**Nevzorov Methods Overview 2/27/2016**

The Nevzorov is an airborne hotwire probe designed to measure liquid and total cloud water content. The instrument consists of two sets of paired heated elements where each set has a leading edge “collection” sensor and a trailing edge “reference” sensor. The liquid water content element is rod-shaped in order to shed ice crystals with minimal sensor contact while the total water content sensor is in the shape of a convex cone so that it captures solid and liquid hydrometeors alike. At a basic level, water content is calculated using heat losses caused by hydrometeor evaporation. The paired sensor design of the Nevzorov somewhat simplifies calculations and eliminates the need for inter-probe calibrations. Each of the two leading-edge sensors are fully exposed to airflow and hydrometeor impact (collector sensors) while the second (reference sensors) are shielded from hydrometeor interaction while still being ventilated by similar airflows. Collector and reference temperatures are maintained at an equivalent value and sensor current and voltage values are continuously collected. Evaporative cooling caused by collector sensor hydrometeor impact causes an increase in comparative power consumption (with regards to reference sensor power). The reference sensor doesn’t experience hydrometeor evaporative heat loss, therefore collector and reference sensor differential power consumption can be used to calculate water content values.

**Liquid Water Content Calculations**

LWC values are calculated using the following formulas available in the Nevzorov hot wire LWC/TWC Probe Operating Manual (Sky PhysTech).

LWC calculation accuracy is affected by collector sensor heat losses due to factors other than hydrometeor heat losses, hereafter called dry air heat loss. Korelev et. al. have shown water content values are most affected by airspeed changes which can cause baseline drift on the order of 2 \* 10-3 g m-3 / 10 m s-1 airspeed. Application of a relationship for dry air heat loss airspeed dependence is required to minimize airspeed dependent LWC error. (see k Airspeed Dependence Correction section for more detail).

Tables 1 through 4 outline the various King Air flight file variables and constants used in liquid water content value calculations.

**Table 1. Flight file variables required for LWC calculation**

|  |  |  |
| --- | --- | --- |
| Variable Name | Description | Units |
| vlwcref | Liquid reference sensor voltage | Volt |
| vlwccol | Liquid collector sensor voltage | Volt |
| ilwcref | Liquid reference sensor current | Amp |
| ilwccol | Liquid collector sensor current | Amp |
| trf | Reverse flow static temperature | Celsius |
| aias | Indicated boom airspeed | Knot |
| pmb | Rosemount pressure | Millibar |
| timeForm | Flight time formatted as HHMMSS UTC |  |
|  |  |  |
|  |  |  |
|  |  |  |

*LWC calculation-required variables obtained from 1 hz King Air flight file.*

**Table 2. Flight file header variables required for LWC calculation**

|  |  |  |
| --- | --- | --- |
| Header Variable Name | Description | Units |
| ilwccol:SampleArea | Liquid sensor sample area | meter2 |
| ILWCCOL\_RAW:temperature | Liquid sensor temperature | Celsius |
|  |  |  |
|  |  |  |

*LWC calculation-required variables obtained from 1 hz King Air flight file header entries.*

**Table 3. Additional constants required for LWC calculation**

|  |  |  |  |
| --- | --- | --- | --- |
| Constant Name | Description | Value | Units |
| eliq | Liquid water collection efficiency | 1.0 |  |
| L\* | Expended energy due to heating & evaporation | 2589.0 | Joule gram-1 |
|  |  |  |  |
|  |  |  |  |

**Table 4. Additional flight file variables used for error investigation**

|  |  |  |
| --- | --- | --- |
| Variable Name | Description | Units |
| avpitch | Pitch | Degree |
| avroll | Roll | Degree |
| hivs | Vertical speed | Meter Sec-1 |
| betaB | Sideslip angle | Degree |
| avyawr | Yaw | Degree |
| bias | Indicated starboard nose pitot airspeed | Knot |
| tas | True airspeed | Meter Sec-1 |
| nevlwc1 | Nevzorov LWC provided by Korelev | Meter Sec-1 |

*Additional King Air flight file variables used in LWC error investigations.*

The following equations for collector sensor heat loss (P) and liquid water content (LWC) rely on fundamental heat transfer principles. Formulas were taken from the Nevzorov hot wire LWC/TWC Probe Operating Manual (Sky PhysTech). Formulas are written in terms of flight file variable names where applicable.

