TAbMEP Assessment: ICARTT O_3 Measurements

1. Introduction

Here we provide the assessment for the ozone (O_3) measurements taken from four aircraft platforms during the summer 2004 ICARTT field campaign [*Fehsenfeld et al.*, 2006]. This assessment is based upon the five wing-tip-to-wing-tip intercomparison flights conducted during the field campaign. Recommendations provided here offer a systematic approach to unifying the ICARTT O_3 data for any integrated analysis. These recommendations are based upon the instrument performance demonstrated during the ICARTT measurement comparison exercises and are not to be extrapolated beyond this campaign.

2. ICARTT O_3 Measurements

Four different O_3 instruments were deployed on the four aircraft. Table 1 summarizes these techniques and gives references for more information.

Table 1. O_3 measurements deployed on aircraft during ICARTT

Aircraft	Instrument	Reference
NASA DC-8	NO Chemilumimescence Detector (NO CLD)	
NOAA WP-3D	NO CLD	
FAAM BAe-146	TECO 49 UV photometric (TECO UVP)	
DLR Falcon	UV ozone photometer TE49 (TECO UVP)	

3. Summary of Results

Table 2 summarizes the recommendations drawn from the intercomparisons. The following sections describe the processes that led to the recommendations. Table 2 recommends a bias correction (see section 4.1 for details) that can be applied to each data set to maximize the consistency between them. The recommended 2σ uncertainty in Table 2 is the larger of either the uncertainty reported by the PI or the quadrature-sum of the recommended bias correction listed in Table 2 and twice the adjusted precision determined for each instrument (see Table 4). When there are multiple intercomparisons available for the same instrument, the maximum adjusted precision value is used. For three O_3 instruments, the bias corrections are smaller than the uncertainties reported by the PIs, so no bias correction need be made when combining these data sets. The O_3 FAAM BAe-146 instrument, however, did not have a reported PI uncertainty associated with it, so the quadrature-sum is used as the recommended 2σ uncertainty.

Table 2. Recommended ICARTT CO measurement treatment

Aircraft	Instrument	Reported 2σ Uncertainty	Recommended Bias Correction[a]	Recommended 2σ Uncertainty
NASA DC-8	NO CLD	3% or 3 ppbv	$1.11 – 0.0260\ O_{3\text{-DC8}}$	3% or 3 ppbv
NOAA WP-3D	NO CLD	0.1 ppbv + 3%	$-0.0969 – 0.0142\ O_{3\text{-WP3D}}$	0.1 ppbv + 3%
FAAM BAe-146	TECO UVP	None	$-2.26 + 0.0494\ O_{3\text{-BAe146}}$	$\{(-2.26 + 0.0494\ O_3)^2 + (0.06\ O_3)^2\}^{1/2}$ ppbv
DLR Falcon	TECO UVP	5%	$-0.958 + 0.0380\ O_{3\text{-Falcon}}$	2 ppbv[b] or 5%

[a] The “true O_3 mixing ratio” = measurement – recommended bias correction (as discussed in Section 4.1).
[b] The 2 ppbv value comes from absolute precision IEIP analysis.

4. Results and Discussion

4.1 Bias Analysis

Figures 1-3 illustrate the need for quantifying the bias between instruments. The difference between the simultaneous measurements reported by two instruments is plotted against the O_3 mixing ratio reported by one of the instruments. The apparent biases in Table 3 are derived from orthogonal linear regression (ODR) analysis (shown in Figs. A1–A4). ODR is used to approximate the bias between the paired instruments as a function of the O_3 mixing ratio. Apparent bias is defined as the difference between a measurement on one aircraft platform referenced to the same measurement made on the DC-8 (i.e. WP-3D - DC-8). In the case of the Falcon instrument, BAe-146 was used as the transferable standard. For convenience, the apparent bias is given in the form a + b*$O_{3\text{-DC8}}$. In this form, it is easier to propagate the apparent biases and so the best estimate bias can be used to calculate the uncertainties summarized in Table 2. It should be noted here that the intercept should not simply be interpreted as a measurement offset; instead it is used in conjunction with the slope to best describe the linear trend found in the data.

