Observing-system Experiments Using the Operational NWP System of JMA

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Abstract

The Numerical Prediction Division of the Japan Meteorological Agency (JMA) conducted observing-system experiments (OSEs) using the operational NWP system of JMA targeted for typhoons Sinlaku (0813) and Jangmi (0815) with T-PARC special observations in 2008. In many cases, positive impacts were found both in track and intensity forecasts using these observations. Additionally, assimilation of operational tropical cyclone (TC) bogus data contributed to the improvement of track and intensity forecasts at the before-recurvature stage, although it degraded track forecasts in some cases. Investigating the usage of special observations in the operational system revealed a number of problems with the assimilation of horizontally dense dropwindsonde observations. In verification of the sensitivity analysis system, OSEs using T-PARC special observations over a high-sensitivity area showed better performance in TC track forecasts for Sinlaku. These results are expected to contribute to improving the TC forecasts of the NWP system in the near future.

1. Introduction

Under the cooperation of the North American, Asian and European THORPEX Regional Committees, the THORPEX Pacific Asian Regional Campaign (T-PARC) for typhoon track forecasts in the summer of 2008 was run, and included special observation techniques such as dropwindsondes from aircraft, extra upper soundings by JMA observatories and research-vessel monitoring. In addition, Meteorological Satellite Center of JMA (MSC) produced MTSAT-2 Rapid Scan Atmospheric

Motion Vectors for T-PARC (MTSAT-2-RS-AMV). OSEs using the operational NWP system of JMA were performed for typhoons Sinlaku and Jangmi with T-PARC special observations. The aim of the OSEs was to demonstrate the impact of special observations and the effectiveness of the next-generation Interactive Forecast System.

This paper describes the OSE results. Sections 4.2 and 4.3 give a brief outline of the global NWP system and the experimental design. Section 4.4 gives the OSE results and details some case studies. Section 4.5 summarizes the results and concludes the paper.

2. Outline of the global NWP system

All experiments were conducted using the operational JMA GSM (TL959L60, horizontal resolution approx. 20 km) and 4D-Var data assimilation system (inner resolution T159L60, horizontal resolution approx. 80 km, 6-hour assimilation window). An outline of the global NWP system is given in Table 1. More details of the system can be found in Nakagawa (2009).

Table 1 Outline of the global NWP system at JMA

Global Data Assimilation System	
Method	4D-Var
Resolution (inner model)	T159L60 (Gaussian grid, horizontal resolution approx. 80 km, model top 0.1 hPa)
Assimilation window	6 hours (±3 hours, time slots approx. 1 hour)
TC bogus data	Not used in TEST and CNTL experiments but assimilated in operational run and BOGUS

Global Spectral Model	
Resolution	TL959L60 (reduced Gaussian grid, horizontal resolution approx. 20 km, model top 0.1 hPa)
Forecast time	84 hours/216 hours (00, 06, 18 UTC/12 UTC)

3. Experimental design

Three experiments were performed in T-PARC:

(I) Special observations were assimilated with techniques including dropwindsonde from aircraft, upper soundings from JMA observatories and research-vessel monitoring (TEST).

(II) TC bogus data (JMA 2007) were assimilated instead of special observations (BOGUS).

(III) No special observations or bogus data were assimilated (CNTL).

The aims of BOGUS were to evaluate the current TC bogus technique and investigate the relative importance of special observations in an operational context.

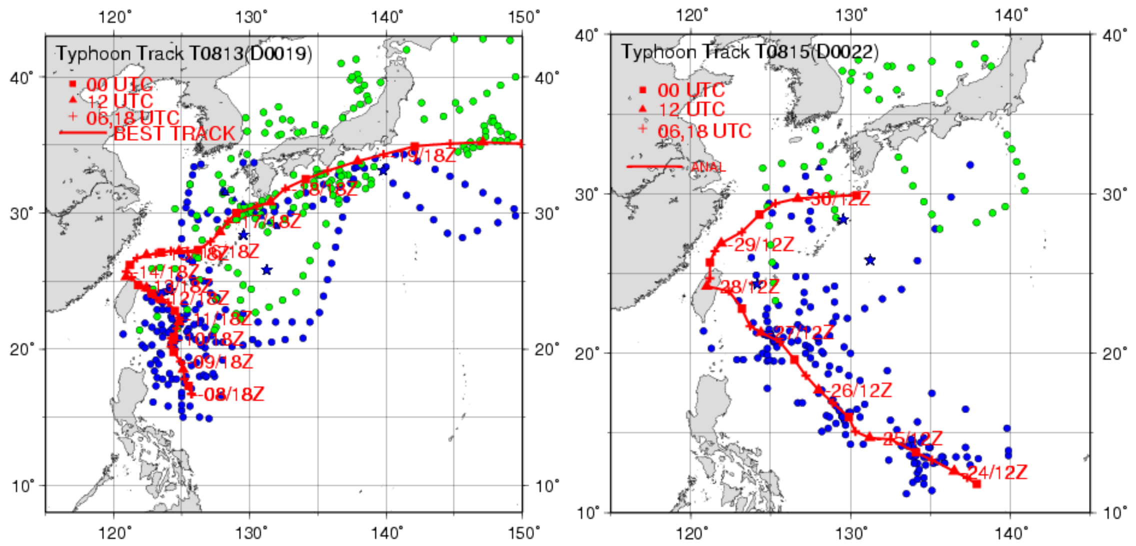

Figure 1　The observed tracks of Sinlaku (left) and Jangmi (right) and the positions of special observations. The blue and green plots show special observations at the before- and after-recurvature stages, respectively. The red solid lines show the best tracks of Sinlaku and Jangmi.

The experimental periods were from 00 UTC on 9 September 2008 (0900; hereafter the date and time are abbreviated as *ddhh* without the month) to 1818 for Sinlaku and from 2412 to 3018 for Jangmi. The observed tracks of the two typhoons are shown in Figure 1. Hereafter, the period is divided into two stages. One is the before-recurvature stage (Sinlaku: before 1418; Jangmi: before 2818), and the other is the after-recurvature stage (Sinlaku: after 1500; Jangmi: after 2900). The effect of the special observations and TC bogus data remained in the later analysis through the data assimilation cycle. For the case study, the first guess was taken from the CNTL run; 84-hour forecasts for all initial times and 216-hour forecasts for the selected cases were conducted. TC track forecasts were verified using the TC best track provided by the RSMC Tokyo - Typhoon Center (OBS). The results of the OSEs were evaluated with CNTL.

