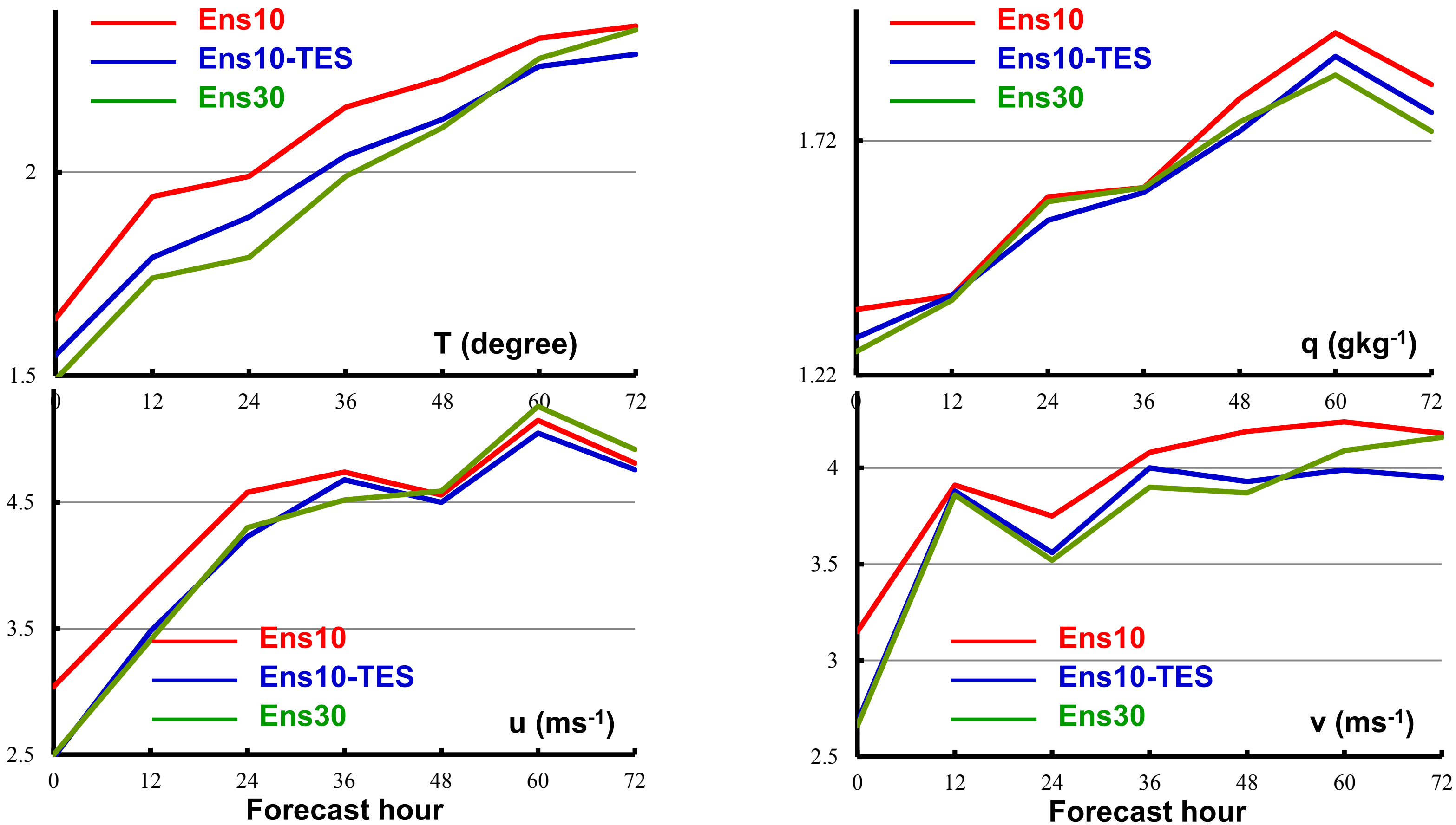
Root-Mean-Square (RMS) Errors of The EnKF Analyses Verified Against RAOB Data

(for 45-km grid, verified at 12Z 23 June 2005)



