IMPACT OF VARIATIONAL DATA ASSIMILATION OF ATMOSPHERIC MOTION VECTORS ON TROPICAL CYCLONE TRACK FORECASTS

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Abstract

The results of twenty-two cases from eight TCs over the western North Pacific in 2002 show that the MM5 4DVar assimilation of the Geostationary Meteorological Satellite-5 water-vapor and infrared AMVs leads to appreciable improvements in the track forecasts, with average reductions in track error of ~5% at 12 h, 12% at 24 h, 10% at 36 h and 7% at 48 h. Preliminary results suggest that the improvement depends on the quantity of the AMV data, especially those available at the lower-levels for assimilation.

One case-study of assimilating AMSU-A retrieved temperatures, QuikSCAT sea-level winds and AMVs using model-constrained 3DVar gives dramatic TC track error decreases, which indicates that more satellite data give better performances.

1. Introduction

Errors of TC forecasts can generally be traced to errors in initial conditions and the imperfect forecast model due to physics and dynamics related approximations. TC spends most of its lifetime over the ocean where the conventional observations are sparse. Therefore, to improve TC initial conditions, in addition to TC initialization techniques, such as bogussing scheme, relocation and bogus data assimilation, satellite data assimilation also plays a very important role.

As the 4DVar data assimilation scheme has been demonstrated to be an effective tool to assimilate non-conventional data, therefore we investigate the impact of assimilating AMVs with the 4DVAR method on prediction of Western North Pacific TC tracks.

However, the 4DVar technique requires a large amount of computer resources, which limits its practical application. On the other hand, the 3DVar technique does not impose constraints on the numerical model such as the dynamics and physics, which are used in the 4DVar technique. Therefore, a numerical forecast model is adopted as weak constraint in the 3DVar, and we label it as the model-constraint 3DVar (MC-3Dvar).

In addition to AMV data, we can also obtain other satellite products, such as AMSU retrieved temperature and humidity, TRMM rain rate retrievals, and QuikSCAT sea level winds, which can provide surface wind structure information of TCs. Given the correlation between dynamic and thermodynamic processes, the synergy of assimilated winds and AMSU retrieved temperatures is anticipated to provide better TC forecasts. In the second part, MC-3DVar is employed to use the combination of AMVs, QuikSCAT and AMSU retrieved temperatures.

2. 4DVar assimilation of AMVs

A 6-h assimilation window is used for the MM5 4DVAR system (Zou et al. 1997) to incorporate the AMVs at the initial time and 6 h later. Twenty-two cases from eight TCs occurring over the western North Pacific in 2002 are studied. AMVs used in this study are provided by the China National Satellite Meteorological Center. They are derived from GMS-5 Water vapor and IR imageries, with resolution of 1 latitude–longitude. On average, 95% are observed above 400 hPa and 55% are concentrated between 200 and 300 hPa. The error in the upper-tropospheric AMVs is determined empirically to be 6 m s^{-1}. Any AMV with a difference from the background > 3 times the error, i.e. 18 m s^{-1}, is rejected.

Because 4DVar is very computationally demanding, the model resolution is relatively coarse, with horizontal spacing of 45 km and 23-layer half-σ levels in the vertical. And to save computational time, only 10 iterations are carried out during the 4DVar minimization procedure.

For the case of Phanfone at 1200 UTC on 17 August 2002, compared with background, the largest adjustment through assimilation occurs south of the TC center between 250 to 300 hPa (Fig.1). In the background, there are inaccurate south to southwesterly winds. In the analysis, they are changed into southeasterly to northeasterly winds. Apparently, assimilation of the AMVs generates an anticyclonic circulation at the upper-levels.

In general, assimilation of AMVs reduces the mean track error at all forecast times (Fig. 2). The mean 24-h position error is reduced from 146 to 129 km, and the 48-h error from 215 to 200 km. Among the 88 forecasts for the 22 cases (12 h interval), 48 forecasts have a reduction in track error after assimilation of the AMV data, 21 forecasts with no change in track error and only 19 forecasts with increased track error (Wang et al. 2006).

