Calculating Dropwindsonde Location and Time from TEMP-DROP Messages for Accurate Assimilation and Analysis

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ABSTRACT

Current practice is to transmit dropwindsonde data from aircraft using the TEMP-DROP format, which provides only the release location and time with 0.1° latitude × 0.1° longitude (about 11 km) and 1-h resolutions, respectively. The current dropwindsonde has a fall speed of approximately 15 m s^{-1}, so the instrument will be advected faster horizontally than it will descend if the wind speed exceeds this value. Where wind speeds are greatest, such as in tropical cyclones, this will introduce large errors in the location of the observations, especially near the surface. A technique to calculate the correct time and location of each observation in the TEMP-DROP message is introduced. The mean differences between the calculated and reported locations are about 0.5 km for distance and 15 s for time, or <1% of the error size for distance and <10% for time.

1. Introduction

Aberson (2008) found large Global Forecast System tropical cyclone track forecast degradations due to the assimilation of dropwindsonde data from operational synoptic surveillance missions during the 2004 and 2005 hurricane seasons. These degradations were due to either erroneous data assimilated into the models or imperfections in the data assimilation system operational at the time. Degradations to Hurricane Ivan (2004) forecasts were due to the assimilation of dropwindsonde data in high wind speed regions of the tropical cyclone. Depending on the intensity and eye size, dropwindsondes released in the eyewall may orbit more than halfway around the center (i.e., Aberson 2008, Fig. 5). Though the global positioning system (GPS) sensor on the dropwindsonde itself can report times and locations with high accuracy, the TEMP-DROP[1] code used to transmit the data from the aircraft provides only one location with 0.1° latitude × 0.1° longitude (about 11 km), and time at 1-h resolutions (Fig. 1). The lack of precision in the TEMP-DROP code may cause location errors of up to 7.8 km (1/20° latitude and longitude) at the release location, and these errors may increase as the wind advects the instrument during descent. This effect could be important in high-resolution numerical models, especially in high-gradient regions. The lack of location information associated with each datum may result in the data assimilation attempting to utilize data more than 180° azimuthally from its correct location relative to the tropical cyclone center. Assimilation of inaccurate dropwindsonde data in the tropical cyclone core can therefore lead to unrepresentative structures in the model initial conditions.

As a result of this finding, the times, pressures, and locations of the highest and lowest (in altitude) wind measurements are now reported in the TEMP-DROP messages. The times are provided to the nearest second, and the locations to the nearest 0.01° latitude × 0.01°

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[1] As defined in WMO (1995) and NOAA (2017).

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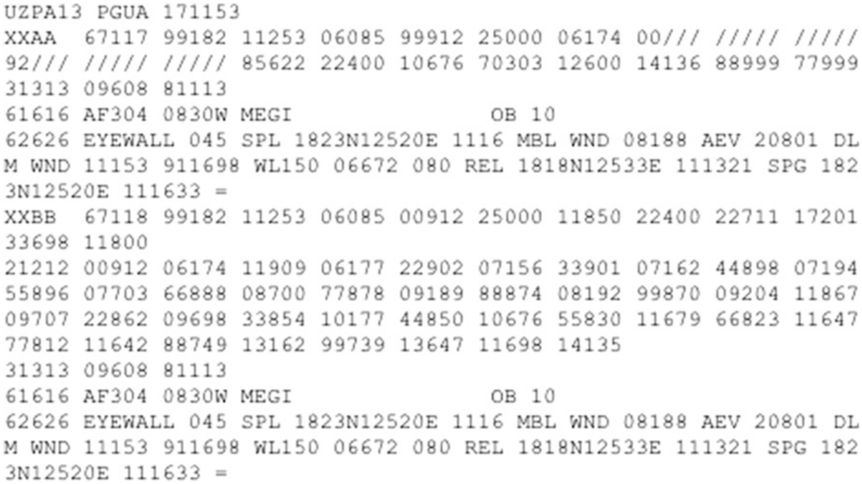

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61616 AF304 0830W MEGI               OB 10
62626 EYEWALL 045 SPL 1823N12520E 1116 MBL WND 08188 AEV 20801 DL
M WND 11153 911698 WL150 06672 080 REL 1818N12533E 111321 SPG 182
3N12520E 111633 =
XXBB  67118 99182 11253 06085 00912 25000 11850 22400 22711 17201
33698 11800
21212 00912 06174 11909 06177 22902 07156 33901 07162 44898 07194
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M WND 11153 911698 WL150 06672 080 REL 1818N12533E 111321 SPG 182
3N12520E 111633 =
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FIG. 1. Sample TEMP-DROP message from a dropwindsonde released during a flight into Typhoon Megi.

