11.4

IMPACT STUDIES OF COSMIC REFRACTIVITY OBSERVATIONS IN MULTI-DOMAIN APPLICATIONS AT THE NCAR DATC

Hui Shao*, Dale Barker, Yong-Run Guo, Syed Rizvi, Ying-Hwa Kuo, Jordan Powers
National Center for Atmospheric Research, Boulder, Colorado

1. INTRODUCTION

The development of the Weather Research and Forecasting (WRF) Model and its variational Data Assimilation System (WRF-Var) have provided the WRF research and operational communities with state-of-the–art, efficient forecast and data assimilation capabilities. The implementation of the WRF-Var system allows for the incorporation of indirect data types into the model and its forecasts. With additional capabilities and improved methods ingested into the system, a new version of the system has been released every one or two years. In terms of operations, the WRF and WRF-Var system is currently the official forecast and data assimilation system for a number of agencies and centers, including the Air Force Weather Agency (AFWA), the National Center for Atmospheric Research (NCAR) Antarctic Mesoscale Predictions System (AMPS) and the Taiwanese Civil Aeronautics Administration (CAA). To apply the mostly recent developed data assimilation techniques and ingest new satellite observations into an operational system requires an end-to-end examination of the system and a thorough evaluation of the impacts of the new components on weather forecasts.

By closely working with both research and operational communities, the Data Assimilation Testbed Center (DATC) at NCAR has been focusing on preparation, testing, and implementation of data and assimilation systems, therefore, leveraging the efforts of the development teams and operational centers. Currently, one of the data types examined in the DATC is radio occultation (RO) data from the Constellation Observing System for Meteorology, Ionosphere & Climate (COSMIC).

The COSMIC mission satellites were launched in April, 2006. COSMIC has dramatically increased the spatial and temporal coverage of the Global Positioning System (GPS) RO data over existing missions on a real-time basis and, thus, provides an opportunity for pre-operational impact studies of these observations over monthly or longer time periods. The DATC has performed a few month-long tests of the COSMIC RO data assimilation for different applications, including CAA southeast Asia, AFWA northeast Asia, and AMPS Antarctic domains (Fig. 1). The achieved results provide a rational and scientific basis for operational implementation of COSMIC RO data assimilation in support of short-term weather forecasts.

This paper will first present assimilation and impact studies of the COSMIC data in the AMPS Antarctic domain. Also, some results from the other two domains will be presented. Finally, discussions and conclusions will be given.

2. ASSIMILATION AND IMPACT STUDIES OF COSMIC OBSERVATIONS IN THE AMPS ANTARCTIC DOMAIN

2.1. Data and Experimental Design

Three experiments were conducted to assess the assimilation capability of COSMIC data in the operational WRF-Var system and the forecast impacts of these data in the south polar region (Table 1). The first experiment, NOGPS, assimilates all available conventional and satellite retrieval data into the real-time AMPS with forecasts four times per day in a full-cycling mode (using the latest 6 hour WRF forecast as a first-guess into the WRF-Var system). The second experiment, WGPS, assimilates all data in NOGPS plus COSMIC refractivity. Finally, the third experiment, WGPS_BE, is the same as WGPS, except uses tuned background error (BE) covariances. The version 2.2 of WRF, its preprocessing system (WPS), and three-dimensional WRF-Var are used with the model configuration shown in Table 2. The “local” refractivity operator is used in the WRF-Var to simulate RO refractivity from three model state variables, temperature (T), relative humidity (Q), and pressure (P). The testing time period is October, 2006.

---

* *Corresponding author address*: Hui Shao, P. O. Box 3000, Boulder, CO 80307; e-mail: huishao@ucar.edu

The COSMIC data used in the experiments are level 2 refractivity profiles in BUFR format provided by the COSMIC Data Analysis and Archive Center (CDAAC). There are more than 7000 RO profiles assimilated in the time period as shown in Fig. 2 (left panel). The data have an approximate vertical resolution of 200 meters. In the same time period, the number of conventional radiosonde observations is only about 20% of the number of the COSMIC data (Fig. 2 right panel).

2.2. Impacts of COSMIC Refractivity on 36 Hour Forecasts

Figure 3 shows the bias and root-mean-square error (RMSE) profiles from a month of 36-hour T forecasts from NOGPS, WGPS, and WGPS_BE, with respect to all radiosonde observations in the domain south of 60°S. Assimilation of COSMIC data reduces the bias in the middle troposphere and the RMSE through the whole troposphere. However, it increases the RMSE of the temperature forecasts by about 30% in the stratosphere (above ~250mb).

Figure 4 is the same as Fig. 3, except for the forecasts of the u-component of wind speed (U). Assimilation of COSMIC refractivity generally reduces the bias and RMSE of the wind speed forecasts. Similar results are also present in the v-component of wind speed (V). Unlike T, Q and P, wind speed is indirectly related to atmospheric refractivity. Therefore, the significant positive impacts from COSMIC data assimilation shown here are gained through model physics. Compared with the NCEP Global Data Assimilation System (GDAS) final (FNL) analysis in the middle troposphere (η value used in WRF system is equal to 0.5255), the monthly average of the 36 hour forecasts of U from WGPS reduces the bias shown in the result from NOGPS (Fig. 5).

Verified against the Surface Synoptic Observations (SYNOP) (mostly located on land), the surface pressure forecasts of WGPS have the slightly smaller bias and RMSE than those of NOGPS. This indicates another indirect impact of COSMIC data on short-term forecasts.

Overall, WGPS_BE produces quite similar results to WGPS. The tuned BE covariances have a minor impact here.