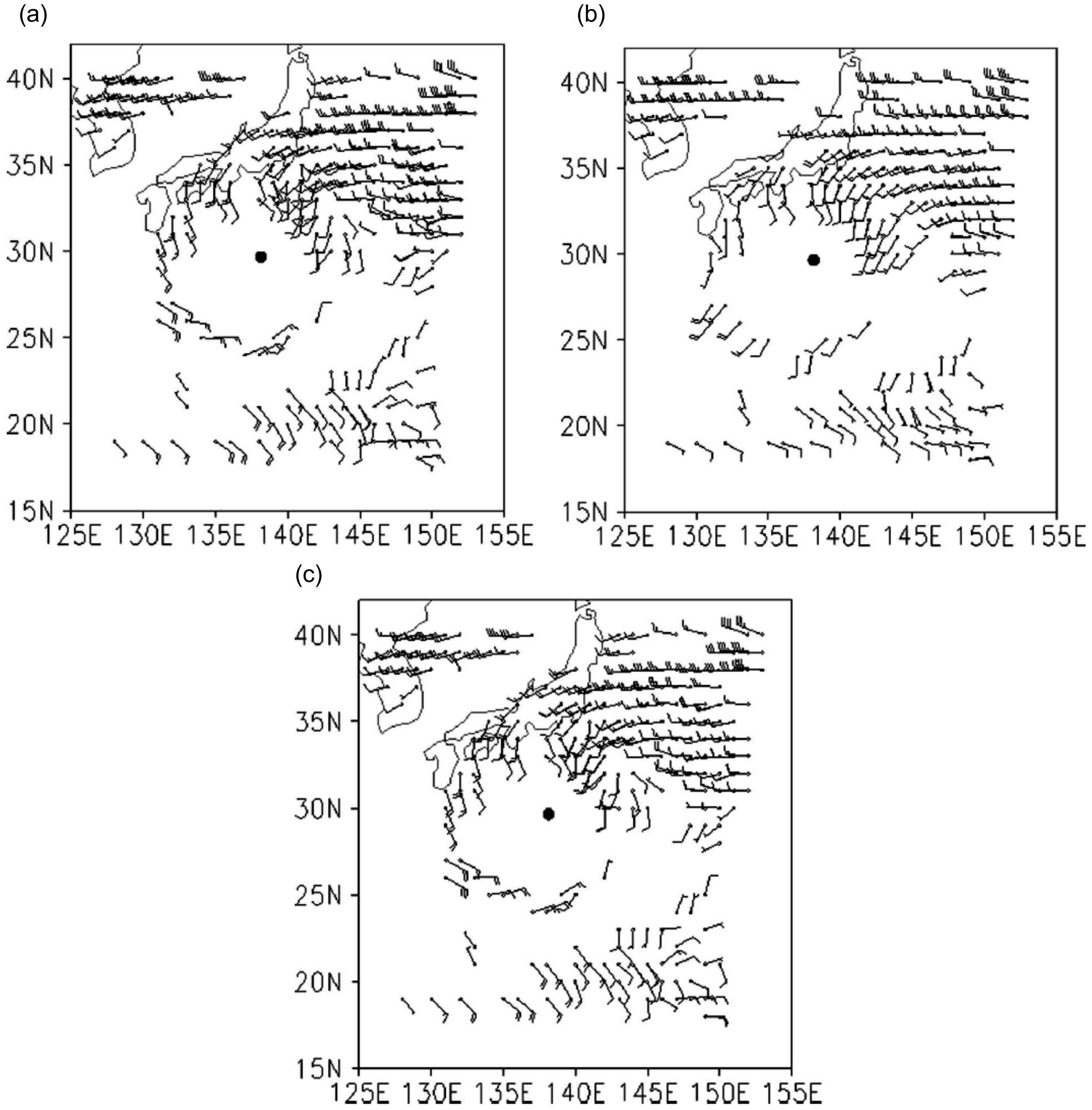


Figure 1: **(a) AMV observations, (b) background, and (c) analysisl winds at 1200 UTC 17 Aug 2002between 250 and 300 hPa. The dot indicates the TC center.**

A further examination of the individual cases suggests that the effectiveness of assimilation of the AMVs varies with the quantity of the AMVs used, especially those at lower levels. Among the 88 forecasts, there are 44 forecasts with assimilated AMVs more than the average number used in these experiments. Among these 44 forecasts, 27 show improvement and only 5 have larger errors. The other 14 forecasts with increased errors use AMVs less than the average (Table 1).