longitude. With this information and the mandatory and significant level wind velocities, the correct times and locations of each datum reported during instrument descent can be calculated with accuracy, and the data can be accurately assimilated into numerical models. The next section provides the algorithm used to calculate the times and locations of each data point in the TEMP-DROP message. Section 3 compares the times and locations calculated using this technique to true values from high-resolution postprocessed dropwindsonde data. Section 4 shows the impact of assimilating the data at the correct locations in a high-resolution model, and conclusions are provided at the end.

2. Technique

An example of a standard TEMP-DROP message taken during a flight into Typhoon Megi on 17 October 2010 is provided in Fig. 1. The location of the instrument to the nearest 0.1° resolution is provided on the line beginning XXAA. The latitude in tenths of degrees is denoted by the three digits after the 99; the subsequent five characters provide the quadrant of the globe and the four-digit longitude is in tenths of degrees. The last two digits of the group preceding the latitude is the time in hours. To get more accurate release and splash locations and times than are regularly provided, further information is provided in the 62626 (nationally developed codes) section. In this section, REL XXXXNXXXXXW hhmmss provides the time and location of the highest (in altitude) wind reported in the message, and SPG XXXXNXXXXXW hhmmss identifies the time and location of the lowest (in altitude) wind reported. With the information in the 62626 section, the location and time of each observation in the message can be calculated.

The instrument fall speed must be known in order to calculate the location. Assuming vertical accelerations aside from gravity are small,

$$W = \sqrt{2m_d g/(c_d A\rho)},$$

where m_d is the dropwindsonde mass, c_d is the drag coefficient, A is the drag cross section (the parachute area), g is acceleration due to gravity, and ρ is the density (Hock and Franklin 1999). Since the vertical levels are provided in pressure coordinates, the fall rate must be converted from height to pressure coordinates. The fall rate at each level is calculated and is linearly interpolated between each to get the time spent to reach the subsequent level. Using these times and the linearly interpolated horizontal wind velocity between each level, the horizontal distance the instrument travels between each level is calculated. The calculation decreases in accuracy the farther from the starting point (either the first or last wind velocity) due to vertical motions that can be especially large in the tropical cyclone eyewall (Stern et al. 2016); in some cases the errors were greater than 10 km at an endpoint. The calculation is thus done twice—upward and downward—and the final result is interpolated between the two values, linearly weighted by distance to each endpoint.

3. Results

a. Single-sonde example

As an example, data from a dropwindsonde observation with exceptionally large differences between the low-resolution TEMP-DROP and the true times and locations (Fig. 1) are used. The transmitted TEMP-DROP message reported wind speeds up to 207 kt (1 kt = 0.51 m s^{-1}) during the 192-s descent from 698 hPa, with multiple layers having wind speeds > 200 kt. The release location and time was 18.2°N, 125.3°E (the red "X" in Fig. 2) at 1100 UTC, respectively. The locations and times of the first and last wind measurements are provided in the 62626 group (18.18°N, 125.33°E at 1113:21 UTC and 18.23°N, 125.20°E at 1116:33 UTC, respectively) and are represented by the red dot endpoints. The true locations (black) are also shown for comparison. The distances between the calculated and true locations are all less than 1 km. The dropwindsonde itself reports the locations to the nearest 0.001 km, whereas the information in the TEMP-DROP message is only to the nearest 0.01 km, which accounts for differences seen in the first and final points, and much of the differences between.

b. *Multiple-sonde example*

The locations of all dropwindsonde data from the same Typhoon Megi flight, when data were obtained from all quadrants of a category 5 tropical cyclone, are shown in Fig. 3. All the data are transformed into storm-relative positions based on centers calculated using the Willoughby and Chelmow (1982) technique. Dropwindsondes were released from near 700 hPa, so no 700-hPa data are generally available due to equilibration of sensors between the aircraft and the free atmosphere. As the altitude decreases, the two locations (the location from TEMP-DROP and the calculated one) drift farther from each other. The two datasets at 750 hPa are close to each other, though some differences exist. The largest differences are at lower levels; since many dropwindsondes splashed into the ocean at pressures just above 900 hPa, that level was chosen. Of note is that, using locations from the TEMP-DROP messages, multiple circulations are evident, whereas this problem does not occur at low levels using the calculated locations.

