Field measurements of Tropical Storm Aere (1619) via airborne GPS-dropsondes over South China Sea

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ABSTRACT

In the past two decades, GPS (global position system) dropsonde has been developed as an effective tool to explore the internal characteristics of tropical cyclones (TCs). To facilitate the short-term forecasting of TCs’ intensity and track over the Hong Kong Flight Information Region (HKFIR), Hong Kong Observatory (HKO) started to launch reconnaissance campaigns by using airborne GPS-dropsondes from 2016. On 7th October 2016 when Tropical Storm Aere (1619) got close to Hong Kong, 10 dropsondes were released from a reconnaissance aircraft at 10 km altitude to sample the TC at different storm-relative positions. This offers a valuable opportunity to examine the functional performance of the dropsonde system. In this study, the validity of collected dropsonde measurements is examined first. Observational results of Aere’s inner structure are then discussed. Results presented in this study are expected to provide useful information for better understanding of the in-situ measurements from dropsondes deployed over HKFIR, and for advancing the knowledge on TC’s inner structure especially at middle and upper TC depth.

1. INTRODUCTION

Global position system (GPS) dropsondes have been developed as an effective tool to explore the internal structures of tropical cyclones (TCs) since its debut in 1990s (Franklin and Hock 1999). This device consists mainly of a GPS receiver to derive horizontal wind speed and direction, and sensors for measurements of pressure,
temperature and humidity. It is conventionally released from a reconnaissance aircraft at the flight level. As the sonde descends, it relays detected data to the aircraft by radio transmission until hitting the Earth’s surface.

A GPS-dropsonde has some overwhelming advantages against traditional instruments. First, it allows flexible deployment at targeted storm-relative positions and different evolution stages of a TC, making it feasible to detect TCs strategically and systematically (Sharanya 2016). Second, dropsondes can offer high-fidelity and high-resolution (along height) samplings of a TC’s inner structure (Franklin and Hock 1999), which facilitates to resolve detailed TC characteristics.

Owing to the above features, GPS-dropsondes have been extensively utilized in TC surveillance campaigns to support operational weather forecasting and meteorological research. The earliest routine deployment of GPS-dropsondes started in 1997 from U.S. hurricane reconnaissance aircrafts (Aberson, 2010), with the vast majority of the devices released above the Atlantic tropical cyclone basin and a small number above the eastern and central North Pacific basins. In 2002, researchers in Taiwan initiated the DOSTAR (Dropwindsonde Observations for Typhoon Surveillance near the Taiwan Region) experiment (Wu et al., 2005). A number of reconnaissance missions were also conducted in the west Pacific Ocean (Aberson, 2011). Based on the collected datasets, typical TC characteristics have been analyzed, including the surface wind factor (Franklin et al., 2003), air-sea interaction (Powell et al., 2003), low-level-jet of wind profiles (Kepert 2006a, 2006b; Vickery et al., 2009; Giammanco et al., 2013), TC boundary layer depth (Zhang et al., 2011; 2013), TC outflow and warm core structures (Komaromi and Doyle, 2017), and so on. GPS-dropsonde data is also utilized to improve the forecasting accuracy of TC track and intensity (Rappaport et al. 2009; Chen et al. 2013; Doyle et al., 2017). Comparison studies conducted by Wu et al. (2007) show that the assimilation of dropwindsonde data could lead to an improvement of 22% in 72 h-average track forecasts.

The southeast China is located at a TC-prone region. TCs can result in severe casualties and economic losses every year in this area. However, detections of the regional TCs are mostly conducted by using ground-based instruments, and TC reconnaissance via aircrafts has been considerably limited (Chan et al. 2011, 2014). To facilitate the short-term forecasting of TCs’ intensity and track over the Hong Kong Flight Information Region (HKFIR), Hong Kong Observatory (HKO) started to launch reconnaissance campaigns by using airborne GPS-dropsondes from 2016, which was the first time a member of the Typhoon Committee of the World Meteorological Organization has conducted routine typhoon reconnaissance using GPS-enabled dropsonde over the South China Sea.