2.3 Sensitivity Studies in Stratospheric COSMIC Data Assimilation

The degradation of the temperature forecasts in the stratosphere shown in Fig. 3 actually increases dramatically within 72 hours. This causes valid concerns regarding the quality of the data in these layers and also raises the issues related to the physics at the model top sponge layers in the WRF forecast model. Therefore, five more experiments are designed as shown in Table 3. Basically, WGPS_damp3 and WGPS_250mb are the same as WGPS, except WGPS_damp3 uses a new enhanced damping scheme at the model top, while WGPS_250mb assimilates COSMIC data below 250mb only. NODA_10mb, NOGPS_10mb, and WGPS_10mb are the experiments where the model top is moved from 50mb to 10mb, changing the vertical levels from 31 to 57. NODA_10mb is a 12 hourly cold-start run of the WRF model initialized by the GDAS FNL analysis. The 12 and 24 hour forecasts from NODA_10mb are then used to estimate the BE covariances by using the NMC method. The BE information is required by NOGPS_10mb and WGPS_10mb. NOGPS_10mb assimilates all available data excluding COSMIC data. WGPS_10mb is the same as NOGPS_10mb, except for the additional assimilation of COSMIC data below 10mb.

Figures 6 and 7 show the bias and RMSE profiles of the 36 hour forecasts of U, V, T and Q from NOGPS, WGPS, WGPS_250mb, WGPS_damp3 and WGPS_10mb verified against all radiosonde observations within the AMPS domain during the testing time period. Impressively, moving the model top to 10mb (WGPS_10mb) results in a remarkable reduction of the bias and RMSE of all forecast fields throughout the vertical range. In addition, the forecasts from WGPS_damp3 are quite similar to those from WGPS, indicating that the enhanced damping at the model top does not help solve the issue shown in the previous stratospheric forecasts. WGPS_250mb, which only assimilates COSMIC data in the troposphere, produces similar results to WGPS in the troposphere and to NOGPS in the stratosphere. It confirms the current treatment of physics around the model top in WRF might not be realistic. Therefore, it will degrade model forecasts by fitting observations to model noise at model top layers.

Comparisons of the results from NOGPS_10mb and WGPS_10mb shown in Figures 8 and 9 illustrate the impacts of COSMIC data on the 36 hour forecasts of U, V, T and Q. The assimilation of COSMIC data generally reduces the biases of U, V and T and reduces their RMSEs at least up to 70mb. The forecast impact on Q is quite marginal.

3. RESULTS FROM OTHER DOMAINS

Compared with the AMPS domain, CAA and AFWA Asian domains have more conventional data than COSMIC data available within the assimilation time windows (refer to Table 2 for the model configurations). For example, within the time window centered at 00Z on December 1, 2006 (12Z on July 1, 2007), there are only 37 (1) RO profiles versus 187 (58) radiosonde profiles in the CAA (AFWA) domain. Therefore, the forecast impacts from COSMIC data assimilation in these domains are neutral or slightly positive, which is still encouraging.

4. SUMMARY AND CONCLUSIONS

The DATC at NCAR performs a few month-long tests of the COSMIC RO data assimilation for different applications, including CAA southeast Asia, AFWA northeast Asia, and AMPS Antarctic domains. These extended pre-operational tests make it possible to understand the role of the COSMIC data in improving weather forecasts over different geographical domains, and gain insights as to where and how the COSMIC data complement existing observation systems.

Generally, COSMIC data contribute to improvements in the short-term forecasting, especially in data-sparse regions (e.g., SH). They improve temperature forecasts in both the troposphere and stratosphere and improve moisture forecasts in the lower troposphere slightly (on average). Their benefits are also remarkable for fields (e.g., wind) indirectly related to T, P, and Q through model physics for the entire forecast period.

Assimilation of COSMIC data is sensitive to the forecast model top configuration. The setup of the current operational WRF model top at 50mb is not sufficient to ingest positive impacts from COSMIC data on stratospheric forecasts. Moving the model top to 10mb is recommended based on the sensitivity studies of the COSMIC data assimilation in the stratosphere. It is also necessary to avoid assimilating data in model top sponge layers since there could be a deficiency or mistreatment of the physics in these layers.

Relative density of COSMIC and other existing measurements proves critical for significant forecast improvement from GPS data assimilation. However, it is valuable to ingest GPS RO data into the current operational forecast model from a global point of view.

Acknowledgements

This research was supported by NSF/OPP, NASA, AFWA and CAA.

TABLES AND FIGURES:

Table 1. Design of the experiments for testing COSMIC data assimilation in the AMPS domain.

Experiment	Description	IC	LBC	Background Error Covariance	Assimilated GPS data	Other assimilated data
NOGPS	Six hourly cycling of 3D-var data assimilation, LBC update and WRF forecast	GDAS FNL analysis at first time Latest 6 hour WRF forecast	GDAS FNL analysis	NMC method using WRF 12 hourly cold-start forecasts for May 2004 **-** *1st generation BE tuning* (separate work)		Conventional: Surface - SYNOP,METAR, SHIP,BUOY Upper air – SONDE, PIBAL, AIREP, AIRSR Satellite retrievals: Atmospheric Motion Vectors (geo/polar), Scatterometer oceanic surface winds, Satellite temperature /humidity
WGPS					COSMIC refractivity within ±2 hr time window centered at 00Z, 06Z, 12Z and 18Z Local refractivity operator.	
WGPS_BE				NMC method using forecasts from **WGPS** for Oct. 2006 *– 2nd generation BE tuning*		

Table 2. Configurations of AMPS, CAA and AFWA.

	Data window	Grid points	Horizontal resolution	Vertical levels	Model top	Testing Time period
AMPS	±2hr	165*217	60km	31	50mb	Oct. 2006
CAA	±3hr	222*128	45km	45	30mb	Dec. 2006
AFWA	±1hr	162*212	15km	42	50mb	July 2007

Table 3. Design of the experiments for the sensitivity study of stratospheric COSMIC data assimilation in the AMPS domain.

