

Quality control of AIRS total column ozone data within tropical cyclones

Yin LIU^{1,2}, Xiaolei ZOU (✉)³

¹ Center of Data Assimilation for Research and Application, Nanjing University of Information Science & Technology, Nanjing 210044, China

² Key Laboratory of Meteorological Disaster of Ministry of Education, Nanjing University of Information Science & Technology, Nanjing 210044, China

³ Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD 20740-3823, USA

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Abstract The Atmospheric Infrared Sounder (AIRS) provides infrared radiance observations twice daily, which can be used to retrieve total column ozone with high spatial resolution. However, it was found that almost all of the ozone data within typhoons and hurricanes were flagged to be of bad quality by the AIRS original quality control (QC) scheme. This determination was based on the ratio of total precipitable water (TPW) error divided by TPW value, where TPW was an AIRS retrieval product. It was found that the difficulty in finding total column ozone data that could pass AIRS QC was related to the low TPW employed in the AIRS QC algorithm. In this paper, a new two-step QC scheme for AIRS total column ozone is developed. A new ratio is defined which replaces the AIRS TPW with the zonal mean TPW retrieved from the Advanced Microwave Sounding Unit. The first QC step is to remove outliers when the new ratio exceeds 33%. Linear regression models between total column ozone and mean potential vorticity are subsequently developed with daily updates, which are required for future applications of the proposed total ozone QC algorithm to vortex initialization and assimilation of AIRS data. In the second QC step, observations that significantly deviate from the models are further removed using a biweighting algorithm. Numerical results for two typhoon cases and two hurricane cases show that a large amount of good quality AIRS total ozone data is kept within Tropical Cyclones after implementing the proposed QC algorithm.

Keywords AIRS total column ozone, total precipitable water, mean potential vorticity, quality control

1 Introduction

Ozone plays an important role in the process of dynamic, thermodynamic, radiation, and chemical processes within and between the troposphere and stratosphere. Since variations of ozone concentration at different heights and latitudes are often a result of the atmospheric motion, ozone can be viewed as a passive tracer at synoptic scales. In fact, ozone is highly correlated with many atmospheric variables. In the early days, Normand (1953) and Ohring and Muench (1960) noted that the temporal variations of surface-station ozone data were inherently related with those of temperature, geopotential, and meridional wind components at 100 hPa. Danielsen (1968) and Shapiro et al. (1982) found that ozone distributions in the tropopause could be treated as the surrogate for potential vorticity (PV) in the stratosphere and could contain useful information on synoptic-scale and meso-scale flow regimes. Davis et al. (1999) noted that the positions of upper-level PV troughs and ridges could be identified in the spatial distribution of vertically integrated ozone. Jang et al. (2003) and Zou and Wu (2005) showed that the total column ozone was highly correlated to that of mean potential vorticity (MPV) within both the middle latitude and tropical cyclones. In addition, assimilation of total column ozone observations improved the forecast skill of a middle latitude snow storm (Jang et al., 2003) and the track and intensity of Hurricane Erin (Wu and Zou, 2008).

With the rapid advancement of remote-sensing technologies, more and more hyperspectral infrared (IR) sounding instruments are designed to obtain total column ozone with high spatial resolution and twice-daily temporal coverage per instrument onboard a polar-orbiting meteorological satellite. AIRS is an advanced hyperspectral infrared atmospheric sounding instrument onboard NASA's Aqua

satellite of the Earth Observing System (EOS). AIRS can measure the upwelling radiances at 2,378 spectral channels from 3.74 to 15.4 μm which include different gas absorption bands. AIRS cross-track swath width is 1,650 km. The spatial resolution of AIRS field-of-view is 13.5 km at nadir. AIRS can provide atmospheric temperature and humidity profiles, ozone profiles, sea/land surface skin temperature, cloud related parameters, and outgoing longwave radiation (Aumann et al., 2003). Many studies have been done to evaluate AIRS-retrieved ozone profiles and total column ozone. Bian et al. (2007) and Monahan et al. (2007) noticed that AIRS-retrieved ozone profiles captured the variability found in the ozonesonde data in the extratropical upper troposphere and lower stratosphere (ExUTLS) regions. Meanwhile, Divakarla et al. (2008) compared AIRS ozone profiles and total column ozone with ozonesonde data, European Centre for Medium-Range Weather Forecasts (ECMWF) ozone data, and Ozone Monitoring Instrument (OMI) data. They found that the AIRS ozone profile retrieval algorithm produced reduced retrieval biases and root-mean-square (RMS) differences in the lower troposphere. The 2005 and 2008 Stratosphere–Troposphere Analyses of Regional Transport Experiments (START05 and START08) showed that AIRS ozone profiles near the tropopause matched very well with aircraft ozone measurements (Pan et al., 2007; Pittman et al., 2009). All these results proved that the AIRS ozone data were credible and feasible for further applications.

However, Wang et al. (2012) found that 20%–30% of AIRS total column ozone data were removed from within typhoons and hurricanes, even though some of these data could be informative. Meanwhile, after the traditional quality control (QC), additional QC is needed for the assimilation of AIRS ozone data in the numerical weather prediction (NWP) models. As an extension of the work by Wang et al. (2012), a new two-step QC scheme for AIRS total ozone is proposed in this study. Two hurricane cases and two typhoon cases in the summer of 2012 are studied to evaluate the performance of the new QC scheme. The arrangement of this paper is as follows: Section 2 describes the cases used in this study; a brief description of data is provided in Section 3; the new QC scheme is discussed in Section 4; Section 5 provides numerical results of the selected cases; and a summary and conclusions are found in Section 6.

2 Overview of the typhoon/hurricane cases

Two typhoons that occurred over the Pacific Ocean and two hurricanes that formed over the Atlantic Ocean in 2012 are chosen in this study. These are tropical storms of category 1 or greater. Table 1 provides names, time periods, horizontal domains, and Saffir-Simpson scale categories of these cases. Figure 1 shows the observed tracks. A brief description of these storms is given below.

Typhoon Tembin progressed from a tropical depression on 19 August 2012. It intensified rapidly and reached a maximum 1-min sustained wind speed of $213 \text{ km} \cdot \text{h}^{-1}$ by 0000 UTC 21 August 2012. The tropical upper tropospheric trough (TUTT) cell over the system caused it to weaken. However, Tembin re-intensified on 23 August and made landfall over Taiwan, China. Afterward, Tembin was expected to accelerate east-northeastward and to loop around Taiwan. At 0000 UTC 30 August 2012, Tembin made landfall over South Korea with winds of $82.8 \text{ km} \cdot \text{h}^{-1}$ and a central sea level pressure (SLP) of 990 hPa.

Typhoon Sanba was initially a tropical depression east of the Philippines on 10 September 2012. It strengthened into a category 1 typhoon on 12 September, experienced a period of explosive intensification, and reached its peak intensity of $205 \text{ km} \cdot \text{h}^{-1}$ maximum sustained wind and a central SLP of 900 hPa on 13 September 2012. At 1500 UTC 14 September 2012, Sanba weakened into a category 3 typhoon. It made landfall over Korea on 17 September as a tropical storm.

Hurricane Isaac began as a tropical wave on 16 August 2012, and strengthened into a tropical depression around 0600 UTC 21 August 2012. Isaac entered the Straits of Florida on August 26, and gradually strengthened to a category 1 hurricane. At 0000 UTC 29 August, it made landfall near the Mississippi River with a maximum sustained wind of $130 \text{ km} \cdot \text{h}^{-1}$. It weakened to a tropical storm, and then to a tropical depression on the following day. The depression continued its northward movement and transformed into an extratropical cyclone on September 1, 2012.