Sensitivity study (Xiao et al. 2002) has shown that TC forecast is more sensitive to winds at lower levels. The sensitivity of the TC forecasts to the low-level winds is therefore examined further although here, the quantity of the AMVs available below 400 hPa is relatively small, with only an average of 57 observations in the model area. Among the 36 forecasts with assimilated AMVs more than this average number, only one has error larger than that of CTRL, while an overwhelming majority shows a reduction in track error. The other 18 forecasts with increased errors all have AMV observations less than the average. This result suggests that for a better TC track forecast, more AMVs at lower levels are needed. In addition, an increase in the AMVs at lower levels apparently has a more significantly positive impact on the TC track forecast.

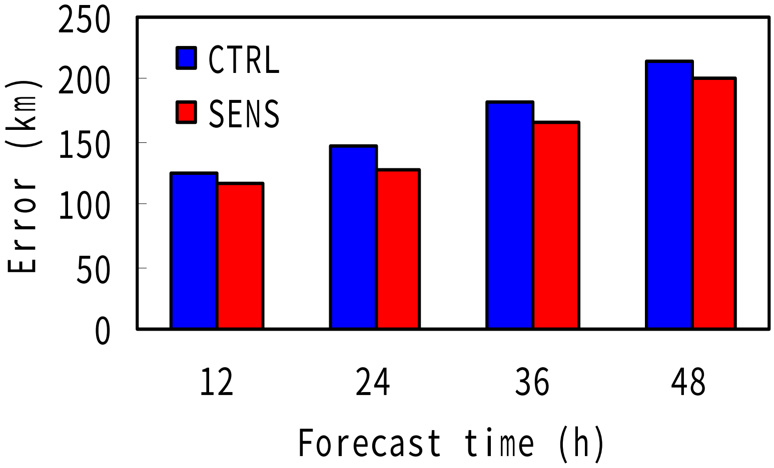
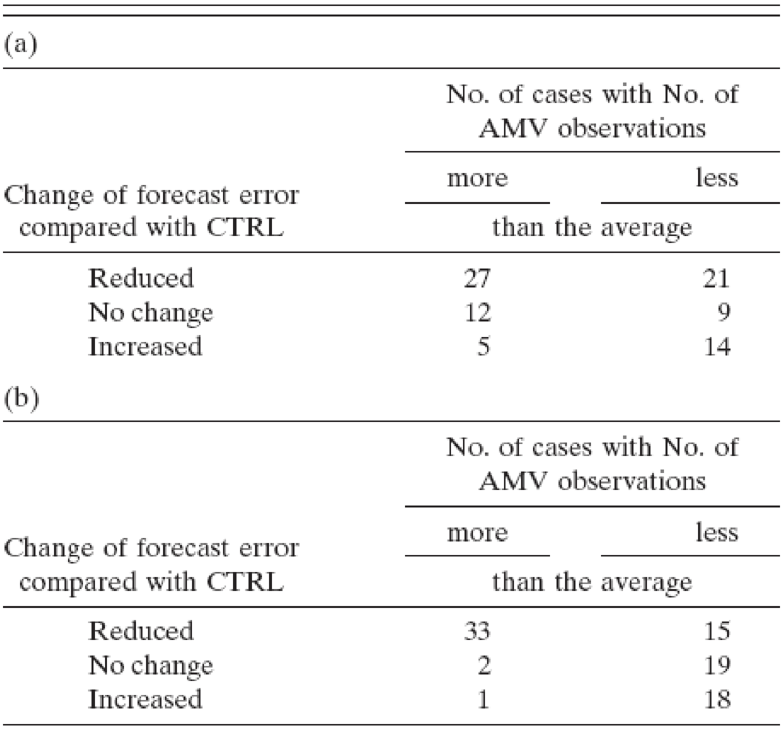


Figure 2: **Mean forecast track errors (km) for the 22 cases: CTRL and WIND experiments.**



(a)

Change of forecast error compared with CTRL	No. of cases with No. of AMV observations more than the average	No. of cases with No. of AMV observations less than the average
Reduced	27	21
No change	12	9
Increased	5	14

(b)

Change of forecast error compared with CTRL	No. of cases with No. of AMV observations more than the average	No. of cases with No. of AMV observations less than the average
Reduced	33	15
No change	2	19
Increased	1	18

