

Development of a 3D Variational Assimilation System for ATOVS Data in China

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Abstract

A new 3D variational data assimilation system (GRAPES-3Dvar) with the emphasis on effective usage of satellite data has been developed in China. The forward observational operator and its tangent linear and adjoint for satellite radiances are adopted from the software package RTTOV developed by ECMWF. A bias correction scheme for input radiances is also developed. At present only AMSU-A and AMSU-B data over the oceans are used to avoid the influences of inaccurate computation of surface emissivity and erroneous first guess at higher levels. In the experiments of typhoon case studies, the assimilation of ATOVS data results in better analyses of both the inner structure of the typhoon and the large scale environment, and improves the numerical prediction of track and intensity of the typhoon. The assimilation system will be tested in an operational environment.

Introduction

The sparseness of observational data has been thought of the most serious difficulty encountered in improving numerical weather prediction in China. During the summer monsoon seasons, most of the weather systems causing disastrous weather events in China initiated either in the western Pacific or in the Tibetan Plateau where few conventional observations, such as rawinsondes are available. It is hard to increase the observational information by setting up new observing stations in these areas. So the use of satellite observations is of great importance. In comparison with the routine weather forecasts for which satellite images are widely used, the numerical weather models need quantitative use of satellite observations. There are two ways to use the space based sounding data such as TOVS radiances in the numerical weather prediction (NWP). The traditional way is to assimilate the temperature and moisture profiles retrieved from the satellite observations. The new approach is to assimilate the radiances data from the satellite directly. The latter is thought of superior over the former for the consistent treatment of observational and background errors. However, the dependence of the radiances observed from satellite on the atmospheric elements is nonlinear. The radiance data may be assimilated directly only in a frame of variational data assimilation system. In 2001, a research and development project aiming at developing new Global and Regional Assimilation and

Prediction System (GRAPES in short) was launched in China. The variational data assimilation system capable of handling satellite radiances is one of the main components of the project. This paper introduces the progress in the development of new data assimilation system with emphasis on the usage of ATOVS data in numerical weather prediction. The results shown in this paper are preliminary, so the near future work is also discussed.

GRAPES variational data assimilation

The GRAPES data assimilation system is a lat-long grid points system consistent with the GRAPES prediction model. The variables analyzed are wind components (u and v), temperature (or geopotential height at user's option) and specific humidity. Let X_a stand for the field of variables to be analyzed, X_b the background field and Y the observations. The assimilation is in fact to minimize the cost function:

$$J = (X_b - X_a)^T B^{-1} (X_b - X_a) + (H(X_a) - Y)^T O^{-1} (H(X_a) - Y) \quad (1)$$

where B and O are the covariance matrices of background error and observational error respectively, and H is the observational operator. Special 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 is realized either by a recursive filter for the regional case or by spectral transformation for the global case. It is also assumed that both dynamic and mass fields consist of balanced and imbalanced components, and the background errors of the latter are independent. The flexibility of the observational operator H allows the use of satellite radiances as observational data in the 3DVar.

Assimilation of satellite radiances

In the case of assimilation of satellite radiances, the observational operator is the radiative transfer model which converts the atmospheric temperature and moisture profiles to the radiances received by the satellite. GRAPES 3DVar uses the fast radiation transfer model RTTOV developed by ECMWF. So the operator H in equation (1) becomes:

$$H(X) = \text{RTTOV}(I_v(I_h(X))) \quad (2)$$

Where I_v and I_h are the operators of vertical and horizontal interpolation from the model grid point to the precise location of the satellite radiances and the vertical levels where RTTOV defines the atmospheric profiles.

The background field is the short term (6-12 hours) prediction of the global model T213 of the National Meteorological Center of China. In this stage, only radiances for those channels not sensitive to the deep clouds, surface states and atmospheric temperature at very high levels (above 10 hpa where serious background errors exist) are assimilated. In the case of ATOVS of NOAA-16 and NOAA-17, the data currently assimilated are AMSU-A channel 5-11 and

AMSU-B 3-5. This channel selection may be rather conservative, so more channels will be tested in the near future.