On 7th October 2016 when Tropical Storm Aere (1619) got close to Hong Kong, a complete dropsonde measurement around the TC center was conducted. This offers a valuable opportunity to examine the functional performance of the dropsonde system. In this study, the validity of collected dropsonde measurements is examined first. Observational results of Aere’s inner structure are then discussed. Results presented in this study are expected to provide useful information for better understanding of the in-situ measurements from dropsondes deployed over HKFIR, and for advancing the knowledge on TC’s inner structure especially at middle and upper TC depth.
2. EXPERIMENT AND DATASET

2.1 Tropical Storm Aere and positions of dropsondes

Aere is the 19\textsuperscript{th} TC storm that developed over the western North Pacific (WNP). As shown in Figure 1, it formed as a tropical depression to the east of Dongsha on the afternoon of 5 October. Then, it moved across the Luzon Strait and entered the northeastern part of South China Sea the next day where it intensified into a tropical storm. After crossing the sea areas south of Dongsha in the early morning on 7 October, Aere slowed down and drifted northwards during the day, reaching its peak intensity in the afternoon (estimated 10-min mean wind speed: 23.6 m s\textsuperscript{-1}).

To detail the inner characteristics of Aere for short-term forecasting of its intensity and track, HKO deployed the reconnaissance campaign at the end of 6\textsuperscript{th} Oct. 2016. During the period of 00:00-02:00/7 UTC (hh:mm/d), 10 GPS-dropsondes were released successively at varied storm-relative positions of Aere from the flight level, i.e., 10 km AMSL. The satellite cloud snapshot captured at 00:00/7 Oct. and the positions of launched dropsondes are shown in Figure 2 where the initially released locations of the dropsondes are marked by 1, 2, 3…10. The solid square in the zoom-in plot of the figure denotes the Dongsha Station which is equipped with radiosonde balloons for upper atmosphere observations.

According to the best track records issued by HKO, Japanese Meteorological Agency (JMA) and National Oceanic and Atmospheric Administration (NOAA), the
geographic coordinates of Aere’s center at 00:00/7 and 06:00/7 were [20.6°/20.4°/20.5N, 116.4°/116.4°/116.5°E] (HKO/JMA/NOAA) and [20.7°/20.7°/20.6°N, 116.2°/116.0°/116.4°E], and the contemporary central pressure were 990/992/993 hPa and 988/985/985 hPa, respectively. Based on the above information, it is regarded that the TC center location at 00:00/7 was [20.5°N, 116.4°E], whilst the contemporary translational speed and central pressure of the storm were 1.41 m s⁻¹ and 991 hPa. It is stressed that the information of TC’s center location plays an important role in determining the storm-relative positions of the dropsondes. Although accurate estimation of this parameter is unavailable, the adopted location should be within 15 km distance from the truth.

Figure 3 depicts the radial distance of each dropsonde from the TC center during the releasing period. For expression convenience, the radial distances for dropsondes No.1 to No. 6 are marked as positive, while those for the others are marked as negative. Detailed information of the launched dropsondes is listed in Table 1. It is noted that dropsonde No. 6 was selected to be released above the TC center. From Table 1, the horizontal distance between this dropsonde and the TC center was only 11-19 km. From the cloud snapshot in Figure 2, there should be a severe background wind shear influencing the vortex which dragged the TC cloud northwards with respect to the TC center. Severe wind shears tend to destroy the hot tower (or warm core) of a TC by invading its inner region with much colder background atmospheres. Thus, they are adverse to the TC’s intensification.