The collector sensor heat loss (*P*) due to hydrometer impact is

*vlwccol – Liquid water collector sensor voltage [Volt]*

*ilwccol – Liquid water collector sensor current [Amp]*

*vlwcref – Total water reference sensor voltage [Volt]*

*ilwcref – Total water reference sensor current [Amp]*

*kliq – Dry air heat loss coefficient (see next section for more detail)*

LWC [g m-3] is calculated based on

*Pliq – Liquid sensor evaporative heat loss [Watt]*

*eliq - Collection Efficiency = 1.0†*

*tas - True airspeed [m s-1]*

*Sliq – Liquid collector sensor surface area [m3]*

*L\* - Expended energy due to heating & evaporation = 2589.0*Ψ *[J g-1]*

*† - TWC Collection efficiency can be assumed to be 1.0 for drops larger than ~ 10 μm with minimal error (Korolev 1998) therefore collection efficiency variations were not considered.*

Ψ - L\* is actually a function of ambient temperaturebut using a fixed value of 2589.0 *J g-1 only introduces error on the order of ±5%. (Sky PhysTech).*

**Clear Air Liquid Power Coefficient (k) Airspeed Dependence**

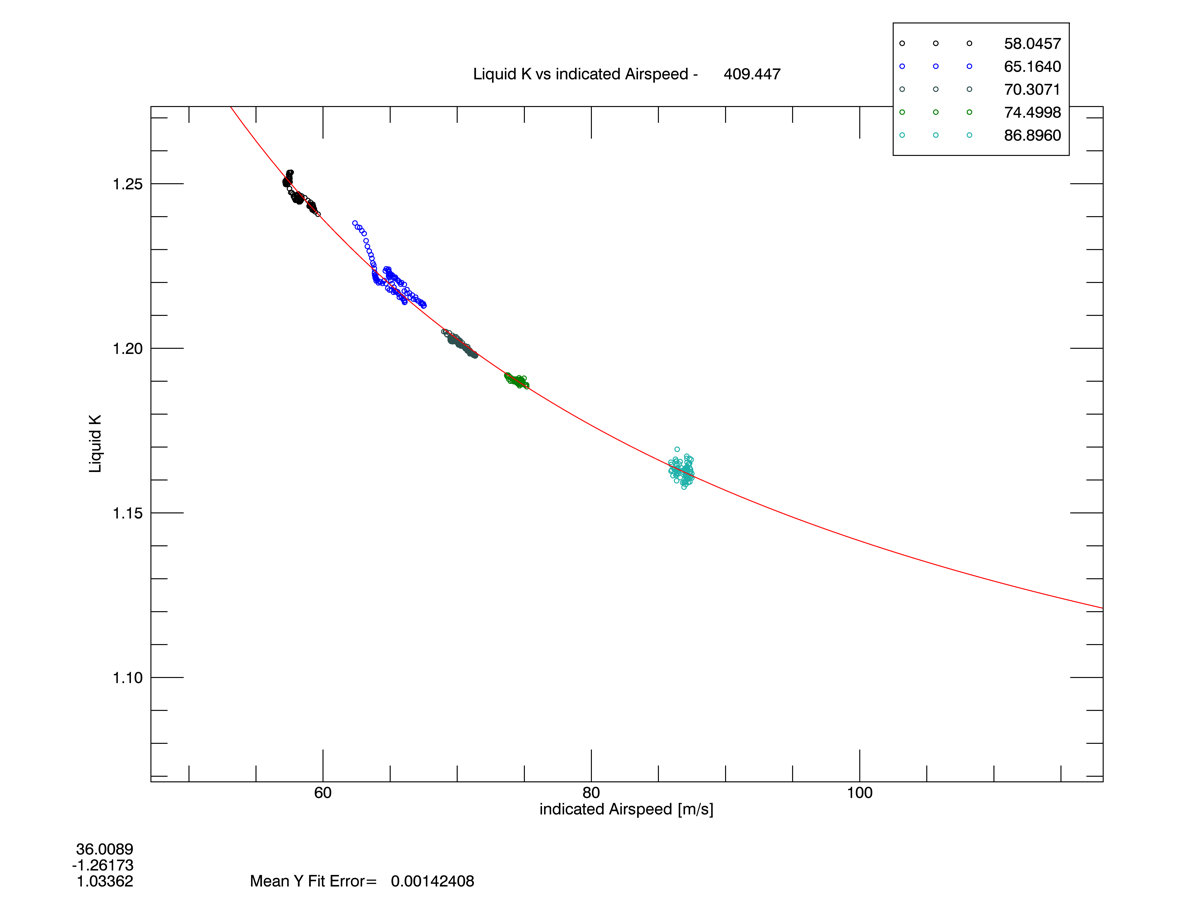
Clear air power coefficient (k) airspeed dependence was examined by calculating the ratio between power consumed by the liquid collector sensor and liquid reference sensor during a July 9, 2013 clear air calibration flight.