Hurricane Sandy developed from a tropical wave in the western Caribbean Sea on 22 October 2012 and reached hurricane intensity at 1200 UTC 24 October. Sandy then reached a maximum wind speed of $175 \text{ km} \cdot \text{h}^{-1}$ and made

Table 1 Names, data periods, horizontal domains, and Saffir-Simpson scale categories of the two typhoons and two hurricanes included in this study

Name	Data Period	Domain	Scale
Tembin	19 Aug. to 30 Aug. 2012	5°N–45°N, 100°E–160°E	4
Sanba	10 Sept. to 17 Sept. 2012	5°N–45°N, 100°E–160°E	5
Isaac	21 Aug. to 1 Sept. 2012	5°N–60°N, 120°W–50°W	1
Sandy	22 Oct. to 29 Oct. 2012	5°N–60°N, 90°W–20°W	2

landfall near Santiago de Cuba at 0525 UTC 25 October. After Sandy passed Cuba, it turned to the north-northwest toward the Bahamas. The trough and the warm Gulf Stream waters caused Sandy to reach its secondary peak of $150 \text{ km} \cdot \text{h}^{-1}$ on 29 October. At 0000 UTC 30 October, Hurricane Sandy made landfall near Atlantic City.

3 A brief description of data

3.1 AIRS ozone data

AIRS ozone profiles and total column ozone data are retrieved from 41 channels, covering a spectrum range from $9.354\text{--}10.029 \mu\text{m}$. These ozone data can be found in both AIRS level-2 and level-3 standard products. AIRS level-2 data sets are available twice daily and contain an ozone mixing ratio at 28 standard pressure levels and the total column ozone, with a horizontal resolution of 45 km at nadir. AIRS level-3 gridded data products have a $1^\circ \times 1^\circ$ resolution and are derived from AIRS level-2 standard products, containing daily ascending and descending data, and 8-day and monthly mean total column ozone data. The AIRS level-2 standard ozone data are used in this study.

It is worth mentioning that AMSU is also onboard NASA's Aqua satellite. The scanning geometry of AIRS is designed in such a way that three AIRS scan lines fit into one AMSU scan line, and three AIRS fields-of-view (FOVs) fit into a single AMSU FOV (Aumann et al., 2003).

3.2 TPW analysis of AIRS and AMSU

The 41 channels for AIRS total column ozone retrieval are located in the window region and are affected by water vapor. Errors in AIRS water vapor mixing ratio retrieval will adversely affect the ozone retrieval. Barnet et al. (2007) pointed out that there could be significant biases (0–100%) in the region between 300 and 80 hPa.

The cloud-cleared radiances of water vapor absorption channels are used to determine the amount of radiation that is absorbed by the atmospheric water vapor molecules in the AIRS moisture profile retrieval algorithm, which consists of an iterative least square procedure. The dependence of the retrieval results on the first guess is minimized. The retrieval problem of a water vapor profile is highly nonlinear; the solution q is expressed as (Susskind et al., 2003, 2006)

$$q^{m+1}(p) = q^m(p) \left[1 + \sum A_\ell F_\ell(p) \right], \quad (1)$$

where m represents the m^{th} iteration, ℓ ranges over J solution functions, A_ℓ is the noise amplification factor, and the functions $F_\ell(p)$ are selected as localized functions of pressure p . AIRS total precipitable water (TPW) can also

be calculated with an equation similar to Eq. (1) without an explicit dependence on pressure.

Since clouds and precipitation can strongly affect infrared radiances, AIRS TPW retrievals are not credible in overcast or nearly overcast conditions, such as the region near the typhoon/hurricane center. AMSU can provide profiles from the surface up to 40 km, even in the presence of non-precipitation clouds. The microwave information is used for cloud-clearing and the cloud-free portion of the infrared scene. The AMSU channels 1, 2, and 15 are sensitive to the water vapor near the surface and thus contain information about TPW, particularly over the ocean (Susskind et al., 2011). The estimate of atmospheric moisture can be obtained by Newtonian iteration, which is similar to Eq. (1). The damping method proposed by Eyre (1989) is used to avoid large relative humidity increments. The AMSU TPW can be calculated by a vertical integration of water vapor profile.

4 Quality control scheme

4.1 AIRS QC scheme

The initial cloud-clearing radiance and the quality of AIRS retrieval products of cloud fraction and water vapor will influence the quality of retrieved ozone data. As a result, the QC flags of the AIRS standard ozone product will be determined by a two-step method: 1) preliminary determination, and 2) an internal “constituent good” check. The preliminary determination step checks for completion of the final retrieval, stability of the cloud-clearing procedure, and confirms that the cloud fraction total is less than 90%. Data characterized by a failure of retrieval, complex terrain, and overcast conditions will be flagged erroneous by the first QC step. In the internal “constituent good” check, the following ratio of the retrieval error of TPW over the TPW will be employed:

$$R = \frac{\varepsilon_{\text{TPW}}^{\text{AIRS}}}{\text{TPW}^{\text{AIRS}}}, \quad (2)$$

where TPW^{AIRS} is the retrieved TPW from the AIRS data, and $\varepsilon_{\text{TPW}}^{\text{AIRS}}$ is the corresponding TPW error. A ratio value of less than 35% is chosen as the QC criterion for ozone data in the AIRS standard retrieval process. Figure 2 shows the spatial distributions of AIRS ozone data after the AIRS QC for the four selected typhoon and hurricane cases. It is clearly shown that almost all of the ozone data around the center of the typhoon/hurricane have been removed, even though some of the data could be useful. An unreasonably low AIRS TPW value ($< 5 \text{ kg} \cdot \text{m}^{-2}$) around the storm centers of all cases (Fig. 3) could have caused large values of R used for the second step of AIRS QC. In the following, a modified two-step scheme is proposed to replace the

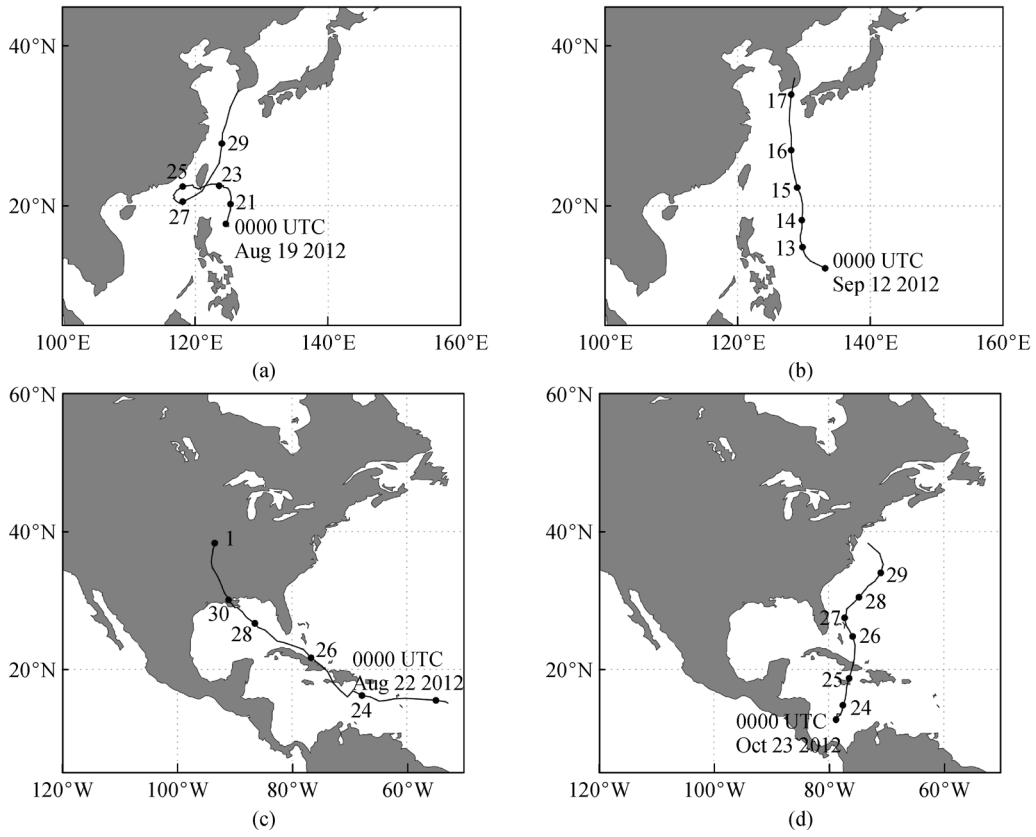


Fig. 1 Observed tracks of (a) Tembin, (b) Sanba, (c) Isaac, and (d) Sandy.