c. *Statistics*

The software used to process the raw dropwindsonde data [the Atmospheric Sounding Processing Environment (ASPEN)] outputs the final data in multiple formats, including TEMP-DROP and full-resolution data. During 2015, the NOAA P3 and G-IV transmitted 177 and 364 TEMP-DROP messages, respectively; a total of 20 459 individual mandatory- and significant-level observations are compared to the full-resolution data at the same pressure levels. The observations tested were obtained in systems from tropical depression intensity to the most intense tropical cyclone on record in the hemisphere (Hurricane Patricia; Rogers et al. 2017). The two aircraft are tested individually due to their different flight levels (usually about 10 000 ft for the P3 and 42 000 ft for the G-IV). The G-IV rarely releases dropwindsondes into the eyewalls of very intense tropical cyclones.

Because the low-resolution TEMP-DROP data include only time information to the nearest hour, the mean absolute differences between the reported times and the actual times are large (Table 1). The calculated times using the abovementioned algorithm reduces these differences by more than a factor of 100 for the P3 data, and almost that much for the G-IV data. The maxima of the differences for the two aircraft from the low-resolution data are more than 45 min, but this is reduced to only 3 min using the algorithm. The mean distances between the low-resolution data and the actual locations are almost 6 km for both aircraft, and these differences are reduced by a factor of 10 using the abovementioned algorithm; the sizes of the largest differences are also reduced. The mean and maximum differences with the low-resolution data represent 3–15 grid points in the current operational numerical models, and the eyewall width and the eye size of an average hurricane, respectively. Especially in large gradient regions, such as in the eye and eyewall, assimilating these data in the improved, calculated locations is expected to make a large difference in the final analysis.

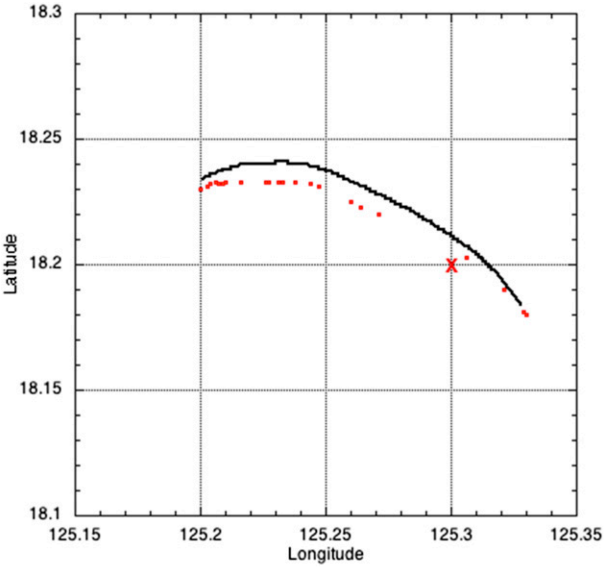

FIG. 2. Observation locations of the mandatory- and significant-level data from the TEMP-DROP message in Fig. 1 (red X), and those calculated using the current technique (red dots). Actual locations from the GPS sensor are shown (black).

