TAbMEP Assessment: ICARTT Wind Direction Measurements

1. Introduction

Here we provide the assessment for the wind direction measurements taken from two aircraft platforms during the summer 2004 ICARTT field campaign [*Fehsenfeld et al.*, 2006, *Singh et al.*, 2006]. This assessment is based upon the two wing-tip-to-wing-tip intercomparison flights conducted during the field campaign. Recommendations provided here offer TAbMEP assessed uncertainties for each of the measurements and a systematic approach to unifying the ICARTT wind direction data for any integrated analysis. These recommendations are directly derived from the instrument performance demonstrated during the ICARTT measurement comparison exercises and are not to be extrapolated beyond this campaign.

2. ICARTT Wind Direction Measurements

Due to the data reporting problems for BAe-146, the ICARTT wind direction intercomparison was limited to between the DC-8 and WP-3D. Table 1 summarizes the measurement techniques and gives references for more information. A brief description of the DC-8 measurement is also given in the Wind Direction Appendix.

Table 1. Wind Direction measurements deployed on aircraft during ICARTT

Aircraft	Instrument	Reference
NASA DC-8	Delco Carousel IV-3 Inertial Navigation System (INS)	*Delco Electronics* [1977]
NOAA WP-3D	Not Available	Not Available

3. Summary of Results

Table 2 summarizes the assessed 2σ precisions, biases, and uncertainties. More detailed descriptions are provided to illustrate the process for assessment of bias and precision in Sections 4.1 and 4.2 respectively. The assessed 2σ precisions reported in Table 2 are equal to twice the highest adjusted precision value for that instrument listed in Table 4. Table 2 also reports an assessed bias (see Section 4.1 for details) that can be applied to maximize the consistency between the data sets. The assessed bias should be subtracted from the reported data to 'unify' the data sets. The assessed bias is derived from intercomparison periods only and may be extrapolated to the entire mission if one assumes instrument performance remained constant throughout the mission. The recommended 2σ uncertainty is the larger of either the uncertainty reported by the PI or the quadrature-sum of the assessed 2σ precision and assessed bias listed in Table 2. It is noted here that the actual wind direction measurement uncertainty varies with the relative direction of the aircraft heading and wind direction. The error tends to maximize when the wind direction and aircraft heading are parallel and tends to minimize when the wind direction and aircraft heading are orthogonal (see Wind Direction Appendix for further details).

Table 2. Recommended ICARTT Wind Direction measurement treatment

Aircraft/ Instrument	Reported 2σ Uncertainty	Assessed 2σ Precision	Assessed Bias (deg)	Recommended 2σ Uncertainty
NASA DC-8 INS	N/A	5.2%	$3.21 - 0.015WindDir_{DC8}$	Quadrature Sum
NOAA WP-3D Not Available	N/A	8.6%	$-3.12 + 0.015WindDir_{WP3D}$	Quadrature Sum

Figures 1a through 1c display the precisions, biases, and recommended uncertainties for the two wind direction instruments. For all aircraft measurements, the wind direction uncertainty is driven by the precision.

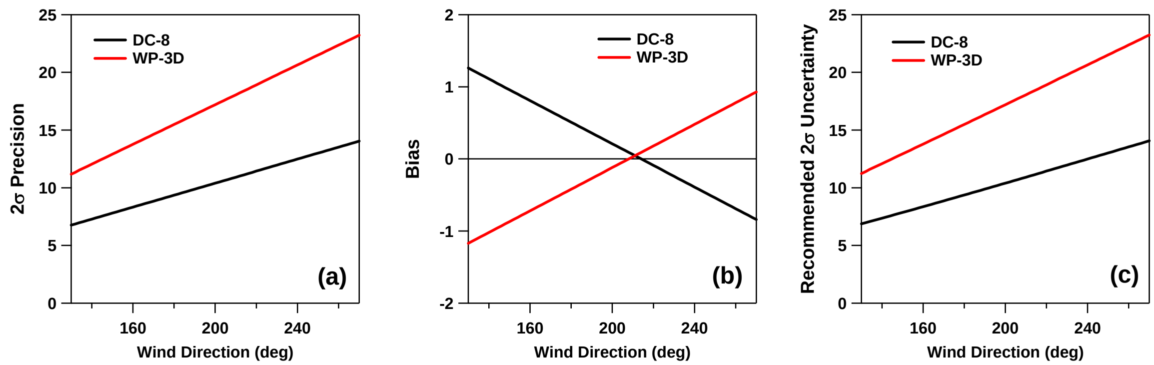

Figure 1. 2σ precision (panel a), bias (panel b), and 2σ uncertainty (panel c) for DC-8 (black) and WP-3D (red) as a function of wind direction. Values were calculated based upon data shown in Table 2.