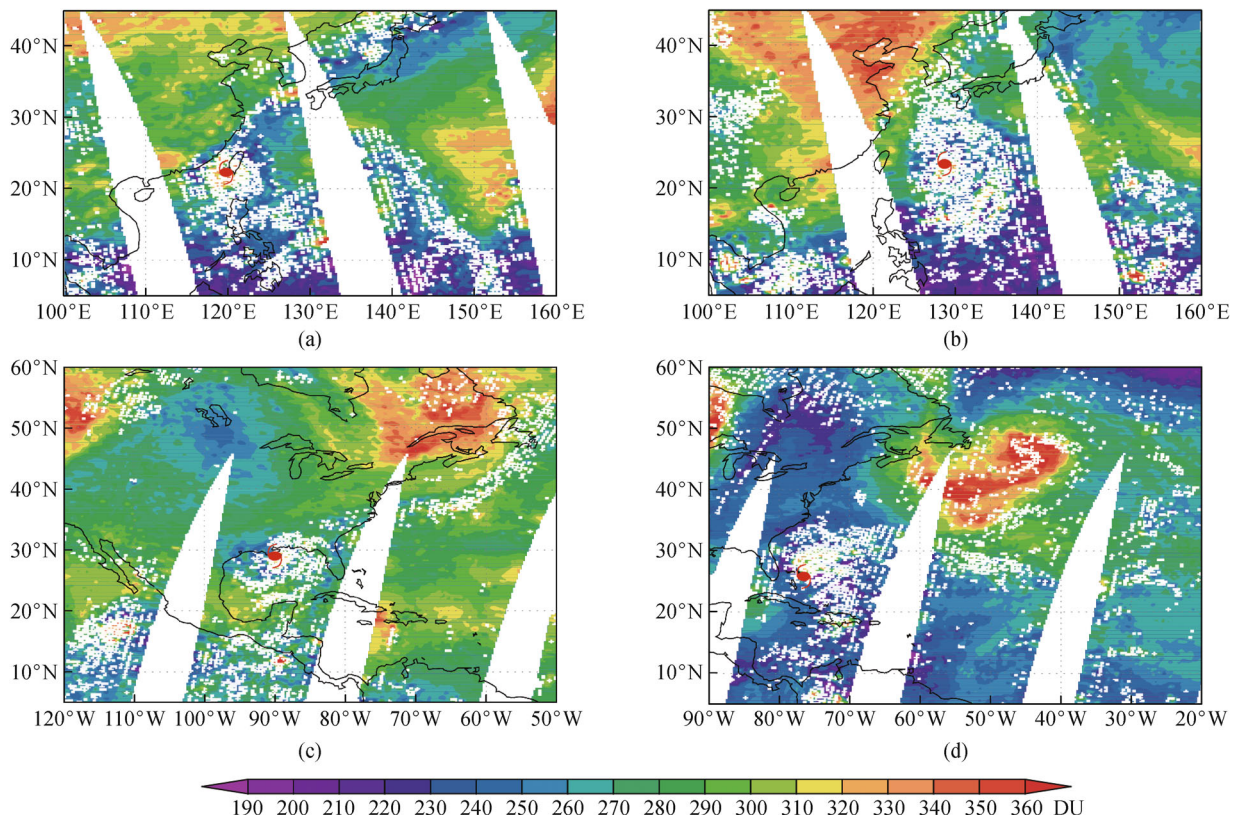


Fig. 2 Spatial distribution of total column ozone with erroneous data points removed at 0600 UTC for (a) Tembin on 24 August 2012, (b) Sanba on 15 September 2012, (c) Isaac on 29 August 2012, and (d) Sandy on 26 October 2012.

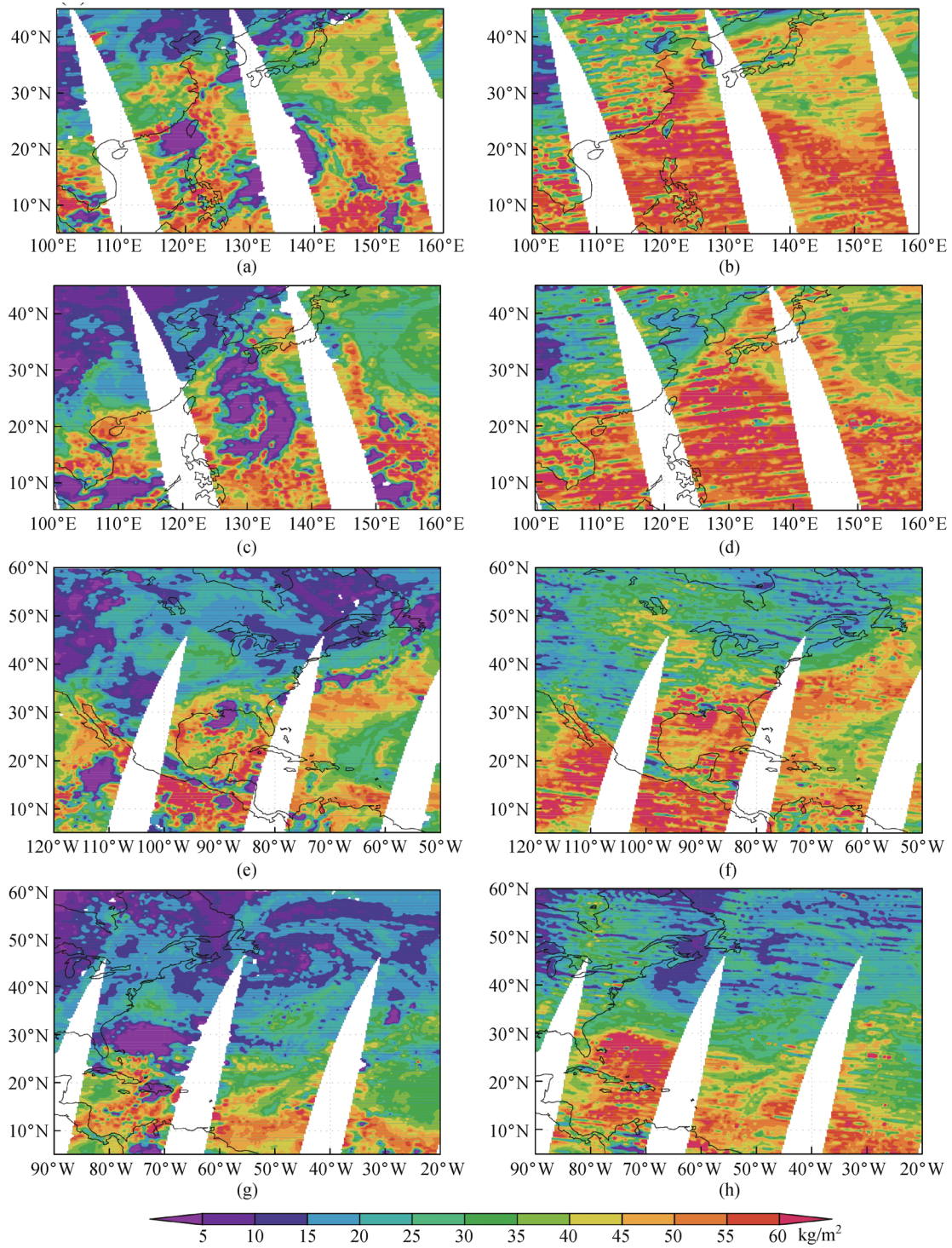


Fig. 3 AIRS-retrieved TPW (left) and AMSU TPW (right) at 0600 UTC for: (a, b) Tembin on 24 August 2012, (c, d) Sanba on 15 September 2012, (e, f) Isaac on 29 August 2012, and (g, h) Sandy on 26 October 2012.

second AIRS QC step. The data that pass preliminary determination will be selected as input to the two-step QC scheme developed by this study.

