Quality Control Algorithms for the Kennedy Space Center 50-Megahertz Doppler Radar Wind Profiler Winds Database

by

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Abstract

This paper presents the process used by the Marshall Space Flight Center Natural Environments Branch (EV44) to quality control (QC) data from the Kennedy Space Center's 50-MHz Doppler Radar Wind Profiler for use in vehicle wind loads and steering commands. The database has been built to mitigate limitations of using the currently archived databases from weather balloons. The DRWP database contains wind measurements from approximately 2.7-18.6 km altitude at roughly five minute intervals for the August 1997 to December 2009 period of record, and the extensive QC process was designed to remove spurious data from various forms of atmospheric and non-atmospheric artifacts. The QC process is largely based on DRWP literature, but two new algorithms have been developed to remove data contaminated by convection and excessive first guess propagations from the Median Filter First Guess Algorithm. In addition to describing the automated and manual QC process in detail, this paper describes the extent of the data retained. Roughly 58% of all possible wind observations exist in the database, with approximately 100 times as many complete profile sets existing relative to the EV44 balloon databases. This increased sample of near-continuous wind profile measurements may help increase launch availability by reducing the uncertainty of wind changes during launch countdown.

1. Introduction

The National Aeronautics and Space Administration (NASA) has been designing, testing, and flying manned and unmanned space vehicles since the second half of the twentieth century. During this time, the Natural Environments Branch (EV44) at the Marshall Space Flight Center (MSFC) has helped ensure that supported launch vehicles can withstand the effects of the ascent wind environment over the central Florida region. EV44 accomplishes this task by developing meteorological databases and providing environmental definitions as inputs to a wide variety of discipline-specific engineering analyses supporting aerospace vehicle design, test, and operations activities.

EV44 has traditionally used observations made with weather balloons to statistically represent the ascent wind environment. However, balloon-based data archives have a number of inherent limitations for this application. Relative high cost makes high-frequency balloon sampling impractical, thereby limiting sample sizes and increasing statistical uncertainty. Downstream balloon drift can lead to potential misrepresentation of the ascent environment in a horizontally inhomogeneous wind field. Also, balloons have lengthy rise times, which prevent high temporal resolution assessments of ascent wind environments. This limitation reduces the ability to verify steering commands late in a launch countdown, possibly leading to larger-than-necessary persistence margins during rapid wind regime change events such as frontal passages. The latter problem was recognized by NASA, and in 1988 a 50-MHz Doppler Radar Wind Profiler (DRWP) was installed at Kennedy Space Center (KSC). During the 1990s, MSFC developed an algorithm to operationally quality control (QC) wind profiles from the DRWP on day of launch (DOL) (Schumann et al. 1995), and various analyses using subsets of the DRWP archive were performed (Wilfong et al. 1993, Merceret 1997, Schumann et al. 1999). However, the Space

Shuttle Program (SSP) did not certify the DRWP in the later stages of the program. Such a certification would have been very expensive and time-consuming since a DRWP database did not exist during the Shuttle's design phase. EV44 highly desires to certify the DRWP for use in the design of future launch vehicles, and one of the first steps in certifying the instrument is to develop a climatological archive that can be used by the ascent loads and trajectory community.

EV44 has recently developed an extensively QC'd database of DRWP wind profiles covering the period of record (POR) from August 1997 to December 2009. This new dataset is expected to be widely applied to engineering analyses for future launch vehicle programs. The database contains a much larger sample size than those from balloons, and has greater temporal coverage, providing flexibility in the pre-launch assessments. Given these two qualities, the DRWP provides the ability to increase confidence in our knowledge of a given wind environment, reducing unnecessary conservation in both design and operational margins, thereby potentially increasing launch availability. To develop the database, an extensive QC process was implemented on wind and spectral output from the DRWP. This paper documents the QC process and the database's application. Following a brief description of the DRWP hardware and data, the QC process is outlined in detail. Then, the resulting database and its current applications are described followed by a summary and forward work plan. A list of acronyms is provided in Table 1.

2. DRWP Database Description

Although detailed descriptions of the DRWP's hardware and data processing algorithm have been previously documented (Schumann et al. 1999), an overview is provided here for context. The attributes of the data stream used in the QC process are also described in this section. The DRWP is located just east of the Shuttle Landing Facility at KSC. Physically, the DRWP consists of an irregular octagon-shaped antenna field spread across 15,600 m^2. Coaxial-collinear elements are set 1.5 m above the ground plane made of copper wire. These elements are arranged to send electronic pulses at 49.25 MHz through three beams. One beam is pointed vertically, and two oblique beams are pointed 15° off zenith at azimuths of 45° and 135° East from North. All beams have a 3° beam width (Bill Gober, personal communication 2010). An adjacent equipment trailer houses the radar instrumentation and data acquisition electronics. Figure 1 provides a photograph and schematic of the DRWP.

To measure wind velocities, the DRWP transmits radio pulses in three beam directions sequentially and measures the return signal backscattered by temperature and humidity fluctuations in the atmosphere with scale lengths of about 3 m (Rinehart 2004). The signals are converted to Doppler power spectra by applying a Fast Fourier Transform over 256 frequency bins at each range gate. In the beginning of the POR, 112 gates were set from 2,011-18,661 m every 150 m. After an upgrade during July-August 2004 (Pinter et al. 2006), 111 gates were set from 2,666-18,616 m every 145 m. Also before this upgrade, profiles were generated every five minutes. After the upgrade, profiles have been generated every three minutes. Once the Doppler spectra are obtained for each beam, horizontal velocities are computed using the Median Filter First Guess (MFFG) algorithm (Schumann et al. 1999), which is applied to the oblique beams only as the vertical beam is not used to calculate horizontal winds (Wilfong et al. 1993, Schumann et al. 1999).

Although the MFFG algorithm has many advantages over the traditional consensus averaging technique used on other wind profilers (Schumann et al. 1999), the algorithm is not immune to acquiring erroneous data. In many instances, the FG simply associates itself with spectral peaks which do not represent the real wind. If a strong, non-atmospheric signal persists within the FG window, then radial velocities would contain contributions from non-atmospheric effects. Other instances of suspect data occur when the signal is too weak to calculate a radial velocity. If the signal to noise ratio (SNR) is less than -15 dB, then the measured radial velocity is replaced by the FG. This process of FG "propagating" continues for an individual beam until the SNR reaches -15 dB. Although the radial velocity profiles are smoothed after at least four first guess propagations (FGPs), using previously recorded measurements for an extended period can introduce errors in the radial velocity estimate, especially if a non-atmospheric signal exists near the signal associated with the wind (Wilfong et al. 1993). Heavy rain could cause spurious wind output as the DRWP can track the velocity of the raindrops instead of the air. Also, large vertical motions can violate the assumption of a homogeneous atmosphere used in the horizontal wind computation.