4. OSE results

4.1 Sinlaku (0813)

(a) Track forecasts

In the before-recurvature stage from 0900 to 1418, the TC track errors of TEST were reduced compared to CNTL by between 23 and 30% for first-12-hour forecasts, and by approximately 10% for 18- to 48-hour forecasts. The results for the first-12-hour forecasts are statistically significant with a 95% confidence level (hereafter referred to simply as statistically significant). The TC track errors of BOGUS increased by between 10 and 23% for first-30-hour forecasts, although the TC track position for BOGUS was close to OBS at the initial time. On the other hand, for 60- to 72-hour forecasts, the track errors were reduced by approximately 15% (Figure 2).

In the after-recurvature stage from 1500 to 1818, the TC track errors of TEST showed a statistically significant reduction of about 10% for 66- to 84-hour forecasts. However, the TC track errors of BOGUS remained almost the same as those of CNTL (Figure 3). These results are not statistically significant. A forecast initialized at 0912 is shown in Figure 4. The tracks of both TEST and BOGUS are closer to OBS data than those of CNTL.

(b) Intensity forecasts

The intensity forecasts were evaluated using the mean errors of the central pressure forecasts. Figure 5 shows the results for the before-recurvature stage of Sinlaku. In this case, intensity forecast errors showed a statistically significant reduction over 10 hPa in both TEST for 36-hour forecasts and BOGUS for 24-hour forecasts. On the other hand, the impact on the intensity forecasts in TEST was almost neutral in the after-recurvature stage. In the case of BOGUS, however, the intensity forecasts showed negative pressure errors after the 12-hour stages (Figure 6). Since the typhoon was not in the extra-tropical transition stage in this case, one reason may be that the operational NWP model did not create a realistic typhoon structure.

(c) Impact of special observations on TC track predictions at 1112

Figure 7 shows the TC track forecasts of TEST, BOGUS and CNTL at 1112. BOGUS and CNTL followed a track close to that of OBS at the beginning. The TC track forecasts of TEST showed rapid recurvature, and this fast movement resulted in large track errors. We found that dropwindsonde observations in the TC core fields within 200 km were assimilated (Figure 8). The positions of observed wind circulations on each vertical level were different from those of OBS, bringing a biased and warped vortex to the south in the analysis. The analysis fields for comparison of TEST with CNTL are shown in Figure 9 as the differences between these results. Deepened geopotential height and strengthened vortex circulation to the south and east of the TC center are found. The TC generally tends to be moved to a deeper geopotential height, and moved southward then northeastward. It can therefore be said that dropwindsonde data for the core region of the TC have a large impact on TC forecasts. However, quality control (QC) procedures for observational data around the TC center are difficult. This problem requires further investigation in the future.

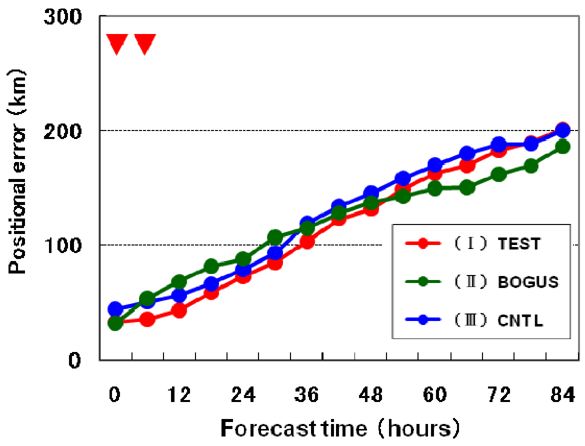

Figure 2 Positional errors for Typhoon Sinlaku in the before-recurvature stage from 0900 to 1418. The red line is for TEST, which assimilated special observations. The blue line is for CNTL, which did not assimilate special observations. The green line is for BOGUS, which assimilated TC bogus data but did not use special observations. The red triangles denote that the difference of TEST minus CNTL is statistically significant with a 95% confidence level.

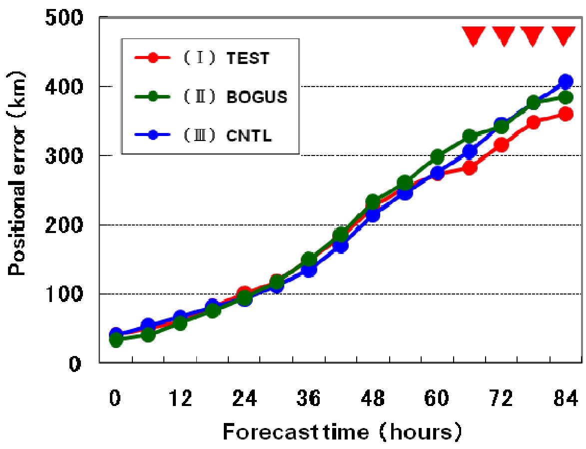

Figure 3 As per Figure 2, but for the after-recurvature stage

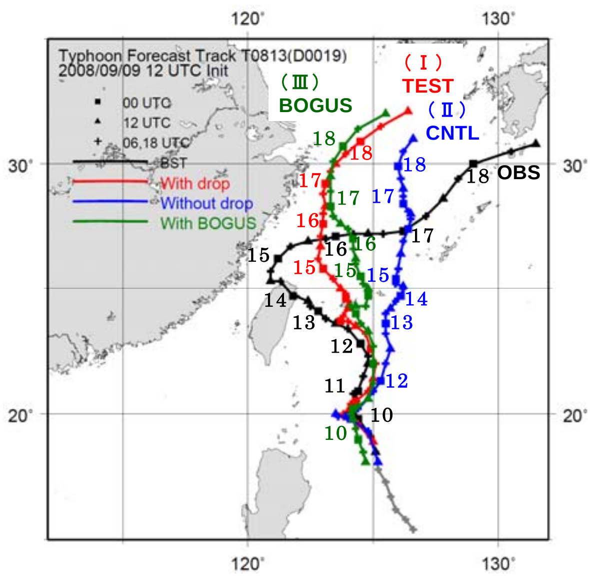

Figure 4 Typhoon track forecasts from the OSEs with (red markers: TEST) and without (blue markers: CNTL) special observations and with BOGUS data (green markers) for Typhoon Sinlaku, initialized at 0912. The black markers show OBS data. The numbers indicate the date of the typhoon’s location at 00 UTC.