Three k value groups were selected from calibration legs flown at distinct flight levels (approximately 900 mb, 600 mb, and 400 mb) where each flight level contained five unique airspeed legs (ranging from approximately 60 to 100 m s-1 indicated airspeed). Care was taken to select sample points with minimal roll, yaw, pitch, and acceleration. k regression values were also calculated at the 900 mb, 600 mb, and 400 mb flight levels based upon true, instead of indicated airspeed.

A geometric fit of the form

was applied to each flight level group based on both true and indicated airspeed (totaling to six regression values). Figure 1 shows a typical k regression curve (this particular case was for the 400 mb level using indicated airspeeds).

**Figure 1 – Typical k airspeed dependence regression curve**



*Dry air heat loss coefficient (denoted as “Liquid K”) regression calculated from 07/09/2013 COPEMED 400 mb (409.447 mb actual mean flight level) calibration leg. Mean airspeed group airspeed values are shown in legend (units of m s-1). Values in lower-left corner are geometric fit coefficient values corresponding to a0 = 36.0089, a1 = -1.26173, and a2 = 1.03362 in the y = a0 xa1 + a2 form.*

**Clear Air Point Filtering**

The determination of out-of-cloud or “clear air” points is necessary for pressure-dependent drift corrections and algorithm diagnostics. Data were filtered on a per-flight basis to isolate clear air points using the following method. Firstly, relevant flight start and end times were selected manually, usually based upon times corresponding to Nevzorov power up and power down. Next the liquid sensor power ratio

provided a signal with discrete sections of low amplitude baseline oscillations and abrupt spikes indicative of signal events. Figure 2 shows an example of a typical liquid power ratio.

**Figure 2 – Typical Liquid Power Ratio Profile**



*Raw liquid power ratio for 07/27/13 COPEMED flight. Note contrast between periods of clear air flight and signal. The power ratio baseline is fairly consistent but to airspeed and pressure induced drift will need to be taken into account.*

The performance of each k regression was examined using COPEMED King Air flight data collected on 07/10/13, 07/25/13, 07/27/13, 07/28/13, 07/29/13, 08/03/13, 08/07/13, 08/14/13, and 08/15/13 including Nevzorov LWC values supplied by Alexei Korolev. k regression performance only considered points deemed to be in clear air, selected using the strong correlation between liquid collector voltages (vlwccol) and LWC value. The time step difference of liquid collector voltage (vlwccolt – vlwccolt+1) was employed to locate sharp voltage spikes typical of LWC signal events. A point was considered clear air if the point’s and the successive three points’ liquid collector voltage time step differences were all less than ±0.01 V s-1. Requiring four successive points to satisfy the ∆V threshold ensured points with small ∆V within clusters of LWC signal were not erroneously flagged as clear air. 77,244 of 97,077 total points met clear air criteria. The clear air point filter accuracy was confirmed using Nevzorov LWC values provided by Korolev (flight file variable = nevlwc1). Points flagged as clear air had a mean absolute LWC (based on Korolev’s calculations) of 0.00133 g m-3 and a standard deviation equal to 0.001892 g m-3.

LWC calculations were carried out for clear air points from all flights using each of the six k airspeed regression values. k regression performance was judged based upon LWC mean absolute error (where error for clear air points is considered to be equal to LWC value), LWC error standard deviation, and LWC error airspeed correlation estimates (based upon linear fits of LWC error with respect to airspeed). The 400 mb indicated airspeed k regression (mean absolute error = 0.00878 g m-3, standard deviation = 0.0118 g m-3, and airspeed dependence = 0.00557 g m-3 10 m s-1) showed the best performance. Figure 2 illustrates mean absolute LWC error of all 6 k airspeed dependence regressions.