Experiment	Description	Model Top	Background Error Covariance	Assimilated GPS data	Other assimilated data
NODA_10mb	12 hourly cold-start run of WRF forecast	10mb (57 levels)			
WGPS_damp3	Same as **WGPS**, except WRF uses damp_opt=3	Same as **WGPS**	Same as **WGPS**	Same as **WGPS**	Conventional: Surface - SYNOP,METAR,SHIP, BUOY Upper air – SONDE, PIBAL, AIREP, AIRSR Satellite retrievals: Atmospheric Motion Vectors (geo/polar), Scatterometer oceanic surface winds, Satellite temperature/humidity
WGPS_250mb	Same as **WGPS**	Same as **WGPS**		COSMIC refractivity up to 250mb	
WGPS_10mb		10mb (57 levels)	NMC method using forecasts from **NODA_10mb** for Oct 2006	COSMIC refractivity up to 10mb	
NOGPS_10mb					

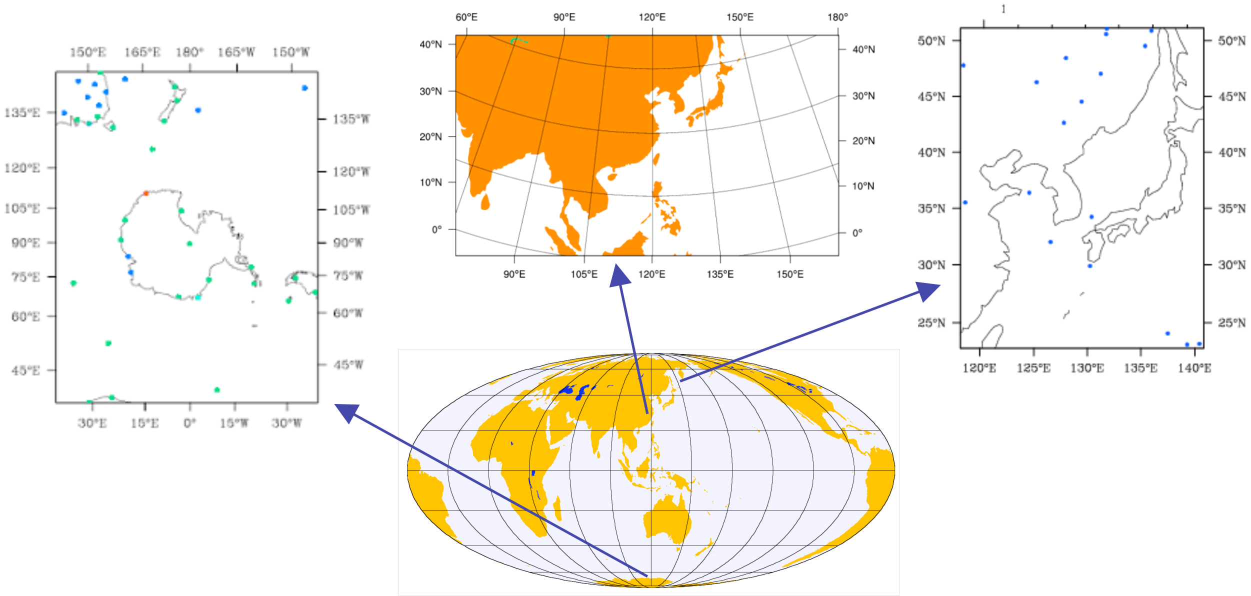


Fig. 1 The AMPS Antarctic domain (upper left), CAA southeast Asia domain (upper middle) and AFWA northeast Asia domain used in the DATC testbeds for COSMIC data assimilation and impact studies.