Table 1: **Number of cases with different changes in the forecast errors compared with the CTRL run when different quantities of AMVs are assimilated. (a) Data at all levels are included and (b) only data below 400 hPa are included. The average number of AMVs including all levels is 1344 and that for AMVs below 400 hPa is 57. For each case, an entry in the "more" than the average category refers to the case having the number of AMVs greater than this average number [1344 in (a) and 57 in (b)], and similarly for an entry in the "less" than the average category.**

3. MC-3DVar assimilation of AMVs, QuikSCAT and AMSU retrieved temperatures

MC-3DVar (Liang et al. 2007a, b) can improve balance between analysis variables by introducing model physical and dynamical constraints into 3D-Var. Because it is still a 3DVar method, it can dramatically reduce the computer resources compared with 4DVar. In this method, a penalty term is added to the traditional 3DVar cost function. It works as a low-pass filter so that the high frequency waves excited by new data can be effectively suppressed. The time tendency in the penalty term is calculated by running the forecast and adjoint models of the 4DVar system of MM5 for one time step (60 s).

The AMSU-A retrieved temperatures from NOAA-15 are provided by the NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) on a 1 latitude–longitude grid at 40 pressure levels from 1000 to 0.1 hPa. To eliminate the rainfall contamination of AMSU retrieved temperatures, those below 600 hPa are discarded due to the large errors. The observation error of AMSU-A temperatures is set to be 1.5 K.

The QuikSCAT data are pre-processed according to the error distribution and characteristic of the TC circulation. Due to rainfall contamination near the TC eye, QuikSCAT sea-level winds have large errors near the eyewall area. Using Fourier analysis, azimuthal waves shorter than wave number 3 are eliminated within 3 ° latitude radius around the TC centre. Then, the QuikSCAT winds within this area are replaced by the sum of wave number 0, 1 and 2, which gives a smoother structure.

For the case of the tropical storm Vongfong at 1200 UTC on 17 August 2002, when only AMSU retrieved temperatures are assimilated, improvement only is observed before the 12 h forecast. When both AMSU and QuikSCAT are assimilated, the forecast errors are reduced greatly. After AMVs are added, the result shows dramatic track error decreases to 11 km at 24 h and 80 km at 48 h (Fig. 3).

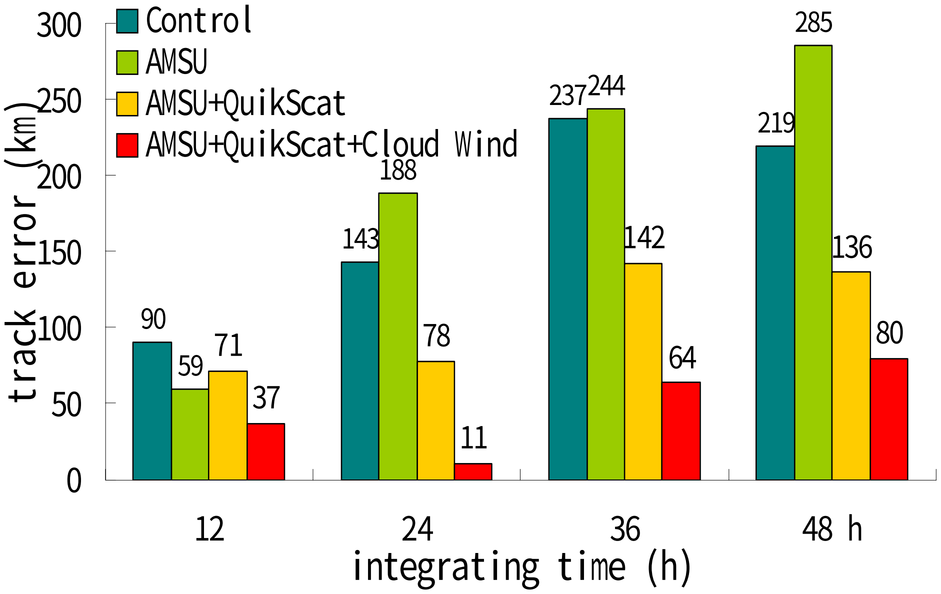


Figure 3: **Track forecast errors of Vongfong from 12 UTC 17 Aug to 12 UTC 19 Aug 2002.**

When AMSU and QuikSCAT are assimilated, the northward movement is slowed and the westward movement is increased compared with CTRL and AMSU assimilation runs. After AMVs are assimilated, it makes the TC move westward in the first 24 h as observed (Fig. 4).