The relay *HRPT* satellite data from NOAA series polar orbiting satellites received in three ground stations are preprocessed with the software package AAPP introduced from EUMETSAT in the National Satellite Meteorological Center and made available for numerical weather prediction. This data set, only covers China and the neighboring area, are used currently for pre-operational trials of the 3DVar system. Raw satellite data with global coverage are expected to be used in the future operational system. The radiances from ATOVS instruments are interpolated to the HIRS sounder's field of view. With high-resolution AVHRR data as well as AMSU data, the cloud detection technique for current ATOVS is improved greatly. When available in the FOV of the HIRS, such information enhances the cloud detection for selecting initial guess and the inversion process.

Before the data are fed to the 3DVar, two kinds of bias in the observation are corrected following the algorithms proposed by Harris and Kelly (2001). They are the bias depending on scan angles and the bias depending on the categories of air mass. The correction to the scan angle related bias changes with latitudes. The air mass related bias is predicted with linear regression based on the statistics of innovation vectors derived from recent cases. The predictors are the thickness between 1000-300hpa and 200-50hpa, the surface temperatures and the integrated water vapor. Fig 1 shows the scan bias of NOAA16/AMSU-A channel 5-12 in the zone 40-50 deg lat. Fig 2 shows the change of the difference between the observed brightness temperatures and the brightness temperatures derived from the background brought by the bias correction.

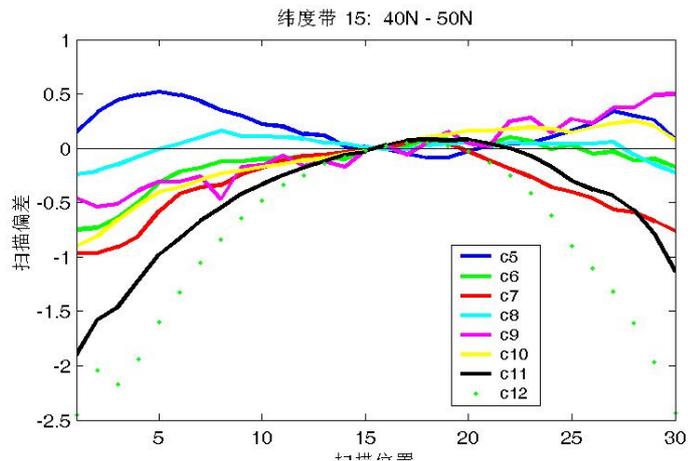


Fig1 Scan bias of NOAA16 AMSU-A CH 5-12 in the zone 40N-50N samples for statistics: Jul.1-10 2003 06/18 UTC (6 hours time window)

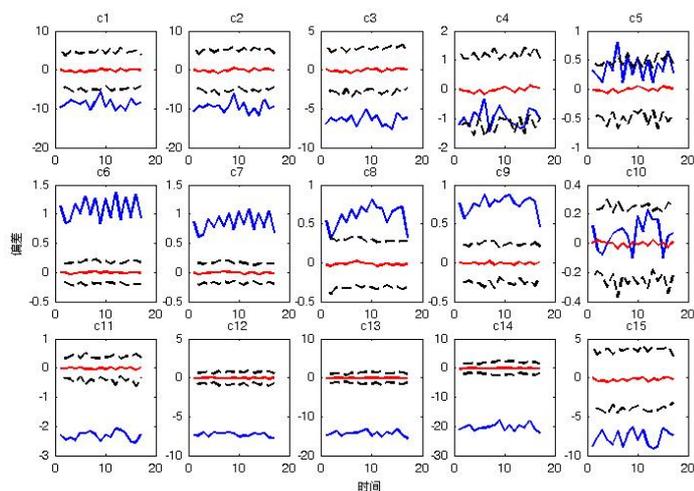


Fig 2 Comparison of brightness temperature (background-obs.) Blue : before correction; Red: after correction; Black : with standard deviation added and subtracted

In addition to satellite radiances, conventional rawinsonde observations, cloud motion vectors from geostationary satellites and surface winds from QUIKSCAT are also assimilated by the assimilation system. In order to investigate the impact of ATOVS data on numerical prediction of high impact weather events in China, a series of experiments of assimilation and prediction have been implemented. The results of most cases show positive impacts of ATOVS data on improvement of the analyses and predictions. The most impressive results are the reduction of forecast errors of the tracks of tropical cyclones over the western pacific. A case study is discussed in the next section.