4.2 Improved QC scheme

A two-step QC scheme is developed to resolve the problem

of AIRS QC near the typhoon and hurricane center.

4.2.1 QC 1: Modified TPW Ratio

It is believed that there should be useful total column ozone data near typhoon and hurricane centers. A modified ratio of TPW, which still uses the retrieval error of AIRS TPW, but replaces the AIRS TPW retrieval with a zonally-averaged AMSU TPW retrieval, is developed to flag the outliers. Specifically, a modified ratio is used instead of R in Eq. (2):

$$R^{\text{modified}} = \frac{\varepsilon_{\text{TPW}}^{\text{AIRS}}}{\overline{\text{TPW}}^{\text{AMSU}}}, \quad (3)$$

where $\overline{\text{TPW}}^{\text{AMSU}}$ is the zonally averaged AMSU TPW. The modified TPW ratio can overcome the problem of low AIRS TPW values near the typhoon and hurricane centers. The sensitivity tests show that the 31%–35% ranges of the new TPW ratio maintain a steady percentage of data rejection over time. Therefore, a threshold value of 33% is chosen as the criterion for determining the QC flag of AIRS ozone data.

4.2.2 QC 2: Biweight algorithm

Observations that are consistent with the model variables are assimilated in the NWP system. The biweight algorithm (Lanzante, 1996; Carrier et al., 2007) is used for identifying the data that are consistent with the model. The mean and standard deviation calculated by the biweight algorithm are less affected by outliers than by the traditional method. Detailed information about the biweight algorithm can be found in Zou and Zeng (2006). The Z -score values are used to determine the outliers, that is,

$$Z_i = \frac{(X^{\text{obs}} - X^{\text{sim}})_i - \mu_{\text{bw}}}{\sigma_{\text{bw}}} \quad (i = 1, 2, \dots, n), \quad (4)$$

where i is the data number, X^{obs} is the observation data, X^{sim} is the simulated data, μ_{bw} is the biweight mean of $(X^{\text{obs}} - X^{\text{sim}})$, and σ_{bw} is the biweight standard deviation of $(X^{\text{obs}} - X^{\text{sim}})$.

A linear regression model linking total column ozone data to the MPV analysis (Jang et al., 2003; Zou and Wu, 2005; Wang et al., 2012) must be established prior to

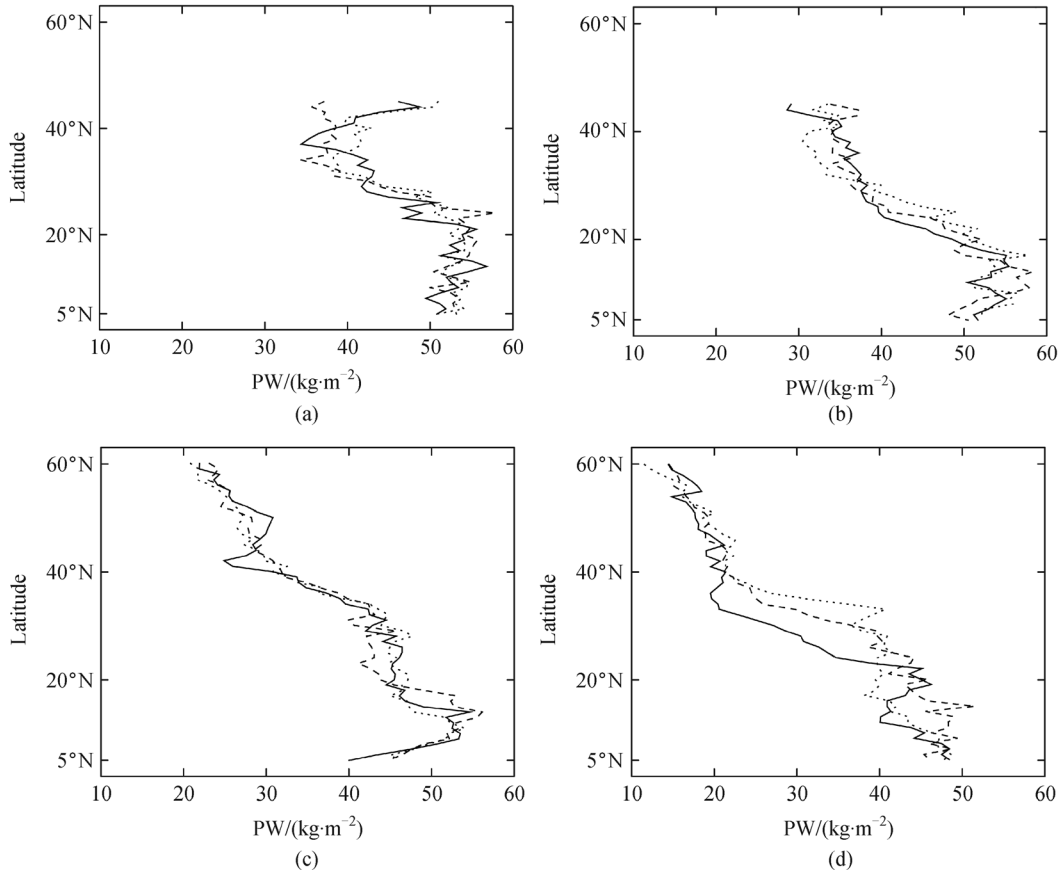


Fig. 4 Zonal averaged total PW ($\text{kg} \cdot \text{m}^{-2}$) from AMSU for (a) Tembin at 0600 UTC on 24 (solid), 25 (dashed), and 26 (dotted) August 2012; for (b) Sanba on 13 (solid), 14 (dashed), and 15 (dotted) September 2012; for (c) Isaac on 27 (solid), 28 (dashed), and 29 (dotted) August 2012; and for (d) Sandy on 26 (solid), 27 (dashed), and 28 (dotted) October 2012.

applying the biweight algorithm to the QC of AIRS total column ozone data (O_3^{obs}). It can be expressed as

$$O_3^{\text{sim}} = \alpha \times \text{MPV} + \beta, \quad (5)$$

where the MPV is calculated by

$$\text{MPV} = \frac{1}{P_1 - P_2} \int_{P_1}^{P_2} \frac{1}{\rho} \eta \cdot \nabla \theta dP, \quad (6)$$

where P is pressure, P_1 is 400 hPa, P_2 is 50 hPa, ρ is atmosphere density, η is absolute vorticity, and θ is potential temperature. The unit of MPV is PVU ($1\text{PVU} = 10^{-6} \text{m}^2 \cdot \text{K} \cdot \text{kg}^{-1} \cdot \text{s}^{-1}$). The atmospheric variables of Eq. (6) are obtained from the National Centers for Environmental Prediction (NCEP) FNL data, which have a horizontal resolution of $1^\circ \times 1^\circ$. Parameters α and β in Eq. (5) are regression coefficients. Their values are updated daily using AIRS total column ozone data and MPV analysis from the previous four days of the initial time of model forecasts. The quality-controlled data are used to determine the coefficients during the following days.

Empirically, the threshold of Z -score should keep most data that satisfy the linear relationship between O_3^{obs} and O_3^{sim} while removing the outliers (Zou and Zeng, 2006). Having examined numerical results by applying different threshold values of the Z -score, the criterion $Z \geq Z\text{-score}$,

with $Z\text{-score} = 1.5$, is chosen as the biweight check for all cases.

