A Comparison of Impacts of Radiosonde and AMSU Radiance Observations In GSI-based Hybrid and 3DVar Data Assimilation Systems for NCEP GFS

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INTRODUCTION

- The impact of observations can be dependent on many factors in a data assimilation (DA) system such as data quality control, preprocessing, skill of the model and the DA algorithm

- A three dimensional variational (3DVar)-based ensemble-variational (3DEnsVar) hybrid DA system was recently developed based on the Gridpoint Statistical Interpolation (GSI) DA system (e.g., Wang 2010, Wang et al., 2013)

- In May 2012, the National Centers for Environmental Prediction (NCEP) operational Global Data Assimilation System (GDAS) has transitioned from the 3DVar to the 3DEnsVar DA system

- The present study focuses on comparing the impacts of observations assimilated by the 3DVar and the 3DEnsVar

- Earlier studies have shown that the Radiosonde and Advanced Microwave Sounding Unit (AMSU) observations provide largest impact in the forecast quality in various operational forecast systems (e.g., Galero and Zhu, 2009; Kelly et al., 2004; Zapotocny et al., 2007)

- Considering the significance of Radiosonde and AMSU observations, the present study quantifies the impact of these two data sets in the 3DVar and 3DEnsVar DA systems using the operational NCEP Global Forecast System through Observing System Experiment (OSE) (Kutty and Wang, 2013)
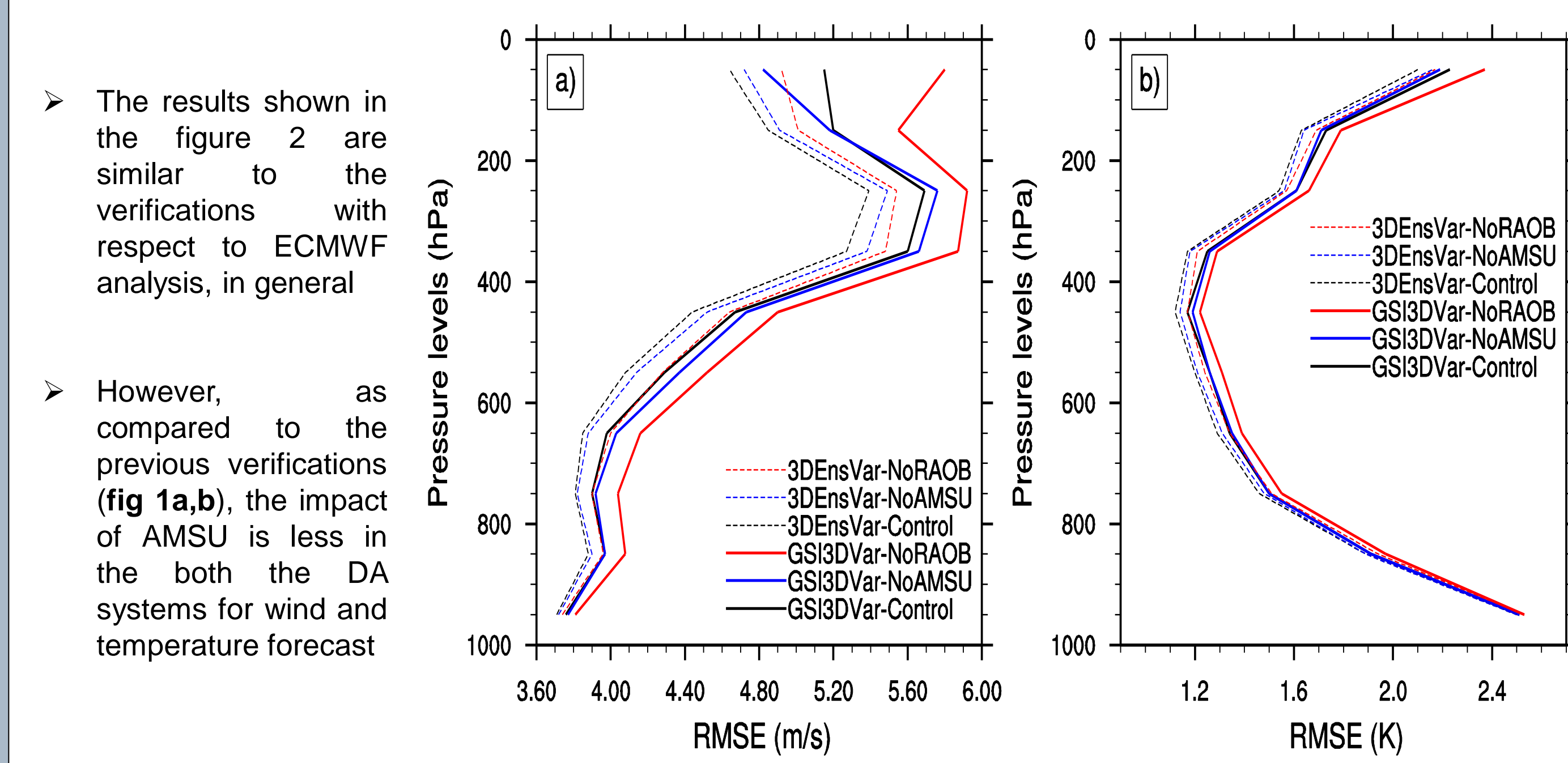
EXPERIMENTAL DESIGN