Impact of ATOVS data on typhoon prediction

The case selected here is typhoon Rammasun 2002. The track of this typhoon is shown in Fig 3. As mentioned in section 3, only the ATOVS data received in three ground stations are available for the test. The prediction model used in this impact study is the weather research and forecast model (WRF) developed in the U.S. The first guess is taken from the operational global model T213 of

the National Meteorological Center, China. The analysis by the GRAPES-3DVar is processed by the WRF standard initialization scheme to

form the initial field of model integration. Three different sets of observational data are used for assimilation. The first set, referred to as the control experiment hereafter, only contains the rawinsondes data available. The second set, the exp1, contains the satellite radiances only. The third set, exp2 hereafter, contains both rawinsondes and satellite radiances. The differences between the predictions with different observational data sets reflect the impact of assimilation of satellite radiances on the forecast. To find the difference of fields of geopotential height on 500hpa level between the above experiments, it is easier to compare the analysis increments, i.e. the difference between analysis and the first guess, for different experiments. The increments are consistent with the coverage of the observational data. When only rawinsondes are used, the analysis is almost the same as the first guess over the western pacific for there are few rawinsondes there. The use of ATOVS data changes the flow characteristics in this region. The positive increment coincident with the subtropical high in the North Western Pacific implies that the high in the analysis is extended more westward and stronger than in the first guess. In many cases, the movement of tropical cyclones over the Western Pacific is dominated by the behavior of the sub-tropical high, so the difference in the position and intensity of the high are very important for the forecast of tropical cyclones.

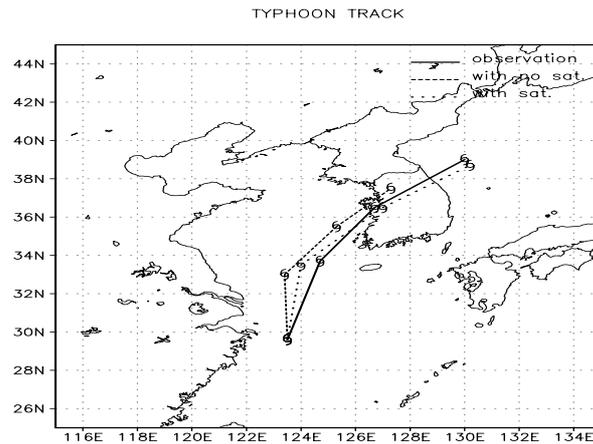


Fig 3 Tracks of typhoon Rammasun 2002
Solid line: observation, dashed line: prediction without ATOVS,

