# TAbMEP Assessment: ICARTT Temperature Measurements

## 1. Introduction

Here we provide the assessment for the temperature measurements taken from three aircraft platforms during the summer 2004 ICARTT field campaign [*Fehsenfeld et al.*, 2006, *Singh et al.*, 2006]. This assessment is based upon the four 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 temperature 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 Temperature Measurements

Three different temperature instruments were deployed on three aircraft. Table 1 summarizes these techniques and gives references for more information.

**Table 1.** Temperature measurements deployed on aircraft during ICARTT

| Aircraft | Instrument | Reference |
|---|---|---|
| NASA DC-8 | Rosemount Temperature Sensor (deiced) (RTS) | *Stickney et al.* [1990] |
| NOAA WP-3D | Rosemount Temperature Sensor (non-deiced) (RTS) | Not available |
| FAAM BAe-146 | Rosemount Temperature Sensors (RTS)[a] | Not available |

[a]Two sensors, one deiced and one non-deiced. The lower of the two temperatures was used as per PI instruction.

## 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.

**Table 2.** Recommended ICARTT Temperature measurement treatment

| Aircraft/ Instrument | Reported 2σ Uncertainty (K) | Assessed 2σ Precision | Assessed Bias (K) | Recommended 2σ Uncertainty |
|---|---|---|---|---|
| NASA DC-8 RTS | 0.5 | 0.26 | $2.17 - 0.0093\ Temp_{DC8}$ | 0.5 or Quadrature Sum[a] |
| NOAA WP-3D RTS | 0.4 | 0.26 | $-0.35+0.0014\ Temp_{WP3D}$ | 0.4 |
| FAAM BAe-146 RTS | 0.4 | 0.22 | $-1.78+0.0078\ Temp_{BAe146}$ | 0.4 or Quadrature Sum[b] |

[a]0.5 is recommended for temperatures up to 280 K, thereafter the quadrature sum is recommended.
[b]0.4 is the recommended for temperatures up to 272 K, thereafter the quadrature sum is recommended.

Figures 1a through 1c display the precisions, biases, and recommended uncertainties for the three temperature instruments. For all aircraft measurements, the temperature uncertainty is typically driven by precision below approximately 270 K and by bias above approximately 270 K.

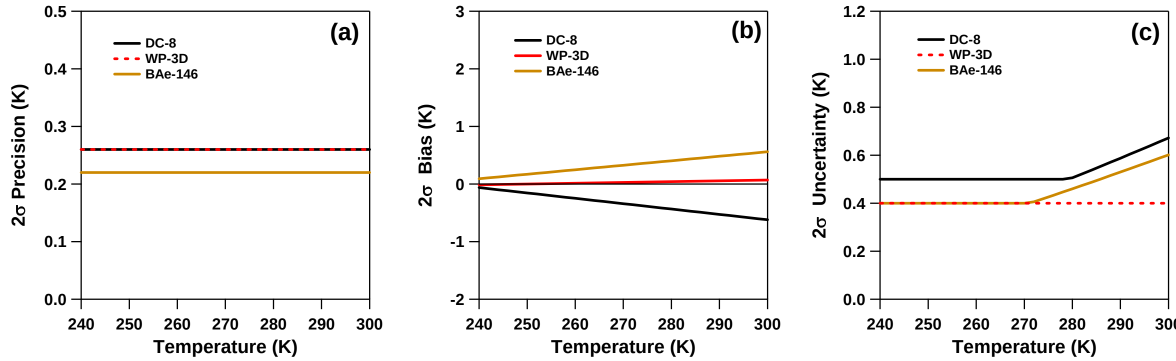


**Figure 1.** 2σ precision (panel a), 2σ bias (panel b), and 2σ uncertainty (panel c) for DC-8 (black), WP-3D (red), and BAe-146 (gold) as a function of temperature. Values were calculated based upon data shown in Table 2.

## 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 Figures 2 through 5. The reference standard for comparison (RSC), as defined in the introduction, is constructed by averaging the NOAA WP-3D, NASA DC-8 and BAe-146 measurements. The resulting RSC can be expressed as a function of the DC-8 temperature measurement as the following:

$$RSC_{Temp} = -2.167 + 1.0093\ Temp_{DC8}$$

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 three ICARTT temperature measurements. Note that additional decimal places were carried in the calculations to ensure better than 0.1 K precision.