EV44 has archived DRWP data output which was used to develop the QC'd database. In addition to the computed horizontal wind speed (m s^{-1}), wind direction (degrees), and altitude (m), spectral width (SW, m s^{-1}), signal power (dB), noise power (dB), vertical velocity (*w*, m s^{-1}), number of FGPs (dimensionless), and an internal shear value (s^{-1}) at each gate and beam have been archived. Vertical velocity is the radial velocity of the vertical beam, with positive values indicating downward motion. The number of FGPs is the number of times the FG was propagated for the particular gate and beam, and the internal shear is the change of the radial velocities per unit altitude. These fields exist for each day from August 1997 through December 2009, but have not been regularly QC'd. The QC process used to develop this database differs from the DOL QC process. The DOL process (Schumann et al. 1995) requires near-real time examination of the Doppler spectra which are not available in the data used for the current QC process. The current QC process will be described in detail in section 4.

3. Data Display System

A graphical user interface (GUI) was developed to implement the current QC process. The GUI contains various functions to perform all QC procedures and save the desired output (Figure 2). Each DRWP data file contains data for a single year, month, and day. Files are read sequentially and time-height sections of meteorological parameters are initially examined for potentially spurious features. In Figure 2, for example, anomalies at very low altitudes appear to correspond to ground clutter, and streaks of enhanced meridional wind (*v*) from 10-12 km at 1500-1700 Coordinated Universal Time (UTC) seem incompatible with the surrounding environment. The automated QC is then run and a new time-height cross section of the given variable is displayed. To perform the manual QC, a box surrounding the data in question is drawn and data which are flagged by the threshold are removed. An “undo” function exists to protect against operator error during the manual QC process. Once the QC process is complete, the QC’d file and manual QC logs are saved. In addition, comparisons between profiles from low-resolution (LR) weather balloons and DRWP profiles at a desired time can be performed and images can be saved as desired. The LR balloon database consists of rawinsondes prior to October 2002 and the Low Resolution Flight Element (Leahy and Overbey 2004) after October 2002.

4. QC Process

In addition to methodologies documented elsewhere, the process used here to QC the DRWP contains some unique attributes based on data examination. A number of distinct steps are performed sequentially with flagged data being removed before the next step is implemented. Indicators are assigned to each gate to denote if data passed all checks or failed a particular check. This section describes in detail the QC sequence.

a. Automated QC Process

The automated QC process contains initial procedures to fill data gaps and screen the vertical beam. The first step in the automated QC process fills data gaps. If greater than six minutes existed between adjacent timestamps in the original data, then timestamps were inserted at five minute intervals in the data gap with all variables in the profile containing the missing data flag. This procedure ensured a data record at least once every six minutes throughout the POR. The second step in the automated QC process evaluates vertical beam measurements. Since the vertical beam is not used to calculate horizontal winds, a valid wind calculation could coincide with an erroneous vertical beam measurement and be falsely flagged. Data from the vertical beam were thus removed if a signal or noise power report were missing, if the vertical beam's SW exceeded 3.0 m s^{-1}, or if a systematic error occurred when the Doppler shift from the vertical beam was near zero (Merceret and Gober 2009, personal communication). This error appeared when abnormally high $|w|$ coincided with relatively low SNR.

The automated process then performs threshold checks and flags data possibly influenced by convection. Table 2 presents each check and its threshold in order. The process consists of checking for unrealistic wind reports and isolated data, performing a small median test, and applying thresholds to oblique beam SW, DRWP internally computed shear, w, FGP, oblique beam signal power, and convection. The rationale for each check is described below, with thresholds for checks other than the FGP, small median, convection, and isolated datum presented in the table.

Several automated checks were based on thresholds, which were derived from Carr et al. (1995) and Merceret (1997) and modified if necessary based on data examination. After detecting physically unrealistic wind reports, a check was implemented on the oblique beam SW so that the homogeneity assumption used to calculate the winds would not be violated due to excessive turbulence. The DRWP internal shear is useful for detecting large objects in the air such as airplanes (Merceret 1997). Over Florida, $|w|$ is generally very small, so any large perturbation in w indicates some anomaly in the air flow or that the DRWP is measuring the velocity of raindrops instead of the air. The threshold selected here is more restrictive than that in Merceret (1997) to flag additional convective situations, especially after August 2004. The meteorological shear check serves the same purpose as the DRWP shear check but it applies to the zonal (u) and meridional (v) wind components. Missing signal power indicated that the DRWP did not receive a signal at that gate. Note that no check exists for the oblique beam noise power. An analysis was performed showing that missing noise values corresponded to some erroneous vertical beam SW and velocity reports. However, no such effect existed when examining oblique beam SW and radial velocities.

The small median check (Carr et al. 1995) flags observations which significantly differ from their nearest neighbors. The check compares a wind speed observation at a given time and altitude to the eight observations surrounding it and was only performed if the wind speed of interest and at least three neighboring observations existed. Thresholds were applied following Merceret (1997). Once all automated checks were performed on data for the day, gates with no surrounding measurements were removed to enhance the continuity of the database.

Two additional QC algorithms were developed specifically for the DRWP database, and differed significantly from the literature. These checks involved testing for convection and developing a criterion for the FGP threshold, and are presented in greater detail in the subsections below.

1) Convection

The convection algorithm is derived from previous work using the 915-MHz DRWP network at KSC. Lambert et al. (2003) developed a discriminant function based on *w* and SNR which had two classes: convection and no convection, and was effective on the 915-MHz DRWP data. However, because the DRWP is much less sensitive to rain than the 915-MHz DRWP and *w* differs from the boundary layer to the free atmosphere, this discriminant function was determined not to suit the DRWP QC process. In addition, a given parameter at an individual gate might have the same output in different situations throughout the year. Therefore, the convection algorithm's parameters were derived for each month.

SW and *w* were used to determine if convection existed at a particular gate. Figure 3 shows *w* and SW for 20 August 2001, a day with typical summertime convective activity over the KSC region. Rain gauge data were obtained from the TRMM website (http://trmm.ksc.nasa.gov/trmm/rain/2001/08/DAILY_RPT_AUG20.HTM). The rain gauge at the field mill closest to the DRWP recorded 0.28 inches of rain during 0300-0500 UTC and 1.42 inches of rain during 2100-2200 UTC. Concurrent SW and *w* show clear signs the convection could be occurring: SW increased from just less than 1.0 m s^{-1} to near 2.0 m s^{-1}, and $|w|$ increases from near 0.0 m s^{-1} to approximately 1.5-2.0 m s^{-1}. Other meteorological variables did not vary as significantly, so they were not used to discriminate between convective and non-convective cases.