The best estimate bias is defined as the difference between the instrument being analyzed and the true O_3 mixing ratio as a function of the instrument being analyzed. This can be calculated by subtracting the true O_3 mixing ratio from the respective apparent bias equation from Table 3 and expressing the result in terms of the instrument being analyzed. The average of the apparent biases for three instruments (-1.11 ppbv + 0.0260 $O_{3\text{-DC8}}$) is assumed to be the “true O_3 mixing ratio” as a function of the DC-8 O_3 measurement. The BAe-146 is not included in the average since the instrument calibration record is incomplete. In effect, this procedure assumes that the true O_3 mixing ratio is the average of the three instruments, and the apparent bias correction is used in calculations to most closely approximate the true O_3 mixing ratio for each instrument.

It should be noted that the initial choice of the reference instrument is arbitrary, and has no impact on the final recommendations. The given bias corrections were based upon the instrument performance demonstrated during the intercomparison periods.

Table 3. ICARTT O_3 bias estimates

Aircraft	**Instrument**	**Apparent Bias[1]** **(a ppbv + b O_3)**	**Best Estimate Bias** **(a ppbv + b O_3)**
NASA DC-8	NO CLD	0	1.11 – 0.0260 $O_{3\text{-DC8}}$
NOAA WP-3D	NO CLD	-1.19 + 0.0116 $O_{3\text{-DC8}}$	-0.0969 – 0.0142 $O_{3\text{-WP3D}}$
FAAM BAe-146	TECO UVP	-3.54 + 0.0793 $O_{3\text{-DC8}}$	-2.26 + 0.0494 $O_{3\text{-BAe146}}$
DLR Falcon	TECO UVP	-2.15 + 0.0665 $O_{3\text{-DC8}}$	-0.958 + 0.0380 $O_{3\text{-Falcon}}$

[1] DC-8 is taken as an arbitrary reference. Apparent bias is expressed as a linear function of DC-8 O_3.

4.2 Precision Analysis

The instrument precision assessment is summarized in Table 4. The Internal Estimate of Instrument Precision (IEIP) analysis procedures were applied for the four continuous, fast measurements. The IEIP procedure is an effective method to estimate “short-term” precision, which accounts for signal variation during a short period of assumed constant O_3 measurements. Because this assumption is not always valid, the IEIP estimate tends to provide an upper limit of the instrument short-term precision. Over longer time scales, however, some instruments are subject to lower precision (i.e. larger variability), which includes variability that arises from uncorrected changes in the zero level or sensitivity of the instrument. These additional contributions to the variability are not likely reflected in the IEIP derived precision, but the intercomparison flights do provide a reasonable check on their influence. This effect was examined through the comparisons of the “expected variability" and "observed variability" given in Table 4. The expected variability is the quadrature-sum of the corresponding IEIP precisions. The observed variability is the standard deviation derived from the three intercomparisons shown in Figs. 4 - 6, denoting the relative difference between the paired instruments. Each standard deviation is expected to be equal to the quadrature-sum of the separate IEIP precisions of the two intercompared instruments. In all cases the observed variability is larger than the expected variability, which indicates that the IEIP derived (short-term) precision needs to be adjusted to reflect the longer term fluctuations. Table 4 contains estimates of this “adjusted” precision obtained by proportionally scaling the IEIP estimates so that the expected variability values would equal to that of the observed variability. Based on the results presented in Table 4, the worst "adjusted precision" (or the largest value) is taken as a conservative precision estimate for each ICARTT O_3 instrument and is used for the derivation of the recommended 2σ uncertainty in the last column of Table 2.