- **Model:** NCEP Global Forecast System (GFS) with resolution T190L64

- **Test period:** 15 December 2009 to 31 January 2010

- **Observations Assimilated:** The conventional and satellite data from operational NCEP GDAS early cycle

- **Six experiments for OSE**

(i) GSI with all observations **(GSI3DVar)**

(ii) GSI denied Radiosonde **(GSI3DVar-NoRAOB)**

(iii) GSI denied AMSU **(GSI3DVar-NoAMSU)**

(iv) Hybrid with all observations **(3DEnsVar)**

(v) Hybrid denied Radiosonde **(3DEnsVar-NoRAOB)**

(vi) Hybrid denied AMSU **(3DEnsVar-NoAMSU)**

RESULTS
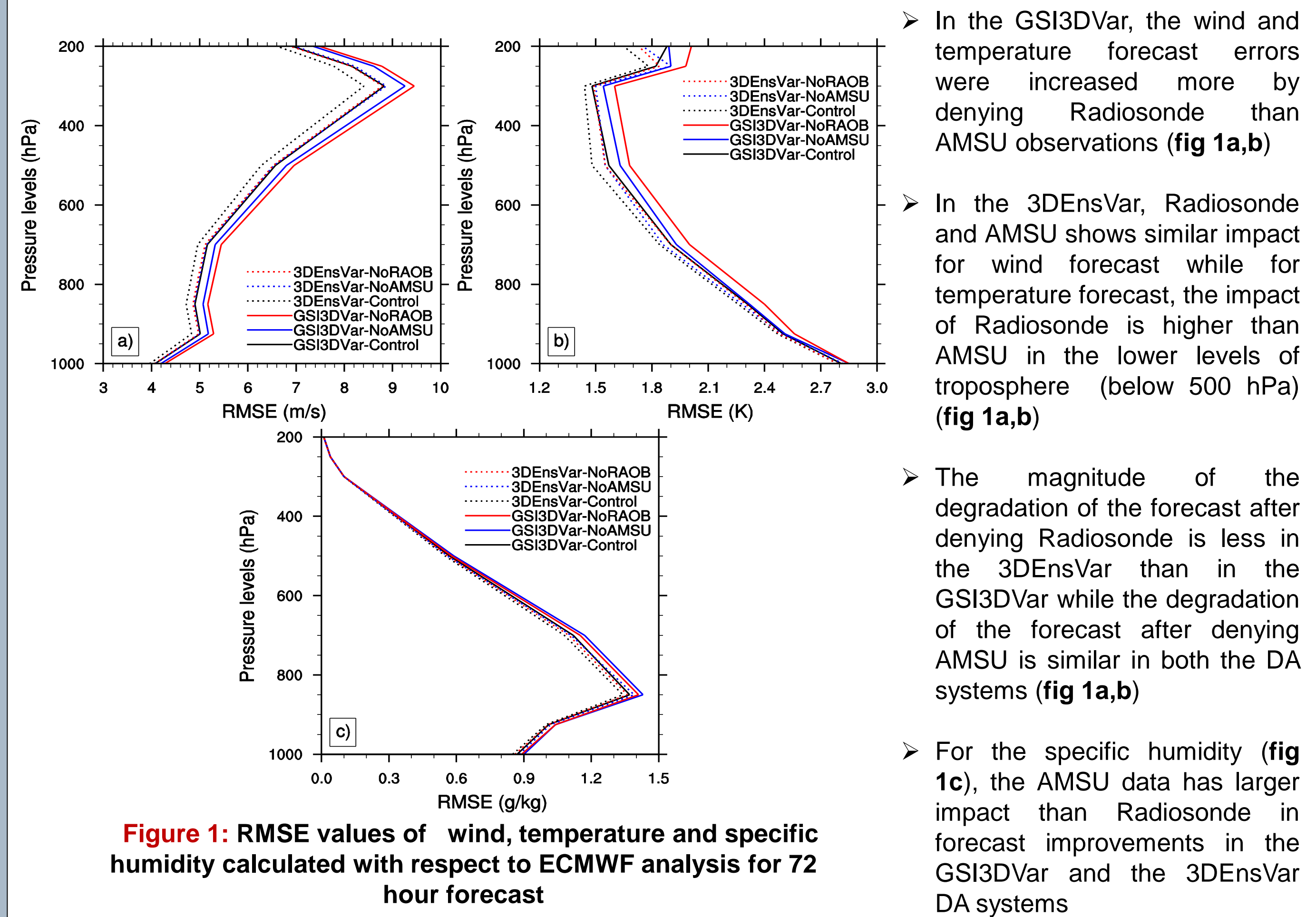
- In the GSI3DVar, the wind and temperature forecast errors were increased more by denying Radiosonde than AMSU observations **(fig 1a,b)**