![Figure 3. Radial distances of dropsondes from TC center](image-url)

<table>
<thead>
<tr>
<th>No.</th>
<th>Starting launching</th>
<th>Ending receiving</th>
</tr>
</thead>
<tbody>
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<td>Latitude (°)</td>
</tr>
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<td>00:42:38/7</td>
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</tr>
<tr>
<td>2</td>
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</tr>
<tr>
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</tr>
<tr>
<td>9</td>
<td>01:44:05/7</td>
<td>19.49526</td>
</tr>
</tbody>
</table>
2.2 Introduction of datasets

The dropsonde involved in this study belongs to the Vaisala RD94 type whose weight is 350 g. It started to sample target meteorological elements after releasing respectively at 0.25 sec intervals for wind measurement and at 0.5 sec intervals for measurements of temperature, pressure and humidity. On average, the dropsondes dropped at a speed of \( \sim 13 \) m/s and lasted for \( \sim 12 \) min before hitting sea surface. During the descending process, they drifted both tangentially and radially with TC winds. The maximum drifting distance was \( \sim 10 \) km. The recorded measurement information includes: recording time, geographical coordinate, altitude, speed and direction of horizontal wind speed and direction (U and \( \theta \)), temperature (T), dew point (\( T_d \)), pressure (P) and relatively humidity (RH). In this study, each profile of the dropsonde data was inspected individually to exclude any identifiable errors. The measurements were then smoothed using a wavelet decomposition filter (wavelet name: db4, decomposition level: 2) to remove occasional spikes due to the switching of satellites and other interference.

3. VALIDITY OF FIELD MEASUREMENTS

The validity of collected field measurements is examined first, through: (1) recalculating the key meteorological parameters based on the directly detected weather information from the dropsonde and then comparing these values with those automatically generated by the dropsonde system, and (2) comparing measurement results from dropsondes and their counterparts from balloons that were released above a nearby position during the same period.

Three parameters are recalculated, i.e., horizontal wind speed (U) and direction (\( \theta \)), and relative humidity (RH), via the following equations:

\[
U = \sqrt{U_\phi^2 + U_\lambda^2}, \quad U_\phi = \frac{d\phi}{dt} \cdot R, \quad U_\lambda = \frac{d\lambda}{dt} \cdot R \cdot \sin(\phi) \tag{1}
\]

\[
\begin{align*}
\theta' &= \begin{cases} 
\arccos(\Delta S_\phi / \Delta S) \\
360 - \arccos(\Delta S_\phi / \Delta S)
\end{cases}, \quad \text{with} \quad \Delta S_\phi = \frac{d\lambda \cdot \sin(\phi) \cdot R \pi}{180} \\
\theta &= \text{mod}(630 - \theta', 360) \quad \text{with} \quad \Delta \phi = \frac{d\phi \cdot R \pi}{180} \\
RH &= 100 \cdot \exp\left(\frac{17.625T_d}{243.04 + T_d} - \frac{17.625T}{243.04 + T}\right) \tag{3}
\end{align*}
\]

where \( \phi, \lambda \) stand for the longitude (\( \phi \)) and latitude (\( \lambda \)) coordinates, \( U_\phi, U_\lambda \) presents the speed components along latitude and longitude, \( t \) denotes time, \( R \) is the radius of the Earth, mod(A, B) means the modulus of A after division by B (A and B are two real number). \( RH \) (unit: %) is computed via the August-Roche-Magnus approximation (Albuchov and Eskridge 1996), based on the measurements of dry-bulk temperature (T) and dew point (\( T_d \)).
Figure 4 compares the recalculated and automatically generated results. Basically, the two kinds of results show good agreement. It is noticed that due to the absence of time information at some altitudes, results of the recalculated U contain a number of spikes. By contrast, results of the auto-generated RH suffer from the appearance of a series of unrealistic breakpoints. Therefore, records of U and θ automatically generated by the dropsonde system and the recalculated RH values will be adopted in the following analysis.

![Graph showing recalculated and auto-generated results](image)

Figure 4. Comparison of recalculated wind speed (U) and direction (θ) and relative humidity (RH) with those auto-generated by the dropsonde system.