Table 3 shows that the measurement bias is a function of O_3 mixing ratio. Thus, the bias may have a significant impact on the observed variability. To minimize the effect of bias, we make corrections for bias before computing the observed variability. In some cases, the bias is small and the impact is minimal. For instance, the observed variability for DC-8/WP-3D on 7/22 is 3.05% without correction and 3.08% with, both of which are significantly lower than the expected variability. However, in the case of DC-8/BAe-146 the observed variability was estimated at 10.8% without correction. This value was reduced to 3.89% when bias correction was applied. The observed variability values given in Table 4 are computed after the bias correction. 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 O_3 precision (1σ) comparisons

Flight	Platform	IEIP Precision	Expected Variability	Observed Variability	Adjusted Precision
07/22	DC-8	1.2%	1.84%	3.08%	2.1%
	WP-3D	1.4%			2.3%
07/31	DC-8	1.3%	1.30%	2.49%	2.5%
	WP-3D	0.1%			0.2%
08/07	DC-8	1.2%	1.56%	2.06%	1.6%
	WP-3D	1.0%			1.3%
07/28	DC-8	1.2%	1.84%	3.89%	2.5%
	BAe-146	1.4%			3.0%
08/03	BAe-146	0.9%	1.35%	2.40%	1.6%
	Falcon	1.0%			1.8%

Appendix A

Figures A1 through A4 show the time series of the O_3 measurements and aircraft altitudes for each intercomparison flight as well as the correlations between the two O_3 measurements.

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.

Figures

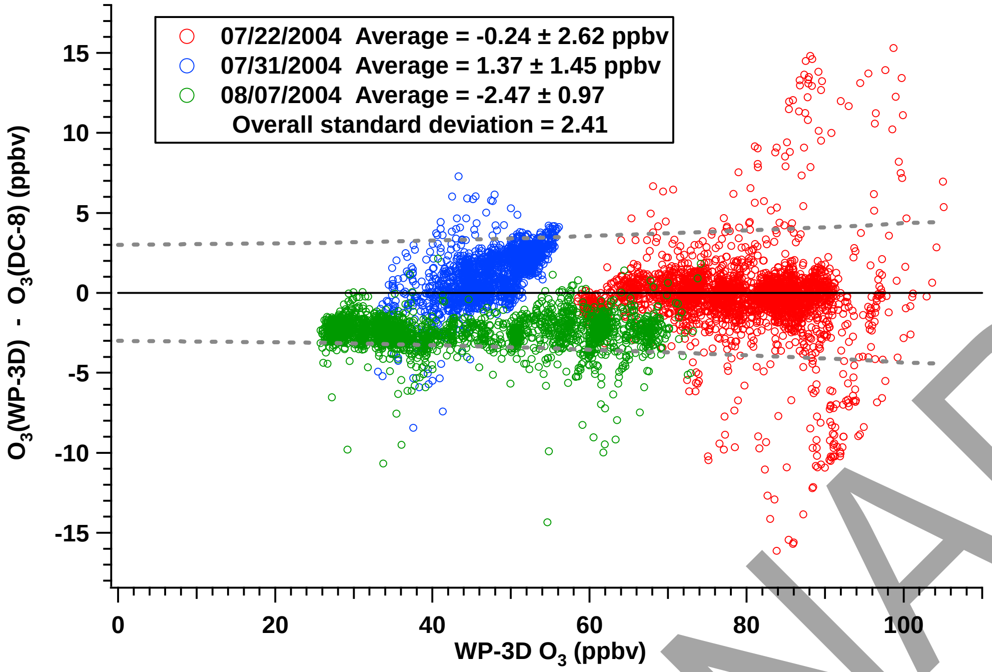

Figure 1: Difference between O_3 measurements from the three DC-8/WP-3D intercomparison flights as a function of the WP-3D O_3. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties.