- In the 3DEnsVar, Radiosonde and AMSU shows similar impact for wind forecast while for temperature forecast, the impact of Radiosonde is higher than AMSU in the lower levels of troposphere (below 500 hPa) **(fig 1a,b)**

- The magnitude of the degradation of the forecast after denying Radiosonde is less in the 3DEnsVar than in the GSI3DVar while the degradation of the forecast after denying AMSU is similar in both the DA systems **(fig 1a,b)**

- For the specific humidity **(fig 1c)**, the AMSU data has larger impact than Radiosonde in forecast improvements in the GSI3DVar and the 3DEnsVar DA systems
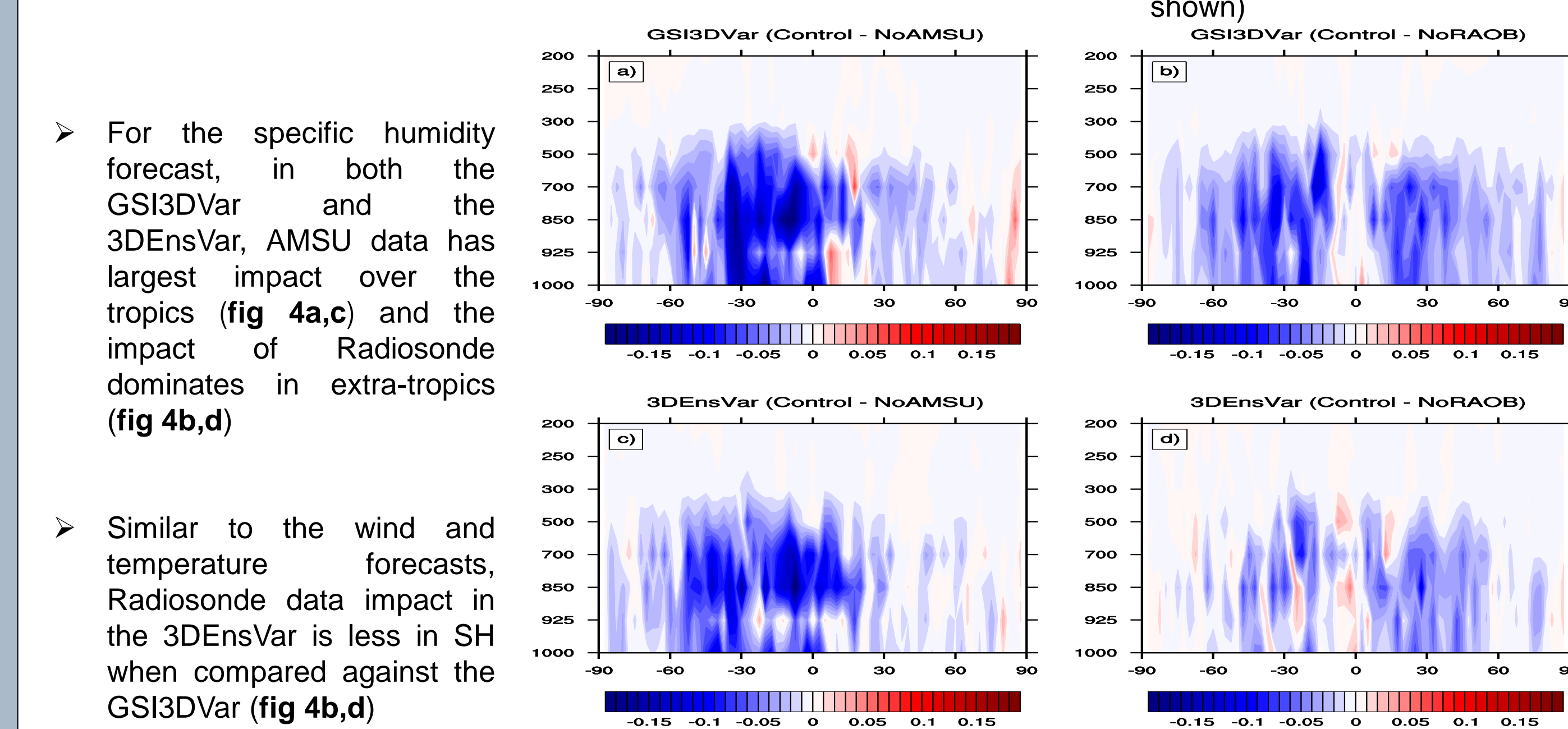
Figure 1: RMSE values of wind, temperature and specific humidity calculated with respect to ECMWF analysis for 72 hour forecast
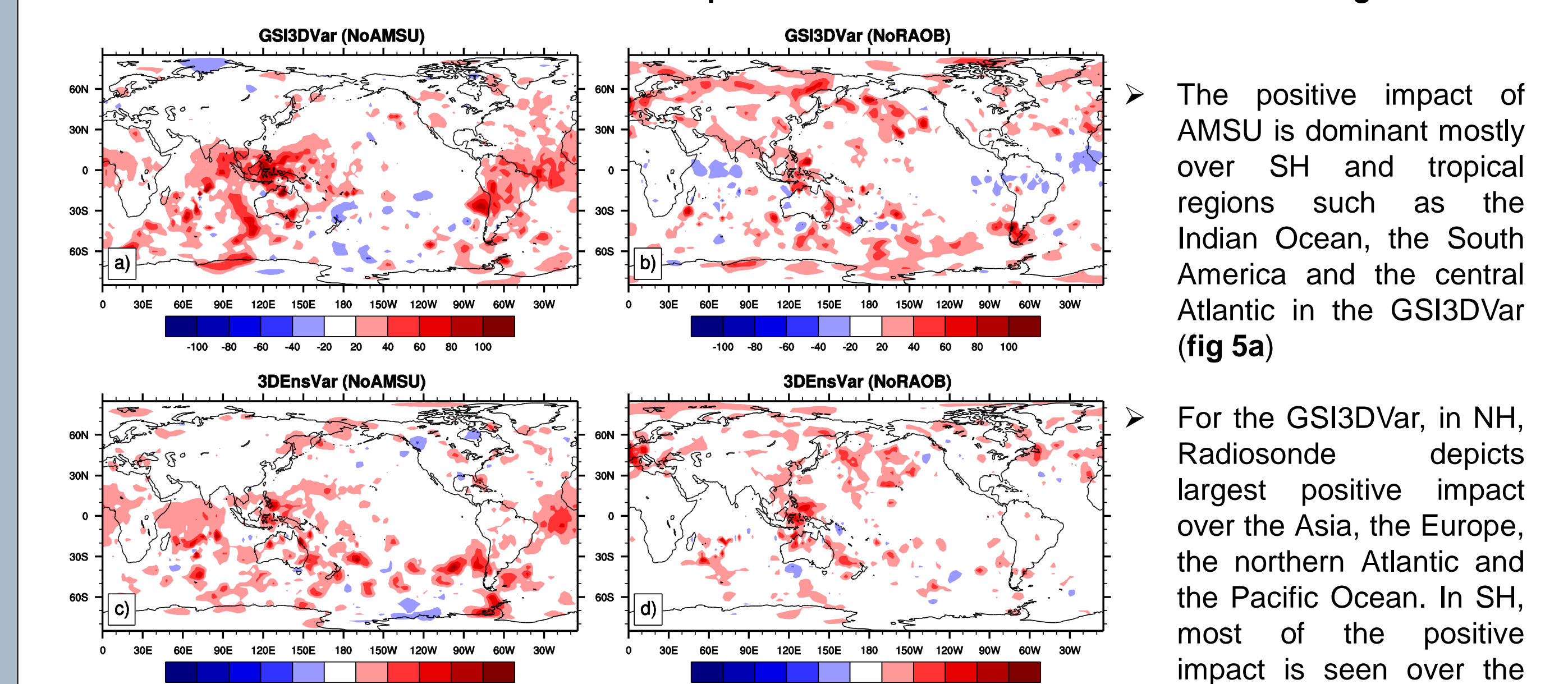
- The results shown in the figure 2 are similar to the verifications with respect to ECMWF analysis, in general