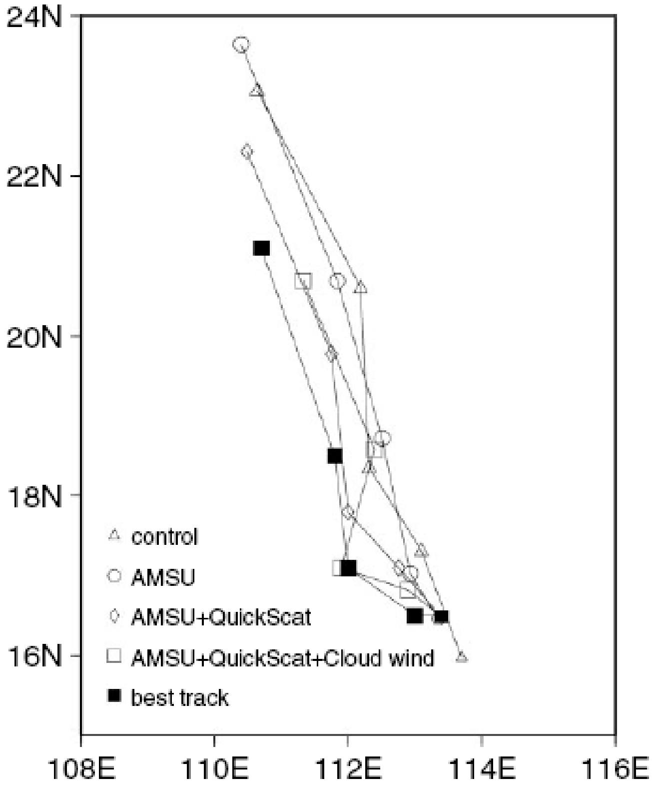


Figure 4: **Tracks of control and different satellite datasets assimilation experiments of Vongfong from 12 UTC 17 Aug to 12 UTC 19 Aug 2002.**

The SLP and lower-level wind structures are fairly symmetric in the background， with much weaker precipitation. After AMSU retrieved temperatures are assimilated, the SLP becomes more asymmetric with enhanced westerly winds in the south and reduced winds in the north. The maximum 1 h rainfall southwest of the TC centre is very similar to the observation. The improvement of the TC structure reduces the error at the first 12 h. However, the amplitude of the asymmetric rainfall around the eye is still small. Assimilating QuikSCAT further increases the asymmetric rainfall structure. Study (Chan et al. 2002) has shown that TC often has a tendency to move towards the area of strong convection. The increased rainfall apparently causes the TC to move more westward. Although assimilation of the QuikSCAT gives a better result, these winds only provide additional information at the lower levels. Assimilating AMVs gives the strongest rainfall in the southwest (Fig. 5).

At 200 hPa, assimilating AMSU retrieved temperatures enhances the anticyclonic flow in the north, so the TC move northward faster than the control run and hence gives a larger track error after the 12 h forecast. When QuikSCAT is added, the enhanced easterly winds favor a westward displacement of the TC. A better track forecast is therefore observed. When AMVs are assimilated, the anticyclonic flow in the north is reduced greatly, so is the northward motion of the TC. Hence it gives the smallest track errors (Fig. 6).