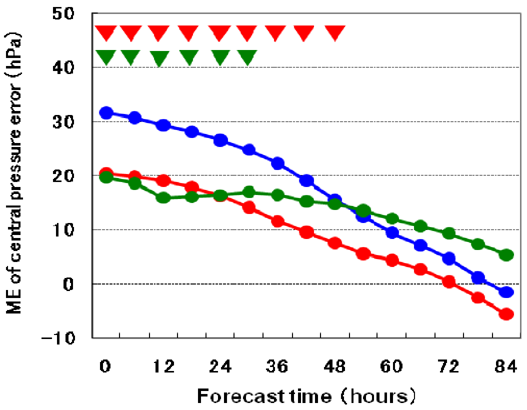

Figure 5 Mean error of TC central pressure forecast for Typhoon Sinlaku in the before-recurvature stage from 0900 to 1418. The line notation is the same as that in Figure 2. The red triangles denote that the result of TEST minus CNTL is statistically significant with a 95% confidence level, and the green triangles denote that the result of BOGUS minus CNTL is statistically significant.

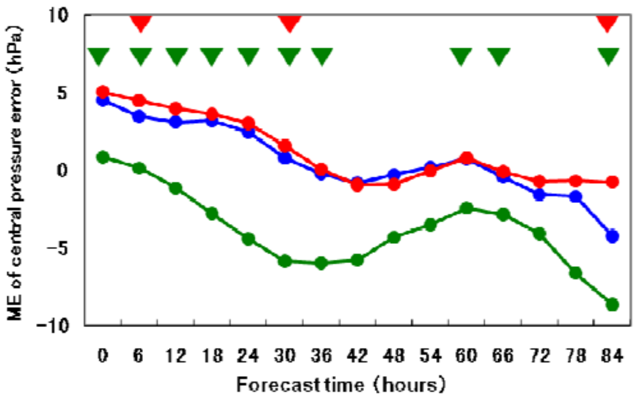

Figure 6 As per Figure 5, but for the after-recurvature stage

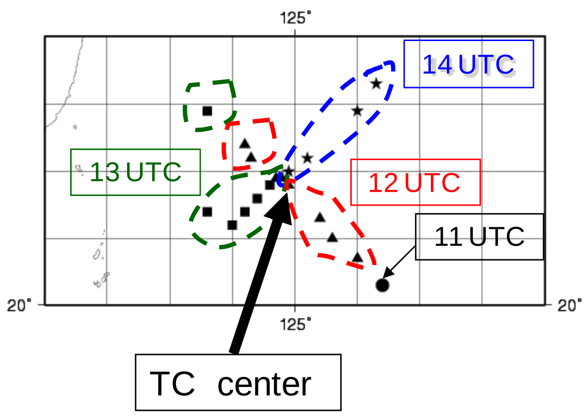

Figure 8 C-130 special observations from 1111 to 1114, initialized at 1112. Black star, triangle, square and circle plots show the positions of C-130 dropwindsonde observations.

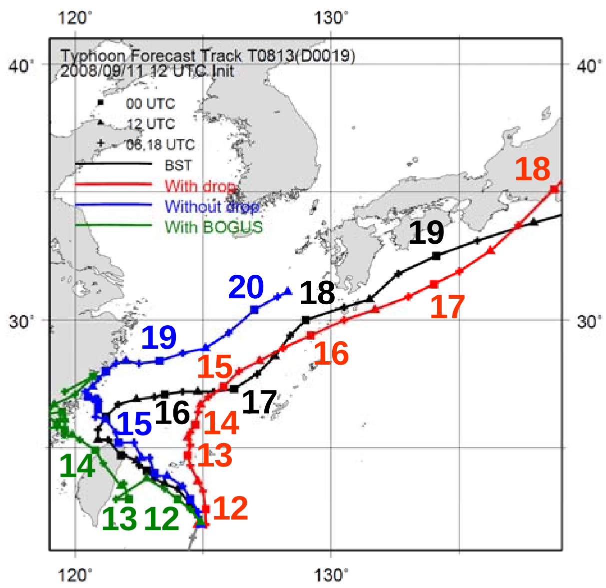

Figure 7 Typhoon track forecasts from the OSEs with (red markers: TEST) and without (blue markers: CNTL) C-130 special observations and with BOGUS data (green markers) for Typhoon Sinlaku, initialized at 1112. The black markers show OBS data. The numbers indicate the date of the typhoon's location at 00 UTC.

