TAbMEP Assessment: ICARTT CO Measurements

1. Introduction

Here we provide the assessment for the carbon monoxide (CO) measurements taken from multiple 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, plus a comparison between the two NASA DC-8 instruments on all ICARTT research flights. Recommendations provided here offer a systematic approach to unifying the ICARTT CO 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 CO Measurements

Six different CO measurement techniques were deployed on the four aircraft. Table 1 summarizes these techniques and gives references for more information.

Table 1. CO measurements deployed on aircraft during ICARTT

Aircraft	Instrument	Reference
NASA DC-8	DACOM (Differential Absorption CO Measurement)	*Warner et al.* [2007]
NASA DC-8	WAS (Whole Air Sampler)	*Barletta et al.* [2002]
NOAA WP-3D	VUVF (Vacuum UV fluorescence)	*Holloway et al.* [2000]
FAAM BAe-146	VUVF (Vacuum UV fluorescence)	*Gerbig et al.* [1999]
DLR Falcon	VUVF (Vacuum UV fluorescence)	*Gerbig et al.* [1999]
DLR Falcon	TDLAS (Tunable Diode Laser Absorption Spectroscopy)	*Wienhold et al.* [1998] and *Fischer et al.* [2002]

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. Note that this bias correction should be subtracted, so a negative bias indicates that the reported CO concentrations should be increased by the absolute value of that bias correction, and a positive bias indicates that the reported concentrations should be decreased. For three CO instruments (DACOM, VUVF on WP-3D, and VUVF on Falcon), 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 CO data reported by the FAAM BAe-146 VUVF instrument, however, are significantly lower than the data sets from all of the other instruments, and are outside that expected from the reported uncertainty. The bias estimate for the DLR Falcon TDLAS instrument (Table 3) is strongly influenced by a short period of the intercomparison flight when large differences were noted (see Figs. 5 and A3.) If these apparent outliers were excluded, then the estimated correction would be significantly smaller. Consequently, no recommended bias correction is included for this instrument as robust statistical assessment cannot be performed. 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 precision value is used.

Table 2. Recommended ICARTT CO measurement treatment

Aircraft	Instrument	Reported 2σ Uncertainty	Recommended Bias Correction[a]	Recommended 2σ Uncertainty
NASA DC-8	DACOM	2% or 2 ppbv	+0.5 ppbv	2% or 2 ppbv
NASA DC-8	WAS	5%	+1.2 ppbv	$((0.11\ CO)^2 + 1.4)^{1/2}$ ppbv
NOAA WP-3D	VUVF	5%	-1.0 ppbv	5%
FAAM BAe-146	VUVF	None	-6.5 ppbv	$((0.028\ CO)^2 + 42)^{1/2}$ ppbv
DLR Falcon	VUVF	10%	-0.7 ppbv	10%
DLR Falcon	TDLAS	5%		>6.8%[b]

[a] The "true CO mixing ratio" = measurement – recommended bias correction (as discussed in Section 4.1).
[b] based on precision analysis only.

4. Results and Discussion

4.1 Bias Analysis

Figures 1-5 illustrate the method for quantifying the bias between instruments. The difference between the simultaneous measurements reported by two instruments is plotted against the CO mixing ratio reported by one of the instruments. The average and standard deviation of the differences are indicated in each graph. An average different from zero indicates a bias between instruments. Addition and subtraction of the averages in Figs. 1-5 allow the derivation of the apparent biases given in Table 3. The apparent biases are calculated relative to the DC-8 DACOM measurement. There is little bias (<1.5 ppbv) between four of the instruments, a relatively large negative bias in the BAe-146 VUVF data, and a moderate bias in the Falcon TDLAS instrument. The Falcon bias is exaggerated by a period of large bias indicated by the vertical line of points in Fig. 5. The average of the biases for the four instruments with relatively small biases (-0.49 ppbv) is subtracted from each of the apparent biases to get a best estimate of the biases, which are given in the final column of Table 3. In effect, this procedure assumes that the best estimate of the "true CO mixing ratio" is the average of the four instruments excluding the BAe-146 VUVF and the Falcon TDLAS results, and the recommended bias correction for each instrument is the value that should be subtracted from the measurement reported by that instrument to most closely approximate the "true CO mixing ratio". It should be noted that the initial choice of the reference instrument is arbitrary, and has no impact on the final recommendations.

Table 3. ICARTT CO bias estimates

Aircraft	Instrument	Apparent Bias[1] (ppbv)	Best Estimate Bias (ppbv)
NASA DC-8	DACOM	0	+0.49
NASA DC-8	WAS	+0.67	+1.16
NOAA WP-3D	VUVF	- 1.48	- 0.99
FAAM BAe-146	VUVF	- 6.97	- 6.48
DLR Falcon	VUVF	- 1.16	- 0.67
DLR Falcon	TDLAS	+3.17	+3.66

[1] positive bias indicates values higher than the DC-8 DACOM measurement, which is taken as an arbitrary reference.

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 five continuous, fast measurements, and did not include the DC-8 WAS (see later discussion in this section). The IEIP procedure is an effective method to estimate so called "short-term" precision, which accounts for signal variation during a short period of assumed constant CO measurements. Because this assumption is not always valid, the IEIP estimate tends to provide a 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 five intercomparisons shown in Figure 6 - 9, which display 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 except two, 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." For the two cases that the "Observed variability" is smaller, the "Adjusted Precision" is set equal to the "IEIP Precision". 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 CO instrument and is used in Table 2 for the derivation of the "recommended uncertainty."

