ICICLE 2019 Data Guide: Atmospheric and Aircraft States

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ABBREVIATION LIST

NRC: National Research Council

ECCC: Environment and Climate Change Canada

FRL: Flight Research Lab

IMU: Inertial Measurement Unit

DGPS: Differential Global Positioning System

GNSS: Global Navigation Satellite System

SCADS: Simultaneous Calibration of Airdata Systems

PEC: Position Error Correction

TAT: Total Air Temperature

TAS: True Airspeed

MSO: Magnetostrictive Oscillator

1.0 EXECUTIVE SUMMARY

This document accompanies the uploaded atmospheric and aircraft states dataset collected during the ICICLE (In-Cloud Icing and Large-Drop Experiment) flight campaign (January – March 2019) onboard NRC's Convair-580 aircraft and during additional test and transfer flights.

This document provides basic information about the sensors and brief notes on data processing and data structure and quality that can aid in use of the data. In Section 2, general campaign information is provided. This is followed by Section 3, where a listing of the instrumentation included in this dataset is provided. Next in Section 4, the quality of all the enclosed parameters is discussed as well as processing methodology applied to these data. The document concludes with discussions on the process of data quality assurance in Section 5.

2.0 DATASET OVERVIEW

2.1 Introduction

2.2 Spatio-Temporal Information

Flight Time Period: January 18 2019 to March 08 2019

Total Number of Flights: 30

Flight Campaign Regions: Southern Ontario Canada, North-Eastern USA

2.3 Dataset Source and Contact Information

Preparation Agency: National Research Council of Canada (NRC)

Agency Subdivision: Aerospace Research Center (ARC), Flight Research Laboratory (FRL)

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3.0 INSTRUMENTATION DESCRIPTION

In this section, we list the instruments and their location on NRC's Convair-580 aircraft for the duration of the flights period (Sect. 2.2). The NRC Convair-580 served as a sole sampling aircraft for the ICICLE project (other complementary measurements were taken from ground, meteorological balloons, satellite and modeling products are not described in this document and can be found in separate datasets in the archive). The Convair-580 is a twin-engine, pressurized aircraft, capable of long-distance operation, carrying up to a dozen research crew members and a wide array of robust instrumentation for environmental in-situ measurements and remote sensing. For ICICLE, the Convair-580 was equipped by NRC and ECCC (Canadian governmental departments) with extensive in-situ and remote sensing instruments (Figure 1), including redundant duplication of measurements in numerous cases. The sensors were installed in various sections of the aircraft, including on pylons located under wing and at the wing tip, on various sections of the fuselage, and inside the aircraft cabin with sampling inlets.

Figure 1 – A diagram of the Convair 580C instrumentation for the ICICLE campaign

In Figure 2, a frontal view of the NRC Convair is shown with labeled locations indicating placement of instrumentation. The subsequent Table 1 provides a list of all the atmospheric and aircraft state instruments, and their location on the aircraft exterior.

This is followed by a diagram of the NRC Convair cabin interior seen in Figure 3, and an accompanying list of instruments housed internally in the aircraft cabin (Table 2).

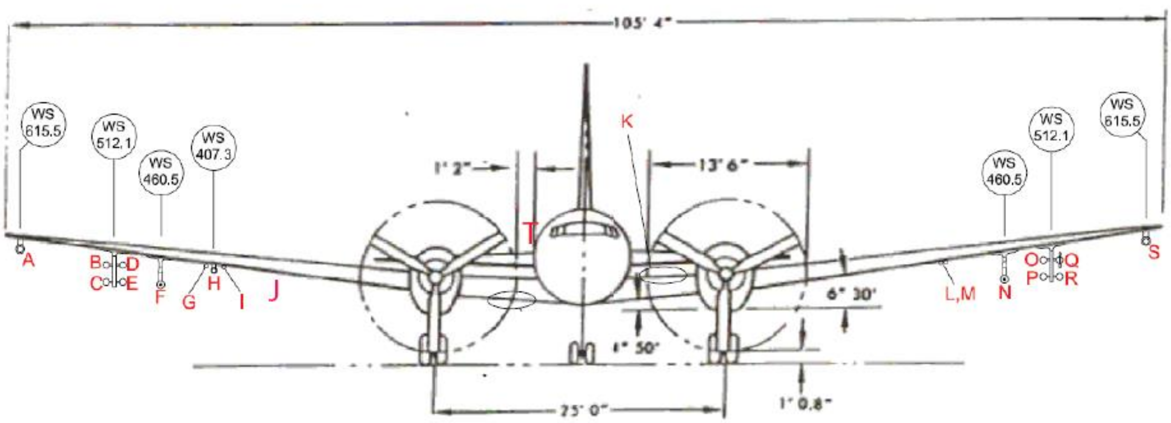


Figure 2. A diagram of the NRC Convair with instrumentation locations labeled.