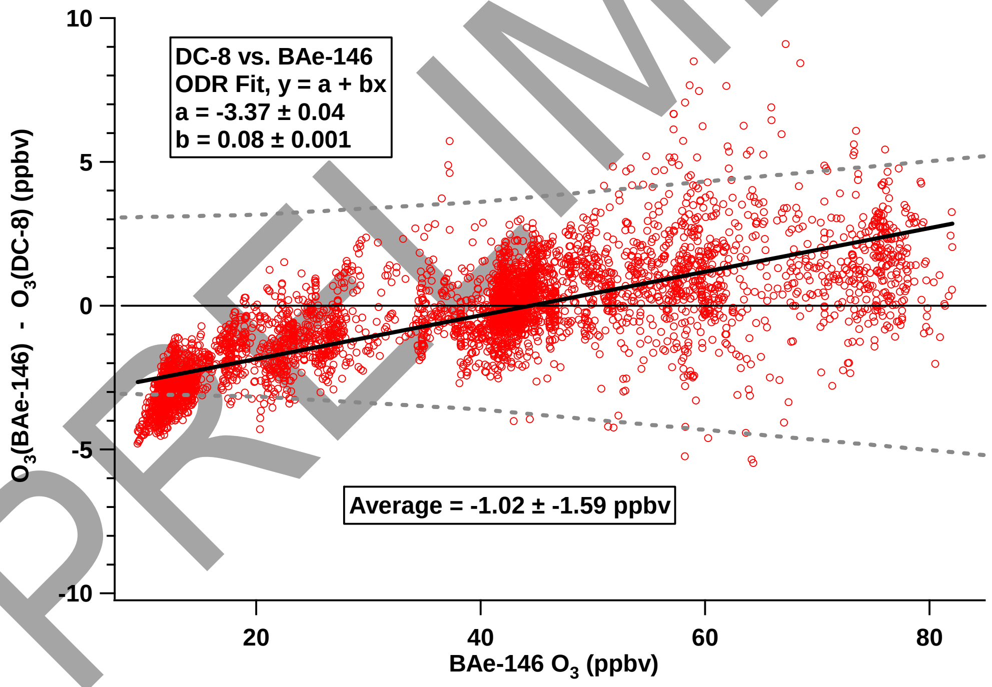

Figure 2: Difference between O_3 measurements from the DC-8/BAe-146 intercomparison flight (07/28) as a function of the BAe-146 O_3. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties. For the purposes of this graph, BAe-146 uncertainty was assumed to be 5% based on similar instruments.

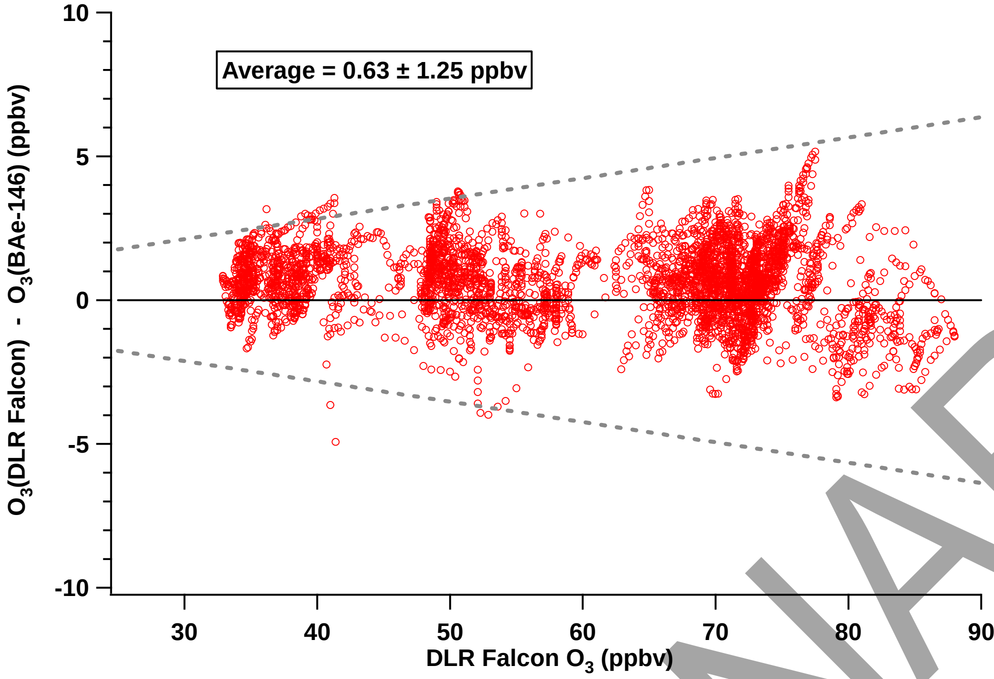

Figure 3: Difference between O_3 measurements from the BAe-146/DLR Falcon intercomparison flight (08/03) as a function of the Falcon O_3. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties. For the purposes of this graph, BAe-146 uncertainty was assumed to be 5% based on similar instruments.