Table 4. ICARTT CO precision (1σ) comparisons

Flight	Platform/ Instrument	IEIP Precision	Expected Variability	Observed Variability	Adjusted Precision
07/22	DC-8 DACOM	0.9%	1.47%	1.62%	1.0%
	WP-3D VUVF	1.2%			1.3%
07/31	DC-8 DACOM	0.8%	1.68%	1.52%	0.8%
	WP-3D VUVF	1.5%			1.5%
08/07	DC-8 DACOM	0.6%	1.50%	1.95%	0.8%
	WP-3D VUVF	1.4%			1.8%
07/28	DC-8 WAS	5.4%[1]	5.42%	3.27%	5.4%
	BAe-146 VUVF	0.5%			0.5%
08/03	BAe-146 VUVF	0.5%	1.01%	3.00%	1.4%
	Falcon VUVF	0.9%			2.7%
08/03	BAe-146 VUVF	0.5%	1.33%	2.88%[2]	1.0%
	Falcon TDLAS	1.3%			2.7%

[1] estimated from DC-8 WAS and DC-8 DACOM comparison, see Fig. 10.

[2] 9% outliers removed to obtain a robust standard deviation estimate (see Figure 9). Outliers are believed to be driven by systematic errors.

The DC-8 WAS technique provides only intermittent results with integration time around 1 min. The IEIP procedures are applicable in this case, but need to be modified in the following way.

As noted in Table 4, the DC-8 WAS precision is estimated from the standard deviation of the relative difference, i.e., {CO(DC-8 DACOM) - CO(DC-8 WAS)}/ CO(DC-8 DACOM) plotted in Fig. 10, which is based on all available overlapping data from the entire ICARTT campaign period. It should also be recognized that the DC-8 WAS precision was required use of, but was not sensitive to the DC-8 DACOM IEIP analysis. The final 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.

Appendix A

Figures A1 through A3 show the time series of the CO measurements and aircraft altitudes for each intercomparison flight as well as the correlations between the two CO measurements.

References

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Fischer, H., et al. (2002), Synoptic tracer gradients in the upper troposphere over central Canada during the Stratosphere-Troposphere Experiments by Aircraft Measurements 1998 summer campaign, *J. Geophys. Res., 107*(D8), 4064, doi:10.1029/2000JD000312.

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Wienhold, F., et al. (1998), Tristar—A tracer in situ TDLAS for atmospheric research, *Appl. Phys., B, 67*, 411 – 417.

Figures

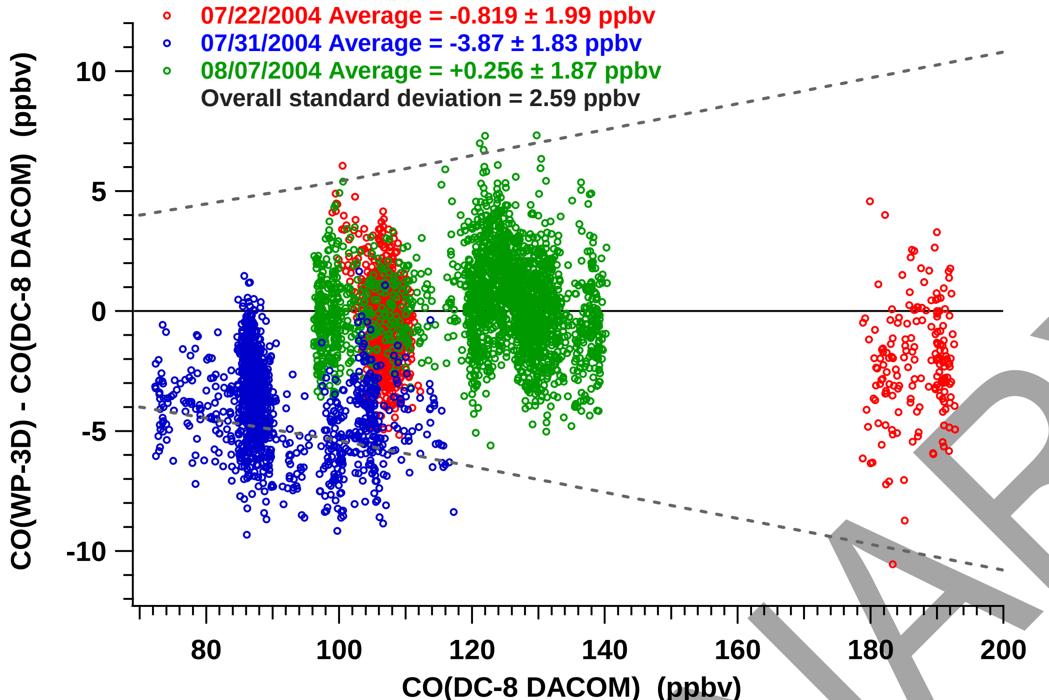

Figure 1: Difference between CO measurements from the three DC-8/WP-3D intercomparison flights as a function of the DC-8 DACOM CO. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties.