**Table 3.** ICARTT Temperature bias estimates

| **Aircraft/ Instrument** | **Linear Relationships**[a] | **Best Estimate Bias (a + b Temp) (K)** |
|---|---|---|
| NASA DC-8 RTS | $Temp_{DC8} = 0.0 + 1.00\ Temp_{DC8}$ | $2.17 – 0.0093\ Temp_{DC8}$ |
| NOAA WP-3D RTS | $Temp_{WP3D} = -2.52 + 1.011\ Temp_{DC8}$ | $-0.35 + 0.0014\ Temp_{WP3D}$ |
| FAAM BAe-146 RTS | $Temp_{BAe146} = -3.98 + 1.017\ Temp_{DC8}$ | $-1.78 + 0.0078\ Temp_{BAe146}$ |

[a]Derived from Figs. 3-5.

### 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 temperature 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. Figures 6 and 7 show the magnitude of the bias for each intercomparison. The assessed values of the observed variability are displayed in Figure 8 and 9. 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 Temperature precision (1σ) comparisons

| **Flight** | **Platform** | **IEIP Precision (K)** | **Expected Variability (K)** | **Observed Variability (K)** | **Adjusted Precision (K)** |
|---|---|---|---|---|---|
| 07/22 | DC-8 | 0.13 | 0.16 | 0.13 | 0.13 |
| | WP-3D | 0.09 | | | 0.09 |
| 07/31 | DC-8 | 0.09 | 0.13 | 0.18 | 0.13 |
| | WP-3D | 0.09 | | | 0.13 |
| 08/07 | DC-8 | 0.12 | 0.15 | 0.12 | 0.12 |
| | WP-3D | 0.09 | | | 0.09 |
| 07/28 | DC-8 | 0.12 | 0.14 | 0.11 | 0.12 |
| | BAe-146 | 0.07 | | | 0.07 |

Note: Error bars are included wherever possible in the following Figures 2-5, although some may not be visible.

