Use and Impacts of Satellite Observations in GRAPES

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Abstract

Satellite observations play a growing role in numerical weather prediction (NWP) model, now they contribute more short- and medium-range forecasts skill than ground-based observations. GRAPES (Global and Regional Assimilation PrEdiction System) is Chinese new generation NWP system for which the pre-operational tests of global system are being conducted currently in NWP center of CMA. After a brief introduction to GRAPES, the use and impacts of satellite observations in GRAPES will be presented, and their performances will also be evaluated. The satellite observations assimilated in GRAPES include radiances data from NOAA, METOP and FY satellites, GNSS radio occultation refractivity data, geostationary and MODIS atmospheric motion vectors and ambiguous sea winds vectors. Results show that satellite measurements provide good analysis information not only in the upper troposphere, lower stratosphere，ocean and the southern hemisphere, but also in the lower troposphere, which produce a clear improvement in the RMS and bias analysis fit to NCEP analysis. Because GRAPES is a newly developing system, the addition of more new satellite, optimizations and improvements of existing satellite data assimilation are still be stressed.

1. Introduction

GRAPES (short form of Global/Regional Assimilation and PrEdiction System) is Chinese new generation operational numerical weather prediction (NWP) system, which is launched in 2001 for response to a growing urgency of more accurate numerical weather forecast, and co-sponsored by Chinese Ministry of Science and Technology (CMST) and Chinese Meteorological Administration (CMA). The system comprises four main components: 1) variational data assimilation systems with stress on the direct assimilation of satellite and radar data; 2) unified model dynamics core suitable to different scales; 3) new global and regional NWP systems based on the unified dynamics frame with optimized physical package; 4) supporting software for the NWP models in high performance computer environment (Chen and Xue, 2004； Chen and Xue, 2005; Xue and Chen, et. al., 2008). Development and improvements of GRAPES has been the heart strategy of CMA. GRAPES-Meso has been in fully operational implementation in the national and a few of regional meteorological centers one after the other since 2006, and GRAPES-Global are in the pre-operational running at present.

Most weather systems causing disastrous weather events in China originate either in the western Pacific Ocean or the Tibetan Plateau where conventional observations are sparse. Data problem is a hard difficulty faced in Chinese NWP. One of the advantages of variational assimilation technique is to directly assimilate the unconventional observation, such as satellite radiance data and radar data, etc. Therefore, developing a data variational assimilation system (GRAPES-Var) with the emphasis on effective usage of remote sensing data is the priority in CMA.

This paper describes the recent progresses in satellite data assimilation in GRAPES global data assimilation (DA) system, and presents results of satellite data impact experiments. The aim of GRAPES is to develop its four dimensional DA system. As a result a new version of GRAPES-3DVar has been updated recently, in which coordinate and variables configurations are consistent with the GRAPES forecast model, and is scheduled to replace the current version employing the pressure coordinate in the near future. Therefore, their performance of assimilating satellite data in these two versions is compared. Finally, future plans for satellite data assimilation are presented.

2. Description of GRAPES

GRAPES is a non-hydrostatic semi-implicit semi-Lagrange model. The model employs latitude-longitude grid point with Arakawa-C staggering in the horizontal and terrain-followin height coordinate with Charney-Philips staggering in the vertical. The model top is about 32Km with 37 vertical levels. More details about the GRAPES forecast model refer to Chen et. al. (2008) and Xue et.al (2008).

As mention before, we have updated GRAPES data assimilation system. So the analysis variables are wind components (u and v), hydrostatic exner pressure and specific humidity. The assimilation is to minimize the cost function J

$$J(x_a) = \frac{1}{2}(x_a - x_b)^{\mathrm{T}}\mathbf{B}^{-1}(x_a - x_b) + \frac{1}{2}(H(x_a) - y)^{\mathrm{T}}\mathbf{R}^{-1}(H(x_a) - y)$$

Where Xa are variables to be analyzed, Xb background field, Y observations, B and O are the covariance matrices of background error and observational error respectively, and H the observational operator. Preconditioning based on the square root of the B matrix is introduced to reduce the scale of matrix computation and to accelerate the convergence of iterations in minimizing the cost function. The preconditioning uses the spectral transformation filter (Xue and Chen et. al., 2008) .