- However, as compared to the previous verifications **(fig 1a,b)**, the impact of AMSU is less in the both the DA systems for wind and temperature forecast

Figure 2: RMSE values of wind and temperature calculated with respect to Radiosonde observations for 24 hour forecast
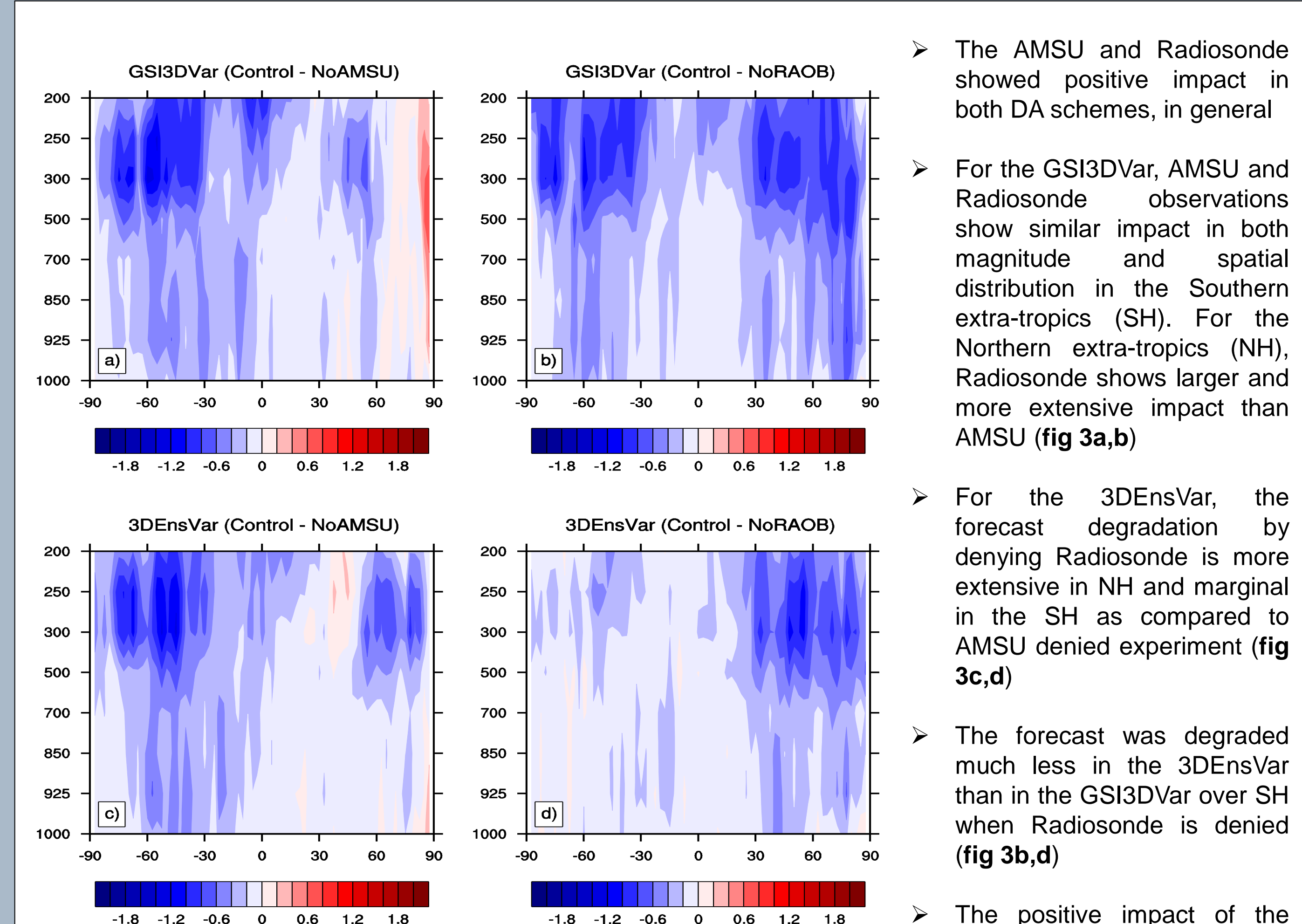