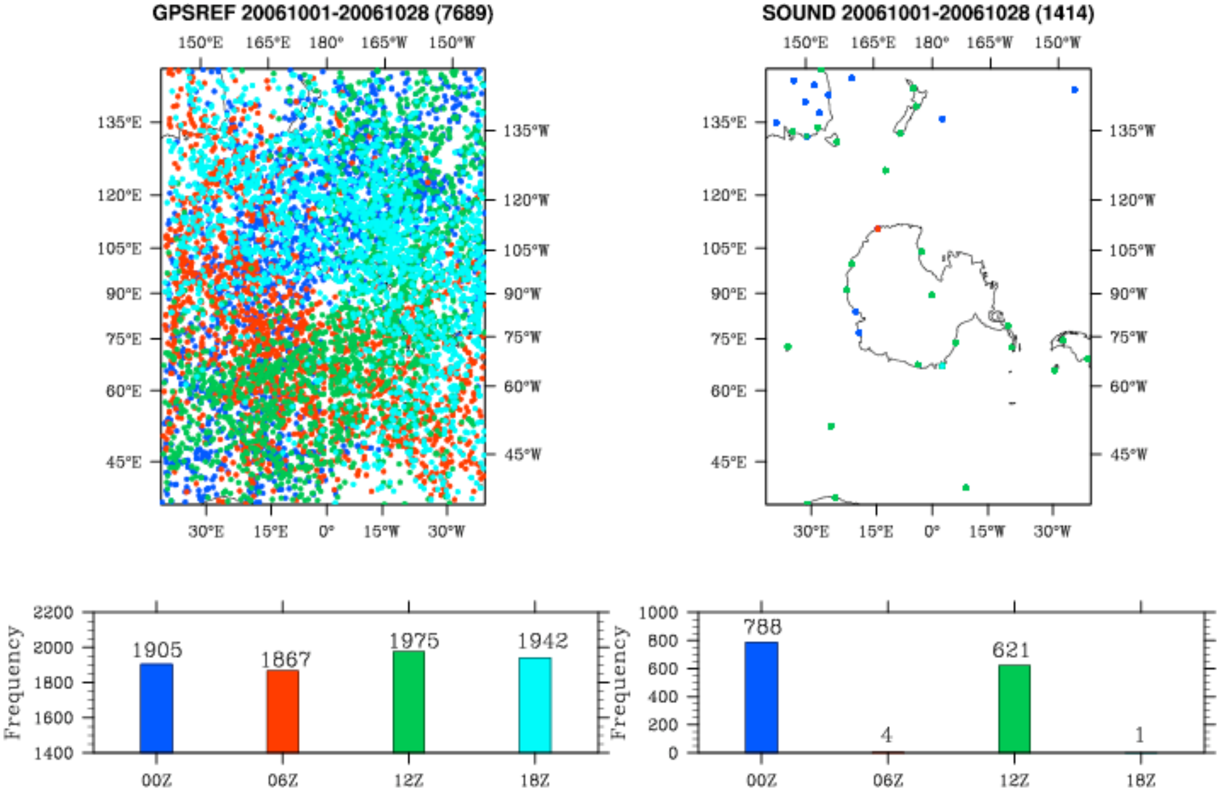


Fig. 2 Distributions of COSMIC ROs (upper left) and radiosonde sites (upper right) for the whole testing period of October, 2006. The bottom panels show the total number of COSMIC ROs (left) and radiosonde sites (right) within the assimilation time windows centered at 00Z, 06Z, 12Z and 18Z during October, 2006. There are a total of 7689 ROs and 1414 radiosonde profiles within the domain.

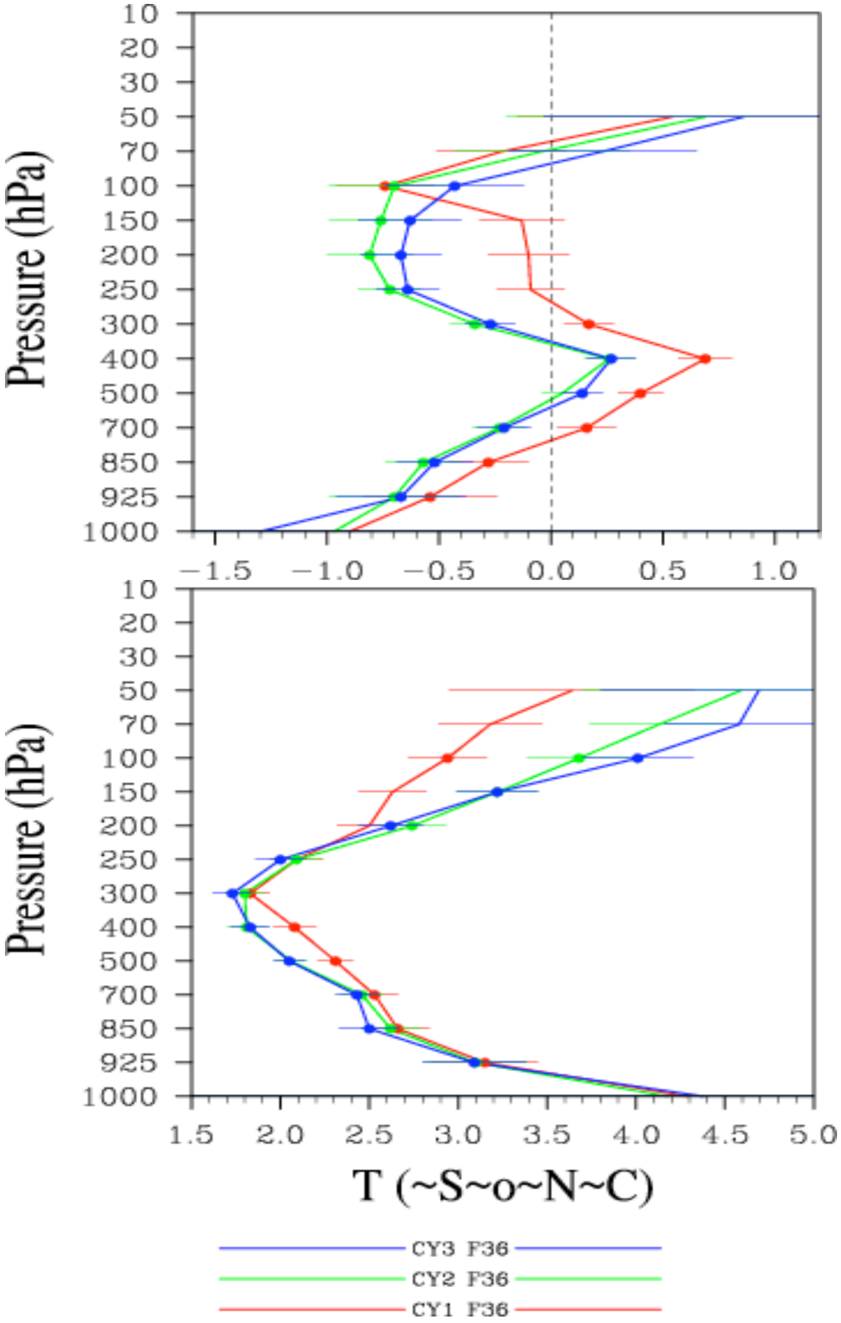


Fig. 3 Vertical profiles of the bias (upper panel) and RMSE (lower panel) of the 36 hour temperature forecasts from NOGPS (red), WGPS (green) and WGPS_BE (blue) during the testing time period, with respect to radiosonde observations within the AMPS domain south of 60°S. Units: K