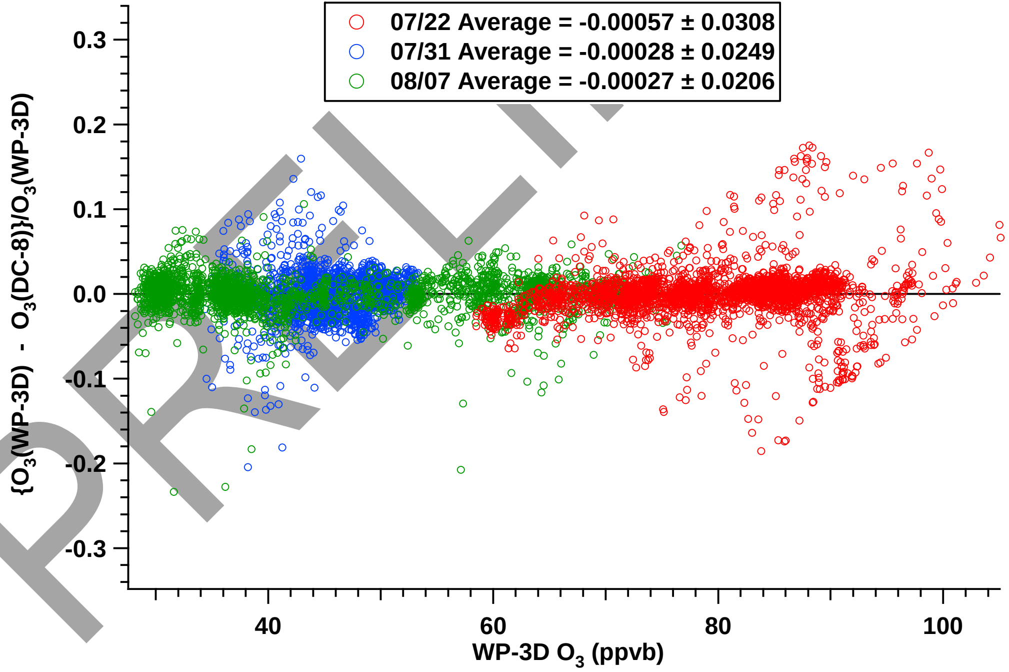

Figure 4: Relative difference between O_3 measurements from the three DC-8/WP-3D intercomparison flights as a function of the WP-3D O_3. A correction was made to account for bias.