Figure 3: Zonally averaged root-mean-square error difference for 72 hr. wind forecast (ms^{-1}) between the control and the data denial experiments . Blue and red color indicates positive and negative data impact, respectively
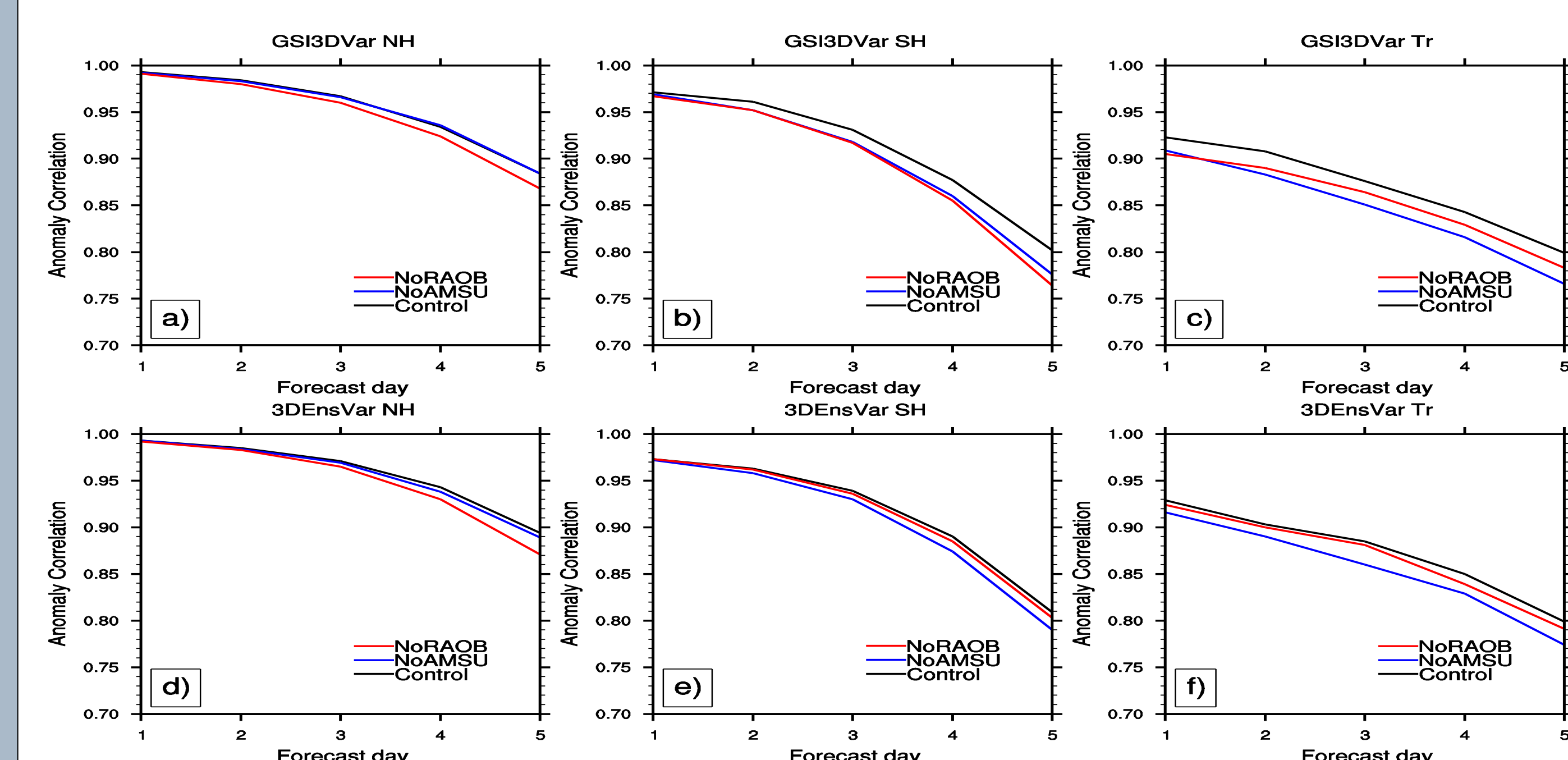
- The AMSU and Radiosonde showed positive impact in both DA schemes, in general