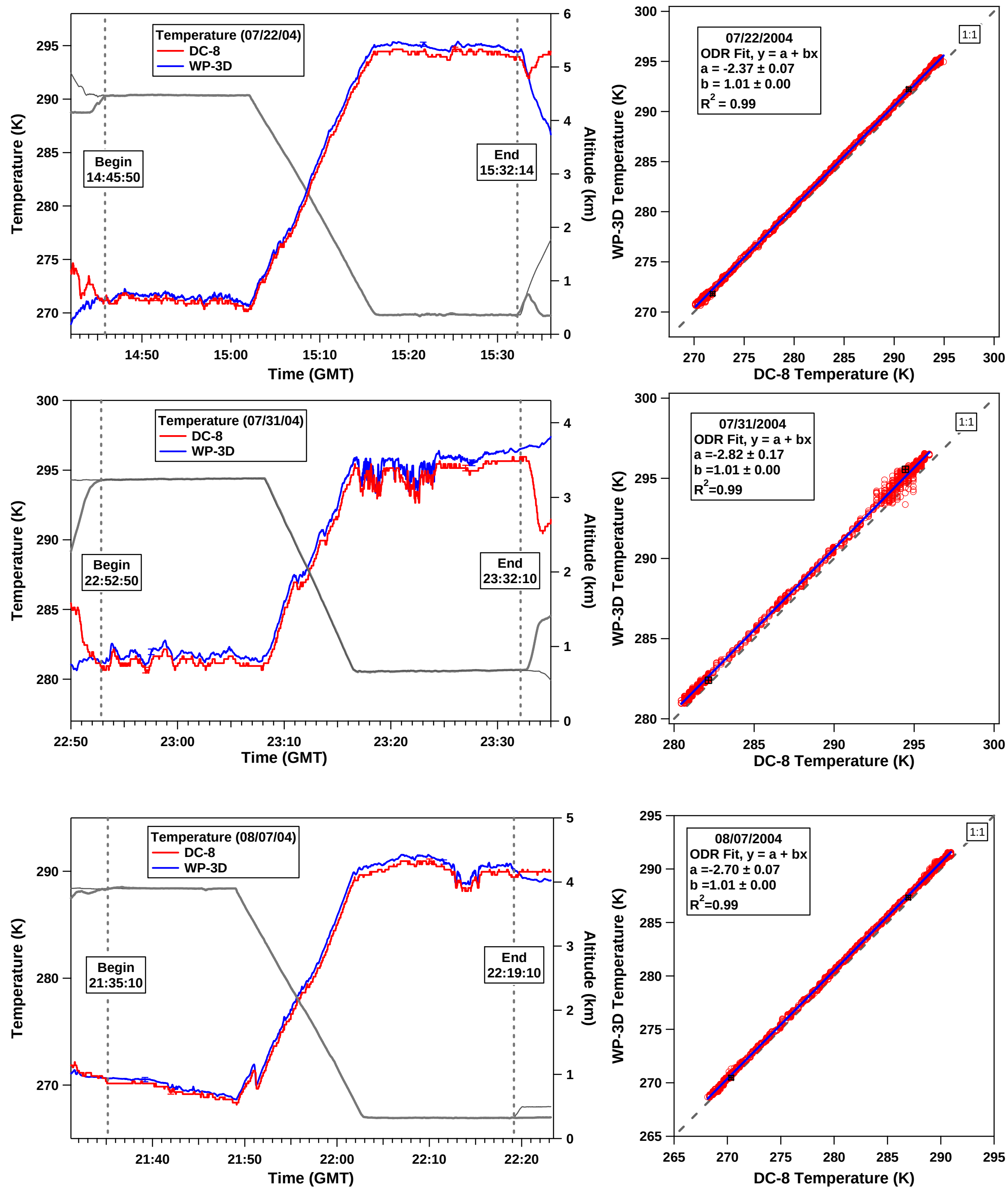


**Figure 2.** (left panels) Time series of temperature measurements and aircraft altitudes from two aircraft on the three intercomparison flights between the NASA DC-8 and the NOAA WP-3D. (right panels) Correlations between the temperature measurements on the two aircraft. Error bars shown depict the reported measurement uncertainties.

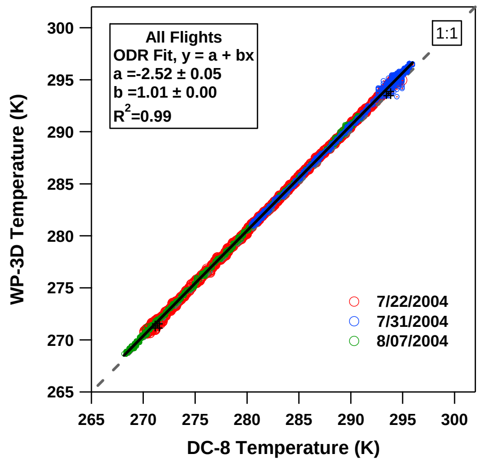


**Figure 3.** Correlation between the temperature measurements on the DC-8 and WP-3D for 7/22, 7/31, and 8/7 2004. Error bars shown depict the reported measurement uncertainties.