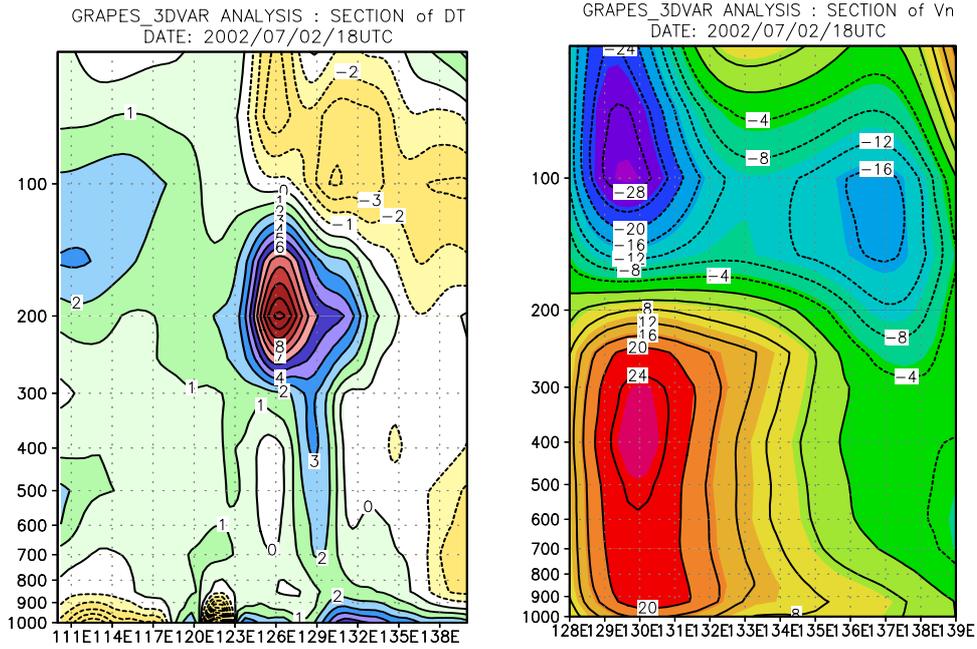


Fig 4 Vertical cross section of analysis with ATOVS along 23 lat Left: temperature anomaly from zonal mean Right: tangential wind

Fig 4 is the vertical cross sections of temperature (anomaly from the zonal mean), and tangential wind component along 23 lat of the analysis with ATOVS data. The warm core near the center and the cyclonic circulation are very well defined. The temperature anomaly and the

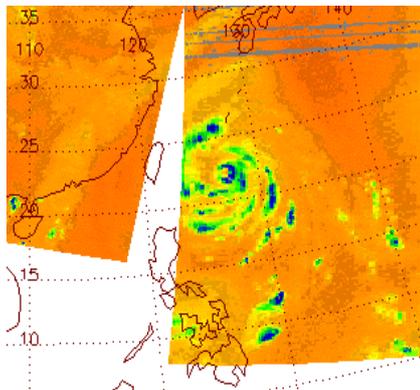
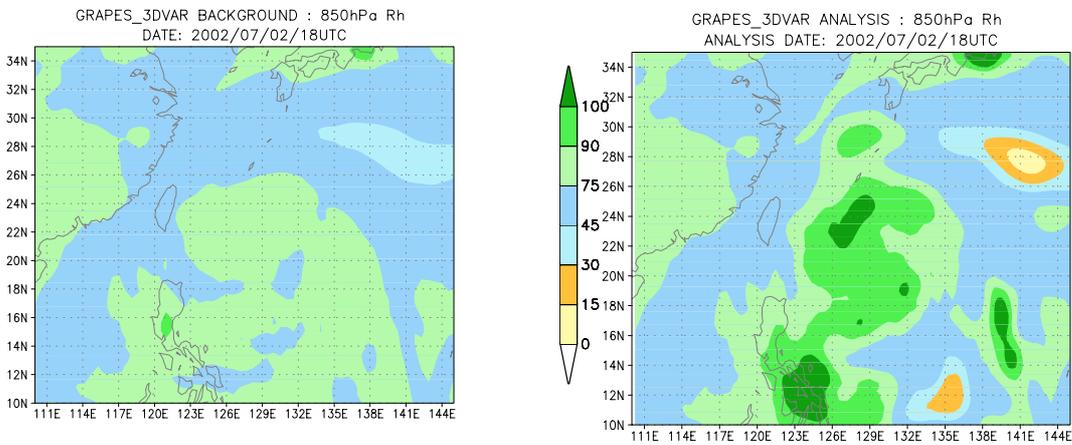


Fig 5 The analysis of moisture on 850hpa with ATOVS (upper right), background (upper left) and microwave image

cyclonic circulation are much weaker in the background fields and similar in the analysis with only conventional rawinsonde data. Fig 5 shows the analyses of moisture with ATOVS data. The background field and the microwave image are also presented in the figure. It is seen from this figure that the assimilation of ATOVS data results in the analysis of moisture much more consistent with the cloud pattern around the typhoon.

Fig 6 shows the comparison of predicted fields of geopotential height on 850hpa level with and without ATOVS data. The analysis used for validation is also presented. It is obvious that the prediction with only conventional rawinsondes incorrectly forecasts the center of typhoon in the central Korea Peninsula. The use of ATOVS data improves the forecast. Fig 3 is the predicted tracks of the center of this typhoon with and without ATOVS data and the track observed. The improvement by using ATOVS data is also seen in this figure.