3. Satellite assimilated in GRAPES and impacts experiments

The satellite observation types which GRAPES global data assimilation system can assimilate include atmospheric motion vectors (AMVs), radiance data (the Advanced Microwave Sounding Unit (AMSU), and Infrared) from NOAA, METOP and FY satellite, global navigation satellite system radio occultation (GNSS RO) data, and scatterometers sea surface wind data. One of the new features of the current DA system is that it can assimilate more satellite than ever before, and the speed of adding new data is quicker.

3.1 atmospheric motion vectors (AMVs)

Figure 1 shows the satellite type and coverage of AMVs data assimilated in GRAPES. At present we can receive about 230,000 AMVs data from global telecommunication system (GTS) at every 6-hour assimilation window, and use about 30,000 data after quality control and thinning, which is considerable compared to other NWP centers. However, the impact of the AMVs data is neutral and relatively small positive in GRAPES, especially in the tropics. Maybe it is related to the poor height assignment of some wind (Xue, 2009). The experiments of tuning the observation and background error ratio, and height adjustment are underway.

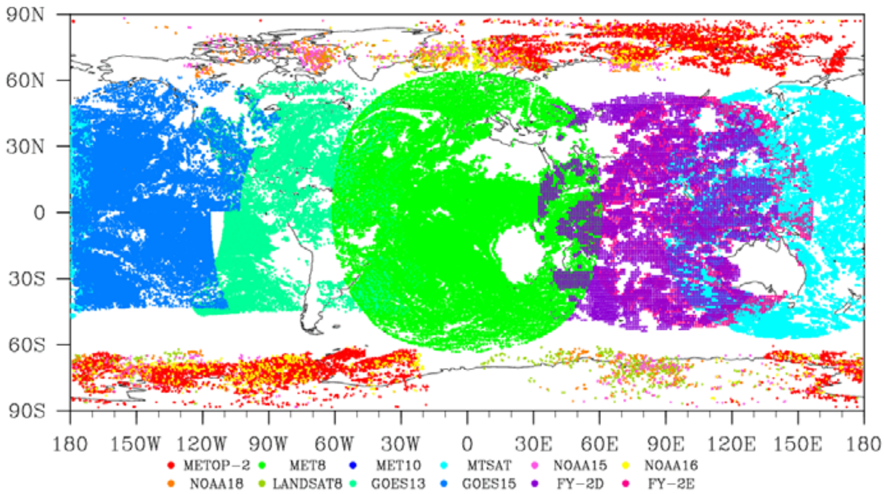

Fig.1 Satellite type and coverage of AMVs used in GRAPES

3.2 GNSS RO

The impact of GNSS RO is evident, which has surprised many people in NWP since COSMIC was launched in 2006. Why are they important? Because they are global coverage, all weather, calibration free, very precise and high vertical resolution. Figure 2 shows the number of RO data from GTS at 6-hour assimilation windows in September 2013. Color lines stand for the different RO mission, and the black line is the amount received. GRAPES can use all RO mission data on the track, the amount at assimilation windows is about 750.