4. Results and Discussion

4.1 Bias Analysis

Section 3.3 in the introduction describes the process used to determine the best estimate bias. The linear relationships listed in Table 3 were derived from the regression equations found in Figure 3. Note that data from the 8/07/2004 intercomparison flight is not included in this report because the PI identified measurement problems on the DC-8. The reference standard for comparison (RSC), as defined in the introduction, is constructed by averaging the NOAA WP-3D and NASA DC-8. The resulting RSC can be expressed as a function of the DC-8 wind direction measurement as the following:

$$RSC_{WindDir} = -3.21 + 1.015WindDir_{DC8}$$

The RSC is then used to calculate the best estimate bias as described in Section 3.3 of the introduction. It should be noted that the initial choice of the reference instrument (DC-8) is arbitrary, and has no impact on the final recommendations. Table 3 summarizes the assessed measurement bias for each of the two ICARTT wind direction measurements.

Table 3. ICARTT Wind Direction bias estimates

Aircraft/ Instrument	**Linear Relationships**[a]	**Best Estimate Bias (a + b WindDir) (deg)**
NASA DC-8 INS	$WindDir_{DC8} = 0.0 + 1.00\ WindDir_{DC8}$	$3.21 - 0.015WindDir_{DC8}$
NOAA WP-3D Not Available	$WindDir_{WP3D} = -6.42 + 1.03WindDir_{DC8}$	$-3.12 + 0.015WindDir_{WP3D}$

[a]Derived from Fig 3.

4.2 Precision Analysis

A detailed description of the precision assessment is given in section 3.1 of the introduction. The IEIP precision, expected variability, observed variability, and the adjusted precision are summarized in Table 4. Based on the results presented in Table 4, the largest "adjusted precision" value is taken as a conservative precision estimate for each ICARTT wind direction instrument and twice that value is listed in Table 2 as the assessed 2σ precision.

To minimize the effect of bias, we make corrections for bias before computing the observed variability, as the bias may have a significant impact on the observed variability. Figure 4 shows the magnitude of the bias for each intercomparison. The assessed values of the observed variability are displayed in Figure 5. The final analysis results are shown in Table 2. Over 90% of the data falls within the combined recommended uncertainties for each intercomparison, which is consistent with the TAbMEP guideline for unified data sets.

Table 4. ICARTT Wind Direction precision (1σ) comparisons

Flight	Platform	IEIP Precision	Expected Variability	Observed Variability	Adjusted Precision
07/22	DC-8	0.22%	0.43%	5.0%	2.6%
	WP-3D	0.37%			4.3%
07/31	DC-8	0.23%	0.26%	0.70%	0.61%
	WP-3D	0.13%			0.34%

