Impact of the Radiosonde Observations of Cold Surge over the Philippine Sea on the Tropical Region and the Southern Hemisphere in December 2012

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Abstract

The impact of the radiosonde observations of cold surge over the Philippine Sea on the tropical region and the Southern Hemisphere has been investigated by the assimilation of radiosonde data obtained during the R/V Hakuho Maru cruise KH–12–6 in late December 2012. After assimilating the observation data, the modified surface winds of the cold surge were generally stronger than those before the assimilation. In addition, cyclonic rotations around the 4 developing tropical cyclones in the Northern and Southern Hemispheres were more intensified. Furthermore, the analysis errors over the Indian Ocean and the Pacific Ocean in the Northern and Southern Hemispheres were reduced by 1 to 10%.

The impacts of the additional radiosonde observations in the cold surge immediately propagated up to the updraft region near the equator and to the mid-latitude downdraft regions through the local Hadley circulation. After the impact spread in the lower troposphere, large impacts were deepened around the tropical cyclones and depressions within 2 days. The propagation process of the additional observation impact over the Philippine Sea suggested that the cold surge could affect large-scale circulation, including typhoons and tropical depressions in the tropics and the mid-latitude regions.

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1. Introduction

An East Asian cold surge is a cold air outbreak originating from the Siberian–Mongolian High in the boreal winter. The cold surge leads to a steep rise in surface pressure with cold northerly winds over the subtropics of the South China Sea and the Philippine Sea and affects convective activity (Chen et al. 2002).

Statistical analysis by Compo et al. (1999) suggests that the cold northerly surge enhances convective activity in the tropics and subtropics through the enhancement of the local East Asian Hadley cell. Moreover, the analysis indicated that the northerly surge greatly affects not only convective activity but also rainfall distributions in the tropics near the equator and over the Indonesian Maritime Continent in the Southern Hemisphere (Hattori et al. 2011; Wu et al. 2013; Pullen et al. 2015). Hattori et al. (2011) showed that the northerly surge/MJO (Madden–Julian Oscillation) combined pattern (16 cases) produced much greater precipitation over the Maritime Continent than either MJO (20 cases) or northerly surge (11 cases) alone. Love (1985) showed that the zonal pressure gradients near the equator induced by cold surges in the winter hemisphere influence the development of tropical cyclones (TCs) in the summer hemisphere.

However, it is difficult to show the specific propagation processes of the cold surge influences to the convective activity and rainfall distributions in the tropics with those statistical studies, and the causes of correlative relationships were not well understood. The effect of the cold surge to other regions has not been clarified too. Therefore, the present study estimates the effects of the northerly cold surge on large-scale circulation using radiosonde observations onboard the R/V Hakuho Maru in the Philippine Sea during the developing period of a cold surge in December 2012 using the ALEDAS2 (AFES–LETKF ensemble data assimilation system 2; Enomoto et al. 2013).

Hattori et al. (2016) investigated the impact of the additional radiosonde observations at the operational stations in the Philippines on the tropical depression developed in the South China Sea from late September to early October 2010 using the same assimilation system, ALEDAS2. During the experiment period, the impact was propagated to the region from the South China Sea to the western Pacific to the south of Japan. Therefore, the present study also makes comparison with Hattori et al. (2016) with a focus on their difference in the region, the period, and the phenomena.

2. Description of the radiosonde observations during KH–12–6 and ALEDAS2

From the south of Japan to the northeast of the Philippines, 6 to 12 hourly moving observations were conducted 5 times from 23 to 24 December, and 3 hourly fixed-point observations were conducted 13 times from 24 to 26 December in 2012 during the R/V Hakuho Maru cruise KH–12–6. The observation points and times are indicated in Fig. 1.

Figure 1 shows the black-body brightness temperature (Tbb) from the Multi-functional Transport Satellite (MTSAT-1R) and the sea surface winds from SeaWinds Scatterometer at 00 UTC on 26 December. The arrows indicate only the sea surface winds with northerly components. The crosshair indicates locations of TCW (Tropical Cyclone in the Western Pacific) 25. The TC data used in this study are based on the Joint Typhoon Warning Center (JTWC) best track dataset.