Table 1. List of atmospheric state sensors and their location on the aircraft.

Figure Label	Instrument	Location
A	*AIMMS-20*	*Starboard Wingtip (SWT)*
C	*Rosemount 858 Airdata Probe (ADP)*	*Starboard Outboard Lower (SOL)*
D	*ECCC Rosemount Icing Detector*	*Starboard Inboard Upper (SIU)*
H	*Rosemount Pitot Tube*	*Starboard Scalar Boom (SSB)*
H	*Rosemount 102 TAT Probe*	*Starboard Scalar Boom (SSB)*
J	*NRC Goodrich Icing Detector 1*	*Starboard Underwing (SUW)*
L	*Rosemount 102 TAT Probe*	*Port Underwing (PUW)*
M	*ECCC Reverse Flow TAT Probe*	*Port Underwing (PUW)*
M	*Rosemount 102 TAT Probe*	*Port Scalar Boom (PSB)*
M	*Rosemount 105 TAT Probe*	*Port Scalar Boom (PSB)*
M	*Aeroprobe 5-Hole ADP*	*Port Scalar Boom (PSB)*
T	*Honeywell PPT2 Pressure Transducer (HGPPT2)*	*Starboard Fuselage (SF)*

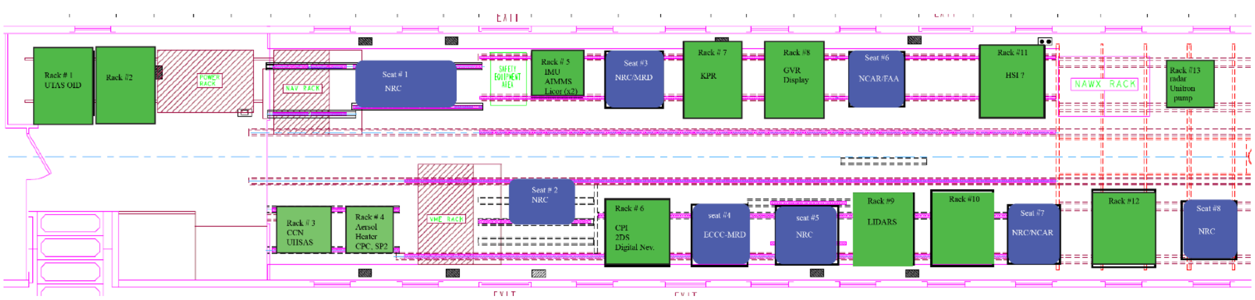


Figure 3. A schematic of the NRC cabin layout during ICICLE.

Table 2. List of instruments housed internally in the aircraft cabin

Instrument	Location
Licor 840a Gas Analyzer	*Cabin*
Licor 7000 Gas Analyzer	*Cabin*
Edgetech Chilled Mirror Hygrometer	*Cabin*
Novatel Flexpak6 GNSS Receiver	*Cabin*
Honeywell Model 1700 IMU	*Cabin*
KVH 1750 IMU	*Cabin*

4.0 PARAMETER LISTING

In this section, we list all the categorized parameters (Tables 3 – 16). In addition, the recommended priority of usage (primary, secondary, tertiary, quaternary) is provided. That is, for each parameter, there is always a ***primary source*** to use, which is the most reliable source for a parameter. Using the wind data as an example, the highest quality data was computed using air data collected from the Rosemount 858 five-hole pressure probe. The second-best source for wind data is the AIMMS-20, and the third-best source is the Aeroprobe. As a final comment, in some situations, different parameters will have an identical quality and are listed as equivalent in measurement reliability. As an example, sources for some parameters are both listed as "secondary" in reliability because the two sources match too closely to be separated in terms of quality.

In addition to the priority list, a summary of the data quality and additional comments are provided for each class of parameters. Finally, we provide relevant technical details regarding the calculations used to derive these parameters.

In the dataset file, the parameters all follow a general naming convention with some exceptions. The parameter naming convention is as follows:

PARAMETERNAME_PROBE-[LOCATION1-2]_[PROBENAMES1-2]_[MODELNUMBERS].

The location, probe name and model are optional parameters that are included when there is redundancy in the measurements and need to show sources of computed parameters.

4.1 Aircraft State

4.1.1 Position

Table 3. Aircraft positioning sensors list.