**Figure 2 – All Flights k Airspeed Regression Performance**

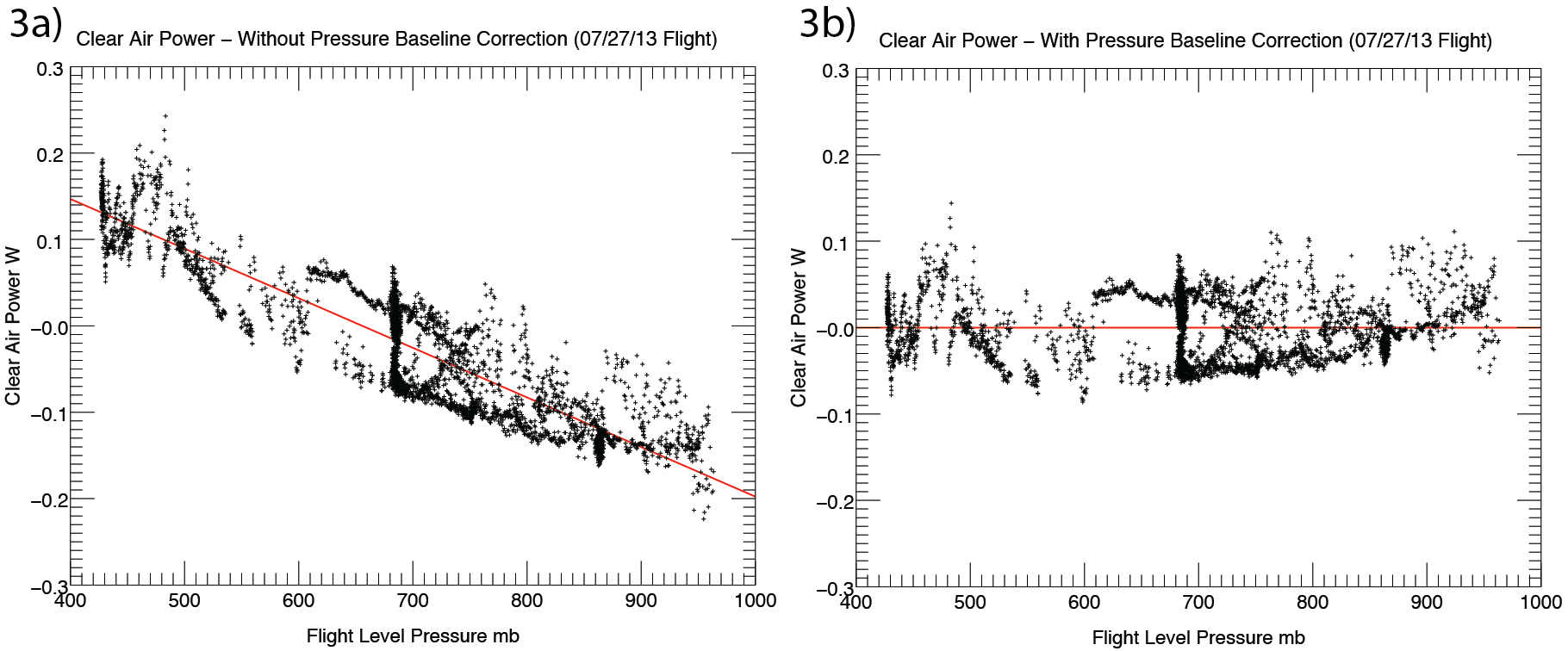
INSERT BASELINE.PS

*k Regression performance based upon clear air mean LWC absolute error (where LWC error is equal to LWC value for clear air points) calculated for* 07/10/13, 07/25/13, 07/27/13, 07/28/13, 07/29/13, 08/03/13, 08/07/13, 08/14/13, and 08/15/13 COPEMED flights. Note – “Ind” in x-axis labels signifies k regressions calculated with indicated airspeed and “True” signifies regression calculated with true airspeeds.