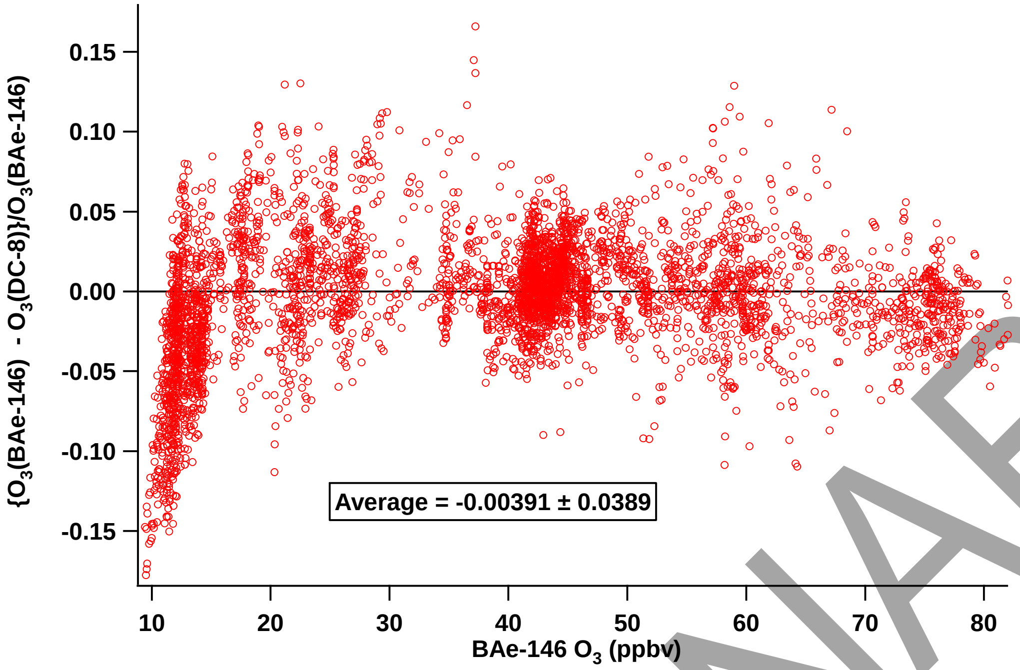

Figure 5: Relative difference between O_3 measurements from the DC-8/BAe-146 intercomparison flight (07/28) as a function of the BAe-146 O_3. A correction was made to account for bias.

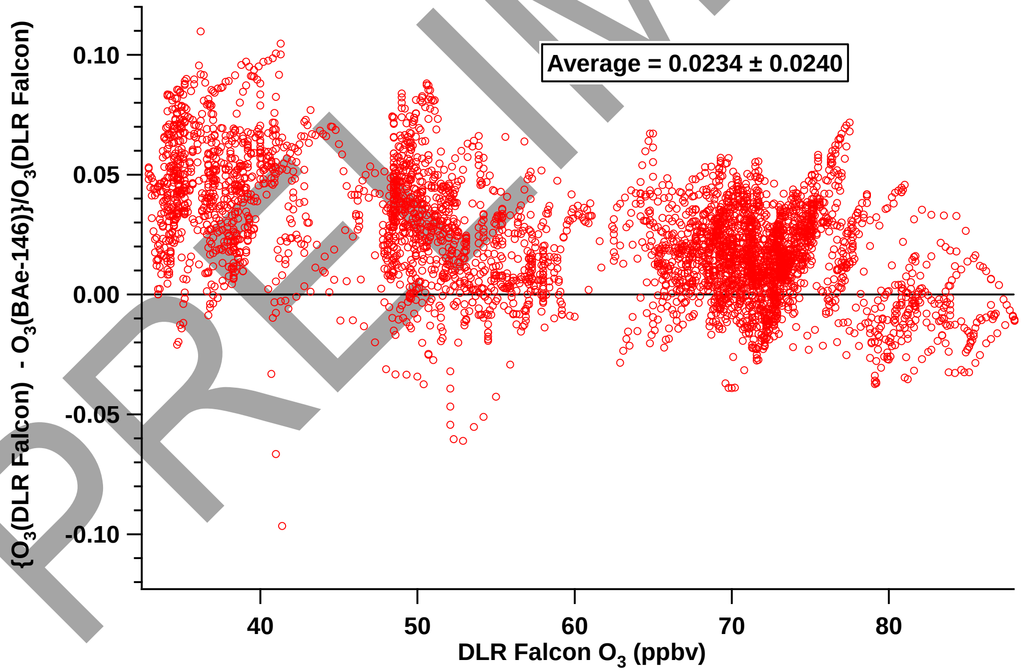

Figure 6: Relative difference between O_3 measurements from the BAe-146/DLR Falcon intercomparison flights as a function of the Falcon O_3. A correction was made to account for bias.