Cloud streaks appeared distinctly in the wide area over the Sea of Japan and the Pacific Ocean. A strong northwesterly of over 10 m s−1 blew from the Eurasian Continent to the Sea of Japan. The northwesterly winds changed to north-easterly after crossing Japan and reached the Philippines and even the Indonesian Maritime Continent.

The convective clouds of TCW25 cut across the central islands of the Philippines. Furthermore, convective activity in the vicinity of the Maritime Continent was significantly active, and TCSs (Tropical Cyclones in the Southern Hemisphere) numbered 4, 5, 6, and 7 developed one after another in the Southern Hemisphere (whose locations are later shown in Fig. 5). According to the Madden–Julian Oscillation (MJO) index of the Australian Government Bureau of Meteorology (BOM), the MJO phase was active over the Indonesian Maritime Continent and the western hemisphere.
Section 3. The analysis ensemble mean modified by the KH observations

Figure 2 shows the horizontal divergence, horizontal vorticity and wind vectors at 925 hPa at 12 UTC on 26 December in KH. Regions of convergence are widely distributed from the eastern Indian Ocean to the western Pacific Ocean between 15°S and 15°N. Strong cyclonic vorticities (> |1 × 10^{-4} \, s^{-1}|) appear along the horizontal wind shear lines in the Northern and Southern Hemispheres, and TCW 25 and TCSs 5 and 6 are embedded, respectively.

Figure 3 shows the KH meridional wind speeds and the KH–CTL difference at 12 UTC on 26 December, 2012, over the Maritime Continent (including TCW25, TCS6, and TCS9) and Oceania (including TCS4 and TCS5). For the KH–CTL difference, only anomalies above the 90% significance level are represented. A strong northerly wind reached the Philippine Sea, the South China Sea, and even south of the equator between 90°E and 120°E, indicating a cross-equatorial northerly surge occurred (Fig. 3a). According to the KH–CTL difference, northerly winds to the north of TCW25 around the Philippines are strengthened by the assimilation of the radiosonde observations from the R/V Hakuho Maru (Fig. 3b). Moreover, northerly wind speed anomalies are dominant from the Java Sea up to 15°S. The difference of the central vorticity between KH and CTL (KH-CTL) for TCW25 (> 0.04 × 10^{-4} \, s^{-1}) and TCS6 (< −0.02 × 10^{-4} \, s^{-1}) indicate that their cyclonic circulations are intensified by this assimilation. To the southwest of Sumatra, the north–south wind shear around 7.5°S–10°S is strengthened significantly due to the increased northerly wind speed in the north (Figs. 3a and 3b). TCS9, which was generated on 11 January 2013, evolved from the cyclonic disturbance in the shear zone southwest of Sumatra. To the east of New Guinea, there is a confluence zone between the northerly wind from the Pacific Ocean and the equatorial easterly winds (Figs. 3c and 3d). The northerly (southerly) wind to the north (south) of TCW25 and TCS5 are intensified by the assimilation of additional radiosonde observations. Furthermore, the difference of the central vorticity (KH-CTL) for TCS4 (< −0.05 × 10^{-4} \, s^{-1}) and TCS5 (< −0.05 × 10^{-4} \, s^{-1}) indicate that their cyclonic circulations are intensified by the assimilation. In addition, it is indicated that the RSME (root mean square error) of the central SLP (sea level pressure) in KH against the best track for TCW25, TCS04, and TCS06 (except for TCS05 without the best track SLP) is 0.2hPa smaller on average and the location of the TCs in KH is 20km closer to the best track on average than those in CTL.