**LWC Error Due to Flight Level Pressure Fluctuation**

Nevzorov kliq values (and ultimately LWC values) are also affected by flight level environmental pressure fluctuations. Typical pressure-related clear air LWC error during COPEMED13 flights is approximately 2.11x10-3 g m-3 / 20 mb. A baseline correction was applied to post airspeed-corrected clear air kliq values on a per-flight basis for all nine afore-mentioned flight days. Value of applied baseline shift was calculated with a linear regression fit to kliq values deemed to be clear air points. Figures 3a and 3b show typical clear air kliq values both before and after pressure-dependent baseline correction application.

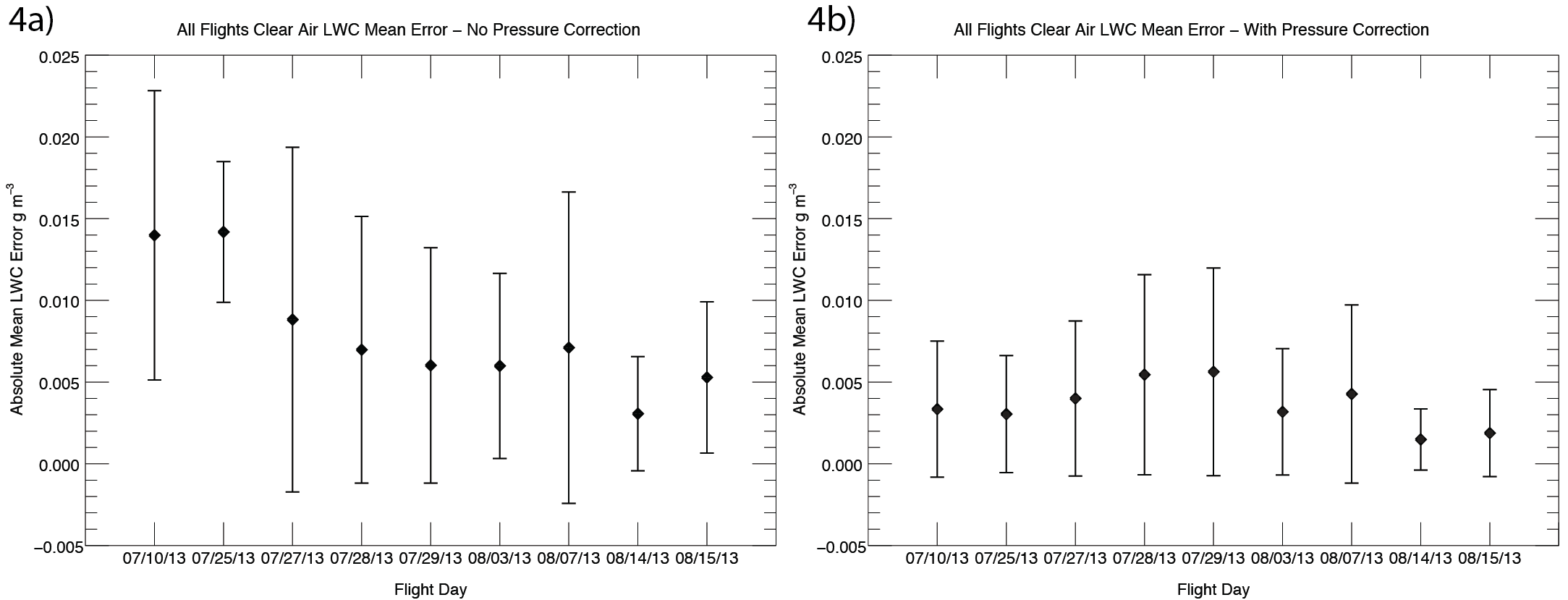
**Figure 3 – Pressure-Related Clear Air LWC Error For Flight 07/27/13, Before and After Baseline Correction**



*Typical clear air pressure dependent LWC error before (figure 3a) and after (figure 3b) baseline correction. This particular kliq baseline correction decreased mean absolute clear air LWC error from 0.008824 g m-3 to 0.003997 g m-3 where error is considered LWC for clear air points.*

The baseline *kliq* correction procedure performed well for all nine COPEMED13 flights. Clear air LWC error means and standard deviations were all reduced significantly. Figure 4 shows clear air LWC means and standard deviation for all flights both before and after baseline corrections application.