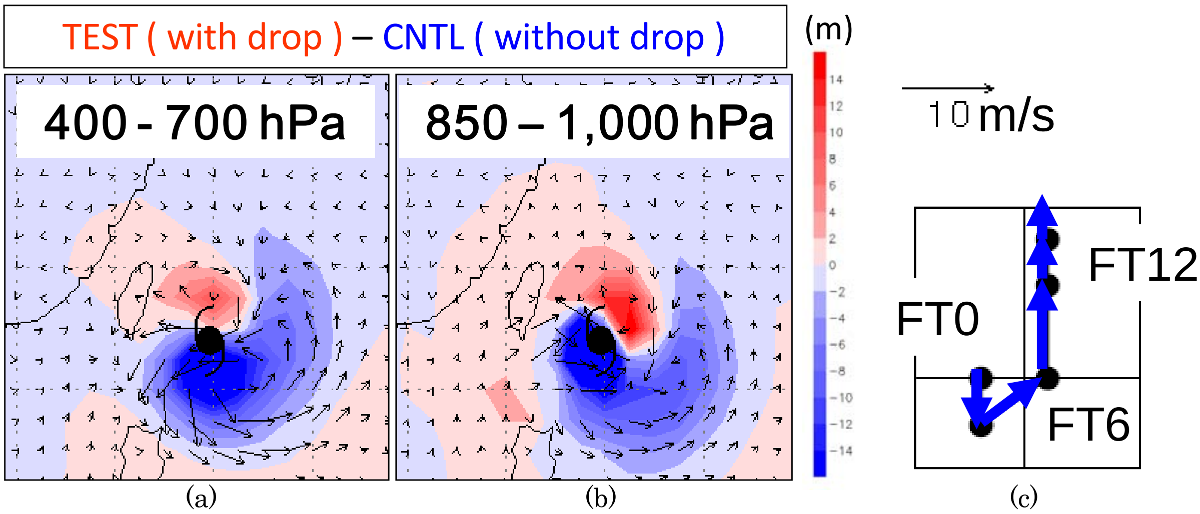

Figure 9 Averaged wind vectors and geopotential height differences ((a) vertically averaged from 400 hPa to 700 hPa; (b) vertically averaged from 850 hPa to 1,000 hPa) defined as TEST minus CNTL in the analysis at 1112. FT represents the forecast time from the initial time. The positions of the typhoon plots and FT0 show the TC center of Typhoon Sinlaku at 1112. (c) TC track forecast of TEST initiated at 1112 from FT0 to FT12.

(d) Verification of sensitivity analysis system

To investigate the effectiveness of the sensitivity analysis system, we conducted another OSE for special observations in the first mode of the-high sensitivity area calculated using the singular vector (SV) method (Komori et al., 2010). The verification times were 1100 and 1000 for 24-hour forecasts initiated at 1000 and 0900 (Figures 10 and 11). In these cases, two high-sensitivity areas were found to the northeast and southwest of the TC center. Three numerical experiments were carried out with different special observations as follows:

(I) Special observations to the northeast of the TC center (CASE_A)
(II) Special observations to the southwest of the TC center (CASE_B)
(III) Both CASE_A and CASE_B (CASE_A+B)
(IV) No special observations (CNTL)
(V) CASE_A without humidity (only OSE for 1100: NOVAPOR)

In the case of 1100, the TC track mean errors of CASE_A were reduced from those of CNTL by between 32% and 45% for the early stages and by 16% after 60 hours. In this case, special observations in the northeastern high-sensitivity area were more effective in improving the TC track forecast. Improvements for NOVAPOR and CASE_A+B of between 32% and 45% for the early stages and of 10% after 60 hours were also found (Figure 12). Comparing CASE_A and NOVAPOR, CASE_A after the 60-hour forecast point showed a smaller improvement than NOVAPOR, indicating that humidity observations contributed to the improvement of TC track forecasts after 60 hours. On the other hand, the mean track errors in CASE_B increased, which may be because the observations did not fit the analysis and the number of special observations for CASE_B was much lower than that in CASE_A. However, these are not considered to be the only reasons for the increased track errors in CASE_B.

In the case of 1000, the TC track errors for CASE_A increased, although this case had observations in the high-sensitivity area. On the other hand, the TC track errors were reduced in CASE_B with observations in the low-sensitivity area. The special observations in CASE_B were reflected appropriately in the analysis both to the southwest and to the northeast of the TC center, resulting in the best forecasts for CASE_B. As for CASE_A, correction of counterclockwise circulation to the northeast of the TC center was found in the analysis, causing the typhoon to move northward and resulting in worse TC track forecasts. The impact of CASE_A+B was almost neutral (Figure 13).

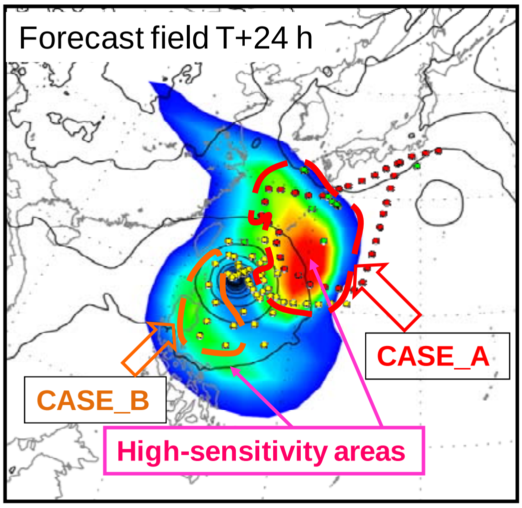

Figure 10 The sensitive areas in the first mode calculated from the one-day forecast field valid for 1100. Extra observation points for upper-soundings by JMA research vessels and ground observatories (green points), dropsondes released by Falcon aircraft (red) and those released by other planes (yellow) are overlaid on the high-sensitivity areas.

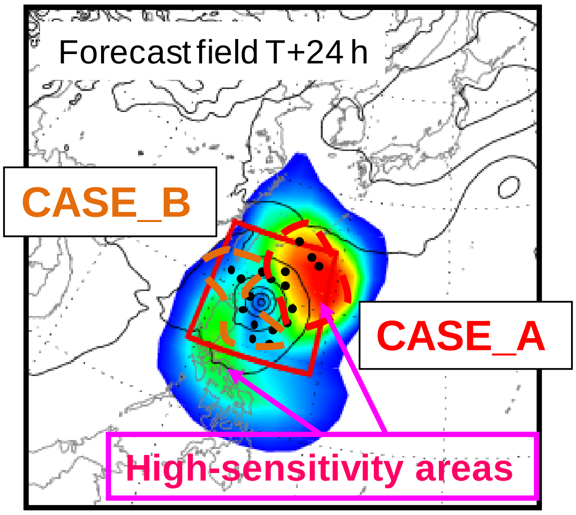

Figure 11 As per Figure 10, but from the one-day forecast field valid for 1000. Observation points for dropsondes released by DOTSTAR aircraft (black) are overlaid on the high-sensitivity areas.