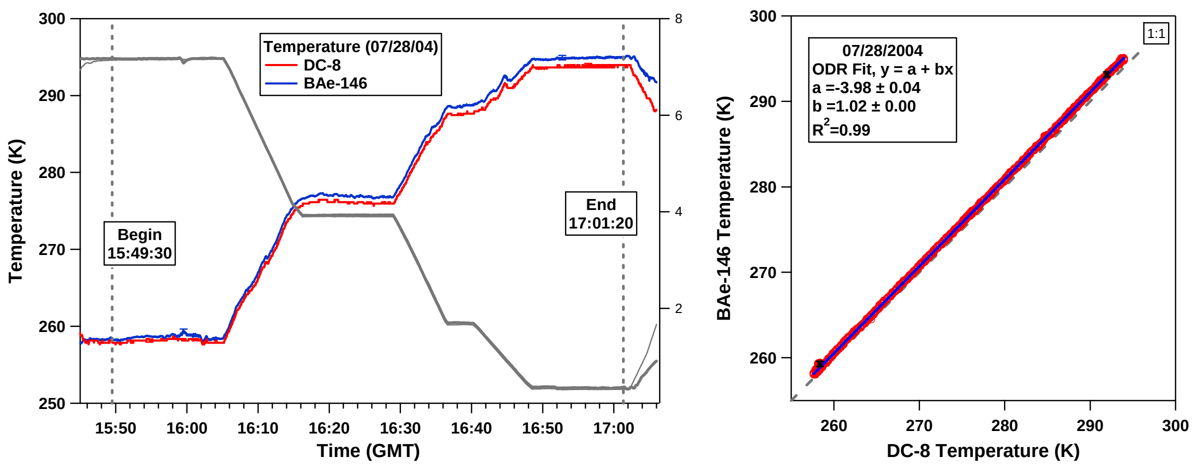


**Figure 4.** (left panel) Time series of temperature measurements and aircraft altitudes from the intercomparison flight between the NASA DC-8 and the FAAM BAe-146. (right panel) Correlations between the temperature measurements on the two aircraft. Error bars shown depict the reported measurement uncertainties.

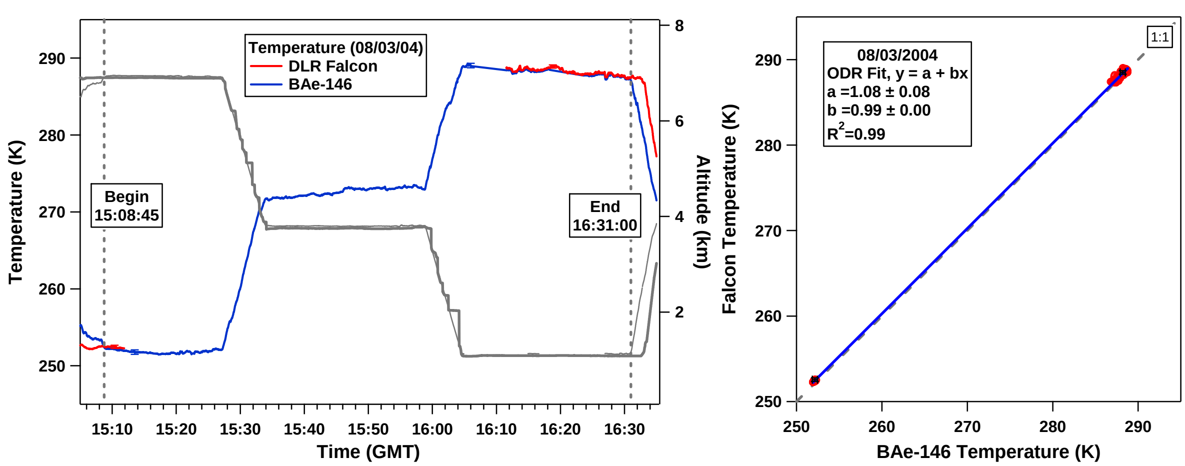


**Figure 5.** (left panel) Time series of temperature measurements and aircraft altitudes from the intercomparison flight between the FAAM BAe-146 and the DLR Falcon. (right panel) Correlations between the temperature measurements on the two aircraft. Error bars shown depict the reported measurement uncertainties.