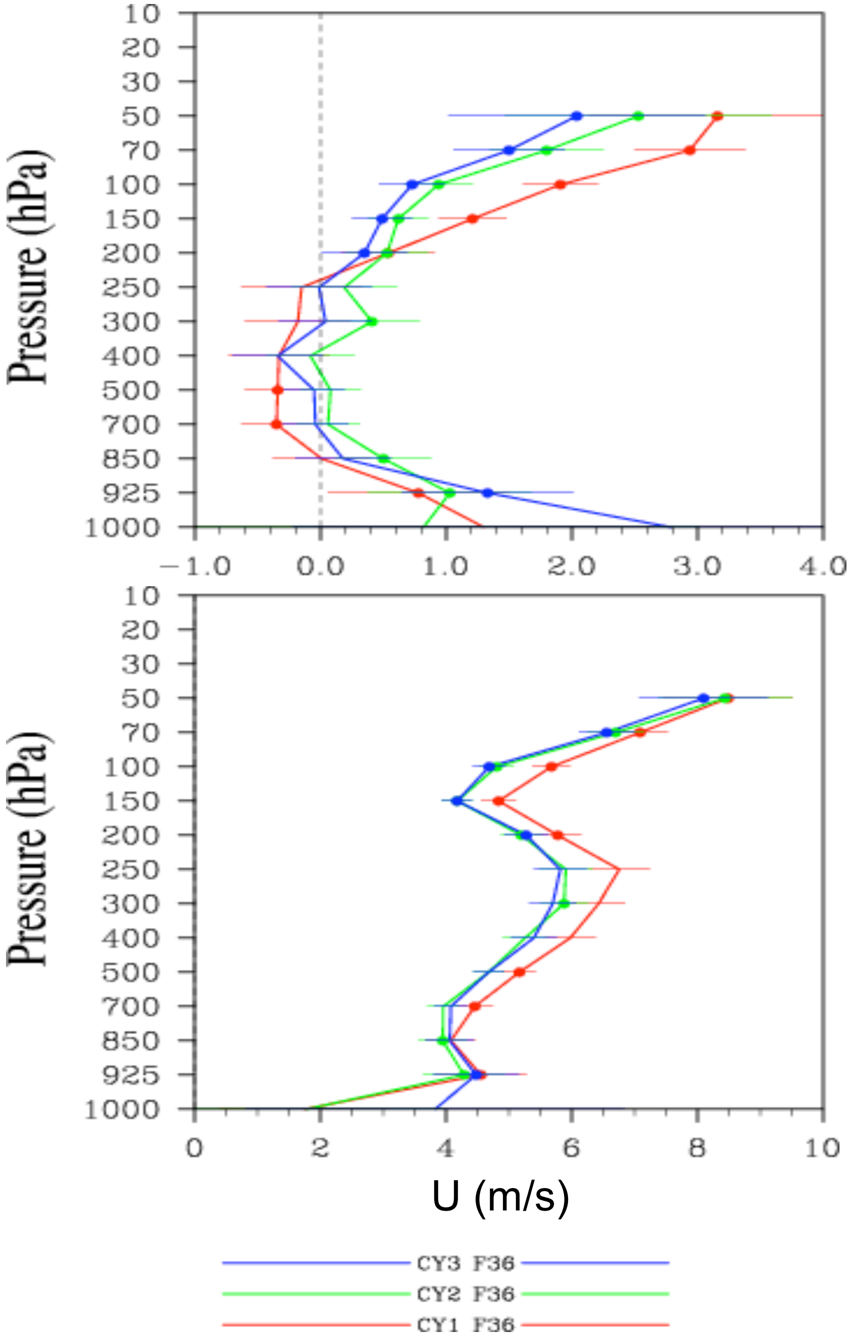
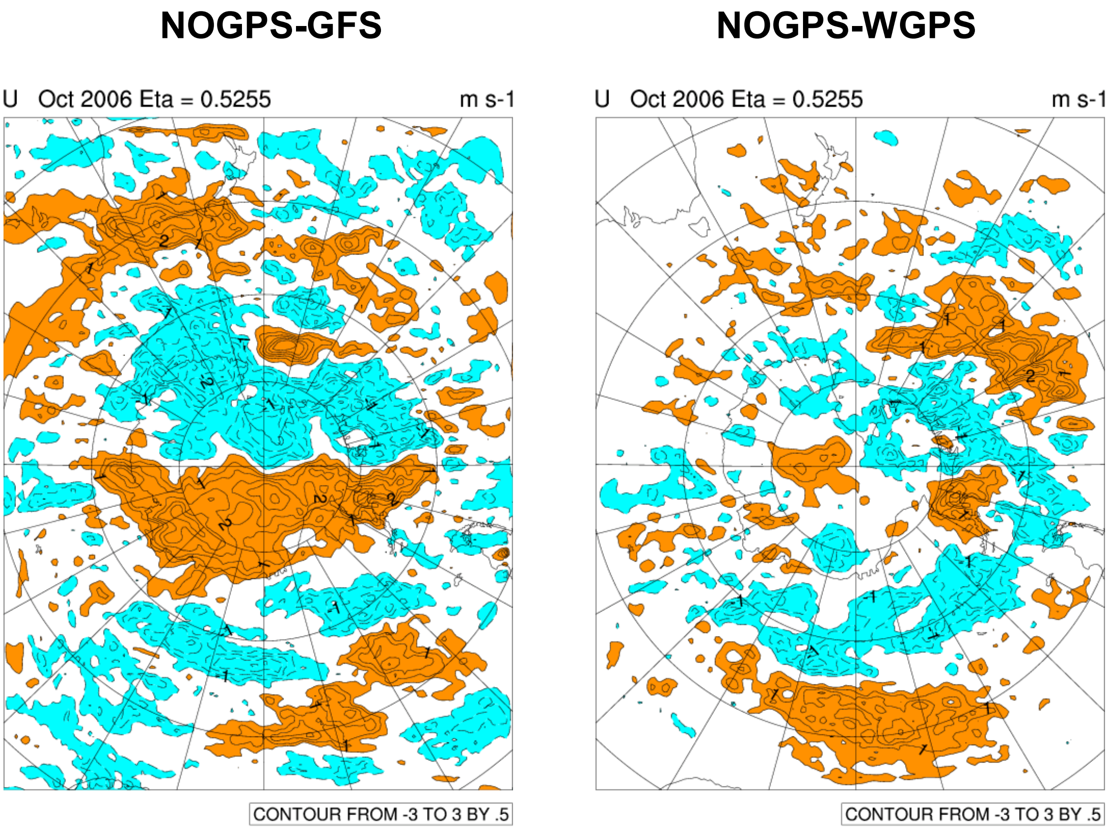