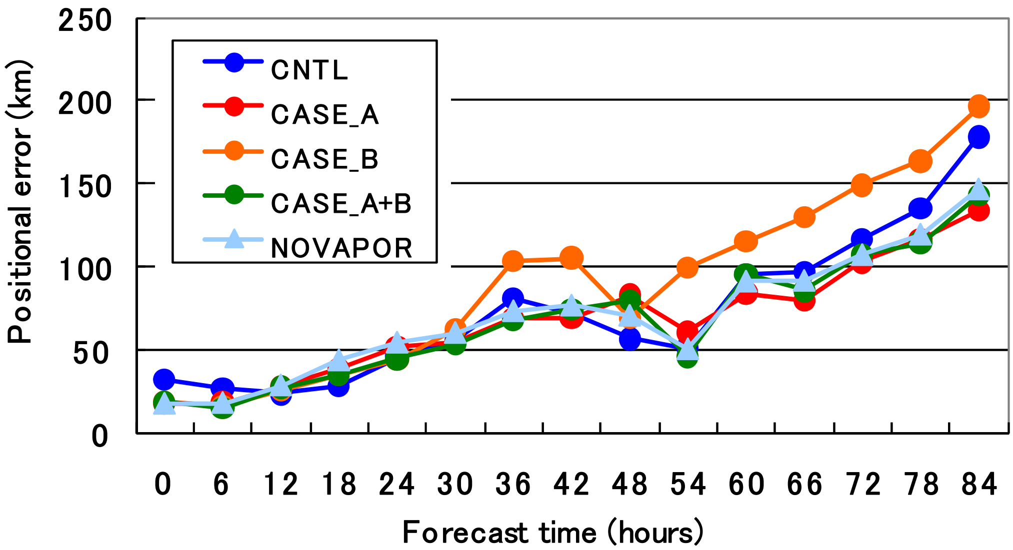

Figure 12 Mean TC track forecast errors of Typhoon Sinlaku for CASE_A (red lines), CASE_B (orange), CASE_A+B (green), NOVAPOR (thin blue) and CNTL (blue) from 1100 to 1112

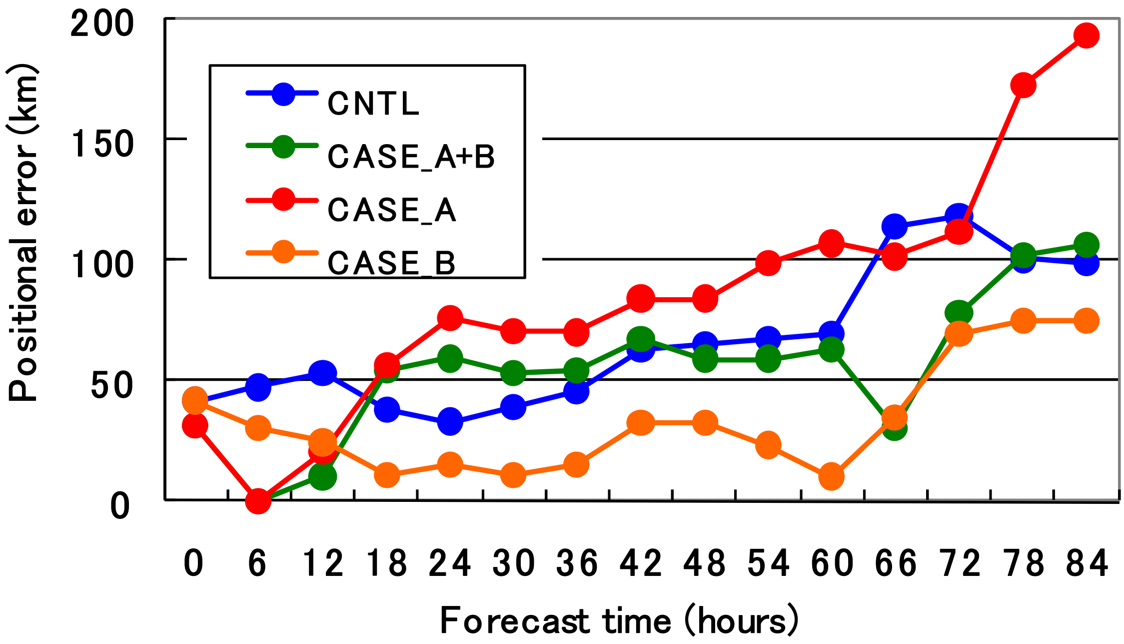

Figure 13 TC track forecast errors of Typhoon Sinlaku for CASE_A (red lines), CASE_B (orange), CASE_A+B (green) and CNTL (blue) at 1000

(e) Trial of OSEs using MTSAT-2-RS-AMV

MSC produced MTSAT-2-RS-AMV data derived from three consecutive images with intervals of 15 minutes (MTSAT-2-RS-AMV_15MIN), 7 minutes (MTSAT-2-RS-AMV_7MIN) and 4 minutes (MTSAT-2-RS-AMV_4MIN) for T-PARC. The OSEs for MTSAT-2-RS-AMV were conducted with an initial time of 1718. The NWP system was the same as that of the OSEs for special observations (see Section 4.2). The experimental design is outlined in Table 2.

Table 2 Experimental design of OSEs for MTSAT-2 Rapid Scan AMV

	TEST	CNTL
TC bogus data	Not used	Not used
Special observations	Not used	Not used
MTSAT-2 Rapid Scan AMVs	Used	Not used
Other observations	Used	Used

In TEST, a two-step thinning scheme was used as a trial. In this method, MTSAT-2-RS-AMV_4MIN and MTSAT-2-RS-AMV_7MIN are thinned to a resolution of 100 km (one AMV in each 1 deg. x 1 deg. x 100 hPa box in the hourly time window) after 200-km thinning (one AMV in each 2 deg. x 2 deg. x 100 hPa box in the six-hour time window) of the other AMVs. The other QC is the same as that for other AMVs. More details on the QC of AMVs can be found in JMA (2007) and Yamashita (2008). Figure 14 shows examples of AMVs after QC at 18 – 19 UTC on

17 September 2008.

As a result, the slow bias speeds for TC track forecasts were slightly improved, indicating the possibility of improvement for TC track forecasts using MTSAT-2-RS-AMV data (Figure 15 and Figure 16).