- For the GSI3DVar, AMSU and Radiosonde observations show similar impact in both magnitude and spatial distribution in the Southern extra-tropics (SH). For the Northern extra-tropics (NH), Radiosonde shows larger and more extensive impact than AMSU **(fig 3a,b)**

- For the 3DEnsVar, the forecast degradation by denying Radiosonde is more extensive in NH and marginal in the SH as compared to AMSU denied experiment **(fig 3c,d)**

- The forecast was degraded much less in the 3DEnsVar than in the GSI3DVar over SH when Radiosonde is denied **(fig 3b,d)**

- The positive impact of the AMSU in the 3DEnsVar is more extensive than the GSI3DVar in NH **(fig 3a,c)**

- Similar results are obtained for temperature forecast (not shown)

- For the specific humidity forecast, in both the GSI3DVar and the 3DEnsVar, AMSU data has largest impact over the tropics **(fig 4a,c)** and the impact of Radiosonde dominates in extra-tropics **(fig 4b,d)**

- Similar to the wind and temperature forecasts, Radiosonde data impact in the 3DEnsVar is less in SH when compared against the GSI3DVar **(fig 4b,d)**

Figure 4: Zonally averaged root-mean-square error difference for 72 hr. specific humidity forecast (g kg^{-1}) between the control and the data denial experiments . Color definitions are same as in figure 3

- The positive impact of AMSU is dominant mostly over SH and tropical regions such as the Indian Ocean, the South America and the central Atlantic in the GSI3DVar **(fig 5a)**

- For the GSI3DVar, in NH, Radiosonde depicts largest positive impact over the Asia, the Europe, the northern Atlantic and the Pacific Ocean. In SH, most of the positive impact is seen over the Pacific Ocean **(fig 5b)**

Figure 5: Geographical distribution of 72 hr. forecast impact relative to the control forecast on 500 hPa Geopotential height. Red (blue) color represents positive (negative) impact of the observations on the forecast

- The comparison of the spatial distribution of positive forecast impact of AMSU and Radiosonde observations in the 3DEnsVar is mostly similar to those in the GSI3DVar **(fig 5c,d)**

- The magnitude of degradation of the forecast after denying the observations is less in the 3DEnsVar than in the GSI3DVar, in general

- Also, the negative forecast impact produced by AMSU and Radiosonde observations is less extensive in the 3DEnsVar when compared to that in the GSI3DVar

Figure 6: Anomaly correlation for Geopotential height averaged vertically for the GSI3DVar (top panel) and the 3DEnsVar (bottom panel) as a function of forecast days for Northern Hemisphere (a,d), Southern Hemisphere (b,e) and Tropics (c,f)

- All the experiments produce skillful forecast as the anomaly correlation (AC) is well above 0.6 for all the forecast lead times [AC having value of 0.6 or higher produces skillful forecasts (Hollingsworth et al., 1980)]

- In the GSI3DVar, Radiosonde shows significant impact in NH as compared to the AMSU from day 2 of the forecast **(fig 6a)**. In SH, Radiosonde and AMSU show similar impact up to day 3 of forecast and Radiosonde shows more impact thenceforth **(fig 6b)**. In tropics, the impact of Radiosonde is slightly larger than AMSU for day 1 of the forecast and the impact of AMSU dominates the impact of Radiosonde thereafter **(fig 6c)**