Fig. 4 Same as Fig. 3, except for u-component of the wind speed forecasts. Units: m/s


NOGPS-GFS

NOGPS-WGPS

Fig. 5 Monthly average of the 36 hour forecast errors for NOGPS with respect to GDAS FNL analysis (left panel) and monthly average of the 36 hour forecast differences between NOGPS and WGPS (right panel) at a vertical level of η=0.5255.

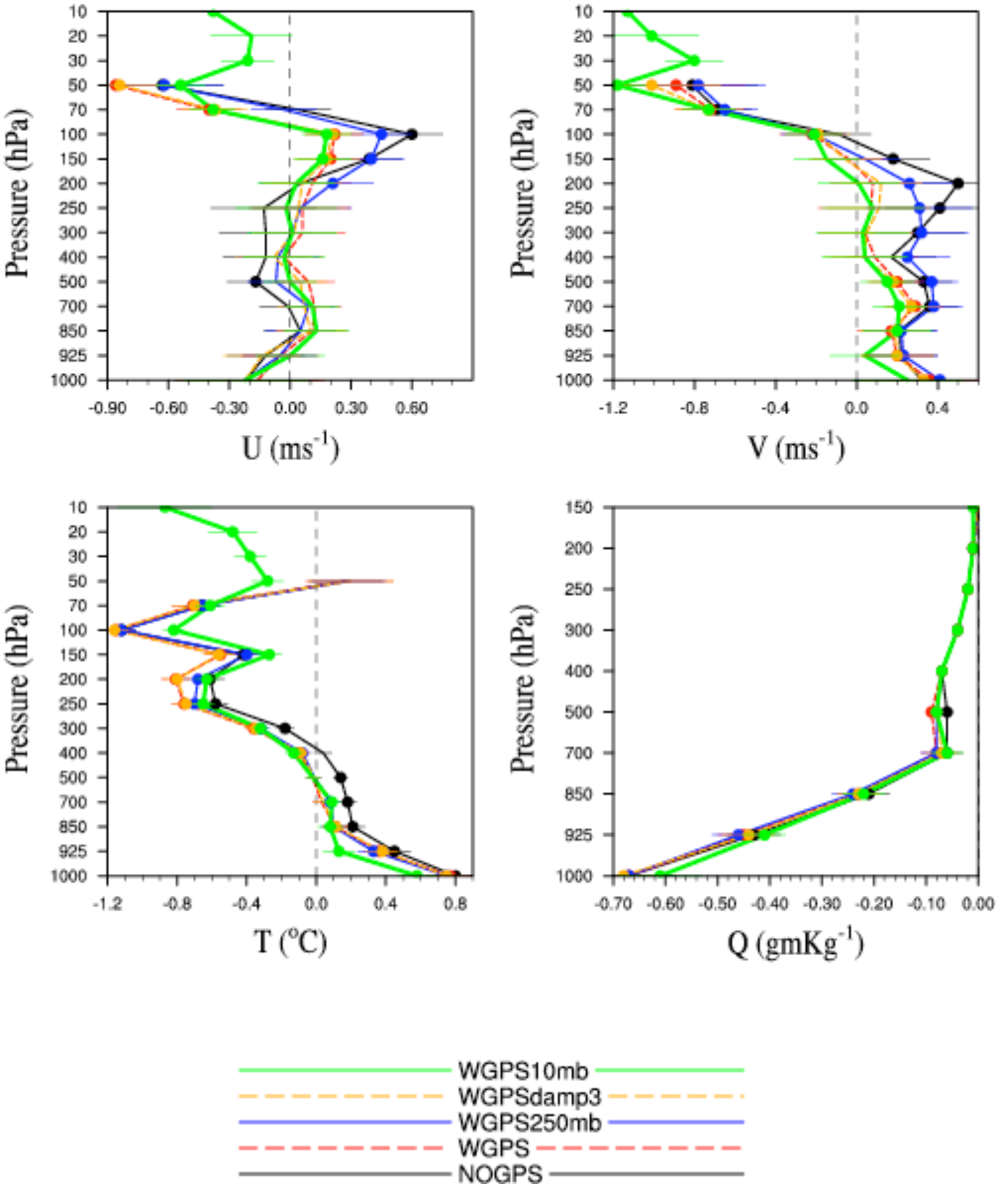


Fig. 6 Vertical profiles of the bias of the 36 hour U, V, T and Q forecasts from NOGPS (black), WGPS (red), WGPS_250mb (blue), WGPS_damp3 (orange) and WGPS_10mb (green) during the testing time period, with respect to radiosonde observations within the AMPS domain. Units: m/s for U and V, K for T and g/kg for Q.