5 Numerical results

5.1 Evaluation of QC1

Figure 3 shows the spatial distributions of AIRS TPW and AMSU TPW for Tembin, Sanba, Isaac, and Sandy. As shown, the main differences between AIRS TPW and AMSU TPW occurred near the tropical storm centers. AMSU TPW retrieval in each case reached a high value ($> 60 \text{kg} \cdot \text{m}^{-2}$) near the storm center, is populated by thick clouds.

Zonally averaged AMSU TPW for typhoons and hurricanes during a 3-day period are shown in Fig. 4. It is observed that the patterns were similar from low to high latitudes at different times during this period. There is a slight fluctuation between 5°N and 20°N , then a rapid decrease with latitude. The error of AIRS TPW also shows a latitude-dependence (Fig. 5). The denominator in Eq. (2) can be replaced with the zonally averaged AMSU TPW.

The spatial distributions of the AIRS QC ratio and the modified QC ratio for all cases are shown in Fig. 6. It is clearly seen that the outliers flagged by the modified QC

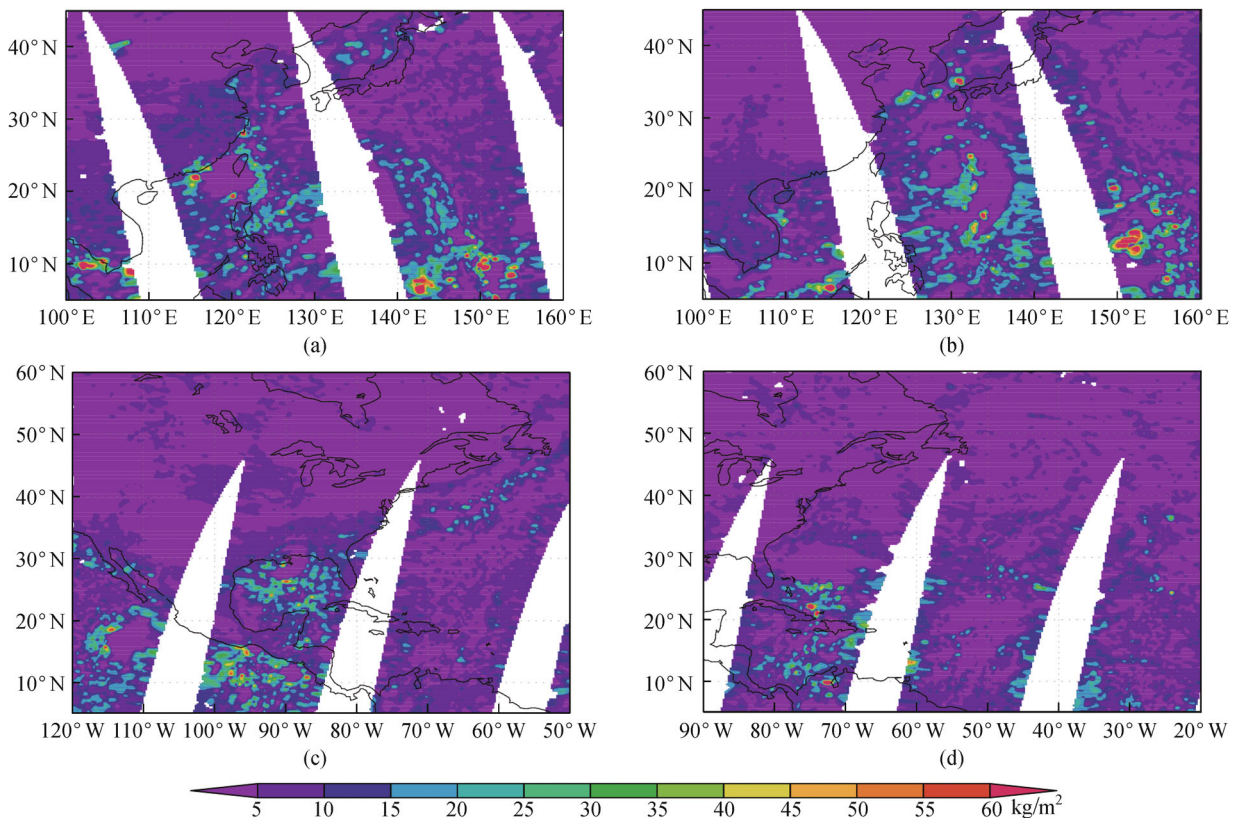


Fig. 5 Total precipitable water error at 0600 UTC 24 August 2012 for (a) Tembin, on 15 September 2012 for (b) Sanba, on 29 August 2012 for (c) Isaac, and on 26 October 2012 for (d) Sandy.

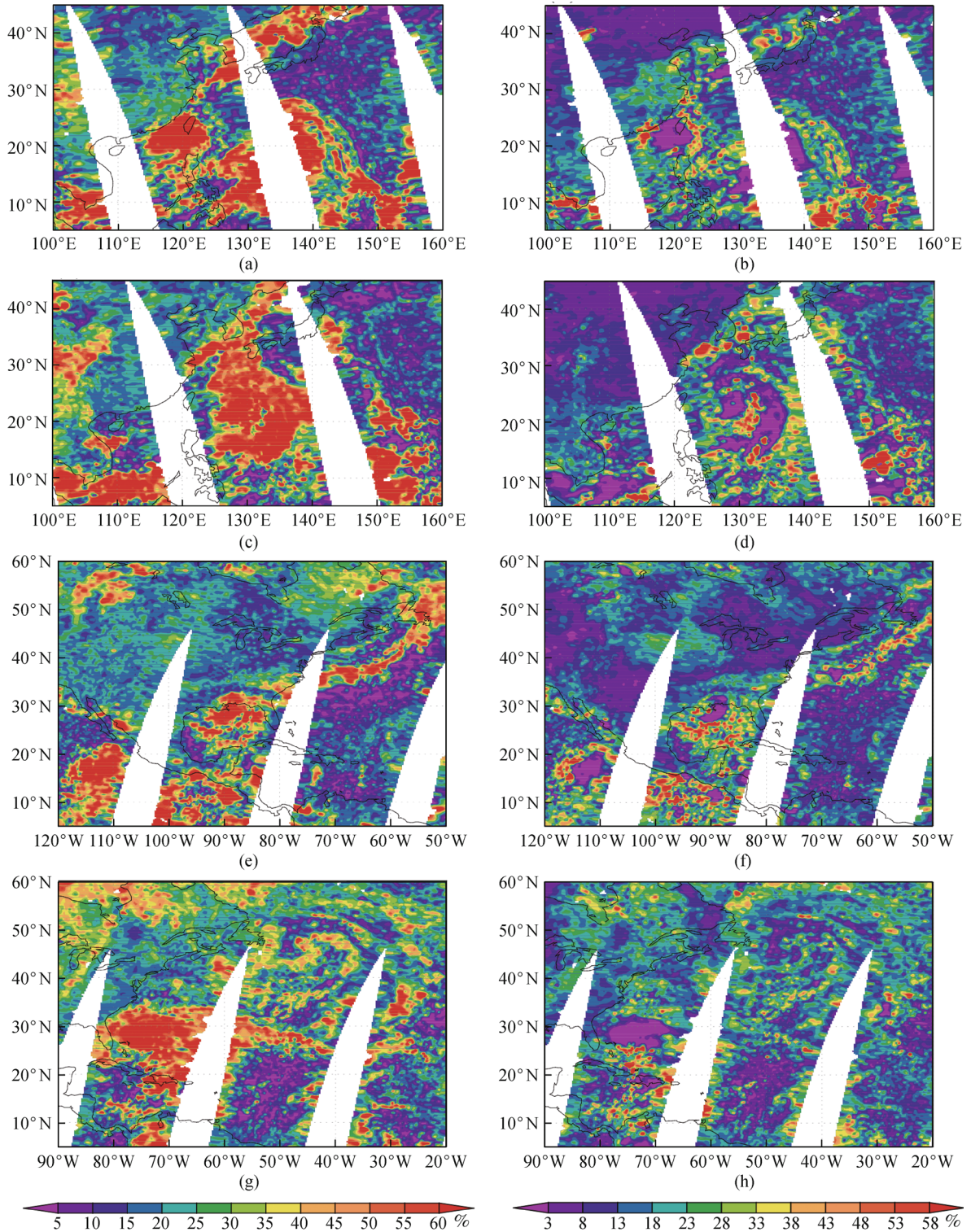


Fig. 6 The AIRS QC ratio (left) and the modified ratio (right) at 0600 UTC for (a, b) Tembin 24 August 2012, (c, d) Sanba on 15 September 2012, (e, f) Isaac on 29 August , and (g, h) Sandy on 26 October 2012.