Figure 5 compares the measurements from dropsonde No. 5 and a balloon released ~1 h ahead of the dropsonde at the Dongsha Island radiosonde station (Figure 2). The horizontal distance between the projects of these two devices was 40 km. From this figure, measurements from the two devices show good agreement for results of T and Td. For the wind measurements, due to the difference of released positions and the large gradient of TC wind field in the inner region, results from the two devices differ more evidently, but both of the U and θ profiles show a similar trend. The comparison results reflect the validity of collected measurements.

![Graph showing measurements from dropsonde No. 5 and balloon](image)
4. RESULTS AND DISCUSSIONS

4.1 Temperature, pressure and humidity

Figure 7 depicts the vertical profiles of temperature (T) and potential temperature (θ). The values of θ are computed based on measurements of T and pressure (P):

$$\theta = T \left( \frac{P_0}{P} \right)^{R/c_p}$$  (4)

where $P_0$ (≈1010 hPa) denotes the sea level atmospheric pressure, $R$ (= 8.314 J mol$^{-1}$ K$^{-1}$) is the universal gas constant, $c_p$ is the specific heat capacity ($R/c_p$ = 0.286).

Results indicate that the ensemble-mean air temperature decreased almost linearly with the increase of altitude. The lapse rate ($\mu$) below ~7 km is 5.1 °C km$^{-1}$, compared to that of 6.3 °C km$^{-1}$ for the upper portion (i.e., 7-10 km). Through the whole detection range, $\mu$ may be roughly regarded as 5.4 °C km$^{-1}$. On the other hand, the ensemble-mean values of θ increase linearly with altitude, with the increasing rate equal to 5.0 K km$^{-1}$.

From the results of dropsonde No. 6 which was located around the TC eye, the atmospheres in range of 1.5-4 km were distinctly warmer than those associated with other dropsondes. The above phenomenon should be attributed to the warm-core feature of the TC. Around 1.5 km, there was an inversion layer of T, beneath which the temperature differed insignificantly among these dropsondes. The inversion layer around 2 km has been reported as a basic feature of the TC structures (Aberson 2010). The less variation of T with respect to storm-relative position below 1.5 km also supports the assumption of isothermal expansion of inflowing atmospheres in the secondary circulation of TCs (Emanuel 1987). By contrast, in the range of 5-6.5 km, the atmospheres associated with dropsonde No. 6 were even colder than those for other dropsondes. As to be further demonstrated, this is caused by the background wind shear which steered colder background atmospheres to invade into the TC’s inner region and meanwhile twisted the vertical profile of Aere’s center. The abnormal appearance of warmer atmospheres in the range of 6-8 km associated with dropsonde No. 4 should be largely attributed to the northward drift of the TC center in this range.
The vertical profile of atmospheric pressure ($P$) is shown in Figure 8. The barometric formula is found to fit the measurements well:

$$P(z) = P_0 (1 - \mu z / T_0)^{gM/R\mu}$$

(5)

where $T_0$ ($\approx 300$ K) is the atmospheric temperature at mean sea level, $z$ denotes altitude, $g$ ($=9.807$ ms$^{-2}$) is the acceleration of gravity on the Earth’s surface; $M$ ($=0.02896$ kg mol$^{-1}$) is the molar mass of dry air.

Also presented in Figure 8 is the pressure deficit that is defined as the pressure contrast between the local air and the ambient atmosphere. In this study, the ambient atmospheric pressure is calculated via Eq. (1). As reflected from the figure, the pressure deficit became insignificant above ~5 km (550 hPa), or the freezing level. Figure 12 shows the vertical profiles of $\Delta P$. As reflected, $\Delta P$ increased almost linearly with the increase of barometric altitude:

$$\Delta P(z) = k \cdot P(z) + \Delta P_0$$

(6)

where, $\Delta P_0$ denotes the pressure deficit at mean sea level and $k$ is the slope of the profile which can be determined by fitting the data via the least square technique.