Figure 4 indicates KH zonal wind speeds and the KH–CTL difference at 925 hPa at 12 UTC on 26 December 2012. In the region around 5°S, westerly winds are dominant to the west of 165°E. TCW25 and TCS6 are located in the region of strong zonal wind shear between the MJO westerly and the easterly composed of the cold surge and equatorial easterly. Shear of these easterlies also strengthen the cyclonic circulations of these TCs in KH due to the modification by the additional radiosonde observations.

4. Analysis error reduction by the KH observations

Since the difference of ensemble mean and the difference of ensemble spread are not the same, even if the difference of ensemble mean is not noticeable, that of ensemble spread may be conspicuously large. In the present study, impact of the observational data assimilation is evaluated by how much the ensemble spread changes. An index of error reduction in KH is quantified by difference of analysis ensemble spreads between CTL and KH meridional winds averaged between 1000 and 10 hPa from 21 UTC on 23 December to 00 UTC on 27 December (Fig. 5). Here, the analysis error reduction rate ERR index is defined as

\[
ERR = \frac{\text{spread (CTL)} - \text{spread (KH)}}{\text{spread (CTL)}}
\]

where spread (CTL) and spread (KH) are the analysis ensemble spread in the CTL and KH, respectively. The same definition of the ERR index as the impact of the special soundings measured by the difference in the ensemble spread was used in the studies of Moteki et al. (2011). Compared to these previous studies, the number of the assimilated observations in the present experiment are quite smaller because the target period
Fig. 2. Analysis ensemble mean of (a) the horizontal divergence and (b) relative vorticity at 925 hPa at 12 UTC on December 26, 2012 in KH. Vectors in the top and bottom panels indicate wind direction and speed in KH. The black dots indicate the locations of the tropical cyclones. The black circles represent the regions within a 500 km radius of the center of a tropical cyclone.

Fig. 3. Analysis ensemble mean of the meridional wind speeds (shading) and wind vectors at 925 hPa at 12 UTC on December 26, 2012 for (a, c) KH and (b, d) the KH-CTL difference at the 90% or greater statistical significance level. The black dots indicate the locations of the tropical cyclones. The black circles represent the regions within a 500 km radius of the center of a tropical cyclone.
is only a week. In the present study, therefore, the area with ERR over 1% is indicated as meaningful value.

Although the largest impact appeared around the observational region of the R/V Hakuho Maru, the impact around TCW25 and TCs 4, 5 and 6 are also significant (ERR is more than 10%). The region corresponding to an ERR of more than 5% is very broad in comparison with the previous OSE study using the same data assimilation system (Hattori et al. 2016). Large analysis error reductions are also found around the low pressure systems in the eastern coast of China and to the west of Hawaii. In addition, analysis error reductions are clearly found around the region where TCW1 and TCs 8 and 9 would be generated from the end of December to the beginning of January after this experiment. Conversely, for TCs, the analysis error is increased along its track. These findings indicate that the error reduction region spreads significantly wide and the influence of the additional observations continues for a long time compared to the previous studies. As a reference, the RSME (root mean square error) between analysis and 6 hours forecast for KH was found to be reduced around TCs in comparison with CTL although the distribution of the forecast RMSE reduction had several difference from that of ERR (not shown).

In order to investigate how the ERR has expanded widely between 100°E and 170°W, latitude–height cross-sections of the ERR and streamline for vertical and meridional wind speeds averaged between 100°E and 170°W are shown in Fig. 6. At 00 UTC on 24 December, error reductions appear only around 25°N near the observations. Then, the impact widely spreads to the Southern Hemisphere at 06 UTC on 24 December. The impact propagates to higher altitudes near 300 hPa on 25 December, and the error reduction rates strengthen further on 26 December. At 06 UTC on 24 December, the impacts are found between 30°N and the equator, not only in the upper layer but also in the cold surge prevailing in the lower layer below 700 hPa.