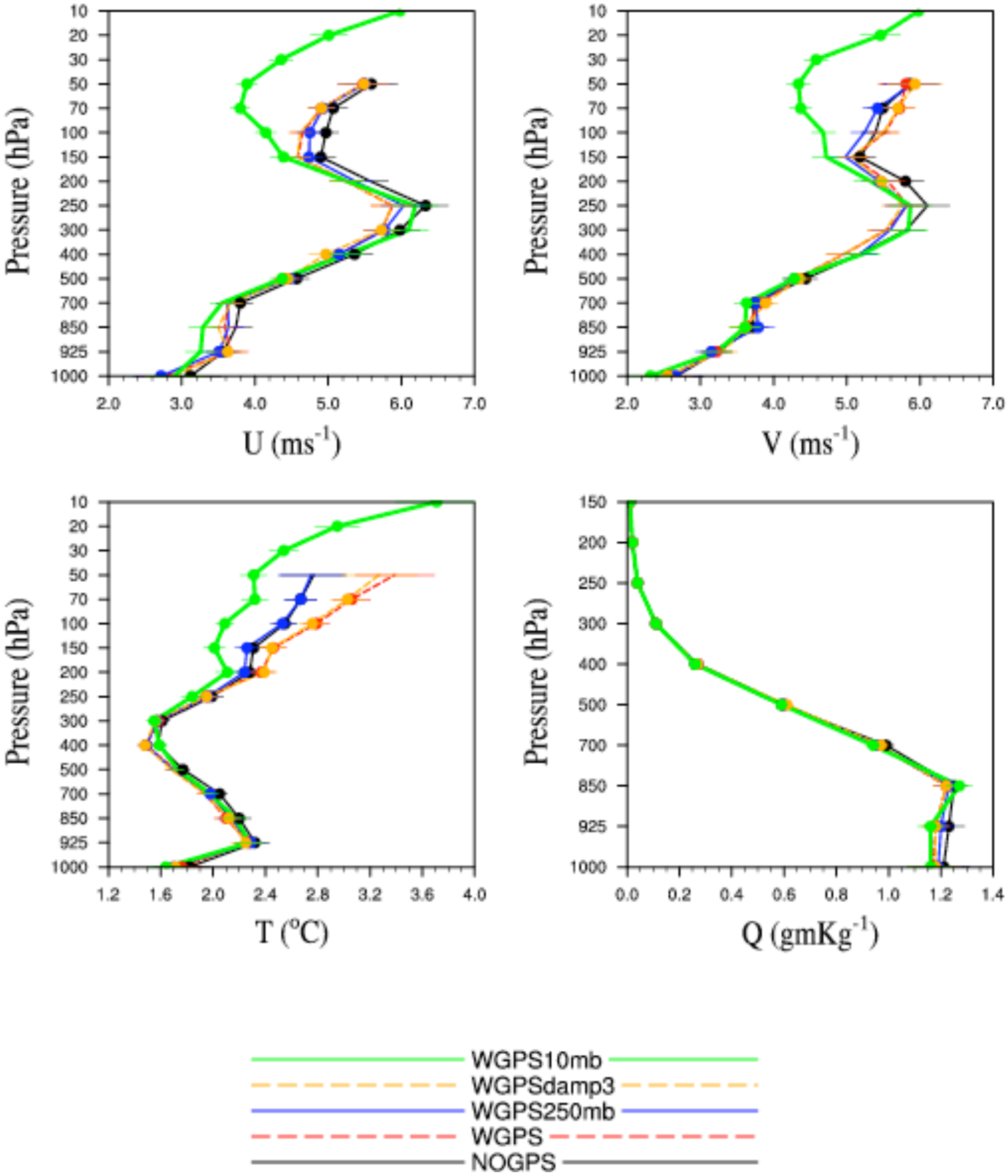


Fig. 7 Same as Fig. 6, except for the vertical profiles of the RMSE.