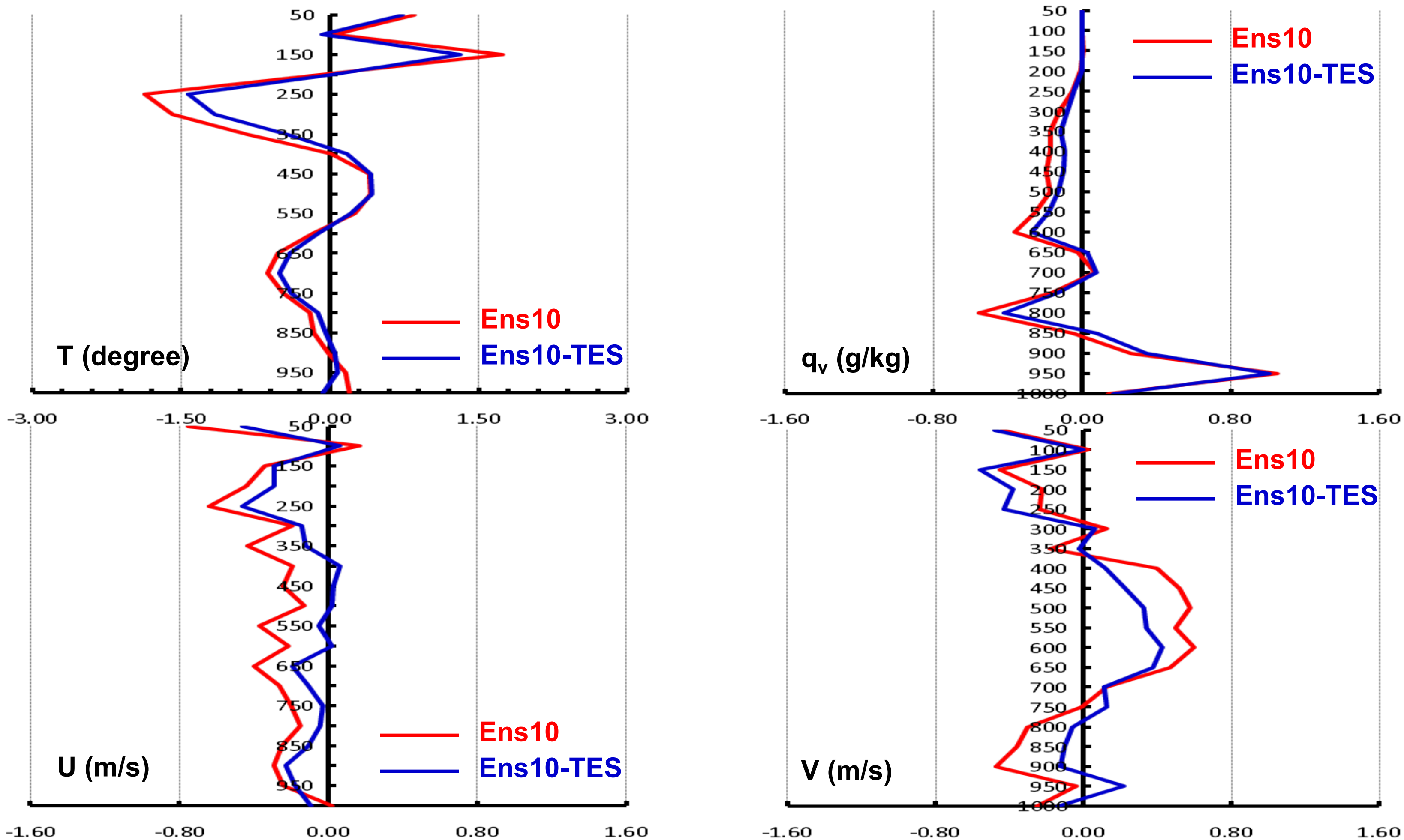
RMS Errors of The Ensemble Forecasts Verified Against RAOB Data

(for 45-km grid, verified at 12Z 23 June 2005)