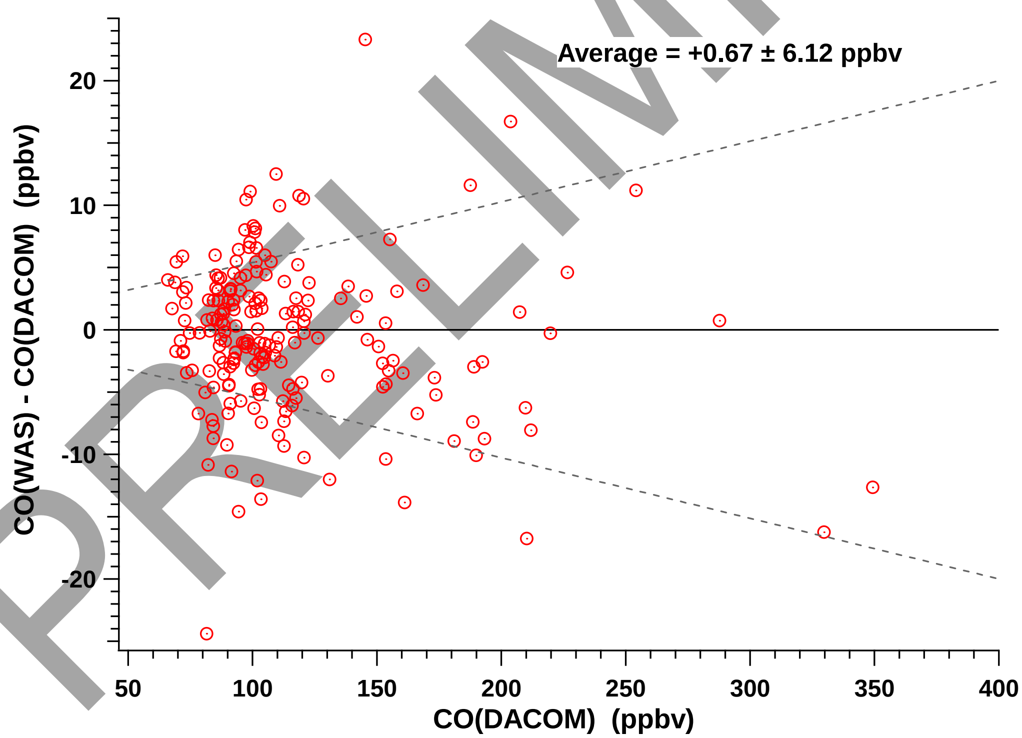

Figure 2: Difference between CO measurements from all ICARTT flights of the DC-8 as a function of the DC-8 DACOM CO. The dashed lines indicate the range of the results expected from the reported measurement uncertainties.

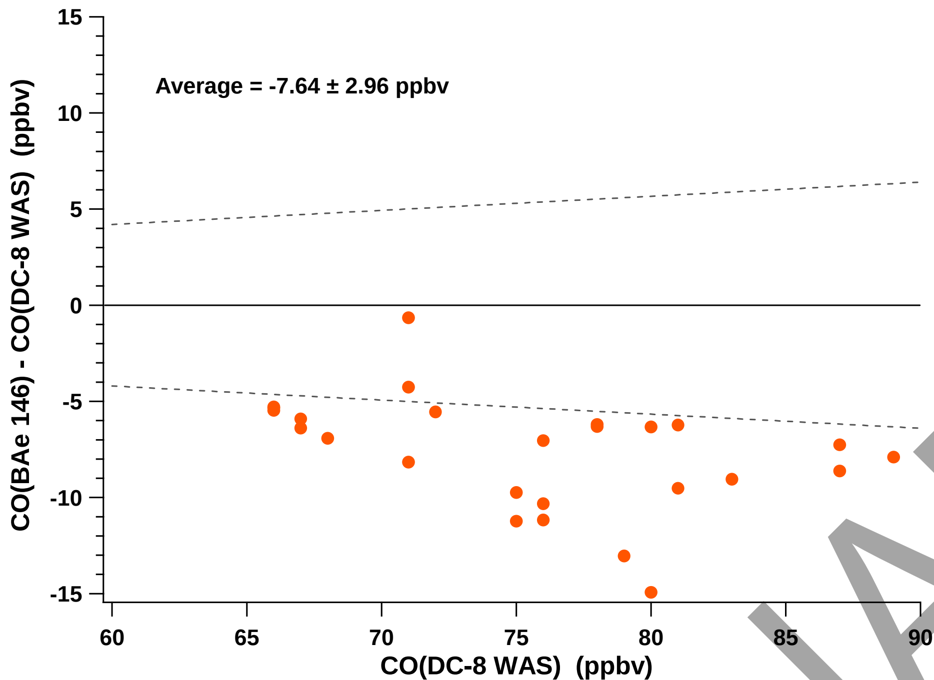

Figure 3: Difference between CO measurements from the DC-8/BAe-146 intercomparison flight (07/28) as a function of the DC-8 WAS CO. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties.