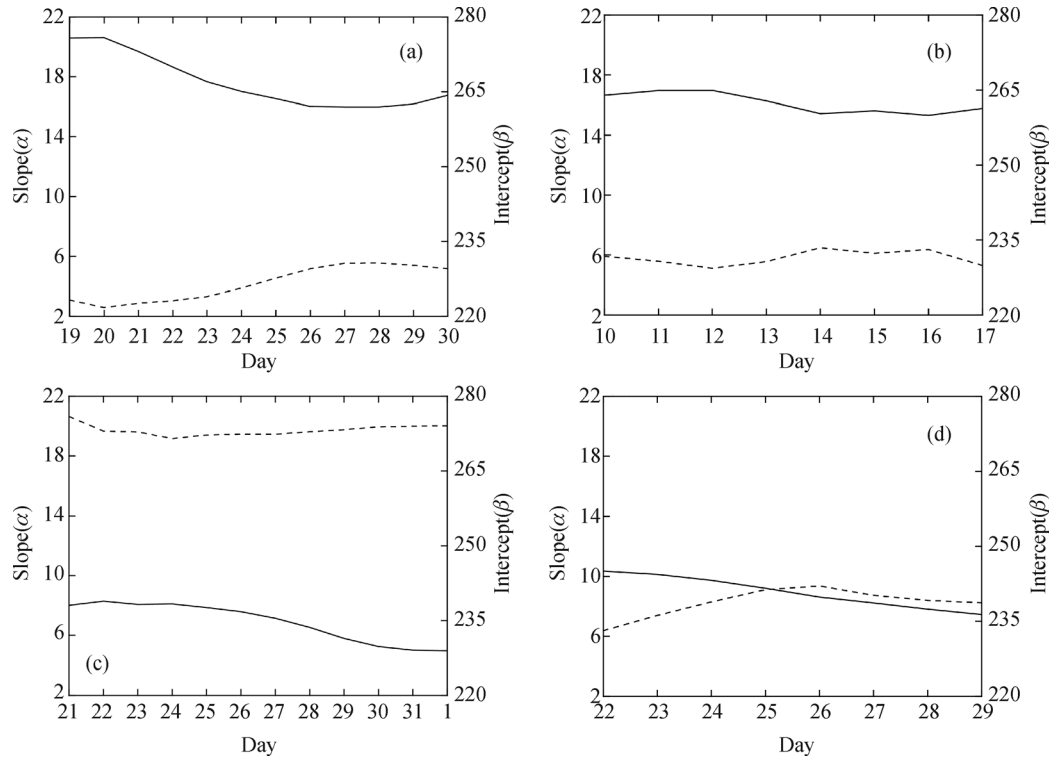


Fig. 7 Daily variations of linear regression coefficients α (solid) and β (dashed) for (a) Tembin during 19–30 August 2012, (b) Sanba during 10–17 September 2012, (c) Isaac from 21 August to 1 September 2012, and (d) Sandy during 22–29 October 2012.

ratio can be identified by the AIRS QC ratio. However, the regions with high AIRS QC ratio are significantly reduced in all cases, especially near the storm centers.

5.2 Evaluation of QC 2

Figure 7 shows the daily variation of slope α and intercept β in Eq. (5). It is worth mentioning that the slopes α of Tembin and Sanba are consistently larger than those of Isaac and Sandy. This feature indicates that the total column ozone varies with the MPV more rapidly for Tembin and Sanba than that for Isaac and Sandy. In addition, the intercepts β are also different in the four cases. Based on these results, it is determined that the regression model should be established for different cases and be updated daily.

Figure 8 shows the scatterplots of total column ozone and MPV. As shown, the variation to MPV for the total column ozone predicted by the linear regression model is similar to that of the AIRS observations. Furthermore, QC with $Z \geq 1.5$ can remove the outliers effectively while maintaining useful total column ozone data for Tembin, Sanba, Isaac, and Sandy.

5.3 Relationship between QC1 and QC2

The QC1 step can identify the ozone data with abnormal retrieval errors, while the QC2 step can remove observa-

tions that differ greatly from model simulations. Figure 9 provides the scatterplot of differences between observations and model simulations against TPW error ratio for Tembin, Sanba, Isaac, and Sandy, where the black dots outside of the red dashed lines are removed by QC1 and QC2. It is shown that the QC1 step can identify the data that cannot be removed by the QC2 step and vice versa, while the core ozone data are retained. As observed by plotting data with TPW ratios greater than 33% and a Z-score less than 1.5 (Fig. 9), most of the data flagged by QC1 are in the regions with small differences in spatial distribution between observations and model simulations, especially near the storm centers.

It is therefore valid to conclude that the two QC steps complement each other and joint implementation can fully identify the outliers from the original data.

5.4 Data characteristics before and after QC

To validate the effects of the two-step QC scheme in the typhoon and hurricane cases, the total percent of outliers flagged by QC1 and QC2 during the data period (see the descriptions in Table 1) are shown in Fig. 10. In addition, the biweight algorithm (AIRS BW) is applied to the AIRS ozone data that pass the AIRS QC scheme for comparison. It is shown that the AIRS QC scheme removes 15%–30% of the AIRS ozone data, which is much higher than by QC1. The total percentage of outliers flagged by AIRS QC