SW and *w* were used in a supervised classification technique to determine if convection existed. First, the classes "convective", "possibly convective", and "not convective" were chosen to classify the convective environment of each gate. Next, training samples representing instances of each class were selected for each month across the POR. Instances where large SW corresponded with large |*w*| across extensive vertical regions were selected as "convective", and instances of small SW and |*w*| were selected as "not convective". Training samples for the "possibly convective" class were selected to help mitigate a false positive "convective" classificaiton. A range of 1,638 to 6,428; 11,546 to 32,265; and 7,528 to 19,935 training samples existed per month for the "convective", "possibly convective", and "not covective" case, respectively. These sample sizes are of one to two orders of magnitude over what is considered highly desirable in the literature (Richards 1993).

The training samples were used to develop a descriminant function, which classifies a pixel as convective or not convective. The descriminant function is a quadratic surface described by

$$DF = K + \begin{bmatrix} w & sw_e & sw_n & sw_v \end{bmatrix} * \begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \end{bmatrix} + \begin{bmatrix} w & sw_e & sw_n & sw_v \end{bmatrix} * \begin{bmatrix} Q_{1,1} & Q_{1,2} & Q_{1,3} & Q_{1,4} \\ Q_{2,1} & Q_{2,2} & Q_{2,3} & Q_{2,4} \\ Q_{3,1} & Q_{3,2} & Q_{3,3} & Q_{3,4} \\ Q_{4,1} & Q_{4,2} & Q_{4,3} & Q_{4,4} \end{bmatrix} \qquad (1)$$

where *K*, **L**, and **Q** are coefficients corresponding to the covariance of the training samples for each class combination and month. SW_e, SW_n, and SW_v are SW from the east, north, and vertical beams, respectively. The training samples were provided as input to the MATLAB discriminant function routine (http:/www.mathworks.com/help/toolbox/stats/classfiy.htm) along with the data to be classified (i.e., the DRWP data for the day of interest). The routine returned the class of each gate, the coefficients of the discriminant function for each class combination, and the posterior probabilities of the gate belonging to its determined class. If *DF* were positive for the “convective / possibly convective” combination and the “convective / not convective” combination with a posterior probability of at least 0.95, then the gate was classified as “convective”.

Plots showing gates flagged by the convection algorithm were examined and data were removed manually based on the extent of the flagged gates and the characteristics of the corresponding wind field. In Figure 4, flagged data over extensive vertical regions which corresponded to anomalies in *v* around 0400 UTC and from 2030-2200 UTC were considered to be convective and were thus removed. However, some flagged gates neither span extensive horizontal or temporal regions, nor seem to correspond to anomalies in the wind field. These gates were not removed as convection was determined not to affect the continuity of the winds on a large enough scale.

2) First guess propagation

A unique FGP check was developed to suit the database’s multiple applications and to determine how propagating the FG velocity affects the wind estimate. Using radial velocity estimates with one FGP is basically equivalent to using estimates which are five minutes old. In situations when the wind changes little, an FGP should not significantly affect the wind estimate. However, in dynamic conditions, even a small FGP could lead to an inaccurate wind estimate. Previous research has thus used limits on the number of FGPs for their respective analyses. Merceret (1997) used a limit of six FGPs; however, no rationale was given for this threshold other than using it to prevent wind estimates greater than 30 minutes old from being incorporated into the analysis. Schumann et al. (1999) used a limit of two FGPs to relate to the capability to distribute DRWP data every 15 minutes to the end user. Using the latter criterion, data with greater than two FGPs would contain wind estimates at least 15 minutes old, and the end user would not be provided with a new wind estimate. This rationale implies that the FGP threshold should be selected based on the end user's application. However, it was desired to have a single FGP threshold for the current DRWP database for three reasons: First, the FGP threshold significantly affects the number of available profiles. Second, the current DRWP database can be used for applications with varying time separations which are currently unknown. Last, the exact relationship between number of FG propagations and resulting measurement errors is unknown. Therefore, the following analysis was performed to better understand the effect of FG propagation on the output of the MFFG algorithm.

Spectra from three days obtained from the DRWP operations and maintenance contractor during 2009 were examined. Each day represented a weather regime common to eastern Florida:

- 21 August: Light winds with an afternoon thunderstorm
- 21 October: No rain, dynamic day with moderate winds
- 4 December: Strong southwest winds

Control wind components from each day were calculated using FG radial velocities derived from the Doppler spectra. First, a three-point median filter was applied to spectra with at least two valid timestamps. Radial velocities were then calculated for each oblique beam, with the calculated radial velocity profile being the FG for the next radial velocity profile. The first profile in the database and the first profiles after data gaps were computed. Radial velocities were replaced by the mean of the radial velocities from the adjacent gates if the shear criteria were violated (Taylor et al. 1993). Wind components were then computed from the radial velocities, and were compared to the wind components in the output data files for accuracy. If the magnitude of the difference between the calculated wind component and the wind component in the output file exceeds 2.0 m s^{-1}, then the wind value from the output file replaces the calculated wind from the spectra.

The control wind components were then differenced from wind components calculated after propagating the FG velocity from each beam. To simulate propagation of the FG velocity, radial velocities were calculated using the spectra for the current timestamp with the FG radial velocity from the previous *n* timestamps, where *n* was incremented from 1 to 20. Modified wind components were then calculated using the previous *n* FG velocities from each beam. FGPs from each beam were simulated by cycling *n* for the north beam before incrementing the east beam (0 East FGPs / 0 North FGPs, 0 East FGPs / 1 North FGP… 20 East FGPs / 19 North FGPs, 20 East FGPs / 20 North FGPs). A median of 29,554 gates were used, varying from 28,310 to 32,820 gates depending on the FGP combination. The vector differences between the modified and control winds were then computed at altitudes over 10 km as the FG is propagated more frequently at higher altitudes. The RMS of the vector changes for each FGP combination was then plotted versus the number of FGPs from the oblique beams (Figure 5). Warm (cool) colors represent large (small) RMS differences from the control wind. As expected, differences increase as the number of FGPs increase from either beam. An RMS vector error of $\sqrt{2.0}$ m s^{-1} was selected as the threshold for this analysis to correspond to the RMS measurement error specification of 1.0 m s^{-1} for each wind component (Pinter et al., 2006). A quadratic fit was then applied to the maximum number of north beam FGPs which yielded an RMS difference below the threshold for each east beam FGP. The fit is expressed as

$$T = -0.010(FGP_e)^2 - 0.784(FGP_e) + 20.309 - FGP_n \quad (2)$$

where T is the threshold parameter and FGP_n and FGP_e are the FGPs from the north and east beams, respectively. If T were less than zero then data at the gate were removed.

b. Manual QC Process

Once the automated process was complete, data for each day were manually examined for temporal and spatial inconsistencies. This process involved examining multiple variables to see if a spurious output from one variable coincided with that of another variable. If spatial discontinuities in multiple variables occurred within the same time-height region, then greater evidence would be presented to remove the data in question. In addition, temporal changes in wind components at each altitude were examined to detect the edges of radar sidelobes and ground clutter. Each manual QC was logged for reference. Data judged to be contaminated by convection or ground clutter were assigned their own QC flags to be tracked separately. On occasion, extensive time-height regions of data were not flagged by the automated QC process but needed to be removed. In these cases, entire time-height boxes or profiles were removed manually.