Figure 9 exhibits the correlation between the $k$ and $\Delta P_0$. It is interesting to find that the two parameters are linearly correlated with each other:

$$k = c \cdot \Delta P_0$$

(7)

where, $c$ is a constant which by fitting the data is determined as 0.00223 hPa$^{-1}$. 
Figure 9. Vertical profiles of the pressure deficit ($\Delta P$) and the correlation between the slope of $\Delta P$ ($k$) and the pressure deficit at mean sea level ($\Delta P_0$).

Eqs. (5-7) provide an empirical model for the vertical profile of TC pressure deficit, which can be used to generate a two-dimensional TC pressure field model by combining it with an existing radial profile model (e.g., the one proposed by Holland 1980). This is of great interests for developing operational height-resolving models for TC wind field (Snaiki and Wu 2017; Fang et al. 2018). Although the universality of the distribution pattern of $\Delta P(z)$, and therefore the proposed TC spatial pressure model, requires further verification, results presented herein should not be interpreted as purely case-oriented. It is noticed that the above findings are consistent with the observations from another case study by He et al. (2018).

Figure 10 presents the RH results in forms of both vertical profile and filled contour plot. The atmospheres beneath the inversion layer (~1.5 km) are found to be considerably humid, with the ensemble-average RH value being 90%. Since dropsonde No. 6 was located around the TC’s eye in range of 1.5-4 km, the atmospheres there were distinctly drier than their counterparts for other dropsondes. Around the 6-8 km range where the wind shear effect was significant, the atmospheres associated with dropsonde No. 4 were more humid than most others since this dropsonde should be located closer to the TC eyewall. By contrast, those for dropsondes 9-10 in the same range were much drier as these dropsondes tend to be located in Aere’s outer range.

Results of the equivalent potential temperature are shown in Figure 11. The equivalent potential temperature $\theta_e$ denotes the potential temperature that a parcel would reach if all involved water vapor was condensed and rained out by raising the parcel upwards and then lowering it to the mean-sea-level adiabatically. This quantity is more conserved during changes of the parcel’s pressure than the potential temperature $\theta$, as effects of water vapor and relevant phase change have been concerned. In this study, the method recommended by Bolton (1980) is adopted to calculate $\theta_e$. 

\[ k = \frac{d(\Delta P)}{dP} \]

\[ R^2 = 0.881 \]
The results suggest that the atmospheres were on average coldest (in terms of $\theta_e$) around the freezing level (centered 5 km). The downward extended valley of $\theta_e$ for dropsonde No. 6 is basically due to the drier atmospheres inside the TC eye region. By contrast, the upward located valley of $\theta_e$ for dropsonde Nos. 8-10 should be explained by the effects of background wind shear. It’s also worth mentioning that the $\theta_e$ values in range of 5-7 km demonstrate a consistent increasing trend toward the wind shear direction. Another point to be noted is about the warm patch in range of 5.5-8 km for dropsonde No. 4. Again, it should be attributed to the northward drifted inner structure of Aere which made this dropsonde to be located closer to the eyewall. The above finding also reveals the warm-core feature of a TC, which may be easily recognized from the results of $\theta_e$, contrast, i.e., $\Delta \theta_e$ which is defined as the difference between the $\theta_e$ values for the TC atmosphere and the background atmosphere. Unfortunately, due to the absence of background $\theta_e$, the $\Delta \theta_e$ records are unavailable.

4.2 Horizontal wind

Results of the horizontal wind speed (U) and direction ($\theta$) as well as the radial (Urad) and tangential (Utang) wind components are depicted in Figure 12 in form of filled contour plots. The measured strongest instantaneous speed was ~27 m s$^-1$, and most of the gale winds existed within 90 km radial range from the TC center. The wind direction varied significantly around the TC center. Since the vertical profile of Aere’s center is unavailable, a fixed coordinate of the TC center from the best track data is
adopted for computing the radial and tangential wind components throughout the whole vertical range. However, the obtained magnitudes of Urad could even exceed 20 m s\(^{-1}\) in range of 3-7 km for dropsondes Nos. 5-7 which were released within the most inner region. It is speculated that Aere’s center was twisted by the background wind shear and the center location in the above vertical range was dragged northwards. Consequently, the calculated Urad values are either too negatively large (for dropsonde No. 7) or too positively large (for dropsonde Nos. 5-6). The above speculation can also explain why the values of U for dropsonde No. 6 (which was located nearby the TC eye) should be so large in range of 3-7 km.