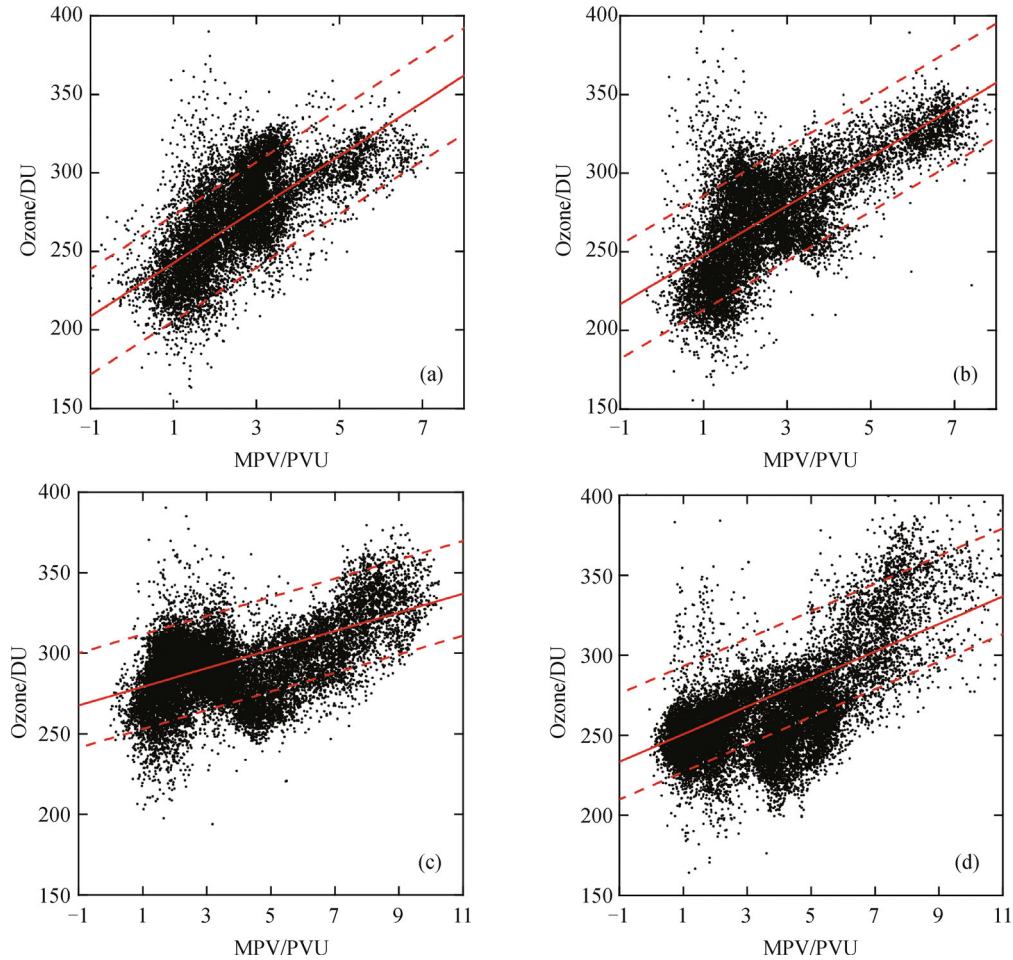


Fig. 8 Scatterplot of NCEP MPV and AIRS total column ozone for (a) Tembin on 24 August 2012, (b) Sanba on 15 September 2012, (c) Isaac on 29 August 2012, and (d) Sandy on 26 October 2012. The Z-score criterion of 1.5 is indicated by a red dashed line. The red solid lines represent the linear regression models.

and AIRS BW is also higher than that removed by the two-step QC scheme in all cases. Moreover, it is found that the total number of outliers removed by QC1 and QC2 is less than (in two typhoons), or approximately equal to (in two hurricanes), that flagged by AIRS QC.

Figure 11 shows the mean and standard deviation of differences between observations and model simulations for the four cases without QC, with AIRS QC, with AIRS BW, and with the two-step QC. Correlations between total column ozone and MPV of the four experiments for all cases are also calculated. The results show that the standard deviation of the data with the two-step QC in all cases is much smaller than that without QC, with AIRS QC, and with AIRS BW. The correlation between total column ozone and MPV for typhoons and hurricanes is also improved significantly after the quality control of the two-step QC, with a typically lower mean.

The above analysis proves that the two-step QC can improve the quality of AIRS ozone data significantly while retaining more observations than AIRS QC and AIRS BW.

6 Summary

In the original AIRS QC scheme, the criterion for flagging data is defined as the ratio of AIRS TPW error to AIRS TPW, while the threshold of 35% rejects most of the data near the typhoon and hurricane centers. This condition may remove useful ozone data due to the unrealistically low TPW near the storm centers.

A two-step QC scheme for AIRS total column data is subsequently designed and applied to two typhoons and two hurricanes in 2012. In the first step, a new TPW ratio, which is defined by AIRS TPW error divided by zonal average AMSU TPW, is used to replace the original ratio. Results show that the threshold of 33% for the new TPW ratio can flag 5%–10% of the total data as the outliers while keeping more data near the storm centers. After the first step, a biweight method, based on the daily updated linear regression model and the relationship between total column ozone and MPV, is applied for the assimilation requirement of AIRS ozone data. Results of this QC step

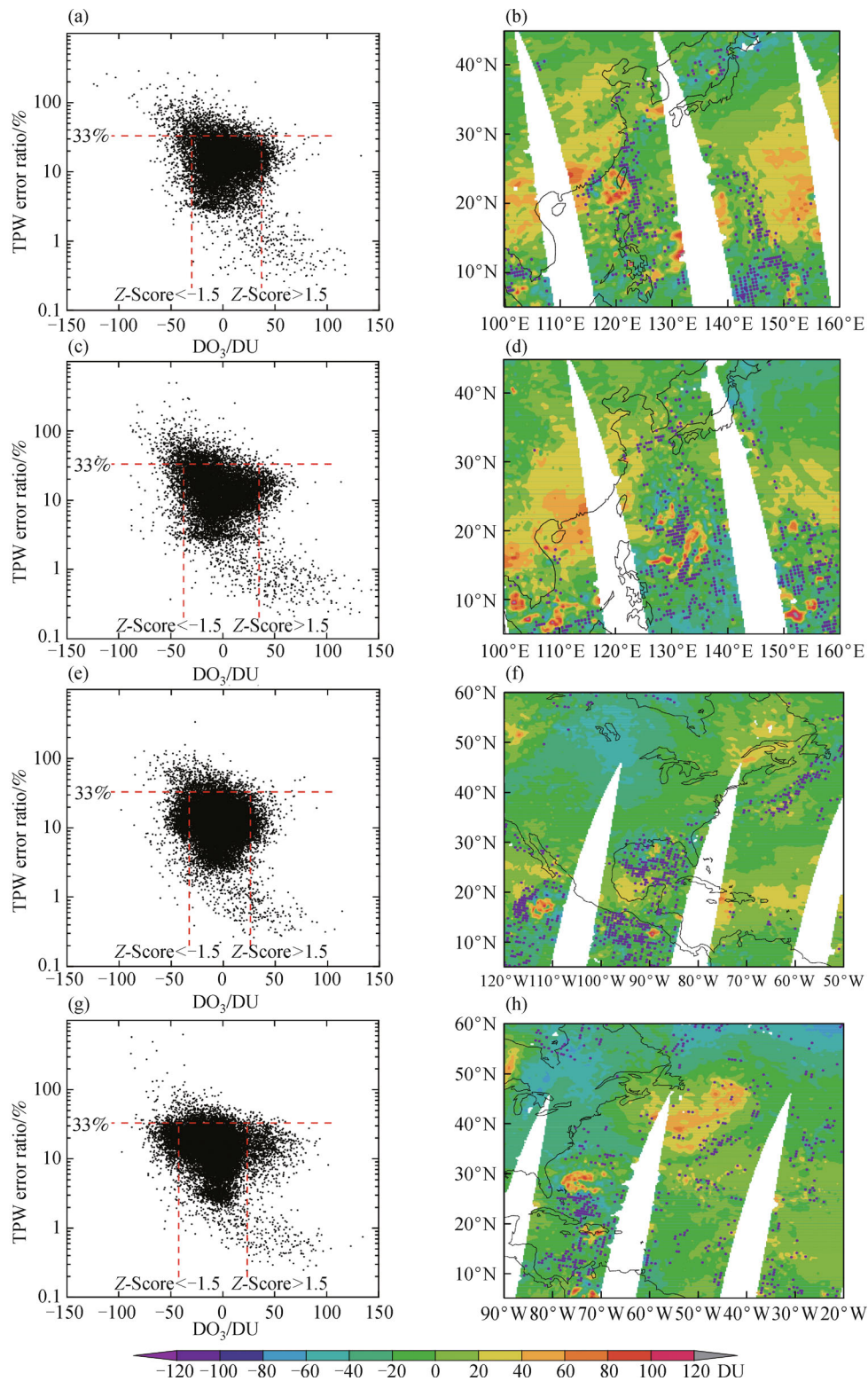


Fig. 9 Scatterplot of differences between observed ozone and simulated ozone (DO₃) against TPW error ratio (left), with 33% TPW error ratio and 1.5 Z-score (red dashed lines), and spatial distribution (shaded) of differences between AIRS-observed and NCEP-simulated total column ozone (right), as well as those points where the TPW error ratio exceeds 33% and Z-score is < 1.5 (blue dots) for (a, b) Tembin at 0600 UTC 24 August 2012, (c, d) Sanba on 15 September 2012, (e, f) Isaac on 29 August 2012, and (g, h) Sandy on 26 October 2012.