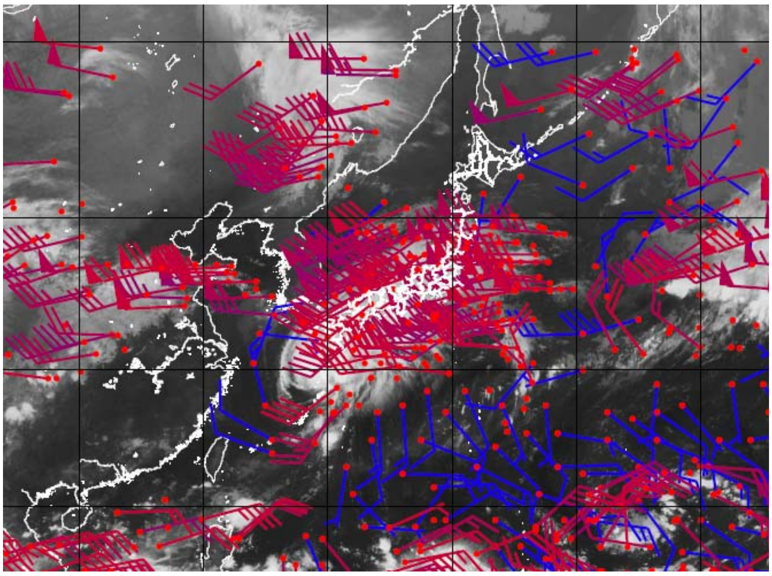

Figure 14 Distribution of MTSAT-2-RS-AMVs after QC from 1718 to 1719. High layer wind barbs (less than 500 hPa, red wind barbs) and low ones (greater than 850 hPa, blue wind barbs) are overlaid on the MTSAT-1R IR image. The unit of wind barbs is knots. Wind half-barbs are 5 knots, and full barbs are 10 knots. Wind flags are 50 knots.

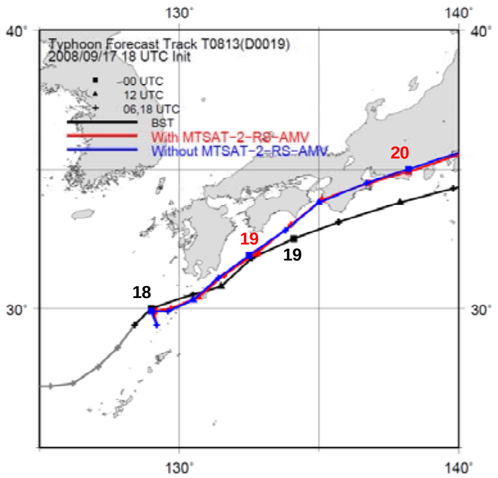

Figure 15 Typhoon track forecasts from OSEs with TEST (red markers) and CNTL (blue markers) for Typhoon Sinlaku with an initial time of 1718. The black markers show OBS data. The numbers indicate the date of the typhoon's location at 00 UTC.

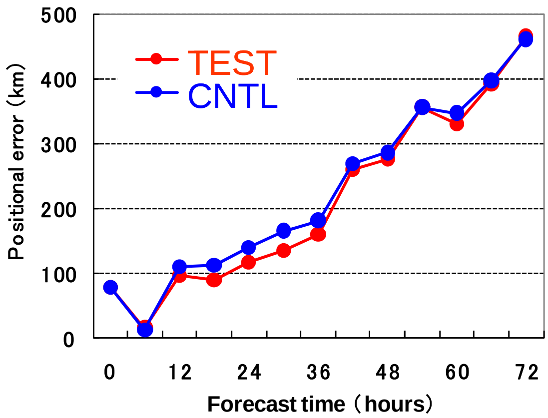

Figure 16 TC track forecast errors of Typhoon Sinlaku for TEST and CNTL with an initial time of 1718

4.2 Jangmi (0815)

(a) Track forecasts

Figure 17 shows average TC track forecast errors for Jangmi in the before-recurvature stage. In this stage, both special observations and TC bogus data improved the track forecasts (24 to 42% with 0- to 18-hour forecasts for TEST and 25% with the 6-hour forecast for BOGUS). It appears that the analysis field was improved using special observations or TC bogus data at the before-recurvature stage because Jangmi was located in an area where conventional observation data were sparse. For BOGUS, the track forecasts became degraded after the 30-hour forecast stage. Figure 18 shows a scatter diagram of positional errors for the 72-hour forecast. With TC bogus data, some forecast tracks were shifted significantly leftward and decelerated. These cases made the average track forecast errors worse.

Figure 19 is the same as Figure 17, but for the after-recurvature stage. No significant difference was found between the mean track forecast errors for TEST and CNTL. As for BOGUS, the track forecasts were slightly degraded for forecasts between 18 to 54 hours and slightly improved for other forecast times.

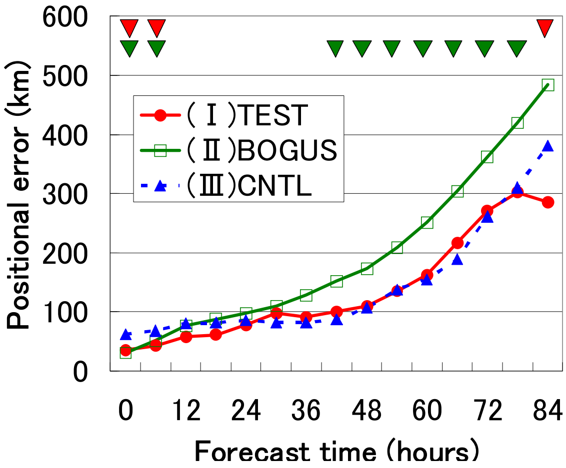

Figure 17 Average TC track forecast errors for Jangmi at the before-recurvature stage. The solid red, solid green and dotted blue lines show the track forecast errors for TEST, BOGUS and CNTL, respectively. The red and green triangles indicate that the differences of error from CNTL are statistically significant at a 95% confidence level.