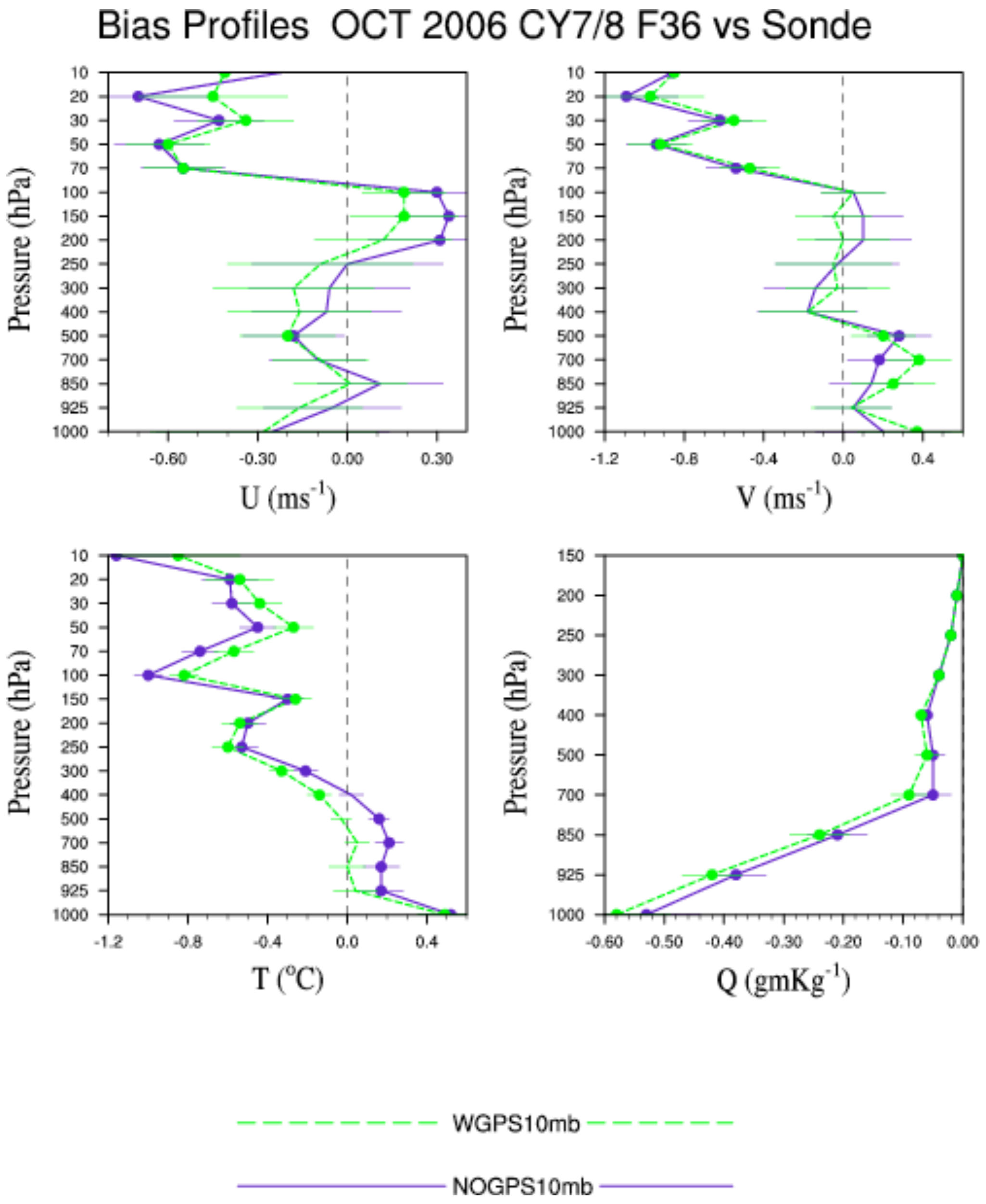


Fig. 8 Same as Fig. 6, except for the 36 hour forecasts from NOGPS_10mb and WGPS_10mb.

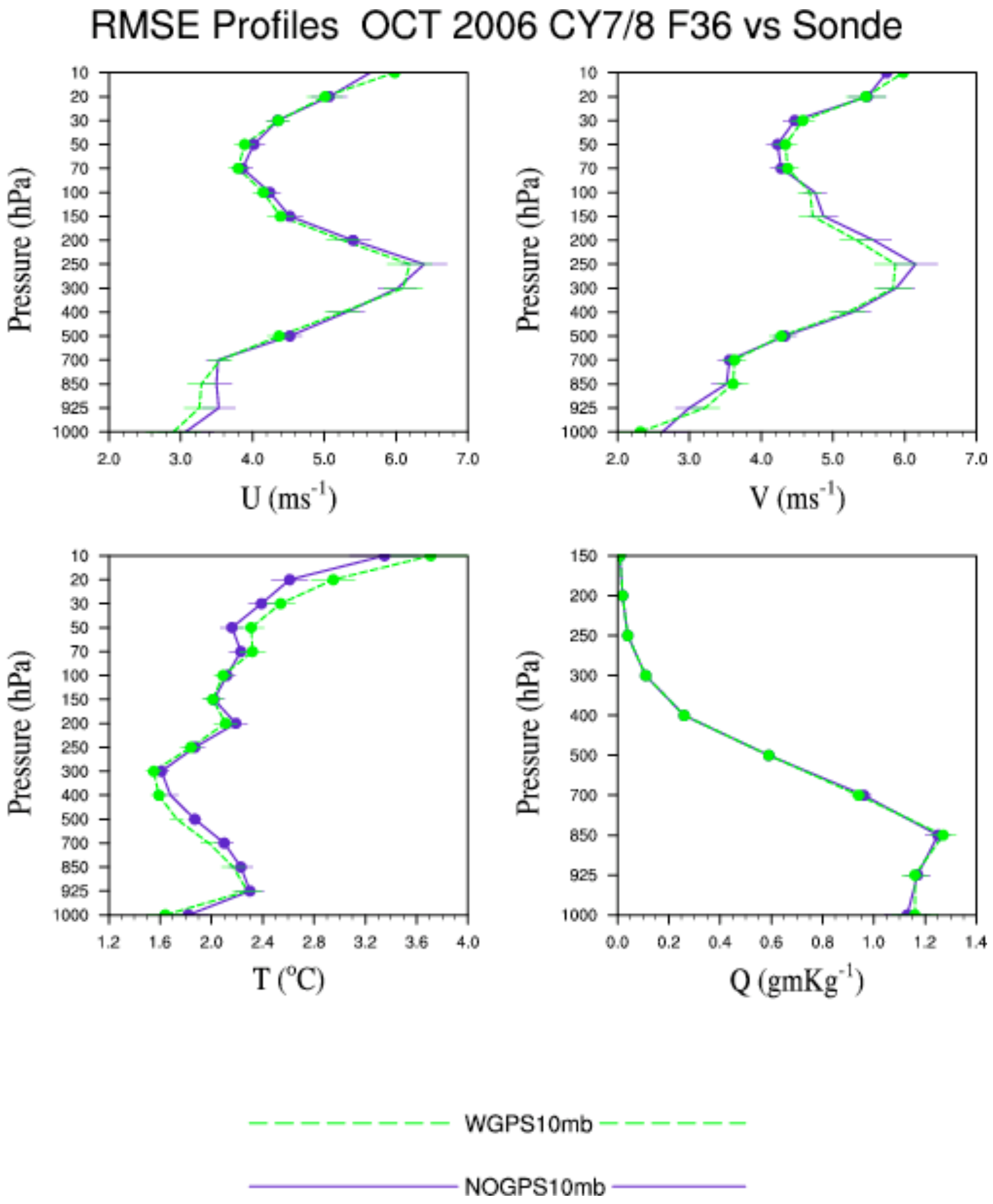


Fig. 9 Same as Fig. 7, except for the 36 hour forecasts from NOGPS_10mb and WGPS_10mb.