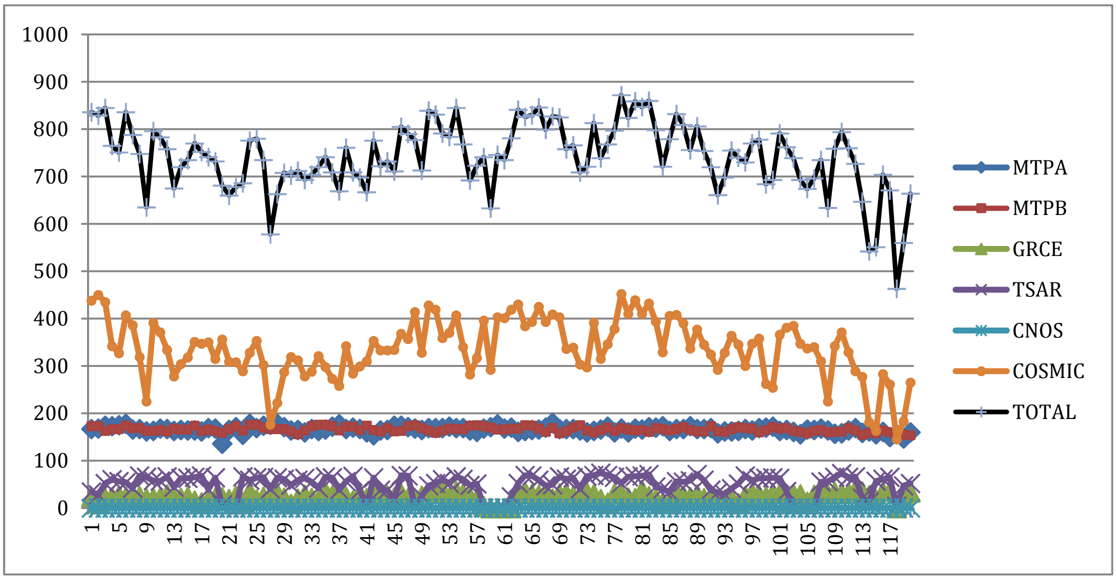

Fig.2 RO data time evolve at six-hour assimilation windows in September 2013 from GTS

The impact of RO is biggest in GRAPES, which has been proved by many observation impact experiments and pre-operational running. We assimilate refractivity due to lower model top at about 32.5Km, and only use one datum nearby per analysis vertical level. Fig.3 present the difference between GRAPES and NCEP analysis for 500-mb in a cycling running from July 1 00UTC 2011 to April 16 18UTC 2012, which assimilate only conventional observation (radio sounding, synops, ships, aircraft and AMVs data) and RO data from COSMIC and METOP-A. The black lines stand for Northern Hemisphere (NH), and red lines for Southern Hemisphere (SH). The dashed lines are differences that GRAPES analysis minus NCEP analysis, and solid lines are their RMS. The role of RO is so strong, and it has significant positive impact on analysis and forecast at all ranges in GRAPES. Even with the conventional data and RO data, GRAPES can cycle stably and not drift compared to NCEP analysis assimilating much satellite data.

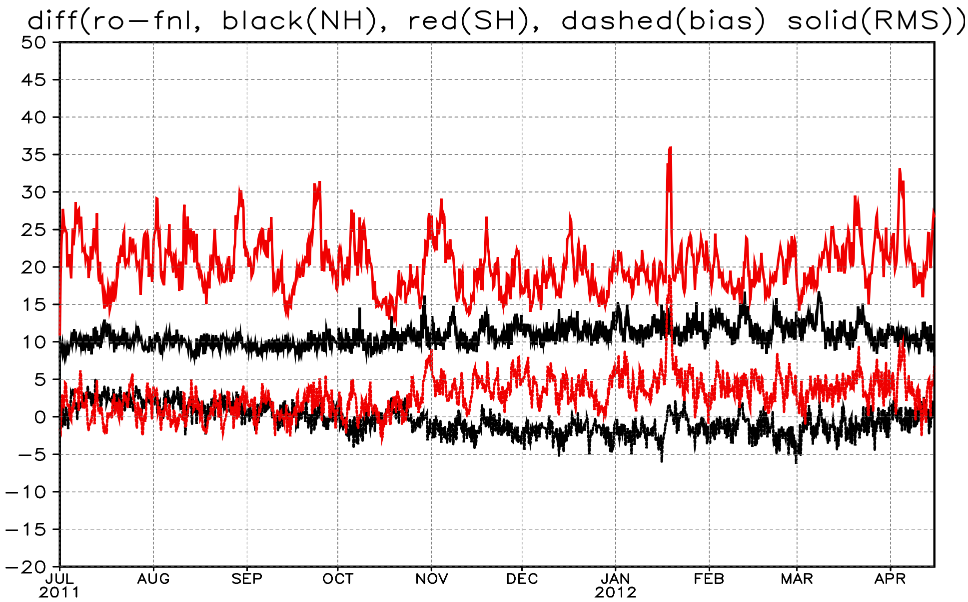

Fig.3 Difference between GRAPES and NCEP analysis in a cycling running (black:NH, red:SH; dashed line: GRAPES minus NCEP analysis, solid line: RMS)

Another indication of the impact of RO data on improving numerical weather forecasts is given in Fig. 4, which shows the anomaly correlation coefficient (ACC) for 500-mb height calculated for the GRAPES 8-day forecast as a function of time. Red lines mean just assimilating conventional observations, and green lines mean addition of RO data, which are the results in the new GRAPES DA system. Black lines are the results of the old DA system with all data assimilated, including radiance data. A steady improvement in the ACC is evident, with a larger rate of improvement for the SH.