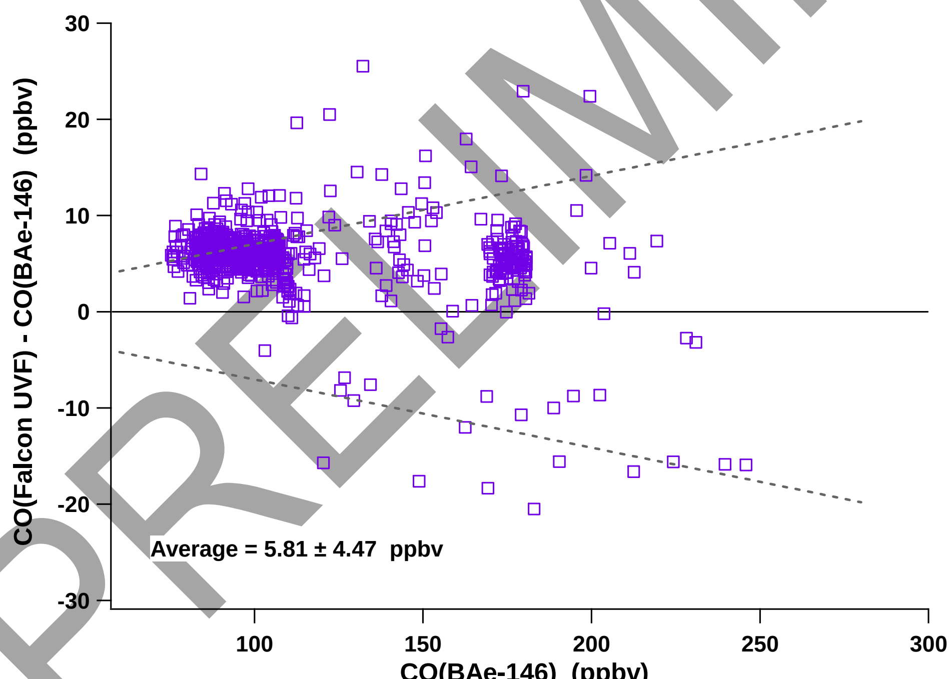

Figure 4: Difference between CO measurements from the BAe-146/DLR Falcon intercomparison flight (08/03) as a function of the BAe-146 VUVF CO. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties.

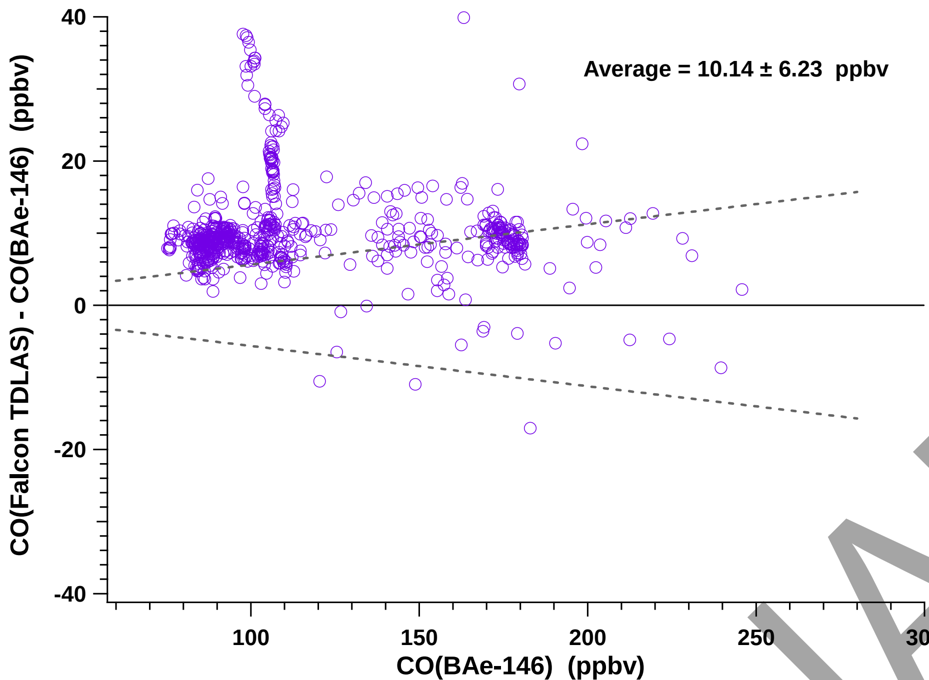

Figure 5: Difference between CO measurements reported from the BAe-146/DLR Falcon intercomparison flight (08/03) as a function of the BAe-146 VUVF CO. The dashed lines indicate the range of the results expected from the reported 2σ measurement uncertainties.