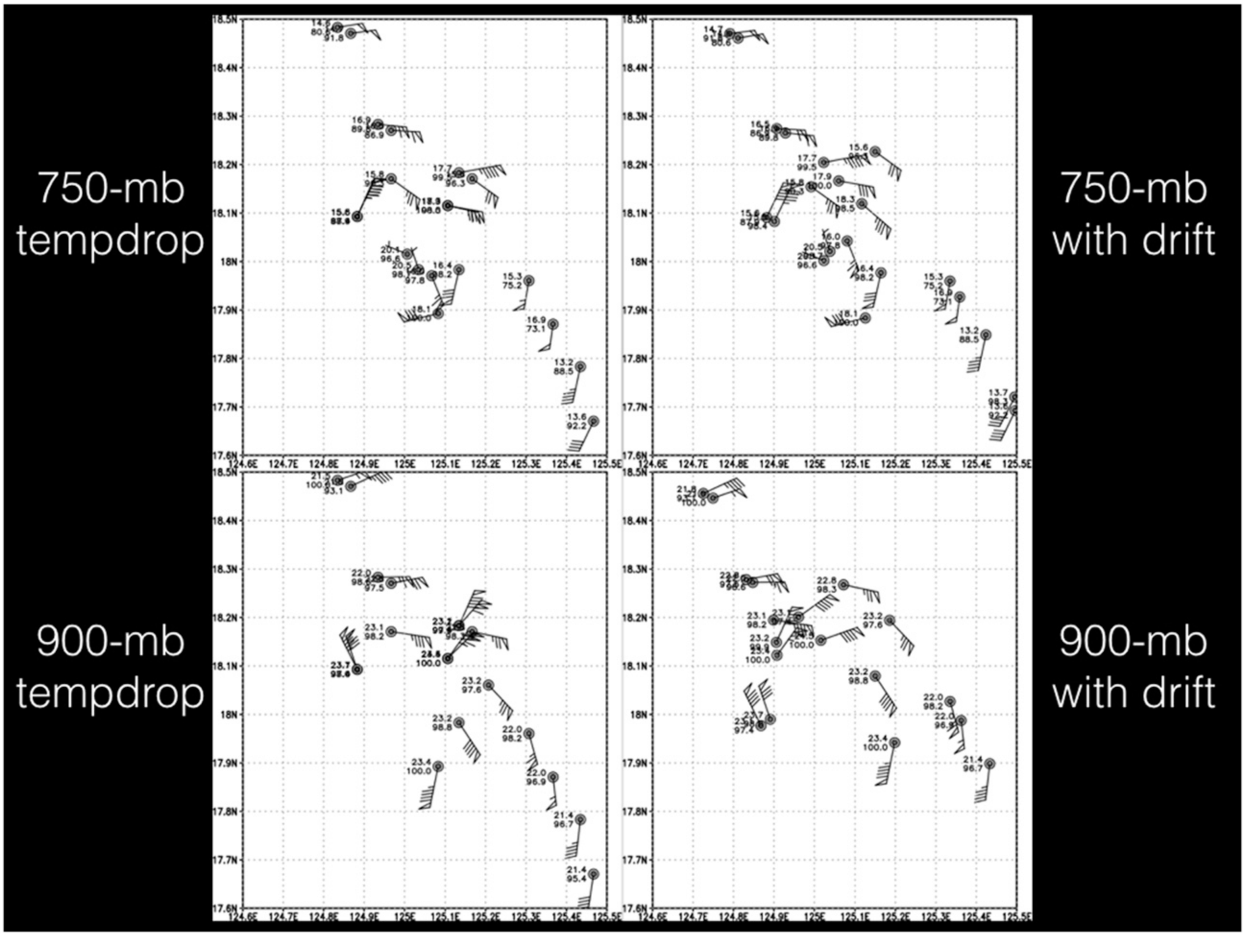

FIG. 3. Horizontal plots of dropwindsonde data from the Megi flight on 17 Oct 2010. The data are shown at (top) 750 and (bottom) 900 hPa. Data at (left) the locations provided in the low-resolution TEMP-DROP messages and (right) the locations calculated using the current method. Numbers to the left of the circle from top to bottom are the temperature (°C) and relative humidity (%). Flags, long banners, and short banners represent wind speeds of 25, 10, and 5 m s^{-1}, respectively.

4. Assimilation test

Dropwindsonde data from the same Megi flight were assimilated into the Hurricane Weather Research and Forecasting Model using the Hurricane Ensemble Data Assimilation System (HEDAS; Aksoy et al. 2013). Operational flight-level and Stepped Frequency Microwave Radiometer data were also assimilated in the typhoon core. Two runs were completed, one using the dropwindsonde data with the low-resolution TEMP-DROP locations and times and one with those that were calculated. The only difference between the two runs is in the dropwindsonde data times and locations.

TABLE 1. Differences between the actual observed (full resolution) times and locations and those reported either in the TEMP-DROP messages (the low-resolution data) or as calculated using the current technique.

	P3 TEMP DROP	P3 calculated	G-IV TEMP DROP	G-IV calculated
Mean time error (min)	15.9338	0.105	16.2711	0.2697
σ time error (min)	8.6934	0.3108	10.7611	0.4537
Mean distance error (km)	5.1571	0.4256	5.57432	0.4139
σ distance error (km)	2.6824	0.3723	3.5386	0.2068
Max time error (min)	34.0	2.0	46.0	3.0
Max distance error (km)	20.0134	5.7953	29.3802	1.6102
No. of comparisons	2383	2383	18 076	18 076