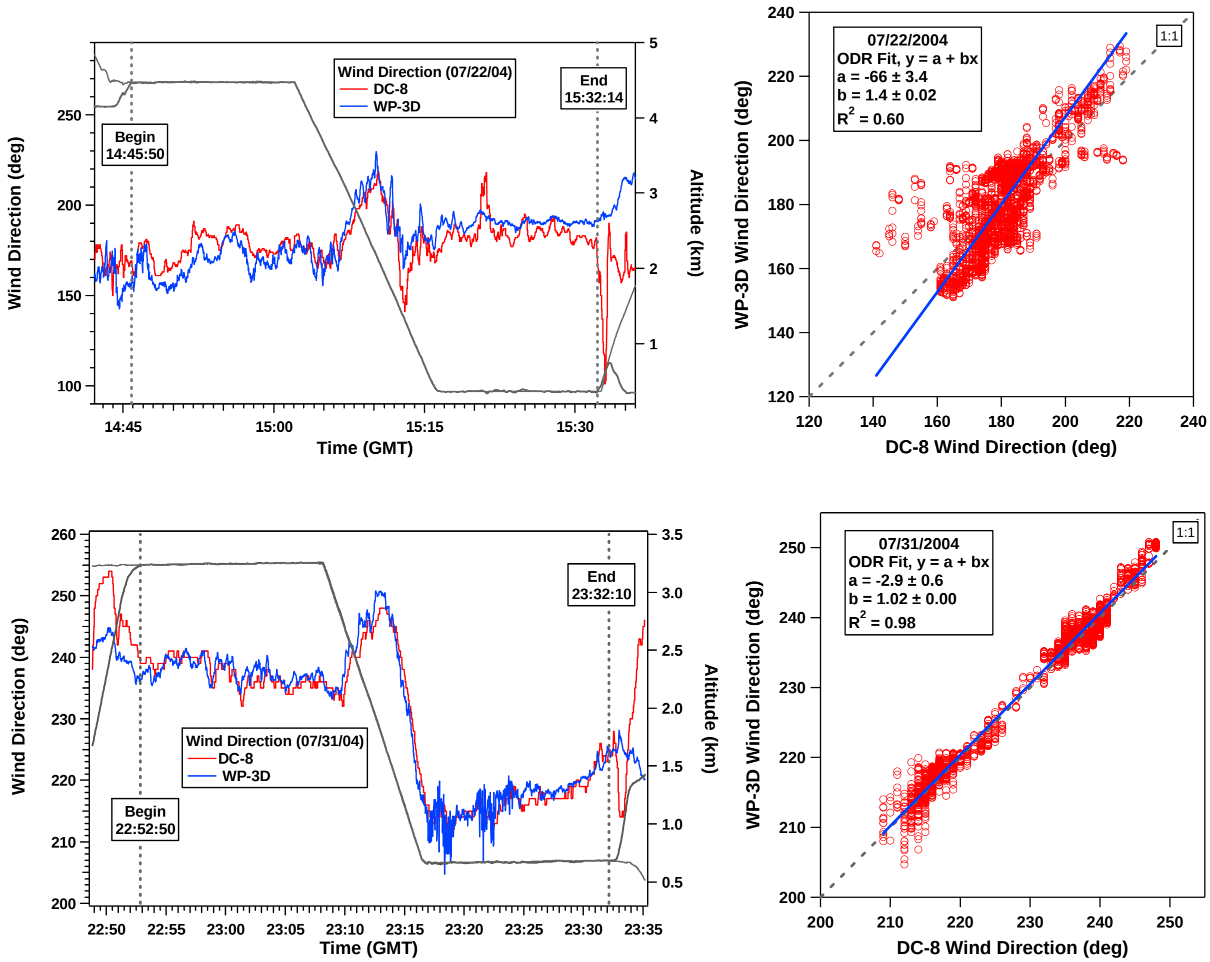

Figure 2. (left panels) Time series of wind direction, wind speed, and heading measurements and aircraft altitudes from two aircraft on the two intercomparison flights between the NASA DC-8 and the NOAA WP-3D. (right panels) Correlations between the wind direction measurements on the two aircraft.

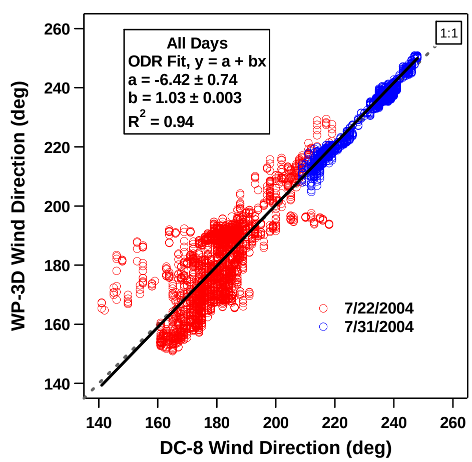

Figure 3. Correlation between the wind direction measurements on the DC-8 and WP-3D for 7/22, and 7/31/2004.

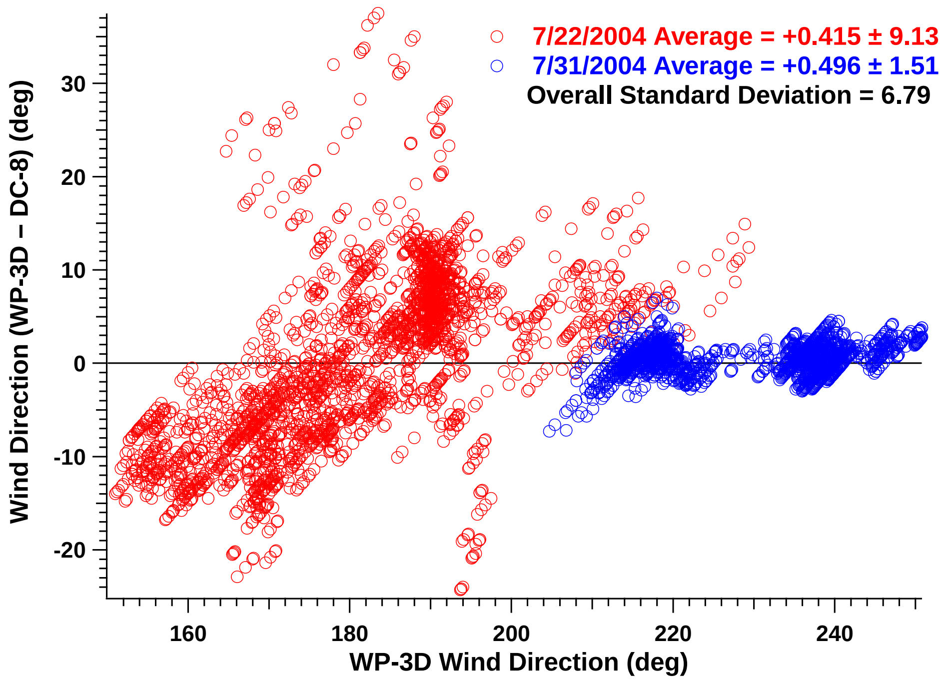

Figure 4. Difference between wind direction measurements from the two DC-8/WP-3D intercomparison flights as a function of the WP-3D wind direction.