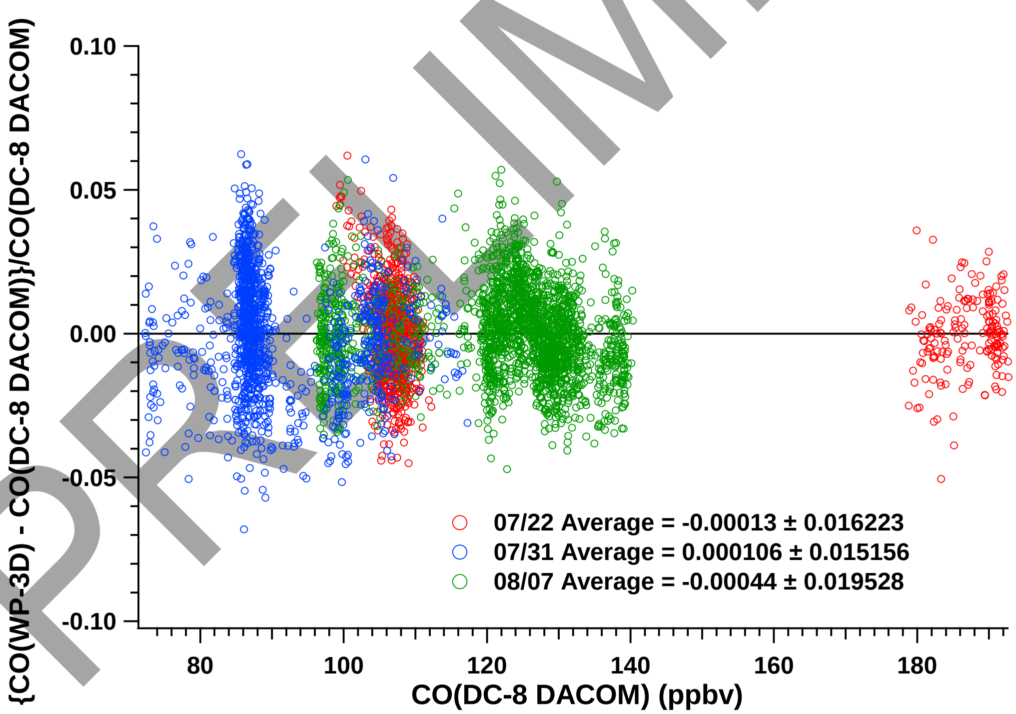

Figure 6: Relative difference between CO measurements from the three DC-8/WP-3D intercomparison flights as a function of the DC-8 DACOM CO. A correction was made to account for bias.

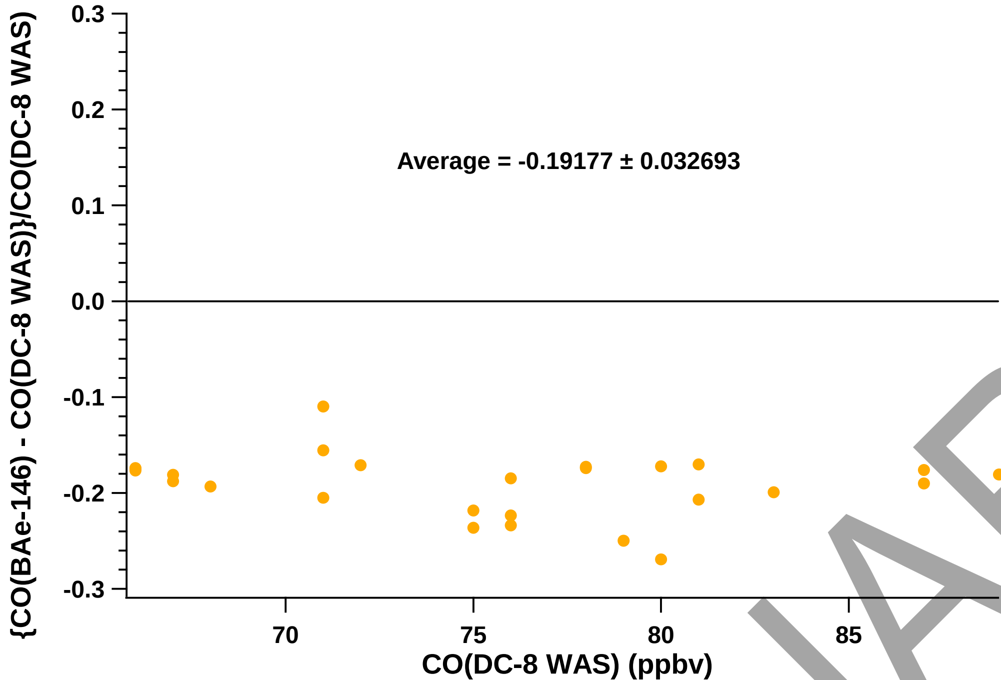

Figure 7: Relative difference between CO measurements from the DC-8/BAe-146 intercomparison flight (07/28) as a function of the DC-8 DACOM CO. A correction was made to account for bias.