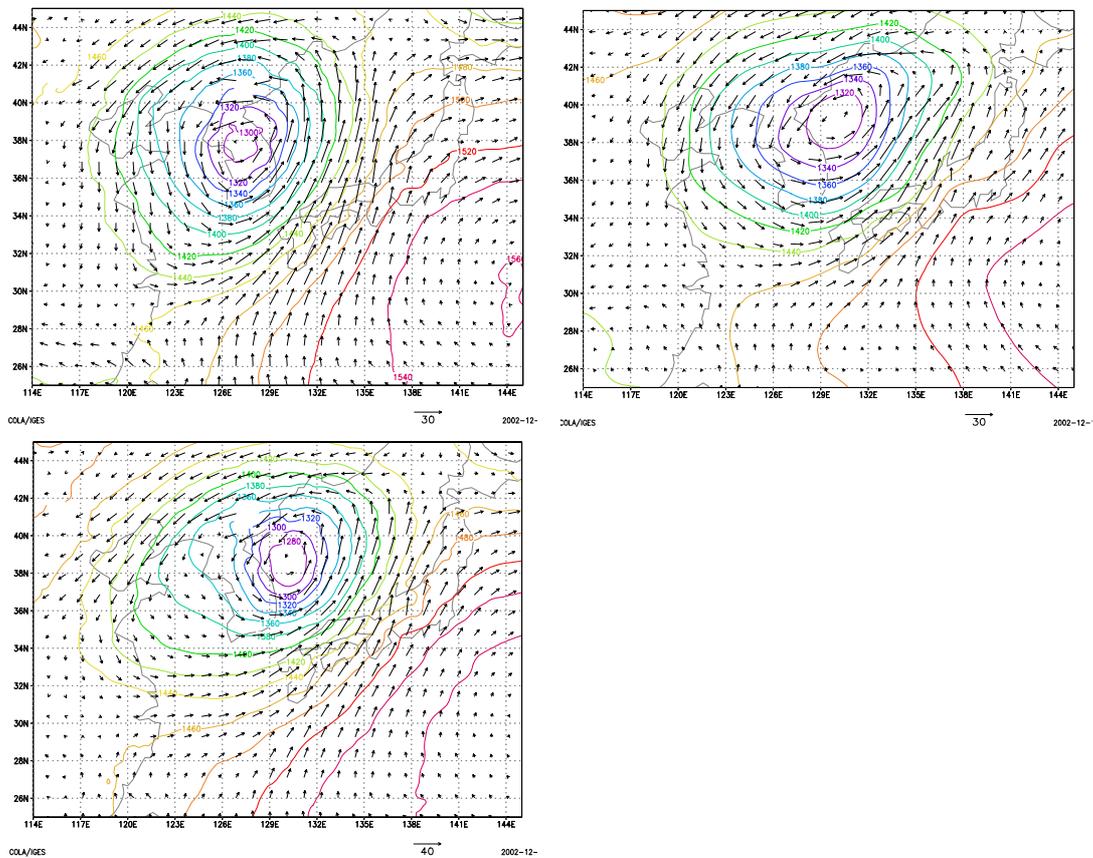


Fig6 Geopotential height on 850hpa. Analysis (upper right), prediction without ATOVS (upper left), prediction with ATOVS (lower).

Discussion

(1) The positive impacts of assimilation of ATOVS data on the typhoon analysis and prediction are found in the real case study of typhoon Rammasun 2002. The use of ATOVS data improves the analyses of the large-scale flow pattern, especially the extension and intensity of the Northwestern Pacific sub-tropic high, as well the moisture fields and inner structure of typhoon. The improvements in the initial fields result in better numerical prediction of typhoon track and intensity.

(2) One of the unrealistic features appearing in the analyzed structure of the typhoon is the relatively low temperature in the mid-low troposphere and weaker tangential wind in the low troposphere which can be seen in fig 5. This may be the result of contamination of radiances by the deep and precipitating clouds near the center of typhoon.

(3) The use of other satellite products may help to further improve the analysis near the center of typhoon. One possibility is to assimilate the wind information from the satellite, such as cloud drift wind from geo-stationary satellites or the surface wind from QUIKSCAT. Some experiments have been done. The results will be reported in other papers.

(4) It has been mentioned that the current channel selection is rather conservative. The use of more channels needs the reduction of errors in the background fields on the upper levels and improvement of the scheme of cloud detection. These issues will be emphasized in the future research.

References

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