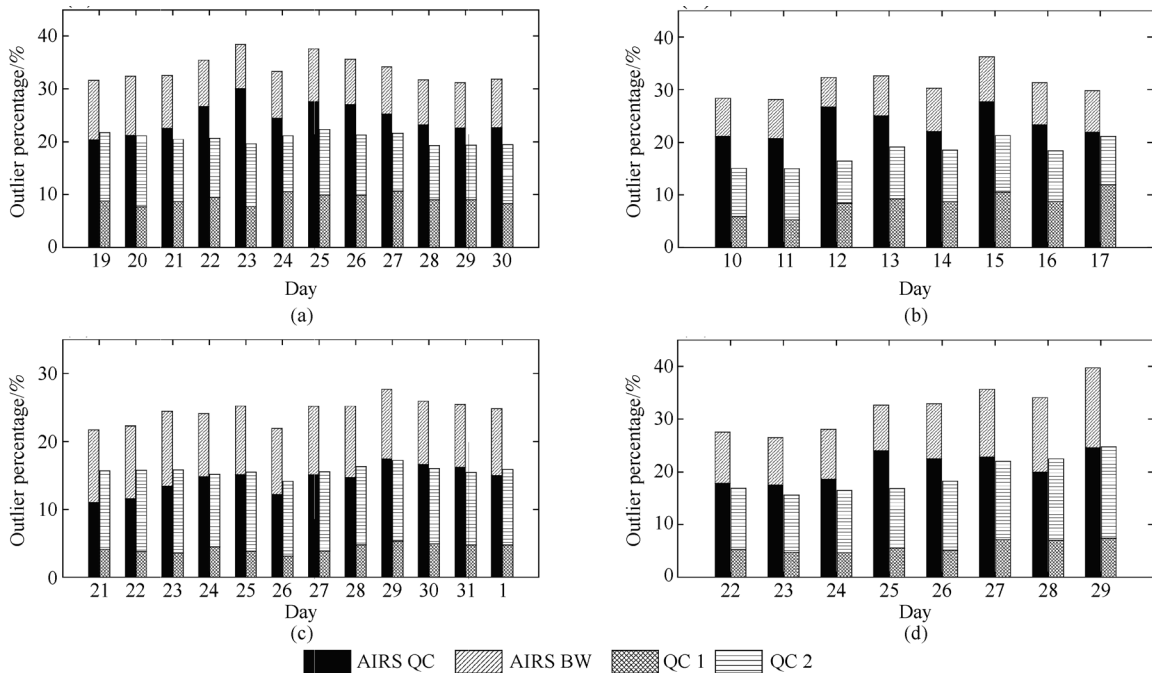


Fig. 10 Percentage of outliers as identified by AIRS QC, the biweight method over AIRS quality-controlled data (AIRS BW), the first TPW error step (QC 1), and the second biweight step (QC 2) for (a) Tembin on 19–30 August 2012, (b) Sanba on 10–17 September 2012, (c) Isaac from 21 August to 1 September 2012, and (d) Sandy on 22–29 October 2012.

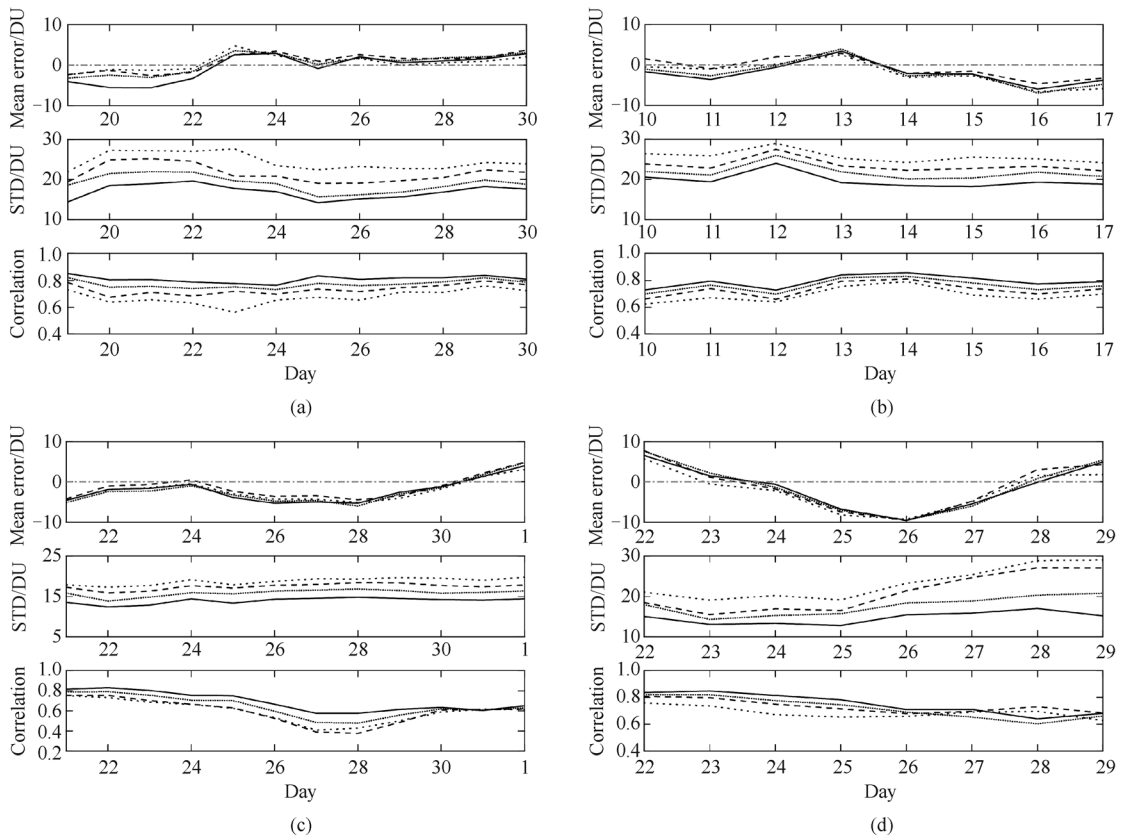


Fig. 11 Mean and standard deviation of differences between AIRS-observed and NCEP-simulated total column ozone without QC (dot) and with AIRS QC (dash), AIRS BW (short dot), and modified QC (solid). Correlations between NCEP MPV and AIRS total column ozone are also plotted. (a) Tembin 19–30 August 2012, (b) Sanba 10–17 September 2012, (c) Isaac from 21 August to 1 September 2012, and (d) Sandy 22–29 October 2012 are shown.

remove approximately 10% of the data and the core information on the ozone data for typhoons and hurricanes is maintained.

It has been shown that the two steps of the new QC scheme complement each other. The first step can remove the ozone data with a high value of AIRS TPW error, while the second step can identify the observed ozone values that significantly deviate from the simulated ozone values. The joint implementation of the two steps is shown to be feasible for typhoons and hurricanes. The two-step QC scheme can improve the quality of the ozone data with a smaller bias and standard deviation, while retaining more observations than the AIRS QC scheme. Furthermore, the high correlation between total column ozone and MPV after the two-step QC is encouraging for future assimilation and application of AIRS ozone data.

The two-step QC scheme proposed in this study is shown to work well for typhoons and hurricanes, providing the foundation for future use of AIRS ozone data in the NWP. However, more cases are needed for a statistical evaluation of the two-step QC scheme. Additionally, the need for further investigation on the assimilation of ozone data and its impact on typhoon and hurricane prediction remains for future research.

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