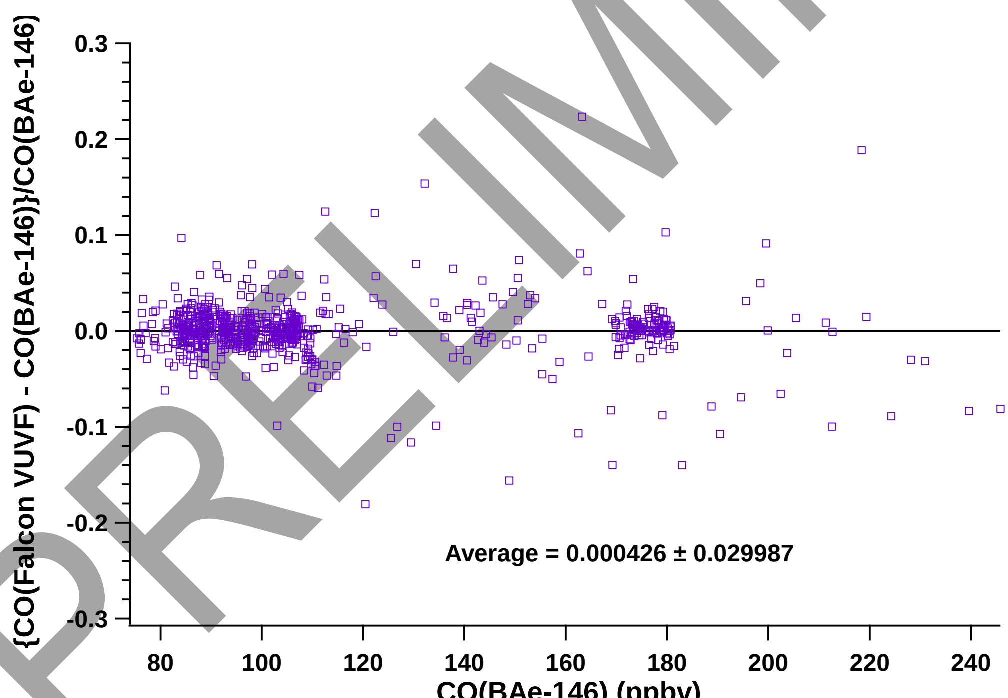

Figure 8: Relative difference between CO measurements reported from two instruments during the BAe-146/DLR Falcon intercomparison flight (08/03) as a function of BAe-146 VUVF CO. A correction was made to account for bias.

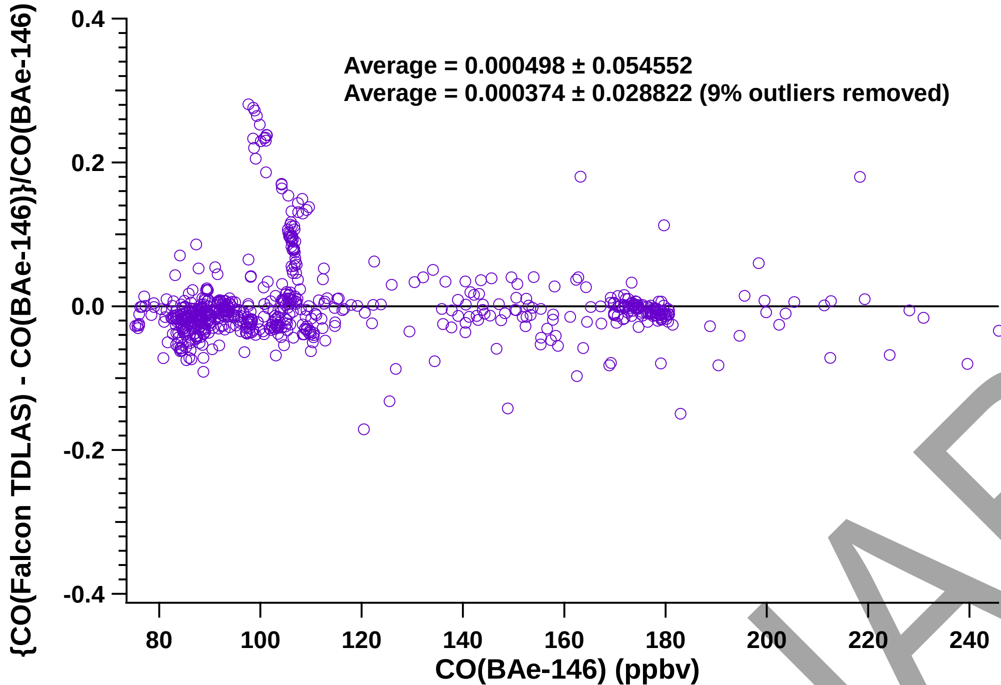

Figure 9: Relative difference between CO measurements from the BAe-146/DLR Falcon intercomparison flight (08/03) as a function of the BAe-146 VUVF CO. A correction was made to account for bias.

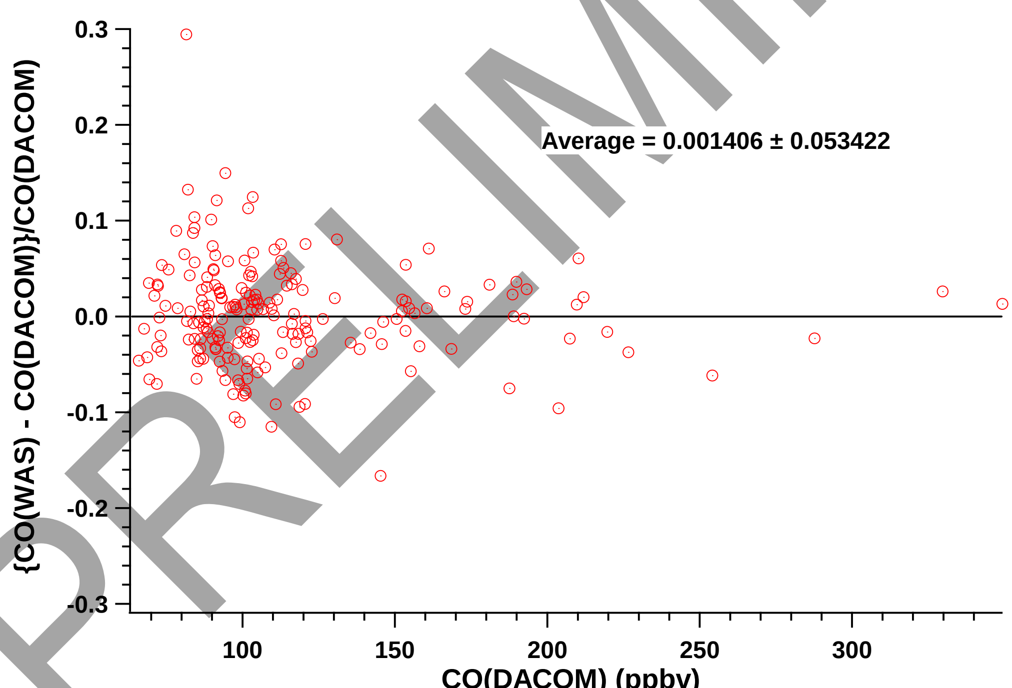

Figure 10: Relative difference between CO measurements reported from all ICARTT flights of the DC-8 as a function of the DC-8 DACOM CO. A correction was made to account for bias.