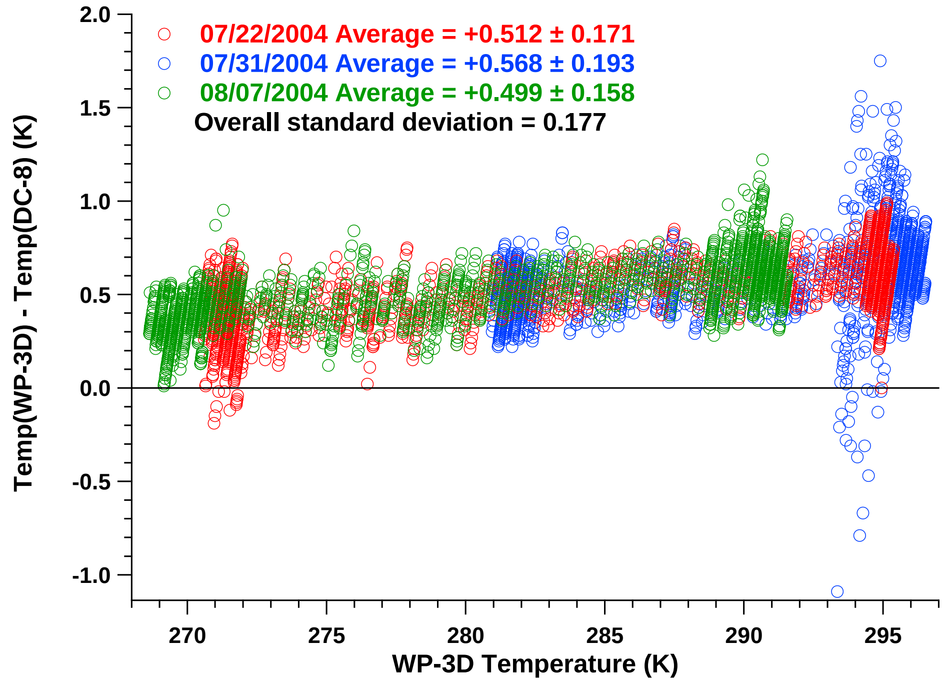


**Figure 6.** Difference between temperature measurements from the three DC-8/WP-3D intercomparison flights as a function of the WP-3D temperature.

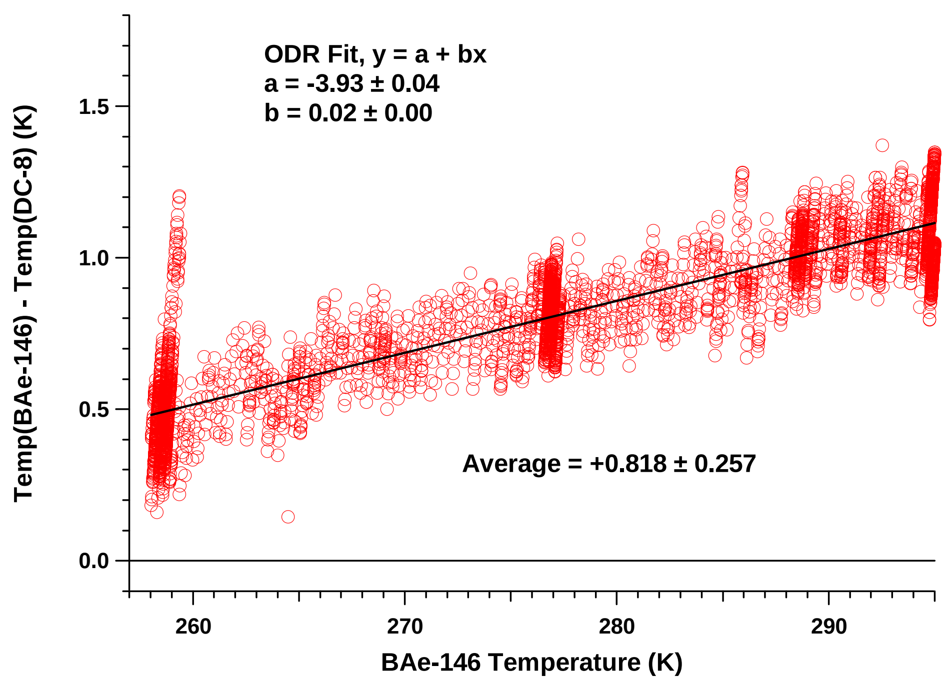


**Figure 7.** Difference between temperature measurements from the DC-8/BAe-146 intercomparison flight (07/28) as a function of the BAe-146 temperature.