Appendix A

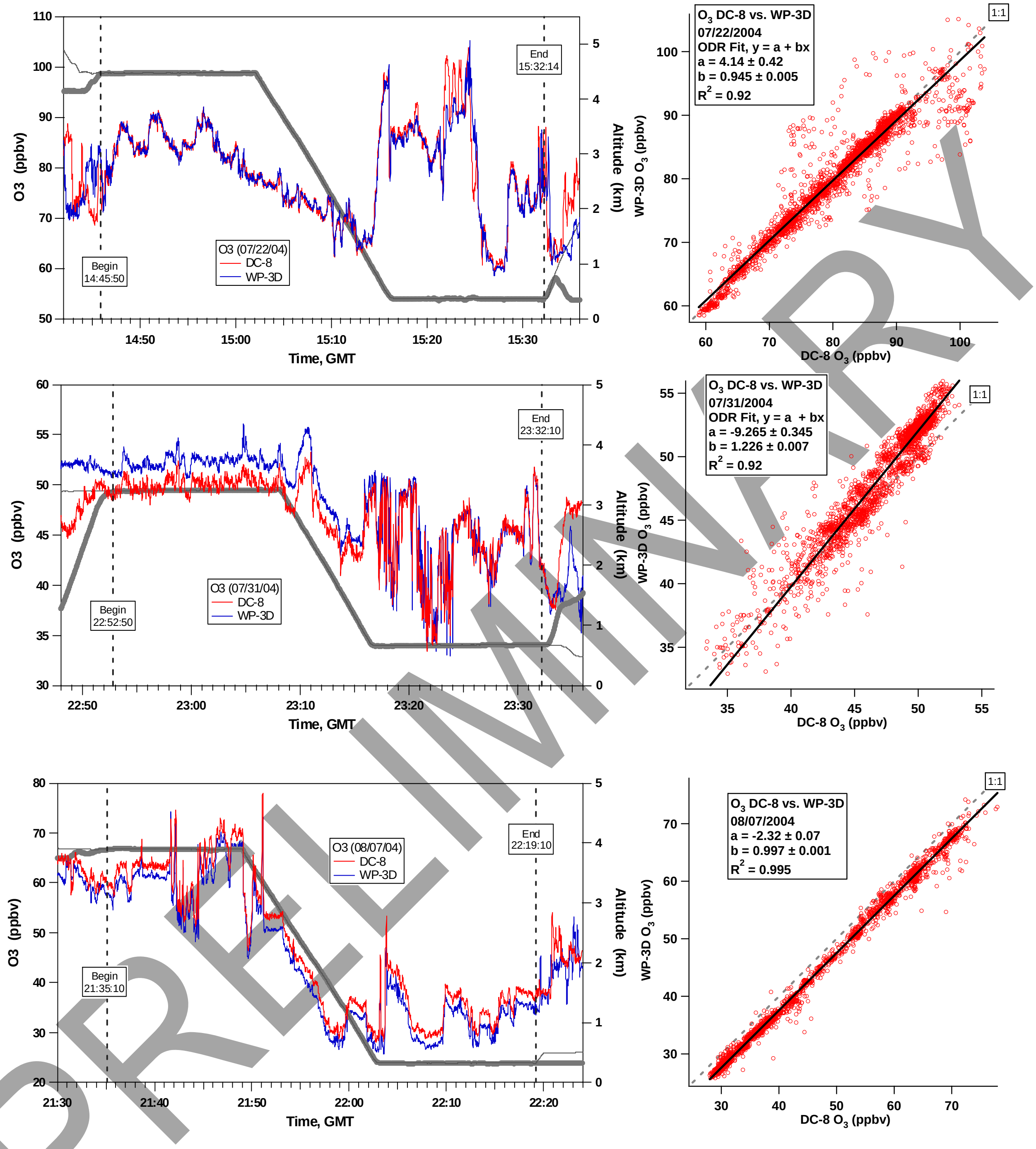

Figure A1: (left panels) Time series of O_3 measurements and aircraft altitudes from two aircraft on the three intercomparison flights between the NASA DC-8 and the NOAA WP-3D. (right panels) Correlations between the O_3 measurements on the two aircraft.