An example of the manual QC process is presented here. Figure 6 shows before-and-after images of v on 19 October 2008. The left panel shows v from the original database. Note the bar-like features which do not compare well with the surrounding environment at approximately 5.0 km during 0100-0300 UTC and at approximately 4.0 km during 0300-0400 UTC. These features are likely attributed to the MFFG algorithm tracking a signal from a sidelobe, and not the real wind between these altitudes. Examining the change in wind components over short time intervals in addition to the wind field itself indicate that ground clutter likely contributed to the signal around 0100 UTC, 0700 UTC, and 2000 UTC at very low altitudes. Thus, data were also removed from these regions. The QC'd data are presented in the right panel.

Wind components from LR balloons and the DRWP could also be compared to determine if the DRWP measurements were acceptable to use on a given day. Balloon data were downloaded from the KSC Tropical Rainfall Measurement Mission website (ftp://trmm.ksc.nasa.gov/midds/sonde), and available data were used to visually examine the characteristics of the wind components from both sources. Following EV44 DOL procedures, wind components from the closest DRWP profile to 30 minutes after balloon launch were examined to minimize errors in the comparison associated with the balloon's rise rate. If the DRWP profile did not compare well with a balloon profile which was considered acceptable, then the DRWP measurements would be removed around the time of the comparison. The left panel of Figure 7 shows that on 11 February 2000 the 1415 UTC DRWP profile deviated from the 1345 UTC balloon profile above 7 km, with both wind components around 10-15 m s^{-1} above 12 km. Thus, DRWP measurements showing this measurement characteristic on this day were removed. Conversely, the profiles during 11 January 2001 (Figure 7, right panel) show similar characteristics from both sources. Thus, the DRWP measurements were considered acceptable on this day.

6. Results

Once the database was QC'd, investigations were performed to examine the algorithm's attributes. Missing data tended to exist throughout entire profiles. The ground clutter check, which is performed manually, mainly affected scattered gates at lower altitudes. However, larger clusters of data contaminated by ground clutter did exist. The vertical beam QC flagged isolated or narrow vertical regions. The SW, small median, noise power, and isolated datum QC algorithms all flagged data at sporadic intervals with no general pattern. However, the SW checks flagged larger clusters of data compared to the other three similar checks. Conversely, the FGP check flagged adjacent gates at the same altitudes. Gates flagged by the convection algorithm were removed if data were flagged across extensive vertical regions. The shear checks tended to flag the boundaries of spurious data regions, with the inside of the regions being removed manually. The manual QC process also removed vertical discontinuities, sidelobes near ground clutter and convection, and any other unacceptable feature.

The number and percentage of gates affected by each QC process were tallied. Each process was assigned a flag, and the number of times an individual flag occurred in each month was recorded (Table 3). The entire POR contains 162.1 million gates, with a given month containing 12.2 million to 14.3 million gates. Percentages of affected data herein are noted as %POR (% lowest month to % highest month). Missing data accounted for 35.4% (30.0% to 41.0%) of all the possible data. The missing data flag was tallied most often because it tended to exist throughout an entire profile and days in which no data existed were recorded as containing missing data at every gate and timestamp. The other QC processes combined removed an additional 6.5% (3.7% to 10.5%) of the possible data. The manual QC process dominated these QC processes, removing anywhere from 4.8% (1.8% to 8.6%) of the data. The convection QC process removed 0.6% (0.1% to 1.1%) of the available data. Note that the automated convection algorithm flagged 2.6% of the data for the POR, but only 0.6% of the data were removed – indicating the significance of removing flagged data manually. The other automated QC processes removed no more than 1.0% of the available data for a given month. The isolated datum check removed data at 4,767 gates over the POR. The meteorological wind shear check removed data at only 570 gates throughout the POR as data that would have been flagged by this check were likely removed by the DRWP internal shear check. No observations existed that had unrealistic reports of wind speed or wind direction. The QC'd database contains 58.1% (51.6% to 64.5%) of the possible wind observations.

Retained complete profiles and pairs were also tallied to support the launch vehicle community's interest in examining the vehicle's entire ascent trajectory. Although the QC'd database contains profiles which contain data removed by the QC process and can be used for any application involving winds aloft near KSC, the central focus of generating a DRWP winds database involved generating a larger sample of complete profiles and profile sets to be used in vehicle loads and trajectory analyses.

Table 4 depicts the number of complete DRWP profiles and pairs. Generally more profiles are retained from more recent years than earlier years. March 2000 was the only month over the POR where zero complete profiles were retained. In addition, the DRWP's poor performance during individual periods can be inferred (e.g., February-March, 2000). An average of 30,320 profiles per month exist ranging from 27,436 (October) to 35,239 (March) profiles per month. No obvious trend in the number of complete profiles seemed to exist from month to month. Two-hour pairs have an average sample of 15,816 per month ranging from 12,352 (July) to 19,023 (March) pairs per month. Sample sizes for other time separations are on the same order of magnitude.

The DRWP database has three major advantages over balloon archives. First, the DRWP database contains on the order of 100 times as many profiles and pairs as the databases derived from balloon measurements, which would improve confidence in launch simulation results.

Second, using the DRWP database provides the capability to examine time separations other than 2.0 hours and 3.5 hours as the DRWP pairs archive is not driven by any Program requirements. In addition, using the DRWP database enables launch vehicle personnel to perform assessments closer than 2.0 hours to launch, which reduces the uncertainty of the wind profile loaded to the vehicle's steering commands and the wind through which the vehicle will fly, potentially leading to launch availability increase due to decreased loads knockdowns. Third, the DRWP database enables launch vehicle engineers to perform simulations with more than two profiles at a time. For example; L-3.0 hour, L-1.0 hour, and L-0.0 hour wind triplets can be used to simulate loading a trajectory at L-3.0 hours, making a GO / NOGO decision at L-1.0 hour, then flying to the L-0 hour wind. This capability would allow more accurate simulations to be performed before launch vehicle requirements are written. Times before launch can also be examined to determine the most optimal DOL assessment sequence.

7. Conclusions

To improve the sample size of MSFC NE's winds database, QC algorithms were developed and implemented on DRWP data for the August 1997 to December 2009 POR. A larger sample of wind measurements not only gives greater confidence in loads and trajectory assessments, but also provides flexibility to simulate different DOL situations. These features of the DRWP database should mitigate the limitations of the balloon databases used to support the SSP and other previous NASA flight vehicle programs.