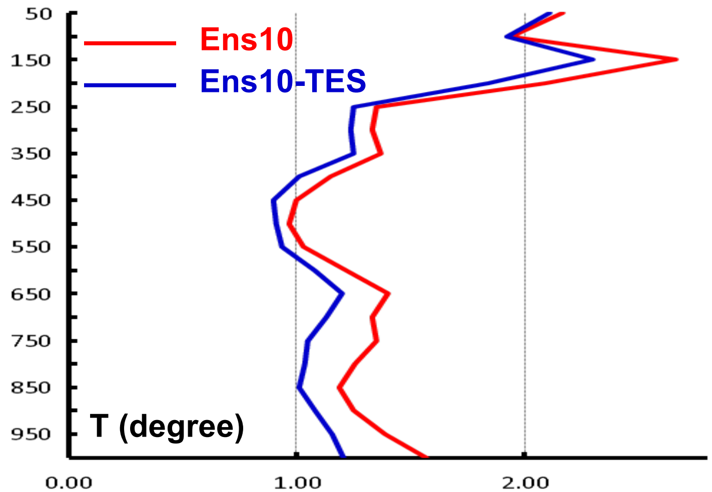
5-Day Averaged BIAS of The EnKF Analyses

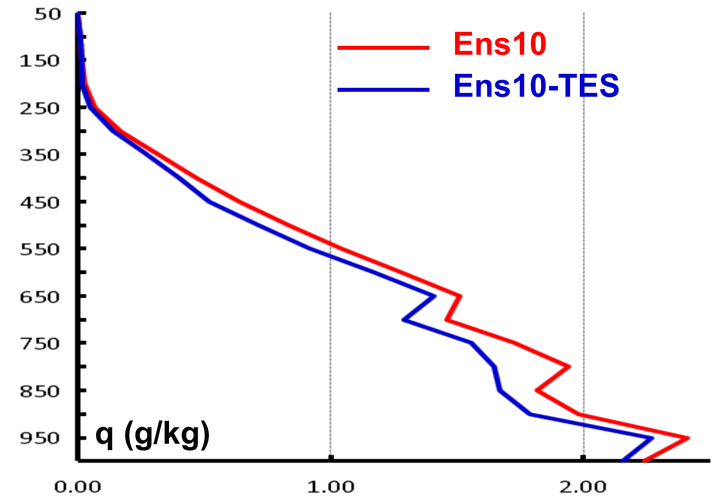
(for 45-km grid, 12Z 23 June 2005 – 12Z 27 June 2005 cycled every 12H)

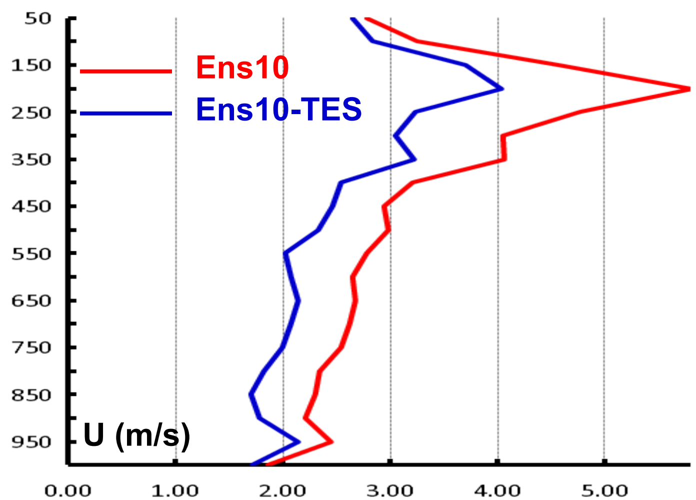


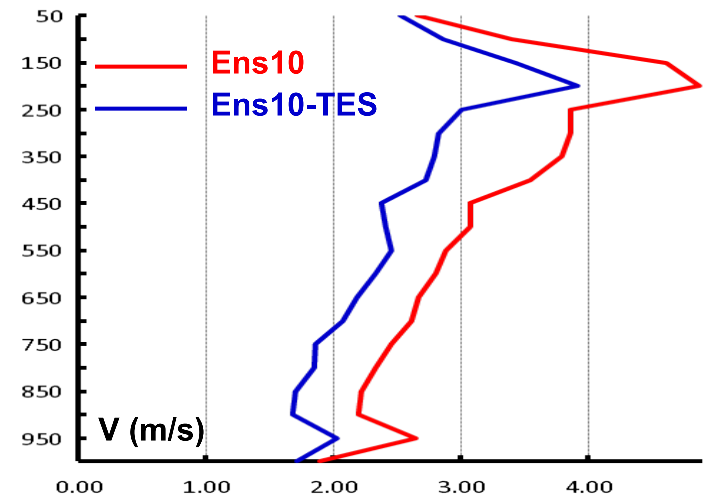
5-Day Average of RMS Errors of The EnKF Analyses