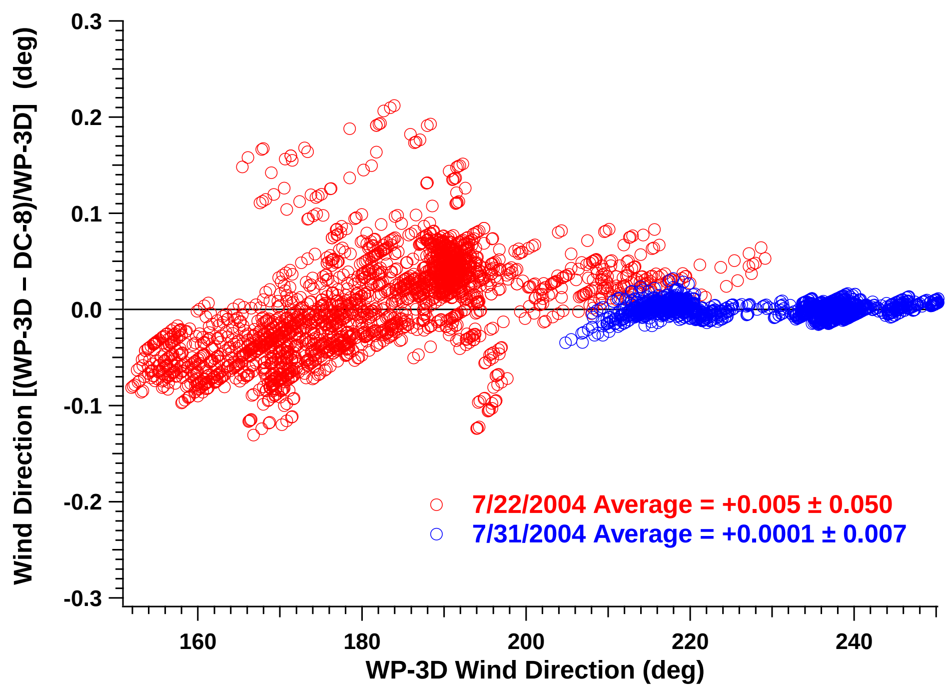

Figure 5. Relative difference between unified measurements of wind direction from the two DC-8/WP-3D intercomparison flights as a function of the WP-3D wind direction. Corrections were made to all data sets to account for bias.

References

Fehsenfeld, F. C., et al. (2006), International Consortium for Atmospheric Research on Transport and Transformation (ICARTT): North America to Europe—Overview of the 2004 summer field study, *J. Geophys. Res., 111*, D23S01, doi:10.1029/2006JD007829.

Singh, H. B., et al. (2006), Overview of the summer 2004 Intercontinental Chemical Transport Experiment-North America (INTEX-A), *J. Geophys. Res., 111*, D24S01, doi:10.1029/2006JD007905.

Wind Direction Appendix

DC-8 Aircraft Measurements of Wind Speed and Wind Direction

The DC-8 aircraft wind speed and wind direction are calculated parameters derived via the aircraft inertial navigation system and air data computer. As shown in the figure on the right, these quantities are obtained using vector subtraction between the vector defined by aircraft heading and true airspeed (i.e., air vector) and ground track and ground speed (i.e., ground vector). The difficulty in obtaining accurate wind speed and wind direction is partially due to the air vector and ground vectors being much larger in magnitude than that of the wind vector. The specified wind speed measurement precision of 3 ms-1 is based on the overall assessment. The uncertainties associated with the calculated wind speed and wind direction also depend on the uncertainties in the air vector and ground vector. Uncertainties associated with wind direction are usually larger for lower wind speed conditions. In general, the wind direction readings are considered to be valid if the wind speed is above 3 ms-1. For the same wind speed, the wind direction and wind speed uncertainties are largest when the wind vector is parallel to the air vector and smallest when the wind vector is perpendicular to the air vector. The wind speed and wind direction uncertainties are also influenced by the flight path, where straight and level flight legs produce the best results.