In addition to increasing the sample size of the database used and providing more flexibility for DOL simulations in the vehicle design phase, the QC'd DRWP database provides any upcoming launch vehicle program with the capability to utilize the DRWP profiles on DOL to compute vehicle steering commands provided the automated and manual QC procedures developed are applied to new DRWP data on DOL. In the past, only balloons have been certified to do this. Although the current DRWP QC process on DOL could be enhanced by an automated QC process, manual intervention would still be needed to ensure only valid profiles are used. If high spatial-resolution profiles are desired (such as the SSP's desire for Jimsphere measurements) then high frequency components could be randomly added to the DRWP profiles. The DRWP database provides lots of flexibility in how DOL simulations are performed, and the QC algorithms provided in this paper will hopefully benefit the aerospace and atmospheric communities which are interested in utilizing the DRWP.

8. Forward Work

Despite the benefits of utilizing the DRWP database, it does contain a limitation in that only measurements above 2.7 km are provided for the entire POR. Currently, no QC'd database exists which contains the sample size of the DRWP database and measurements from near the surface to 2.7 km. EV44 is thus performing a similar QC to that presented in this paper to data from the 915-MHz DRWP network at KSC. If an adequate sample exists, complete profiles from both sources will be combined to generate an extensive database of DRWP profiles extending from approximately 0.13-18.6 km. The QC algorithms presented in this report, and any others that are developed for the 915-MHz DRWP, will then be evaluated for operational use during DOL.

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Table 4: (Top) Number of complete DRWP profiles assuming at least five minutes between each profile for each month and year. (Bottom) Number of pairs for each month and time interval, which ranges from 0.5 hours to 6.0 hours. At least five minutes were skipped between the first profiles in each pair.

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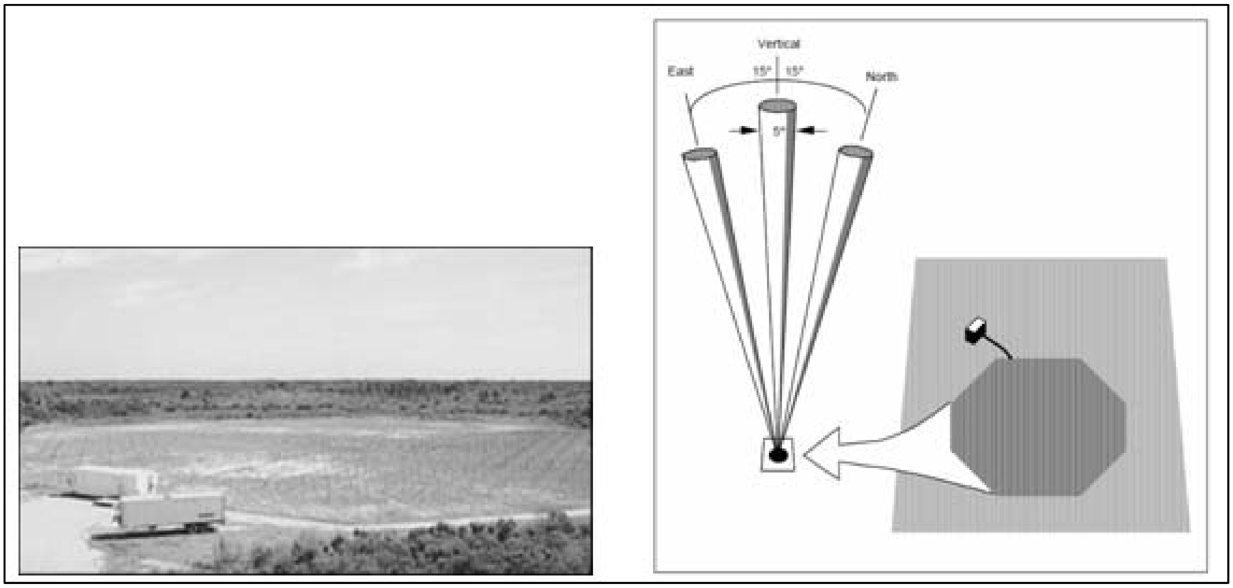

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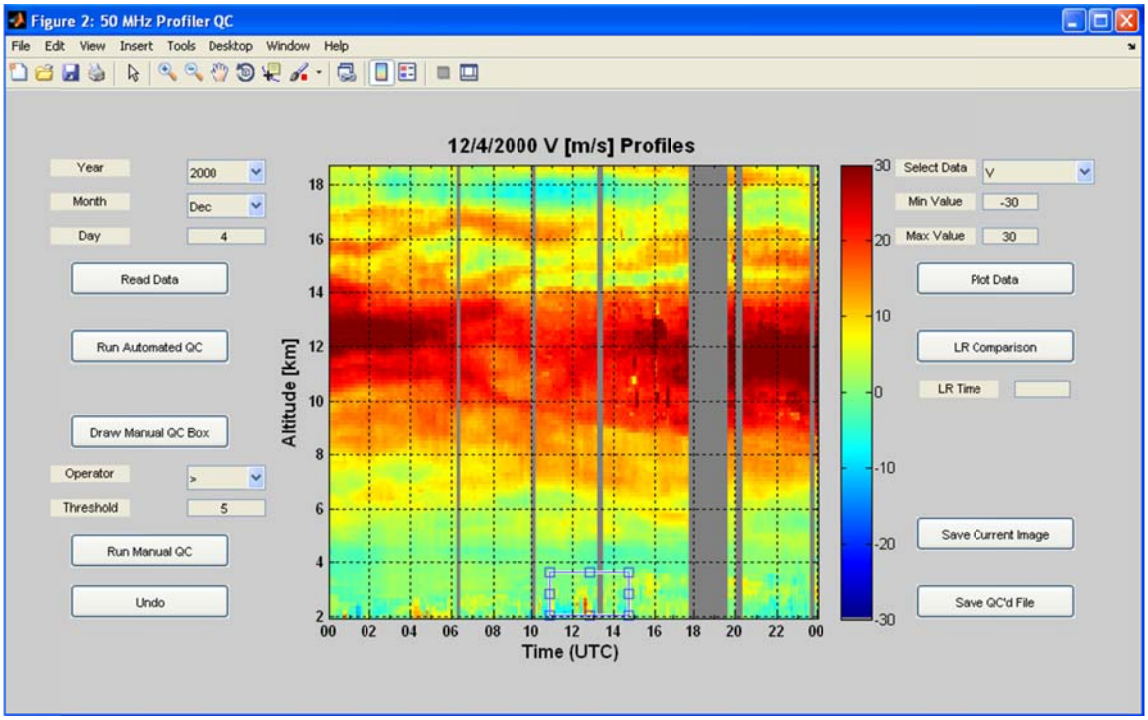