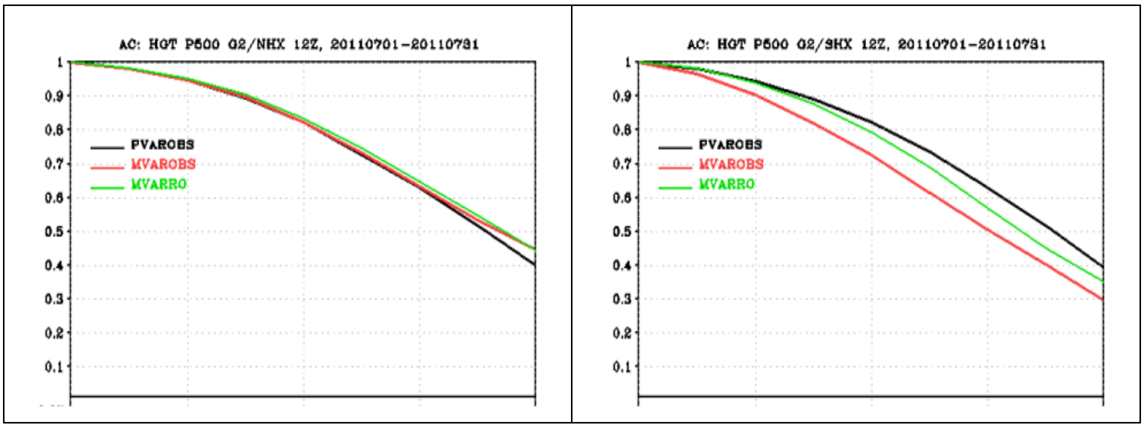

Fig. 4 Anomaly correlation coefficient (ACC) for 500-mb height for the 8-day forecast (left: NH; right:SH)

3.3 Radiance data

Radiance data from the NOAA, METOP and FY-X series satellite are assimilated in GRAPES, and the amount of AMSU-A, AMSU-B, and MHS data has increased more quickly than ever before due to the capability improvement of exchanging data in recent year. The forward observational operator and its tangent linear and adjoint for satellite radiances are from RTTOV software package (Xue et.al, 2003; Zhang et. al., 2004; Zhu et. al., 2005). The bias correction scheme follows the algorithms proposed by Harris and Kelly (2001), which correct the biases depending on scan angles and the categories of air mass. The predictors are the thickness between 1000-300hpa and 200-50hpa, the surface temperatures and the integrated water vapor (Xue et.al, 2003). However, the scheme assumes no bias in model, and the current GRAPES cannot guarantee it. Therefore, we only use the data over the oceans to avoid the influences of surface emissivity (Dong, 2005) and erroneous first guess at higher levels. The data used are still conservative in GRAPES.

Recent impact experiments have demonstrated the benefits to Northern and Southern Hemisphere forecasts from satellite radiance assimilation greatly. One of the important reasons is the complete global coverage. More data improve more forecasts if they fill gaps in data coverage. Even with much conventional observations in northern hemisphere, there remains room for continued improvement. Therefore, accelerating the use of existing and new satellite data is the direction of GRAPES.

3.4 Scatterometers wind

GRAPES can assimilate the sea surface wind from ASCAT from METOP-A and –B, and OSCAT from Oceansat-2 satellite. The impact experiments on GRAPES are on underway.

4. Discussion

It is very clear that assimilation of satellite observations have made key contribution to improve analysis and forecast skills for both hemispheres. As a result, there is a need for increasing the emphasis on satellite data usage, both in terms of introducing new satellite data, and refining the assimilation methodologies.

High spectral Infrared sounder provide temperature and humidity information with very high resolution, which have been proved the importance in the NWP centers. Clouds and precipitation observations have a wide coverage, especially over the data-sparse oceans. They provide a means for adjusting the vertical profile of latent heating in the atmosphere, and increase the consistency between the model precipitation and the observed precipitation during a dynamic assimilation period. However, the assimilations of hyperspectral infrared observation, Clouds and precipitation observations have not been implemented in GRAPES. So we shall advance them.

In summary, GRAPES has made a strong start since its inception in 2001. If we can make use of satellite data, we can continue to improve the GRAPES analysis and forecast skill.

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