However, between the equator and 10°S, large ERRs are found up to much higher altitudes. The vertical–meridional streamline indicates the upward current of local Hadley circulation located between the equator and 10°S. This location indicates that large impacts appear in the upward current region of the local Hadley circulation through the cold surge. In addition, large impacts appear up to the higher altitudes in the region near 30°S where the southern subsidence of the local Hadley circulation exists. In these three regions, much larger impacts appear up to much higher altitudes at 00 UTC on 25 December. Then, large impacts become apparent in the regions of TCs and depressions at 10°N, 28°N and 20°N at 00 UTC on 26 December.

These temporal changes show the process of the impact propagation; that is, upward current and subsidence of the local Hadley circulation are first modulated by the observation of cold surge, and then TCs and strong disturbances are modulated from the bottom to the top. The impacts of the KH observations inside the Hadley circulation expanded drastically and widely but those outside the Hadley circulation was quite small. This process could be the reason for the fact that the ERR rapidly became larger and broader after 00Z 24 December even though the additional observations were assimilated from 23 December.

5. Discussion and conclusions

The impact of the radiosonde observations of cold surge over the Philippine Sea in late December 2012 on the tropical region and the Southern Hemisphere is investigated. Compared to the results from Hattori et al. (2016), the impact for the present study spreads widely and strongly. The stronger impacts are considered to be caused by strengthening of sparse observation over the ocean, and strong response from the intense low pressure systems (tropical depressions) associated with active phase of the MJO convection and widespread response from the stable large-scale high pressure system (cold surge). It is suggested that the spatial representativeness of an observation in a broad high pressure system should be larger than that in an intense, compact low
Fig. 5. Analysis error reduction rate of the meridional wind (shading) between 1000 and 10 hPa averaged from 21 UTC on 23 December to 00 UTC on 27 December 2012. The black circles indicate the best tracks of tropical cyclones and the black filled circles indicate those during the averaged period. The x-marks indicate locations of low pressure system. The crosshairs indicate radiosonde observation points from R/V Hakuho Maru.

Fig. 6. The latitude–height cross–sections for the analysis error reduction rate of meridional wind (shading) and streamline for vertical and meridional wind speeds averaged between 100°E and 170°W at (a) 00 UTC on 24, (b) 06 UTC on 24, (c) 00 UTC on 25 and (d) 00 UTC on 26 December 2012 for KH.
pressure system, and the impact of the additional observations in the cold surge would be much broader than those in the tropical disturbances.

The present results show that the additional radiosonde observations over the Philippine Sea during the winter have a strong effect on the analysis quality over the Indian Ocean, the Maritime Continent, and the western Pacific Ocean between 40°N–40°S. These results are consistent with the previous studies showing that the cold surge in East Asia influence the development of TC in the Southern Hemisphere (Love 1985). Our OSE suggests that the tropical cyclones in the Southern Hemisphere originating from the MJO convection are also affected by the cold surge from the Northern Hemisphere. TCs have developed during the convectively active phase of MJO and its cyclonic circulation has been intensified by the increase of northerly wind from the cold surge (Fig. 3b).

The impact by the additional observations around 25°N propagated across the equator in the lower troposphere below 300 hPa and expanded outside of the cold surge within 2 days from the first additional observation on 23 December. Supposedly, the large impact immediately expands in the lower troposphere between 40°N and 40°S because the observations of the cold surge directly affect the upward motion and the subsidence of the local Hadley circulation.

After 25 December, large impacts were deepened around the tropical cyclones near Philippines and in the southern hemisphere from the surface up to 100 hPa. These impacts appeared after sufficient spread of the impacts through the local Hadley circulation. TCs, which generated to the east of Papua New Guinea, was also strengthened by the using additional observations because the northwesterner to the northeast of its center and the southeastern to the southeast of it have been analyzed to be much stronger. In the case of TCs, this analysis indicated that the cyclonic circulation of the tropical cyclone even at 40°S was intensified, corresponding to the intensification of the cold surge in the Northern Hemisphere.

The present study revealed that the observations of the cold surge over the Philippine Sea have wide impacts on tropical cyclones, even in the southern mid-latitude regions.

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