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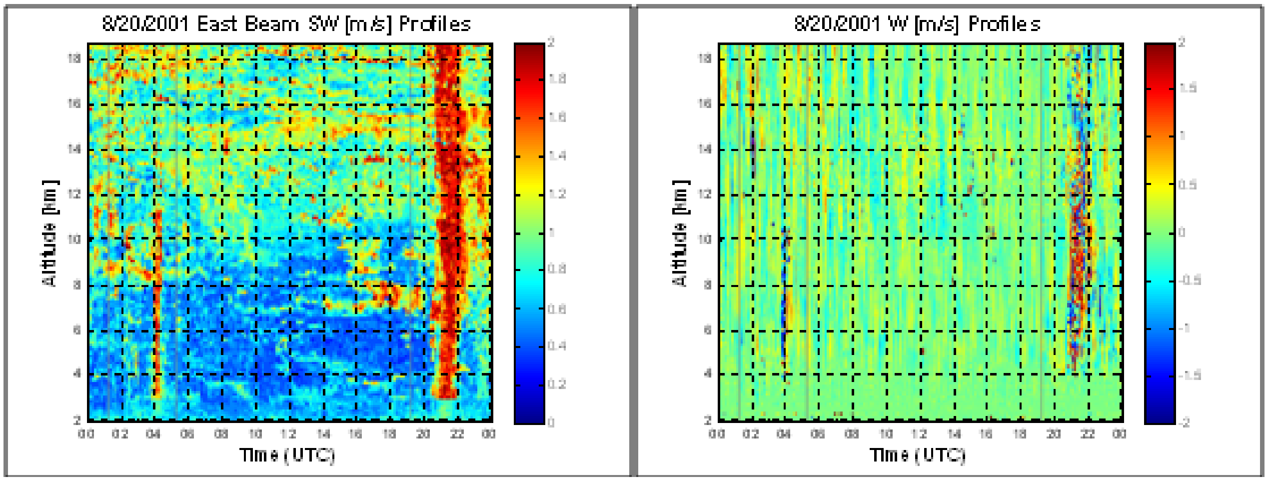

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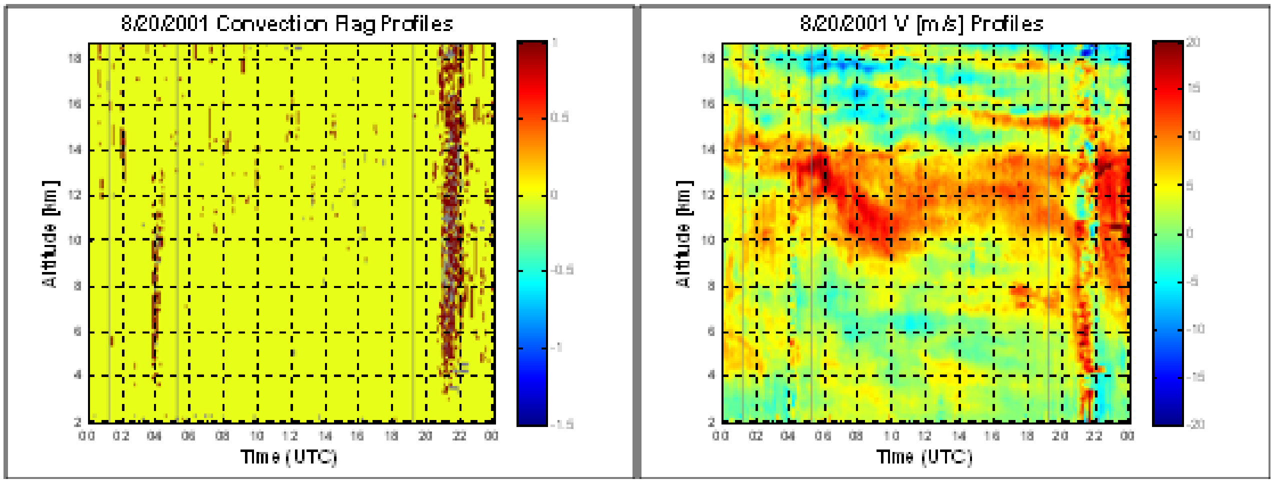

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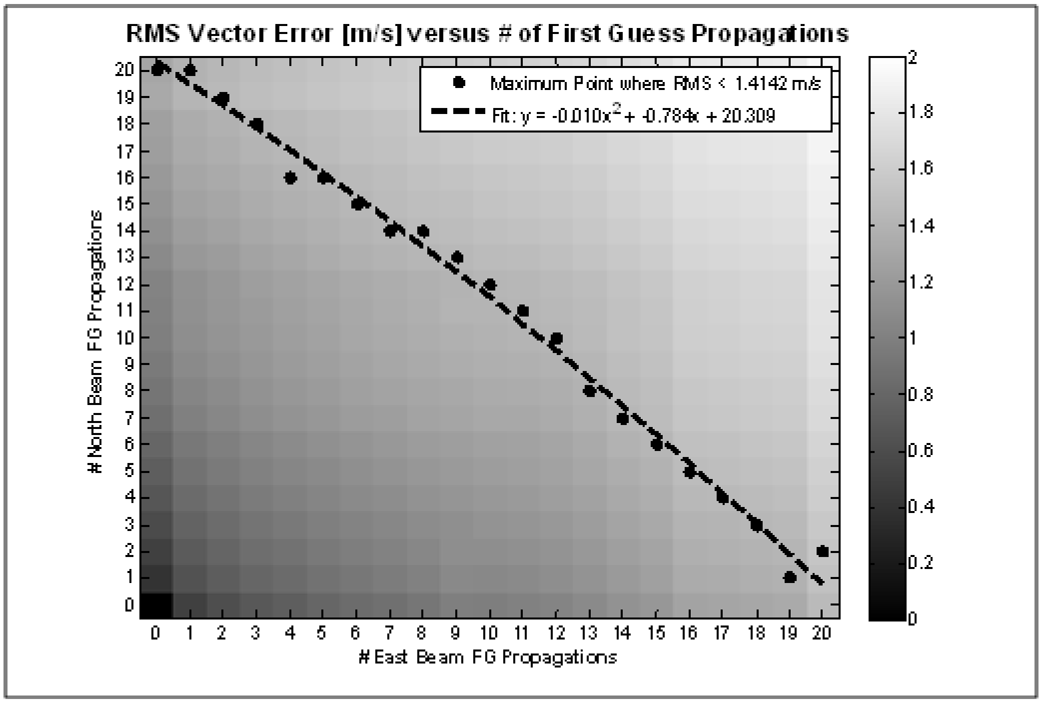