Figure 12. Filled contour plots of the horizontal wind speed (U) and direction (θ) and the radial (Urad) and tangential (Utang) wind components

The vertical profile of instantaneous horizontal wind speed, i.e., U, is stratified into 50 bins according to altitudes at 200 m intervals. Each bin contains ~10 measurement points. To investigate wind turbulent characteristics, the bin wind turbulent intensity \(TI_b\) is introduced which is defined as the ratio of the standard deviation \(\sigma_b\) to the mean \(U_b\) of bin wind records. The equivalent turbulent intensity \(TI_e\) for a given height range of the speed profile is then defined as the median of \(TI_{b,i}\), \(TI_{b,i}\) being the bin wind turbulent intensity of records in the studied range. To study the storm-relative dependence of wind turbulence, \(TI_e\) for the whole detection range of each profile is computed based on both unfiltered (Method-1) and filtered (Method-2) profile records. The empirical-modal-decomposition (EMD) technique (Huang et al. 1998) is adopted for the filtering process. This technique has the merit of self-adaption for nonstationary and nonlinear signals. After an EMD process, original signal can be decomposed into a
group of intrinsic model functions (IMFs). In this study, only the first 3 IMFs are selected and combined to create the high-pass filtered profile signal. By doing this, the trending components involved in each speed profile can be well removed.

Figure 13 compares the results obtained via the above two methods. The lower and upper error-bars stand for 25th and 75th percentiles, while the markers denote 50th percentiles, or \( e_{TI} \). Also plotted in Figure 13 are the filled contours of \( b_{TI} \) derived on the basis of filtered speed profiles. The results reveal that \( e_{TI} \) in the TC inner region (roughly within 90 km from TC center) was generally smaller than the one in outer areas. The \( e_{TI} \) values for the strongest winds were in range of 1-3 \%. The results also suggest that downward-shear atmospheres were more turbulent than those located in upward-shear region.

![Figure 13. Equivalent turbulent intensity \( (e_{TI}) \) and bin wind turbulence intensity \( (b_{TI}) \)](image)

### 4.3 Vertical wind speed

The measured falling speed (denoted as \( W \)) of dropsondes consists of two parts: the falling speed of dropsonde in still atmospheres \( W_d \), and the vertical wind velocity \( VV \) (Wang et al. 2009):

\[
W = W_d + VV \tag{8}
\]

with the value of \( W_d \) can be calculated via (Hock and Franklin 1999; Wang et al. 2009):

\[
W_d \approx -\sqrt{2mg / (C_d A \rho)} \tag{9}
\]

where \( m = 0.350 \text{ kg} \) is the weight of dropsonde, \( C_d = 0.61 \) is the drag coefficient, \( A = 0.0676 \text{ m}^2 \) is the projection area of the parachute, and \( \rho \) is the air density calculated via:

\[
\rho = \frac{P_d M_d + P_v M_v}{RT} \tag{10}
\]

in which \( P_d \) and \( P_v \) are the partial pressure of dry air and water vapor, \( M_d = 0.028964 \text{ kg mol}^{-1} \) and \( M_v = 0.018016 \text{ kg mol}^{-1} \) are the molar mass of dry air and water vapor.