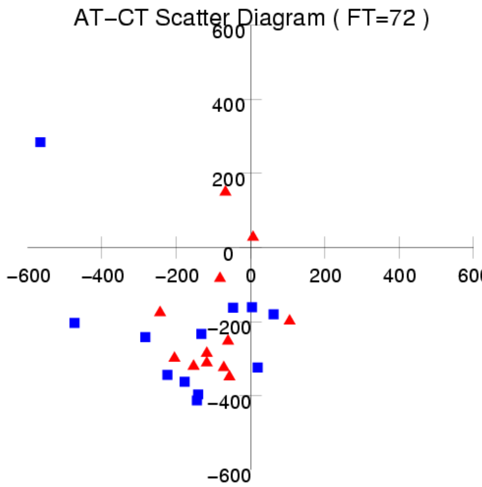

Figure 18 Scatter diagram of TC positional errors for Jangmi in the before-recurvature stage (72-hour forecast). The vertical and horizontal axes denote along-track and cross-track errors. The blue squares and red triangles show BOGUS and CNTL, respectively.

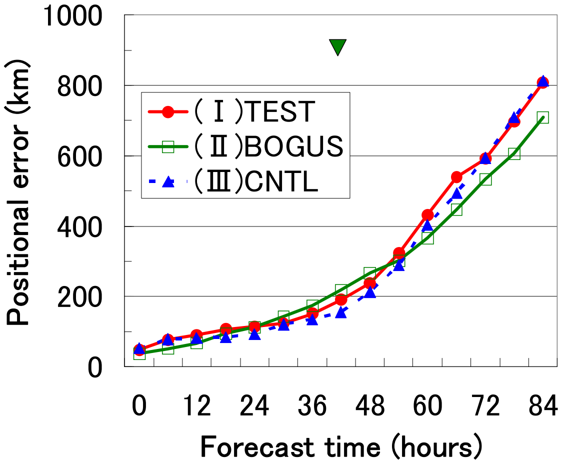

Figure 19 As per Figure 17, but for the after-recurvature stage

(b) Intensity forecasts

Figure 20 shows the mean errors of central pressure forecasts at the before-recurvature stage. Without special observations or TC bogus data, the intensity of Jangmi remained too weak considering that it was one of the strongest typhoons of 2008 (the minimum central pressure was 905 hPa). Using special observations or TC bogus data resulted in significant improvements for intensity forecasts, especially the short-range type. It seems that the assimilation of these data made realistic TC structures and helped TC intensification at the development stage.

Figure 21 is the same as Figure 20, but for the after-recurvature stage. No significant difference was found between TEST and CNTL. Using TC bogus data, the intensity forecast showed a TC that was slightly too strong after the 48-hour forecast stage. Since Jangmi was in a period of transition to an extra-tropical cyclone, the forecast after 48-hours appears to have been worse. In this case, using TC bogus data made a cyclone that was too strong after the extra-tropical cyclone transition stage.

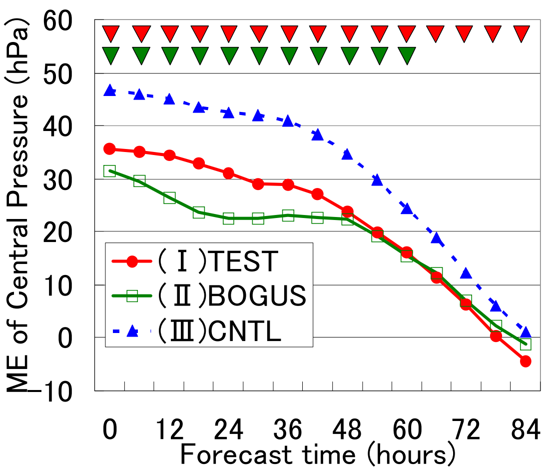

Figure 20 Mean errors of TC central pressure forecast for Jangmi at the before-recurvature stage. The notations of the lines and marks are the same as those in Figure 17.

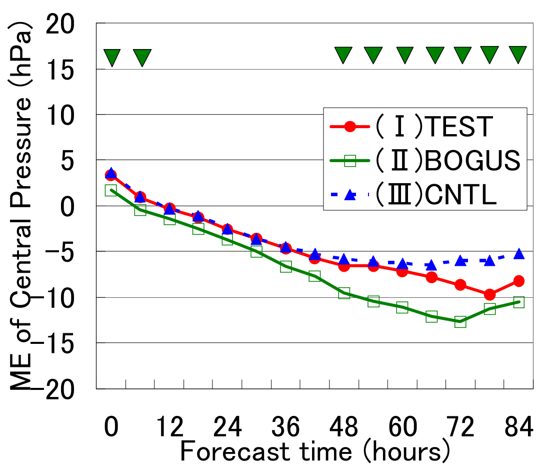

Figure 21 As per Figure 20, but for the after-recurvature stage

(c) Case study

Further experiments were performed for a number of typical cases. On the forecasts initiated at 2500, the GSM forecast track with special observations showed much better agreement with the observed track and predicted recurvature after landing on Taiwan, which was not the case in the forecast without special observations (Figure 22).