- In the 3DEnsVar, the AMSU shows larger impact than Radiosonde for mostly all the forecast lead times in SH and tropics **(fig 6e, f)**. In NH, the impact of Radiosonde is more significant than the AMSU **(fig 6d)** from day 3 of forecast.
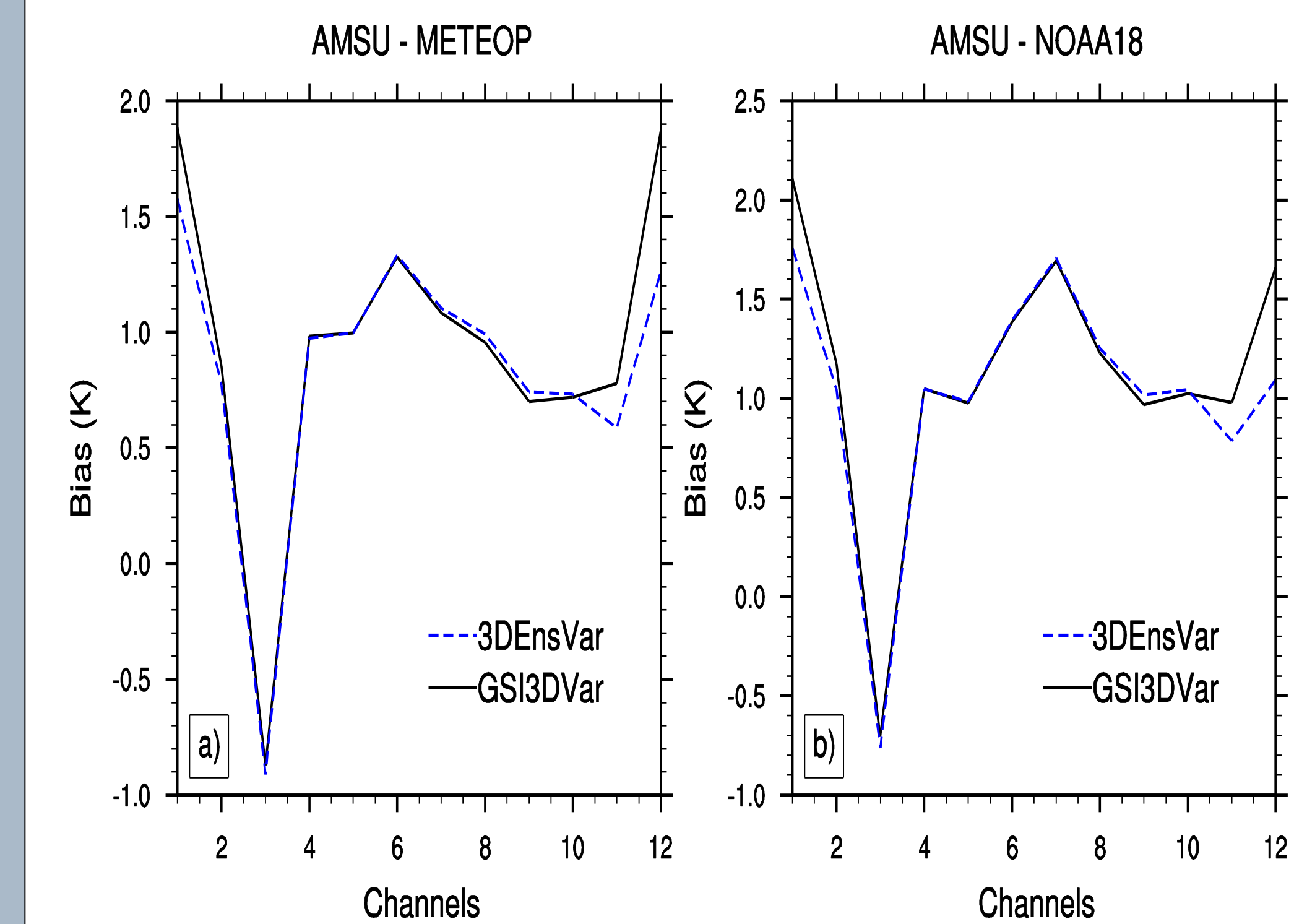
Figure 7: Bias estimated by the GSI3DVar and the 3DEnsVar averaged over the experiment period for (a) AMSU –METEOP (b) AMSU –NOAA18 satellites. Solid black and dashed blue line represents bias estimated by the GSI3DVar and the 3DEnsVar, respectively

- The bias estimated by the GSI3DVar and the 3DEnsVar are similar, in general

- It is therefore consistent with the results in the previous verifications as the impact of AMSU in the GSI3DVar and the 3DEnsVar are mostly similar

CONCLUSIONS & FUTURE DIRECTIONS

- For both the control and data denial experiments, the forecasts produced by the 3DEnsVar are more accurate than the GSI3DVar experiments

- The AMSU and Radiosonde, showed positive impact in both the DA schemes, in general

- In the GSI3DVar, the root mean square error of global wind and temperature forecasts were increased more by denying Radiosonde than denying AMSU observations

- In the 3DEnsVar, such impacts of the AMSU and Radiosonde are mostly similar

- For the GSI3DVar, the Radiosonde and AMSU observations show similar impact in both magnitude and spatial distribution in the SH. For the NH, Radiosonde shows larger and more extensive impact than AMSU

- The largest difference in the degradation of the forecast between the 3DEnsVar and GSI3DVar was seen in the SH when Radiosonde was denied, where the forecast was degraded much less in the 3DEnsVar than in the GSI3DVar

- The magnitude of degradation of the relative forecast skill after denying Radiosonde and AMSU observations is less in the 3DEnsVar than in the GSI3DVar

- The anomaly correlation of forecasts up to 5-day forecast lead time indicates that the impact of AMSU and Radiosonde observations increases with forecast lead time in both DA systems

- The AMSU radiance biases estimated by the GSI3DVar and the 3DEnsVar show similar values.

- It is expected that the future studies will account for the impact of other major observing systems such as Atmospheric Infrared Sounder (AIRS), Infrared Atmospheric Sounding Interferometer (IASI) in the NCEP GSI hybrid DA system.

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