Appendix A

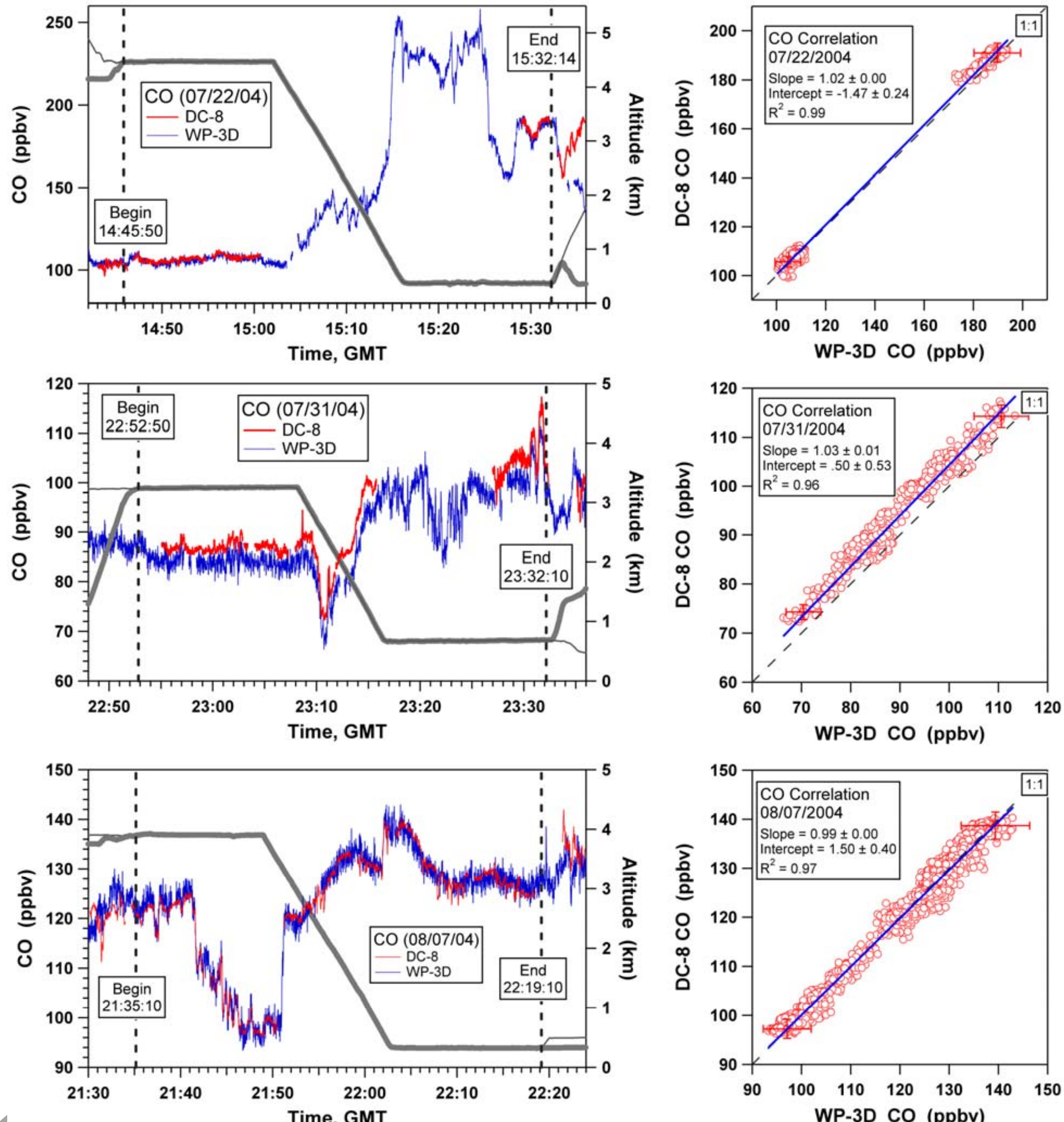

Figure A1: (left panels) Time series of CO measurements and aircraft altitudes from two aircraft on the three intercomparison flights between the NASA DC-8 and the NOAA WP-3D. (right panels) Correlations between the CO measurements on the two aircraft.