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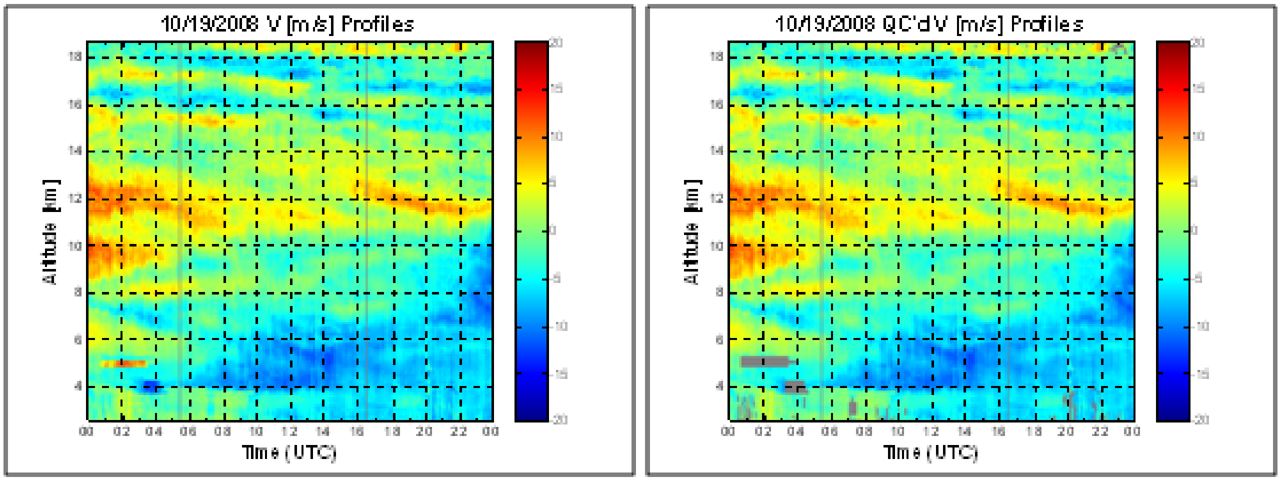

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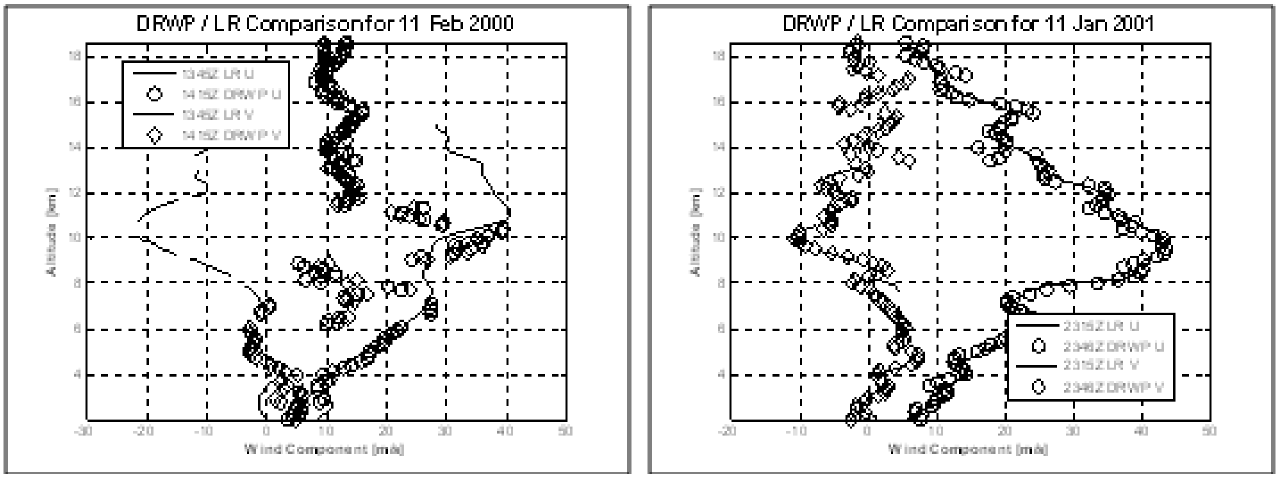

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Tables

Table 1: List of acronyms used.

DOL	day of launch
DRWP	50-MHz Doppler Radar Wind Profiler
ESTS	Engineering, Science, and Technical Services
EV44	Natural Environments Branch
FG	first guess
FGP	first guess propagation
GUI	graphical user interface
KSC	Kennedy Space Center
LR	low resolution
MATLAB	Matrix Laboratory
MFFG	Median Filter First Guess
MIDDS	Meteorological Interactive Data Display System
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Adminstration
POR	period of record
QC	quality control
RMS	root mean square error
SNR	signal-to-noise ratio
SSP	Space Shuttle Program
SW	spectral width
u	zonal wind component
v	meridional wind component

Table 2: Automated QC thresholds. Data were removed if it met the criteria in the threshold column.

QC Check	Threshold
Vertical SW*	> 3.0 m/s
Vertical 0 Doppler Shift*	$\|w\|$ > 1.5 m/s and Vertical SNR < 40 dB
Vertical signal or noise*	Missing
Unrealistic wind	Wind speed < 0 m/s or wind direction < 0° or wind direction > 360°
East or North SW	> 3.0 m/s
DRWP Shear	> 0.1 s^{-1}
$\|w\|$	> 2.0 m/s
FGP	See text
Meteorlogical Shear	> 0.1 s^{-1}
Small Median	See text
East or North signal	Missing
Rain / Convection	See text
Isolated datum	See text

* Denotes that only data from the vertical beam is removed

Table 3: Number (top) and percentage (bottom) of range gates which were affected by the QC process. Data for each month exists on each row and data for each QC process exists on each column. Data matching the criteria in the first three columns were not removed. Percentages are rounded to the nearest tenth of a percent.