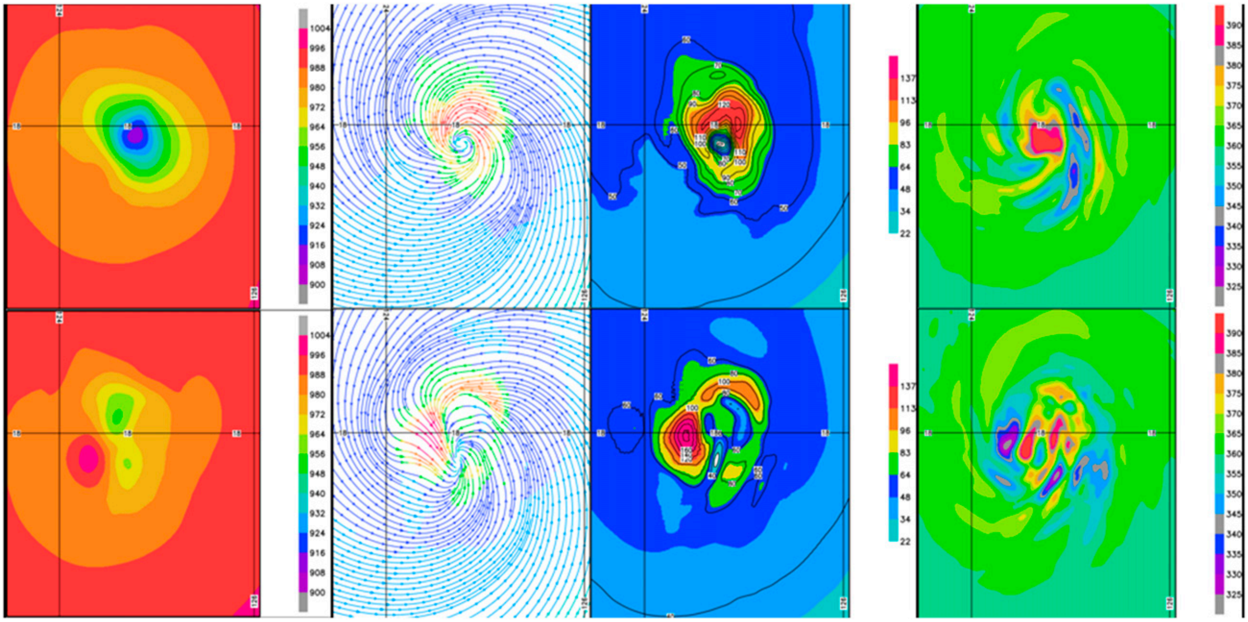

FIG. 4. HEDAS analyses with dropwindsonde data assimilated at (top) the calculated locations and (bottom) the locations provided in the TEMP-DROP messages. Analyses (left to right) are surface pressure (hPa), surface wind velocity and surface wind speed (m s^{-1}), and 850-hPa equivalent potential temperature (K).

The HEDAS analysis using the calculated dropwindsonde locations is superior to that using the locations from the TEMP-DROP messages (Fig. 4). The analysis using the calculated dropwindsonde locations (top row) has a predominantly wavenumber 0 and 1 surface circulation and pressure field, with a high equivalent potential temperature inside the radius of maximum wind speed. The analysis using the locations from the TEMP-DROP messages has an unrealistic asymmetric wind field with no clear surface circulation center, a radius of maximum wind speed, or a surface low pressure. Multiple equivalent potential temperature maxima are evident. Though these differences are maximized at the surface, they extend throughout the troposphere.

5. Conclusions

A technique to calculate the time and location of each individual mandatory- and significant-level observation using information provided in the TEMDROP message is described. Using the dropwindsonde fall speed and the times and locations of the first and last wind measurements, the times and locations of the individual data can be calculated both upward and downward from each endpoint and averaged. The mean differences between the calculated and actual locations are about 0.5 km (distance) and 15 s (time); these values are less than 10% (1%) of the differences using the low-resolution data from the TEMP-DROP messages for distance (time). Assimilation of dropwindsonde data at the correct times and locations is shown to provide a more realistic initial analysis for numerical models.

Dropwindsonde data are currently transmitted from aircraft and onto the Global Telecommunication System using the TEMP-DROP format. In the near future, these data will be communicated in Binary Universal Form for the Representation of Meteorological Data (BUFR); this will allow each datum to be transmitted with its true time and location. The abovementioned technique is proposed to be used by numerical modeling centers until the transition to BUFR is completed and for retrospective data assimilation experiments when BUFR is unavailable.

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