(for 45-km grid, 12Z 23 June 2005 – 12Z 27 June 2005 cycled every 12H)



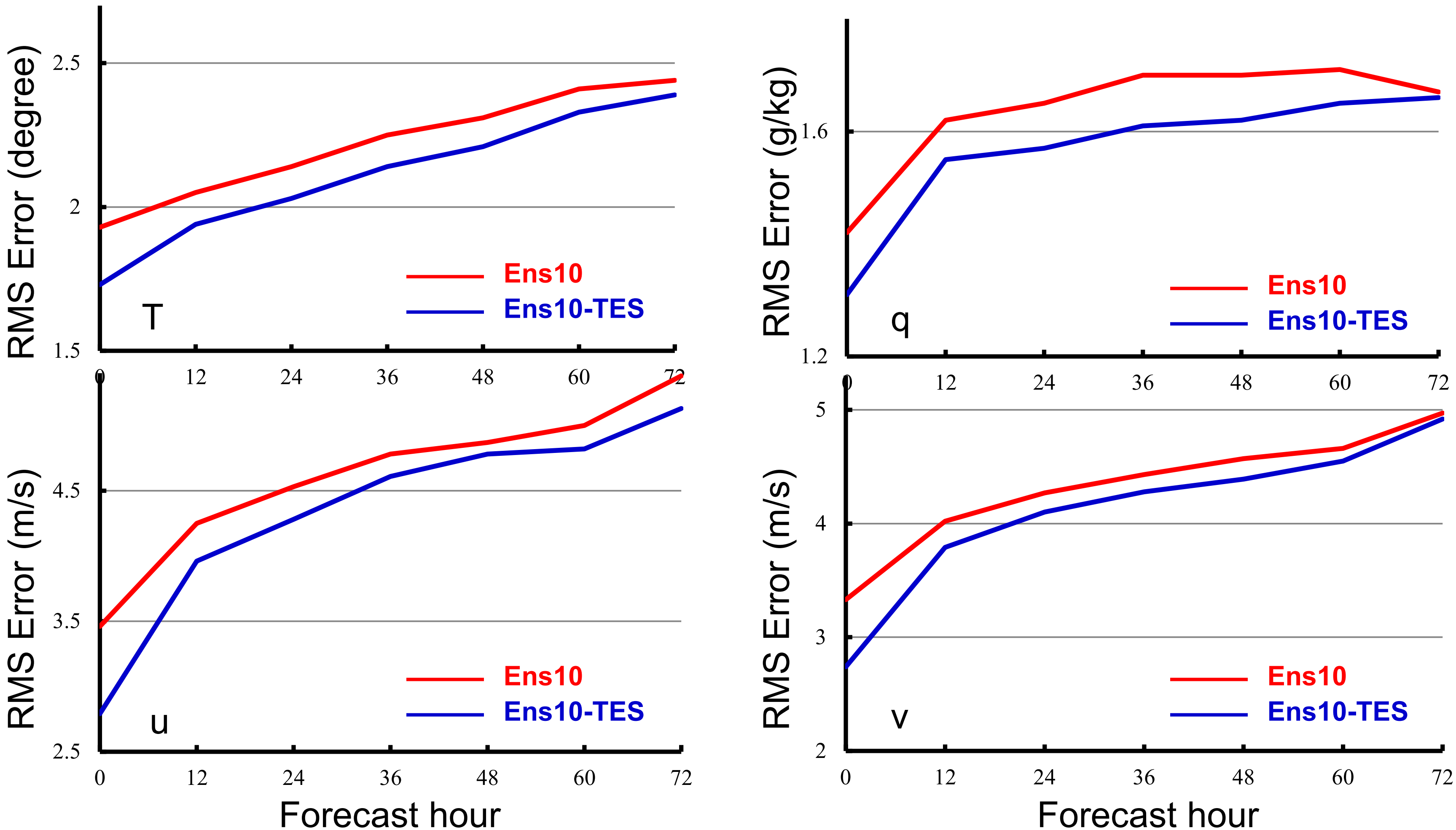






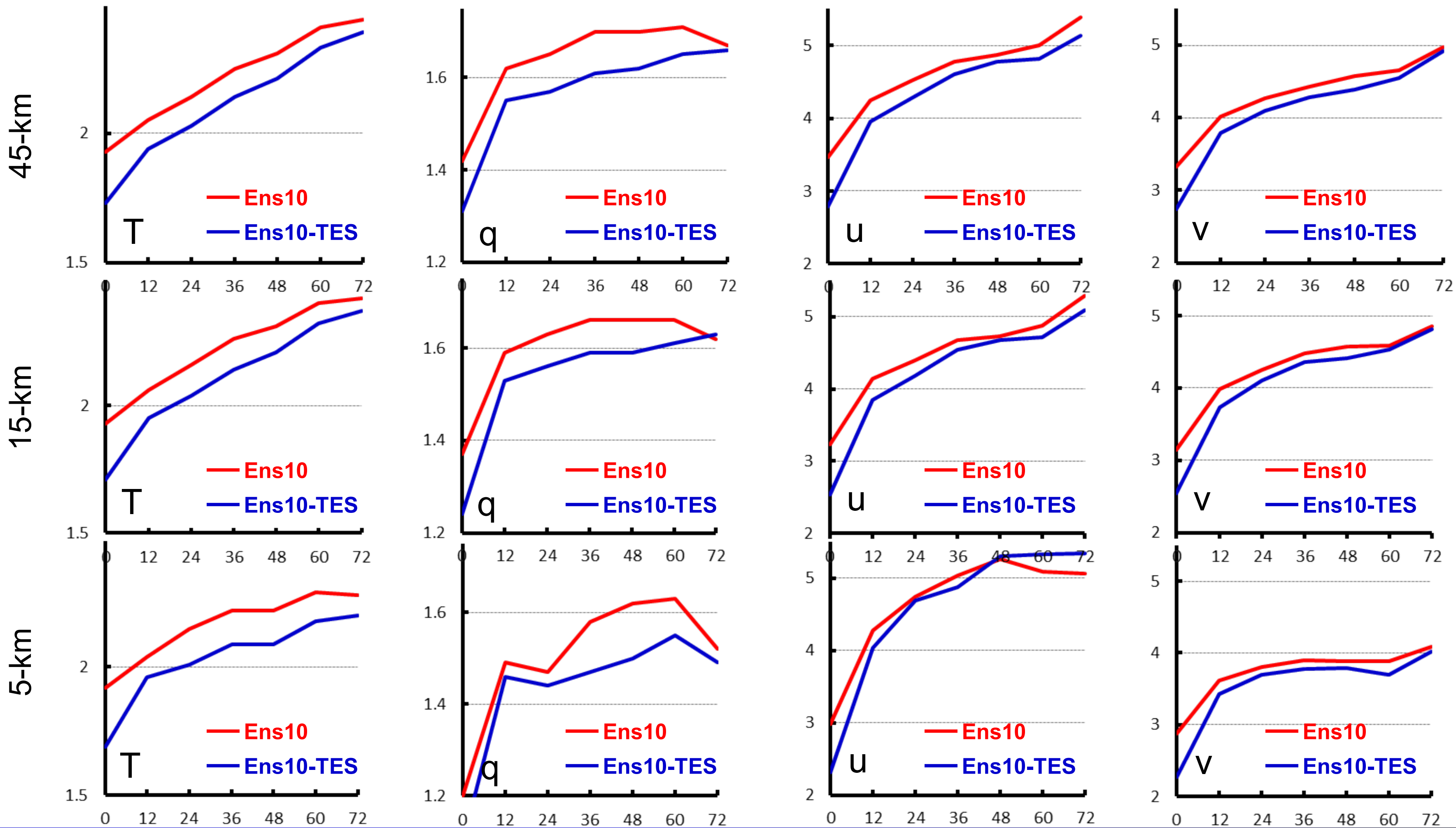
5-Day Average of RMS Errors of the Ensemble Forecasts

(For 45-km grid, 00Z 23 June 2005 – 12Z 27 June 2005 Cycled Every 12 H)