 # Gates

	No Flag	Vert QC	Conv Flag	Missing	Unreal	SW	DRWP Shr	Vert Spd	FGP	MET Shr	Median	Clutter	No Signal	Isolated	Manual	Conv	Removed	Retained	Total
Jan	7314470	60741	243050	5163528	0	10253	20120	1126	73110	58	1356	31609	4728	189	329040	19279	5654396	7618261	13272657
Feb	7419446	57903	388697	3668782	0	10253	24042	2002	76883	56	1109	39236	4445	180	510815	44764	4382678	7866046	12248613
Mar	8230493	63065	273003	4269252	0	13995	20830	2324	52205	60	1382	29101	5637	236	290216	39672	4729858	8588561	13313491
Apr	7700267	59582	213366	3951625	0	15614	25165	1777	108530	64	1372	23192	13918	838	765915	77053	4985063	7973215	12958278
May	7333640	94688	467357	4380353	0	5804	14832	3671	100244	23	929	25583	5898	226	725314	130479	5393356	7895685	13289041
Jun	7182381	131040	252253	3920058	0	17129	18983	5262	41367	28	1641	14602	3159	271	1100586	147578	5270664	7565674	12836338
Jul	7033569	193486	130304	5095884	0	14354	18488	3406	46424	12	2267	11745	5229	307	650590	128616	5977546	7357359	13334681
Aug	6882623	207579	209523	5790597	0	12166	17579	3654	46315	7	903	13703	5441	320	860606	105904	6857195	7299725	14156920
Sep	7424239	212907	556662	4380134	0	8803	27689	4634	142618	40	1383	12417	11644	374	1036649	144058	5775483	8193808	13964251
Oct	7515898	160775	339465	5491141	0	14680	30086	5123	55093	48	1343	9775	4597	171	676892	77746	6366917	8016138	14382833
Nov	7062286	121171	691290	5371870	0	14880	27970	1694	99956	89	1921	9646	16592	1001	526093	46967	6118679	7874747	13993426
Dec	7436746	90622	490134	5889984	0	8819	19376	1420	85635	85	1417	17575	9065	654	260845	36731	6331606	8017502	14349108
Total	88556038	1455559	4235104	57373208	0	146750	265160	36093	928380	570	17023	238184	90373	4767	7733361	998847	67843441	94266721	162099637

% Total Gates

	No Flag	Vert QC	Conv Flag	Missing	Unreal	SW	DRWP Shr	Vert Spd	FGP	MET Shr	Median	Clutter	No Signal	Isolated	Manual	Conv	Removed	Retained
Jan	55.1	0.5	1.8	38.9	0.0	0.1	0.2	0.0	0.6	0.0	0.0	0.2	0.0	0.0	2.5	0.1	42.6	57.4
Feb	60.6	0.5	3.2	30.0	0.0	0.1	0.2	0.0	0.6	0.0	0.0	0.3	0.0	0.0	4.2	0.4	35.8	64.2
Mar	62.0	0.5	2.1	32.1	0.0	0.1	0.2	0.0	0.4	0.0	0.0	0.2	0.0	0.0	2.2	0.3	35.5	64.5
Apr	59.4	0.5	1.6	30.5	0.0	0.1	0.2	0.0	0.8	0.0	0.0	0.2	0.1	0.0	5.9	0.6	38.5	61.5
May	55.2	0.7	3.5	33.0	0.0	0.0	0.1	0.0	0.8	0.0	0.0	0.2	0.0	0.0	5.5	1.0	40.6	59.4
Jun	56.0	1.0	2.0	30.5	0.0	0.1	0.1	0.0	0.3	0.0	0.0	0.1	0.0	0.0	8.6	1.1	41.1	58.9
Jul	52.7	1.5	1.0	38.2	0.0	0.1	0.1	0.0	0.3	0.0	0.0	0.1	0.0	0.0	4.9	1.0	44.8	55.2
Aug	48.6	1.5	1.5	40.9	0.0	0.1	0.1	0.0	0.3	0.0	0.0	0.1	0.0	0.0	6.1	0.7	48.4	51.6
Sep	53.2	1.5	4.0	31.4	0.0	0.1	0.2	0.0	1.0	0.0	0.0	0.1	0.1	0.0	7.4	1.0	41.4	58.7
Oct	52.3	1.1	2.4	38.2	0.0	0.1	0.2	0.0	0.4	0.0	0.0	0.1	0.0	0.0	4.7	0.5	44.3	55.7
Nov	50.5	0.9	4.9	38.4	0.0	0.1	0.2	0.0	0.7	0.0	0.0	0.1	0.1	0.0	3.8	0.3	43.7	56.3
Dec	51.8	0.6	3.4	41.0	0.0	0.1	0.1	0.0	0.6	0.0	0.0	0.1	0.1	0.0	1.8	0.3	44.1	55.9
Total	54.6	0.9	2.6	35.4	0.0	0.1	0.2	0.0	0.6	0.0	0.0	0.1	0.1	0.0	4.8	0.6	41.9	58.2

Table 4: (Top) Number of complete DRWP profiles assuming at least five minutes between each profile for each month and year. (Bottom) Number of pairs for each month and time interval, which ranges from 0.5 hours to 6.0 hours. At least five minutes were skipped between the first profiles in each pair.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Month Total
Jan	0	244	920	183	97	956	1686	4045	1385	4904	5310	5102	3959	28791
Feb	0	342	1031	51	538	2376	1170	4101	1878	4542	5486	4888	4142	30545
Mar	0	610	1242	0	1874	1935	2276	5045	3102	5563	5334	5734	2524	35239
Apr	0	486	1020	692	897	898	1943	4476	2538	5213	3849	4564	4770	31346
May	0	1299	22	953	397	493	2230	2600	5124	5152	1462	4696	5424	29852
Jun	0	1019	1028	778	1332	721	2324	2969	3012	4626	3991	3625	4692	30117
Jul	0	127	1395	1239	1325	138	289	1189	2477	4946	4979	2866	5052	26022
Aug	679	549	2150	375	2142	1645	4328	592	654	2528	6212	3696	4776	30326
Sep	2071	1499	1156	220	228	1732	4757	1109	2006	3860	4150	4100	4284	31172
Oct	1292	892	245	332	1166	2253	2811	2667	2882	3530	4267	4720	379	27436
Nov	2675	1432	40	914	166	386	4666	4216	4801	2605	2846	1556	3138	29441
Dec	1757	635	564	1975	510	1517	3817	4426	4542	2731	6182	2622	2280	33558
Year Total	8474	9134	10813	7712	10672	15050	32297	37435	34401	50200	54068	48169	45420	Sum: 363845

	0.5	1	1.5	2	2.5	3	3.5	4	5	6
Jan	17516	16238	15718	15111	14738	14589	14245	14209	13548	13251
Feb	18833	17558	16965	16335	15804	15759	15420	15252	14553	14227
Mar	22037	20586	19772	19023	18475	18279	17912	17733	16916	16576
Apr	19161	17799	17037	16290	15754	15433	14950	14709	13976	13491
May	17894	16543	15852	15136	14481	14228	13709	13579	12918	12479
Jun	18039	16467	15890	15192	14448	14199	13713	13407	12630	12396
Jul	14768	13422	12918	12352	11887	11624	11124	10896	10390	10326
Aug	18571	16959	16152	15447	14832	14518	14268	14058	13464	13226
Sep	19037	17336	16604	15924	15256	14954	14489	14345	13641	13291
Oct	16828	15369	14857	14168	13566	13251	12705	12514	11880	11600
Nov	18612	17316	16595	15923	15368	15109	14719	14394	13826	13472
Dec	21104	19869	19326	18891	18388	18221	17801	17644	16754	16376