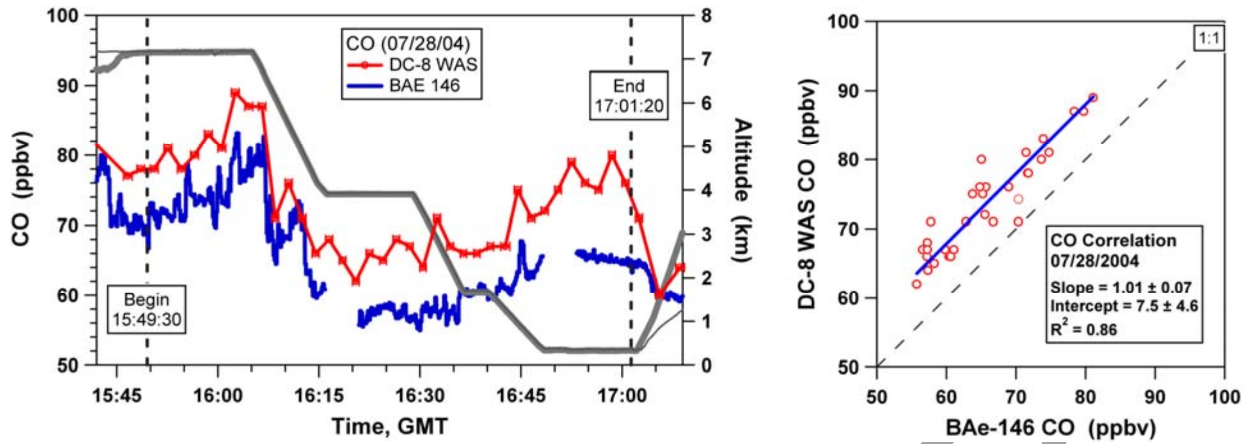

Figure A2: (left panel) Time series of CO measurements and aircraft altitudes from the intercomparison flight between the NASA DC-8 and the FAAM BAe-146. (right panel) Correlations between the CO measurements on the two aircraft.

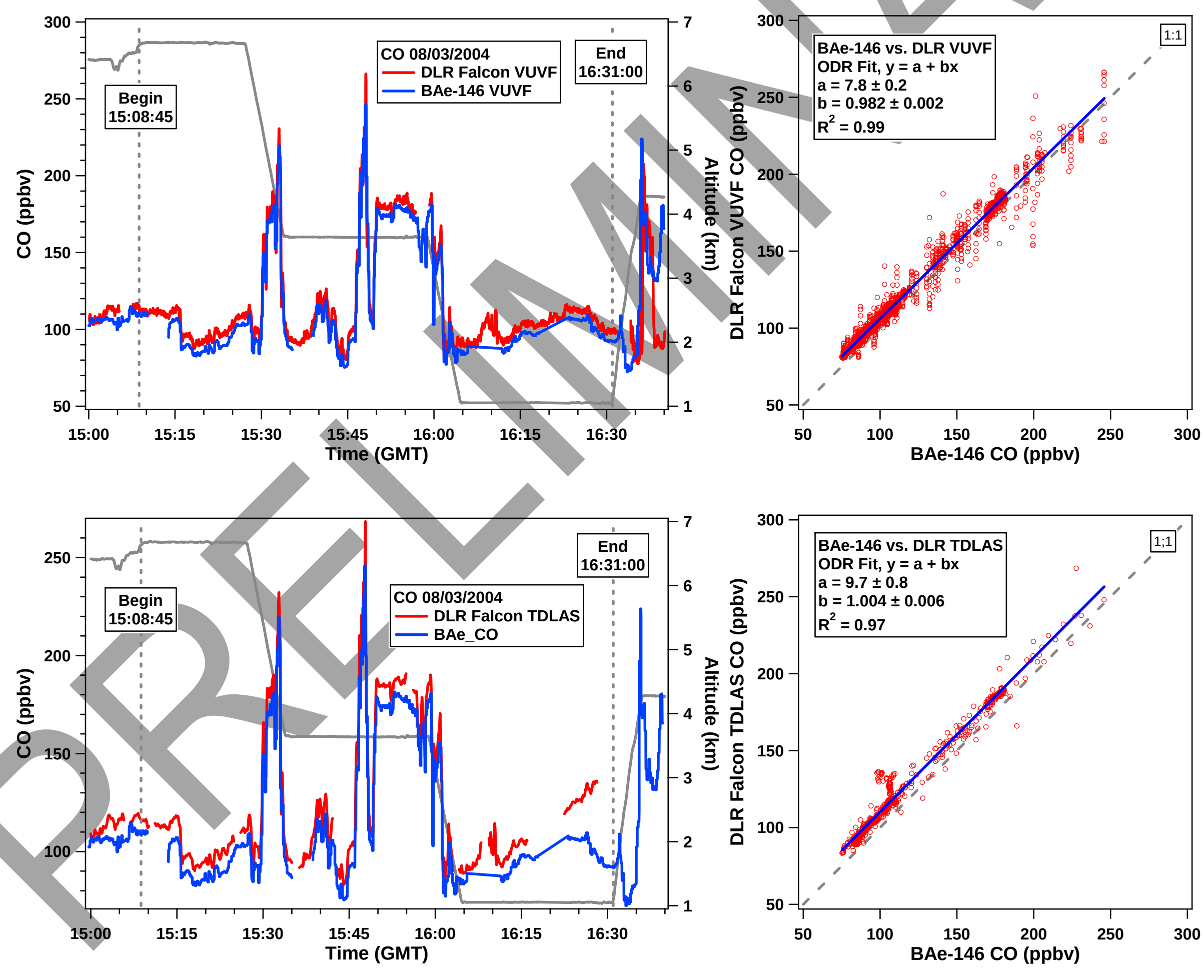

Figure A3: (left panel) Time series of CO measurements and aircraft altitudes from the intercomparison flight between the FAAM BAe-146 and the DLR Falcon. (right panel) Correlations between the CO measurements on the two aircraft.