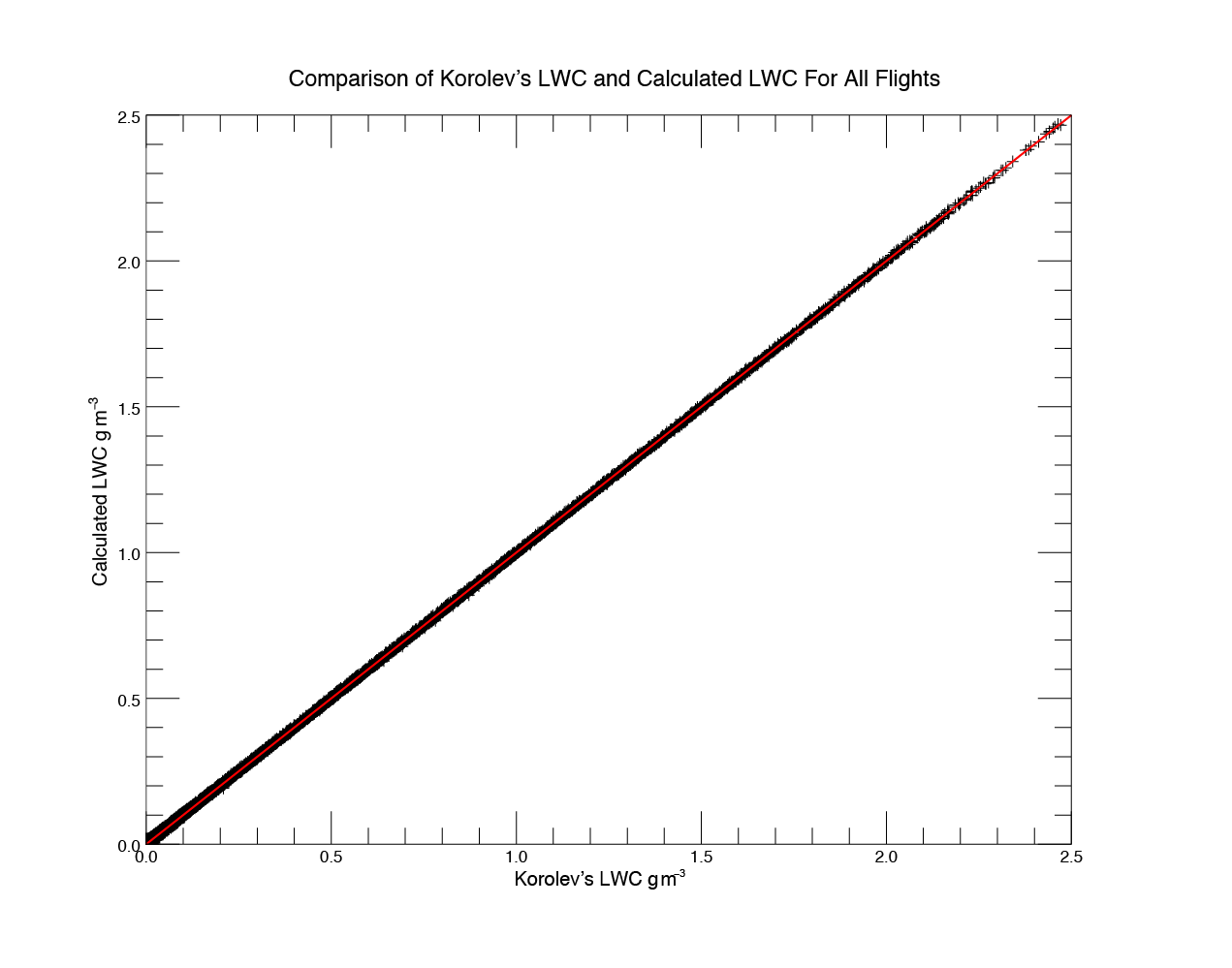
**Figure 4 – Pressure-Related Clear Air LWC Error For All Flights, Before and After Baseline Correction**

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*Clear air pressure dependent LWC error absolute mean and standard deviation both before (figure 4a) and after (figure 4b) baseline correction.*

**LWC Calculation Verification**

**Figure 5 – Comparison of Korolev’s LWC and Calculated LWC For All COPEMED Flights**

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*Direct comparison of Korolev’s LWC and Calculated LWC values.*