The vertical profiles of \( W \) and \( VV \) are drawn in Figure 14. For \( W \), results from dropsondes Nos. 2 and 10 differ from the others distinctly by a nearly doubled falling speed. This occurred because the parachutes failed to deploy during the descending
period. The results of $VV$ reveal an ensemble-mean upward speed of $\sim 2 \text{ m s}^{-1}$ for the TC atmospheres, which is less consistent with one’s expectation. It is still unclear if this nominal speed should be purely contributed to the convective movements of the wind flows or it might be (or partially) due to the estimation bias involved in the computational process for $VV$. Despite the above uncertainties, the fluctuations of the $VV$ profiles provide useful reference information to further understanding the local characteristics of the TC’s thermodynamic and kinematic structures. Taking dropsonde No. 4 for example, distinct upward and downward flows are found in the ranges around 4 km (downward flows) and 6-8 km (upward flows). During the vertical movement processes, the local atmospheres tend to be invaded by the non-local flows with exchanges of moment, humidity and temperature, which leads to corresponding fluctuations in the profiles of U, RH and T (or $\theta_e$) as shown in Figures 10-12. It is highlighted that even if an estimation bias of $2 \text{ m s}^{-1}$ for $VV$ is assumed, the maximum value of $VV$ for dropsonde No. 4 still reached to $10 \text{ m s}^{-1}$ at 7.5 km where the dropsonde should be located around Aere’s eyewall. The large positive value of $VV$ reveals the existence of severe upward convection of eyewall flows.

Figure 14. Vertical profiles of falling speed (W) and vertical wind velocity (VV).

5. CONCLUSIONS

For the first time, routine reconnaissance campaigns by using airborne GPS-dropsondes were initiated from 2016 in the South China Sea to explore the TC inner structures above this region. Related outcomes are expected to facilitate the forecasting of TC activities around southeast China and advancing the knowledge on TCs’ internal structures above the north western Pacific basin.

This study presents the preliminary results for a sampled tropical storm via 10 GPS-dropsondes that were released at selected storm-relative positions above the flight level ($\sim 10 \text{ km AMSL}$). The validity of collected measurements has been examined through comparing them respectively with the recalculated results for some key weather elements and those collected from a radiosonde balloon. The overall good agreement between these results enhances our confidence on the credibility and accuracy of the dropsonde measurements. However, efforts should be made for the quality control of the dropsonde profiles to eliminate the unrealistic, e.g., RH records (Figure 4). Meanwhile, the analytical results reveal that the parachutes of two dropsondes failed to deploy during the descending period. Thus, it is required to clarify the reasons and to avoid such issues as far as possible in the following reconnaissance campaigns.
There are several interesting findings obtained in this study. (1) The ensemble-mean profiles of both air temperature (T) and potential temperature (θ) were linearly distributed along altitude. The lapse rate (μ) for T and the increasing rate for θ throughout the whole detection range were 5.4 °C km⁻¹ and 5.0 K km⁻¹, respectively. (2) The ensemble-mean profile of air pressure (P) is found to follow the barometric formula. More interestingly, the profiles of TC pressure deficit (ΔP) were linear along barometric altitude, with the slope increasing linearly with the increase of the mean sea level pressure deficit (ΔP₀). An empirical model for the vertical profile of TC pressure deficit has been established which can be used to generate a two-dimensional TC pressure field model, by combining it with an existing radial profile model. The above findings are of great interests for developing operational height-resolving models for TC wind field. (3) An inversion of air temperature existed around 1.5 m inside the TC eye. The portion of TC eye below this layer was dominated by warm and humid flows, while the one above it was governed by warm but much drier atmospheres. (4) The background wind shear can influence the TC structure significantly, since it can either twist the TC center or steer colder background atmospheres to invade the vortex’s warm core. It is speculated that the severe wind shear did affect Aere’s intensification negatively. From the best track data, Aere almost reached to its highest strength at the campaign period. However, it did not intensify into a stronger storm in the following 1-2 days even that it all the way moved over a vast of warm sea at a desirable translational speed.

In consideration of the significant role of a TC’s center coordinate and the thermodynamic characteristics of background atmospheres in analyzing the inner structures of the TC and in predicting the evolution of the TC’s track and intensity, it is suggested that special instruments be mounted further in the reconnaissance aircrafts in the future so as to obtain complete datasets.

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