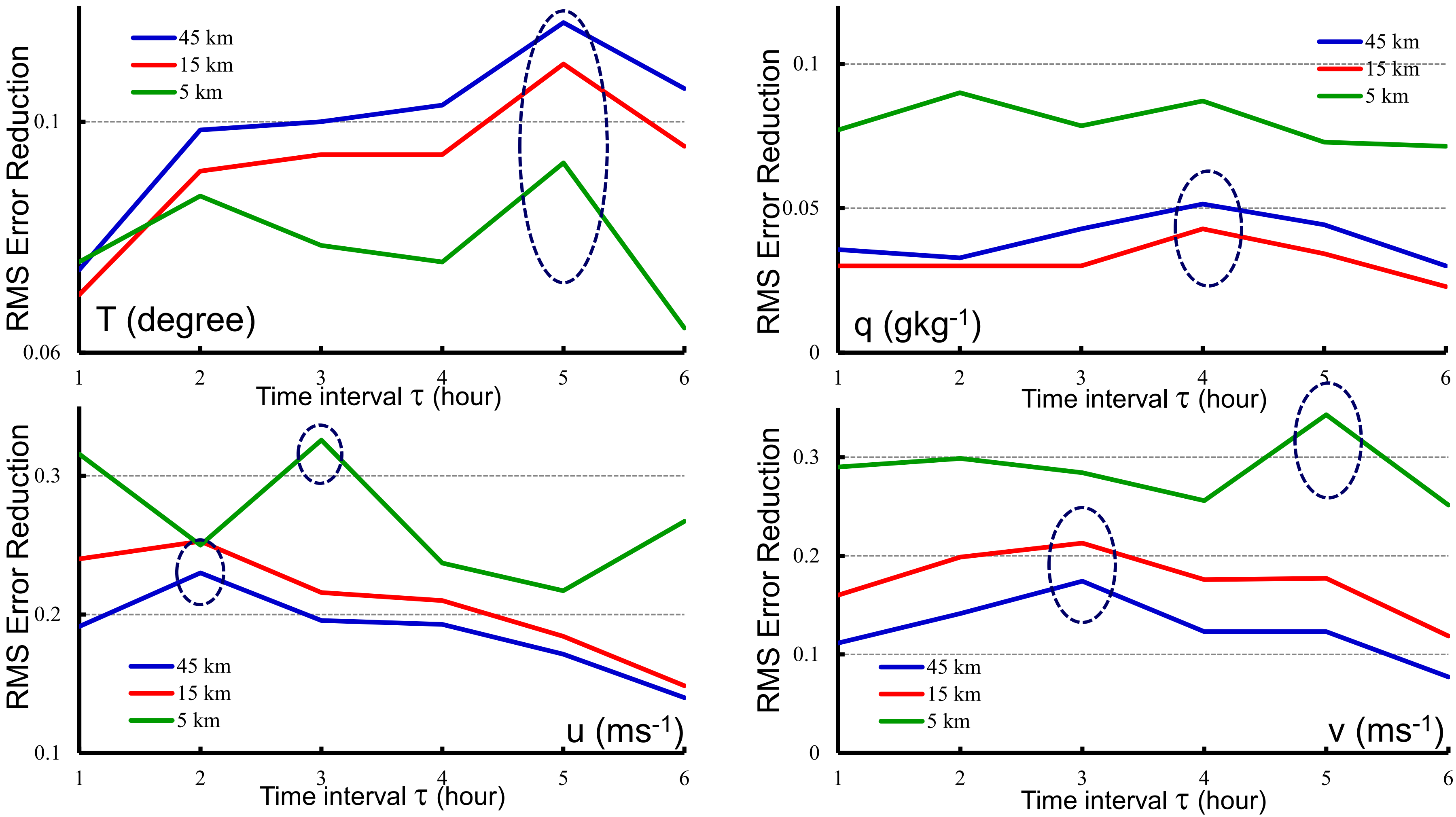
5-Day Average of RMS Errors of The Ensemble Forecasts

(For 45-km, 15-km & 5-km grids, 00Z 23 June 2005 – 12Z 27 June 2005 Cycled every 12 H)



Impact of Time-Sampling Interval τ on TES

RMS Error Reduction = RMS Errors (Ens10) − RMS Errors (Ens10-TES)
(Averaged Over the 10 cycled Forecasts)



Summary

- TES shows the ability to significantly improve ensemble analyses and forecasts when the ensemble size is restricted due to limited computational resources.
- In dynamically active areas, the correlation among the ensemble forecasts at different time levels is relatively small and TES can improve the representation of the uncertainties in model forecast errors in these areas.
- Continuously cycled forecasts further enhance the TES impact.
- Model grid solution does not show noticeable impact on TES performance.
- The selection of τ can impact the TES performance, but the impact is not very sensitive to the variation of τ (between 1 and 6 hours). Thus, with τ selected between 1 and 6 hours, TES can always show a positive impact.

Thank you

Questions?