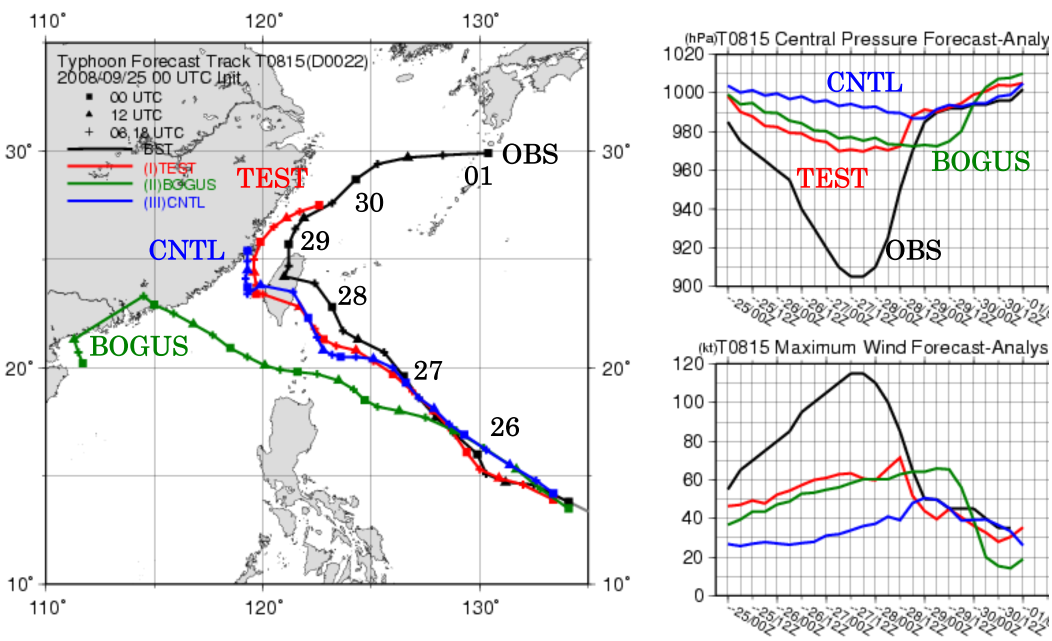

Figure 22 Forecast tracks for Jangmi (initial time 2500). The red, green and blue lines show the forecast tracks of TEST, BOGUS and CNTL, respectively. The black lines show OBS values.

In further experiments, the special observations conducted around this initial time were assimilated separately according to their observation points. Figure 23 shows the forecast without observations (CNTL) and with all observations in the center and the northern quadrant of Jangmi (NC ALL). It was found that using dropwindsonde observations near the center and in the northern quadrant improved the intensity forecast, while using them in the eastern and southern quadrants improved the track forecast (not shown).

An impact study regarding the selection of observation elements was conducted. Each element of dropwindsonde observation (horizontal wind, temperature and humidity) was assimilated separately. In Figure 23, the green lines show the forecast with wind observations to the north and center of Jangmi only (NC WIND). Comparing these forecasts shows that wind observations had the largest impact on the forecast of Jangmi in this case, especially for the short-range track forecast. Other observation elements also had an impact on the intensity forecast.

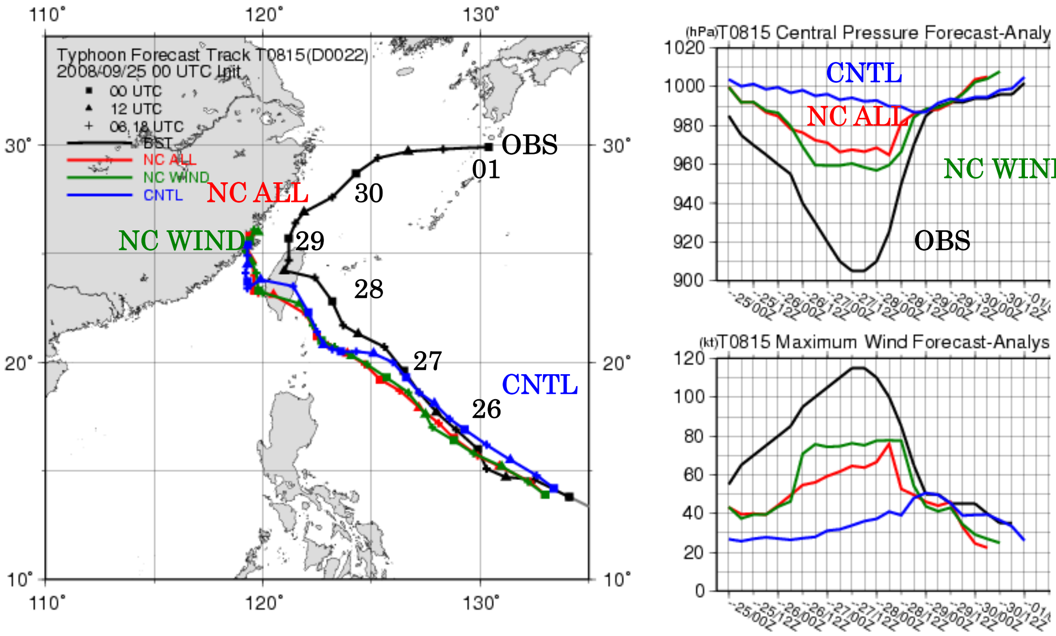

Figure 23 Forecast tracks for Jangmi (initialized at 2500). The red, green and blue lines show the forecast tracks for NC ALL, NC WIND and CNTL, respectively. The black lines show OBS data.

(d) Observations and data assimilation system of JMA

The characteristics of the special observations and their usage in the operational global data assimilation system of JMA were investigated. Large differences in wind observations from the first-guess field were found around the center of Jangmi, and these decreased considerably after the analysis. As for the dropwindsonde and additional upper sounding observations, most of those on mandatory levels were assimilated, and no horizontal data thinning was applied. Thus, in most cases, assimilation of these observations contributed to improvement of the analysis field, but there may be some problems with a lack of horizontal thinning for such spatially dense observations. In fact, as mentioned earlier, the assimilation of dropwindsonde observations near the center caused significant degradation of the track forecast in some cases.

5. Summary and conclusion

The OSEs performed revealed the positive impacts of special observations in the operational JMA GSM mainly at the before-recurvature stage of Sinlaku and Jangmi. Using TC bogus data also contributed to the improvement of intensity forecasts and short-range track forecasts at the before-recurvature stage. However, the assimilation of TC bogus data sometimes led to a degradation of track forecasts.

Further experiments for Jangmi on a number of typical cases were conducted, and the impact of each observation was investigated. Through these experiments, it was found that wind observation had a large impact on the analysis and forecast fields.

Although the OSEs for Sinlaku and Jangmi demonstrated the effectiveness of special observations, some problems were found with the assimilation of dropwindsonde data, especially for those near the TC centers. These problems need to be investigated in more detail and treated carefully to achieve further TC forecast improvements.

In the verification of the sensitivity analysis system, special observations in high-sensitivity areas were more effective in improving TC track forecasts, indicating the high possibility of their use as interactive forecast system tools. However, as there was a case in which special observations caused deterioration in TC track forecasting, these studies should be continuously implemented to address the problem.

In the trial involving OSEs using MTSAT-2-RS-AMV, the possibility of improvement for TC track forecasts was shown.

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