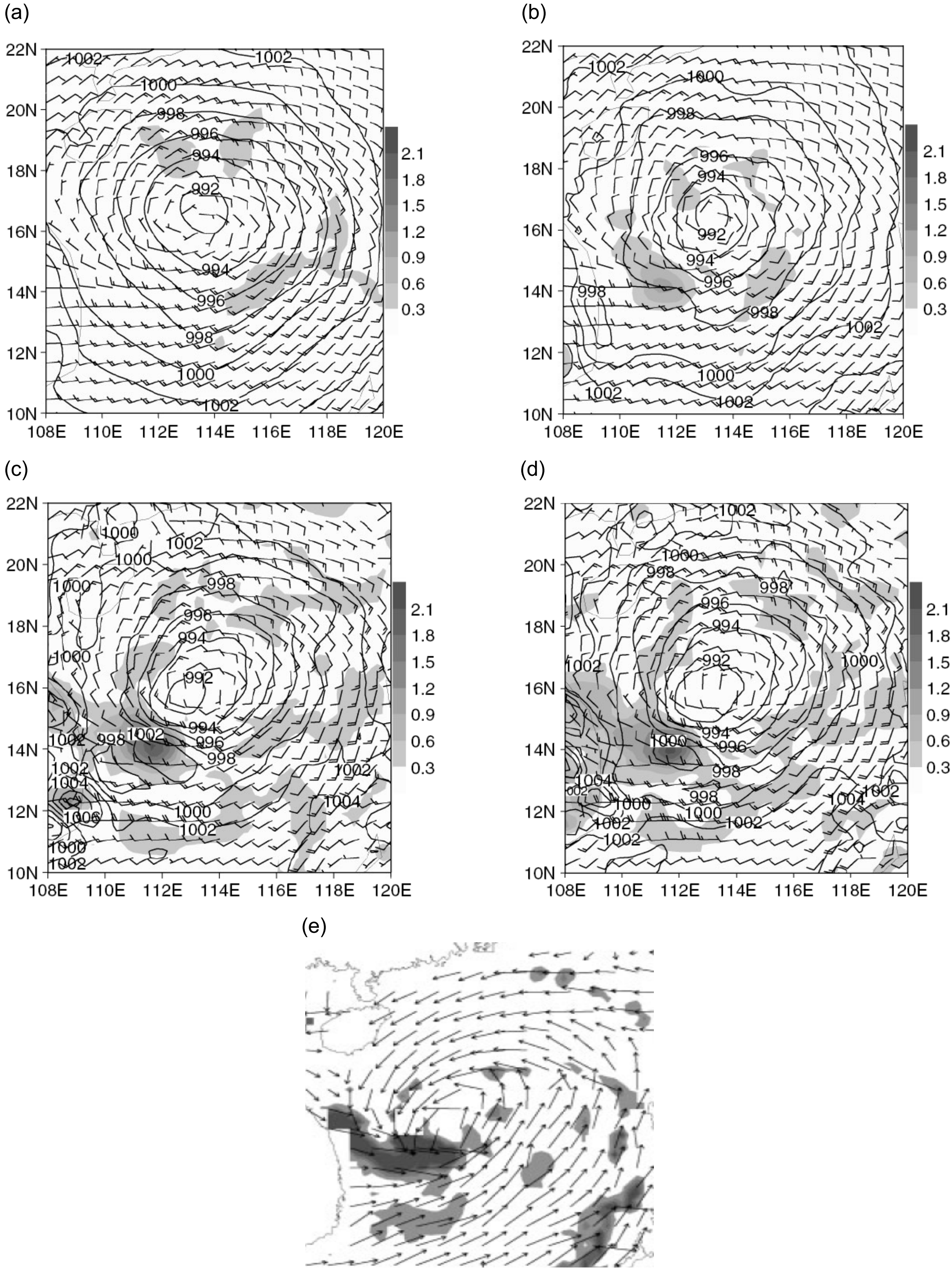


Figure 5: **The initial SLP (contour, unit: hPa), sea-level winds (barbs), and 1 h rainfall (shaded, unit: cm) in the**

(a) control, (b) AMSU-A temperature, (c) AMSU-A temperature plus QuikSCAT winds,

(b) and (d) AMSU-A temperature plus QuikSCAT winds and AMVs assimilation experiments.

Shaded in (e) is the rainfall area according to SSM/I rain rates extracted from the website http://www.ssmi.com,