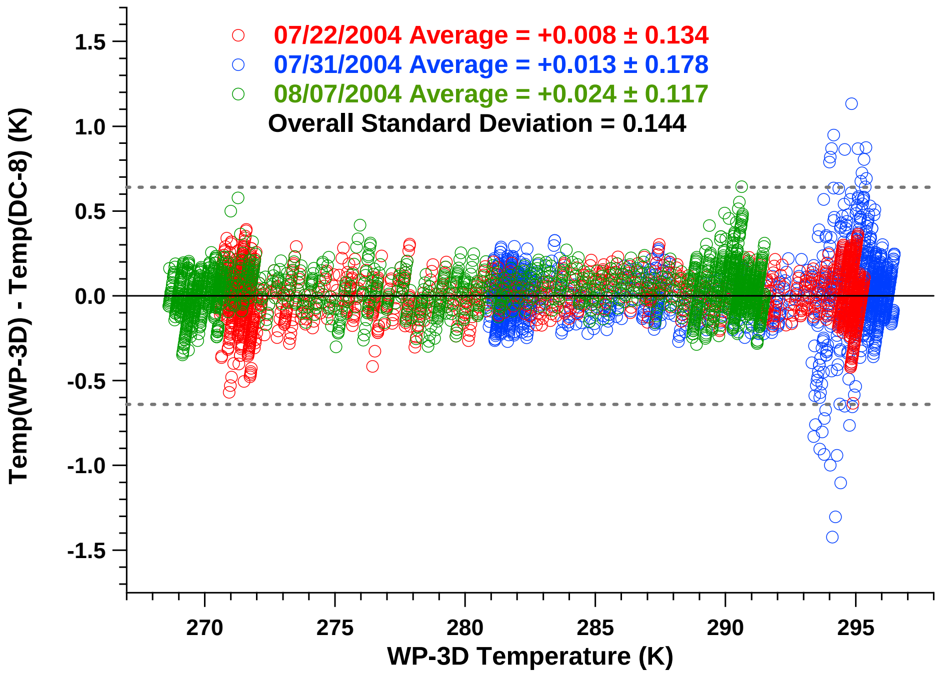


**Figure 8.** Difference between unified measurements of temperature from the three DC-8/WP-3D intercomparison flights as a function of the WP-3D temperature. Corrections were made to all data sets to account for bias. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties.

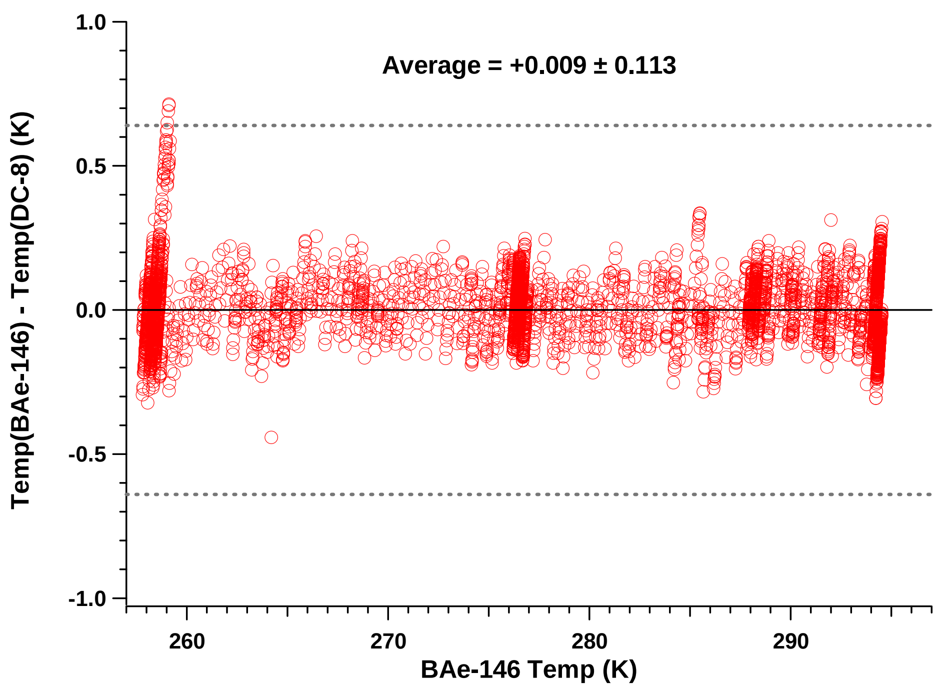


**Figure 9.** Difference between unified measurements of temperature from the DC-8/BAe-146 intercomparison flight (07/28) as a function of the BAe-146 temperature. Corrections were made to all data sets to account for bias. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties.

## 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.

Stickney, Truman M., et al. (1990), *Rosemount Total Temperature Sensors. Tech Rep*. 5755, Rev B, Rosemount, Inc.