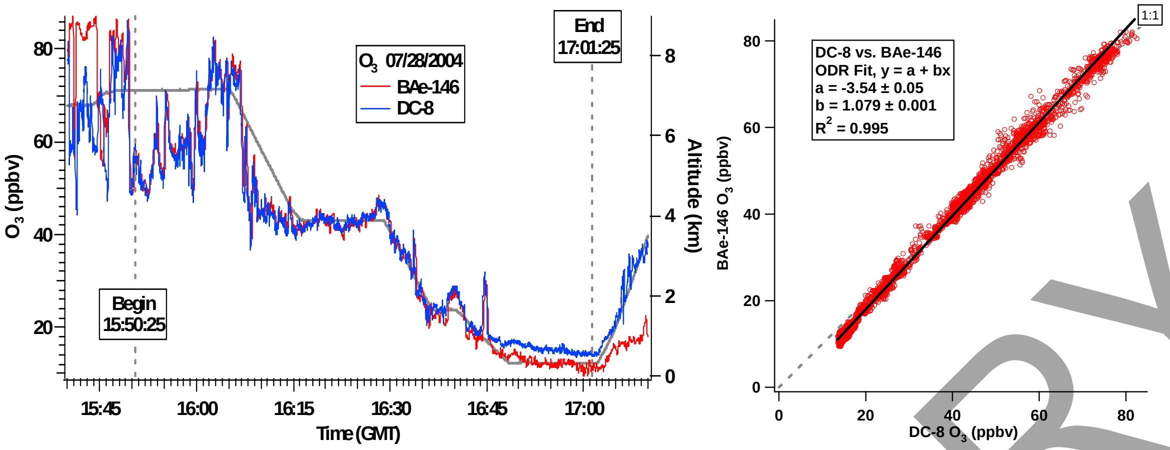

Figure A2: (left panel) Time series of O$_3$ measurements and aircraft altitudes from the intercomparison flight between the NASA DC-8 and the FAAM BAe-146. (right panel) Correlations between the O$_3$ measurements on the two aircraft.

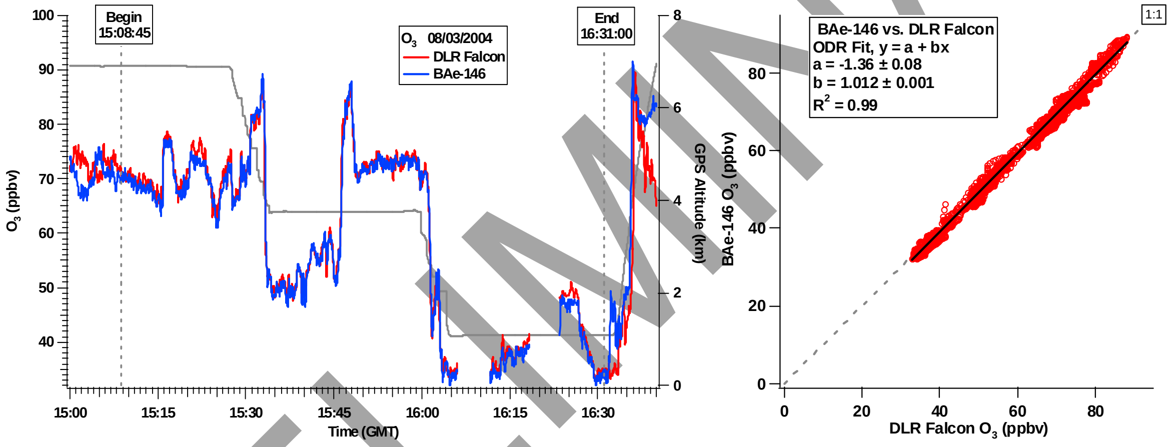

Figure A3: (left panel) Time series of O$_3$ measurements and aircraft altitudes from the intercomparison flight between the FAAM BAe-146 and the DLR Falcon. (right panel) Correlations between the O$_3$ measurements on the two aircraft.

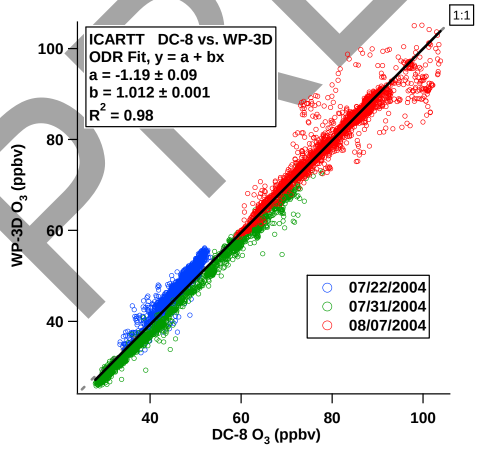

Figure A4: Correlations between the O$_3$ measurements on the two aircraft for all three days.