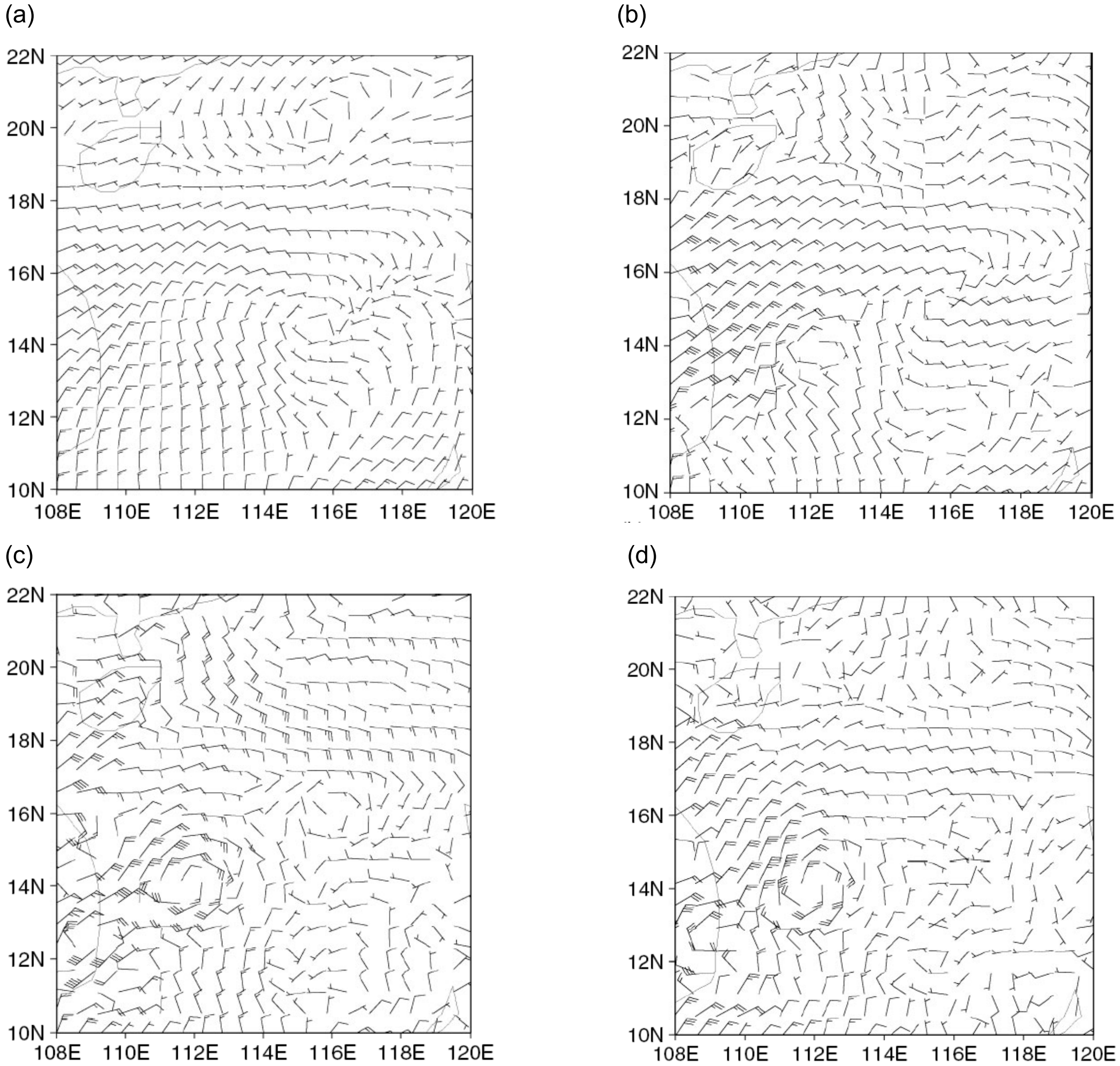


Figure 6: **As Figure 5 a-d, except wind fields are at 200 hPa.**

4. Summary

Quite promising overall 48-h forecast results are obtained by assimilating the AMV observations. However, the effectiveness of the assimilation of this GMS-5 AMV data appears to vary with the quantity of the assimilated AMVs. Improved forecasts tend to occur for cases with more AMVs, especially if these observations are available below 400 hPa.

It is worth noting that the AMV observations from the GMS satellite used in this study have limitation in data coverage. However, this limitation now can be overcome with AMVs from GOES and MTSAT-1R, etc., which are providing much improved coverage of the lower levels.

One case study shows that the MC-3DVar data assimilation method can be used to improve the initial conditions of TC numerical forecasting. In addition, more satellite data such as AMSU-A retrieved temperatures, QuikSCAT sea-level winds and AMVs are also shown to be favorable for improving the numerical TC forecasts.

Because of the limitation in model resolution and spatial resolution of the satellite data used in the study, only TC track forecasts are considered. With Rapid increase in computing power and enhancements in the accuracy and density of the satellite data, improvements in TC intensity forecasts are also anticipated with assimilation of AMVs and other satellite data.

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