Instrument Name	*Position*	*Reliability Level*
KVH 1750 IMU	*Cabin*	*Primary*
HG 1700 IMU	*Cabin*	*Secondary*
Novatel Flexpak6 GNSS Receiver	*Cabin*	*Tertiary*
AIMMS20	*SWT*	*Quaternary*

The aircraft position consists of **Latitude (degrees North), Longitude (degrees East)** and **Altitude (m).**

4.1.2 Velocities

Table 4. Aircraft velocity sensor list.

Instrument Name	*Position*	*Reliability Level*
KVH 1750 IMU	*Cabin*	*Primary*
HG 1700 IMU	*Cabin*	*Secondary*
Novatel Flexpak6 GNSS Receiver	*Cabin*	*Tertiary*
AIMMS20	*SWT*	*Quaternary*

The aircraft velocities consist of **Ground Speed**, **North-South Velocity**, **East-West Velocity**, and **Vertical Velocity**. These quantities are all in units of m s^{-1}. Please note the orientation of velocity vectors. The forward nose direction is x-positive, the starboard wind direction is y-positive, and the *downward ground-pointing* direction is z-positive. This sets up the orientation for roll, pitch and heading as well.

4.1.3 Orientation

Table 5. Aircraft orientation sensor.

Instrument Name	*Position*	*Reliability Level*
HG 1700 IMU	*Cabin*	*Secondary*

The aircraft orientation consists of **Heading**, **Roll**, **Pitch** and the associated **Angular Velocities**. Additionally, **Aircraft Track** is provided as well.

4.1.4 Aircraft State Data Processing Details

The aircraft position is initially recorded in real-time from the GPS receivers onboard the aircraft. It is combined with Inertial Measurement Unit (IMU) information via a Kalman Filter to improve the accuracy of both the aircraft state and position estimates. The AIMMS20, HG1700 and KVH1750 IMU data have all been Kalman Filtered with GNSS data in *real-time.* This entails combining high-rate (100Hz for HG1700 and KVH1750) GNSS and IMU signals while the aircraft is flying. However, greater accuracy can be obtained on the aircraft state by using the recorded raw data and *post-processing* it. Thus, a subset of the data is also post-processed for the maximum degree of accuracy.

In order to increase the precision of the aircraft positioning down to the sub-meter level, the raw GNSS data was post-processed using Differential GPS (DGPS) post-processing. The KVH1750 IMU raw data with input of the DGPS post-processed data were post-processed using Kalman Filtering. This post-processed GPS and IMU data included in this data release has much better precision than the real time computed values that were disseminated during the field campaign and also included in the preliminary data set that was released after the campaign.

Three other aircraft state/position sources are also included as part of the aircraft and atmospheric state dataset. These are the post-processed Novatel Flexpack GPS data with no Kalman Filtering, the AIMMS20 aircraft state data, and the Honeywell 1700 IMU aircraft state/position. The HG1700 and AIMMS20 are real-time processed.

In terms of final accuracy results, the graphs in Figure 4 show positioning accuracy. Real-time positioning results in an agreement within 1 – 4 meters, while with post-processing, this inaccuracy is reduced to 0.01 – 0.3 meters. Please note, this is a comparison between two *post-processed* datasets, showing the extent of accuracy for post-processed data only. This excellent agreement will of course not be found between real-time and post-processed data. However, it demonstrates the range of accuracy for the post-processed data whenever it is present in the dataset.

Figure 4 - Demonstration of agreement between the KVH and HG IMUs before (top) and after post-processing (bottom).

4.1.5 Summary of Aircraft State Data Products

- For the most precise aircraft positioning, down to a sub-metre precision, the post-processed KVH data should be used. Nonetheless, aircraft positioning data from the other two sources are available with acceptable accuracy and can also be used.
- The AIMMS data is available for the aircraft state but should be used with higher scrutiny and only in comparison with the KVH and HG IMUs.

- For some flights, the post-processed KVH data is unfortunately not available. These are **F10**, **F17**, **F23**, **F24**, **F28**, **F29** and **F31**. This is also indicated in the “dependencies” field of the variable attributes in the data file.
- The aircraft roll/pitch/heading is precise down to a sub-degree level for the HG and KVH. The AIMMS is not as robust and the data is included only for completeness.

4.2 Pressures and Airflow Angles

Static Air Pressure

The Static Pressure is estimated from multiple pressure transducers that are installed at various locations on the aircraft (Table 6).

Table 6. Aircraft static air pressure sensors.

Instrument Name	*Position*	*Reliability Level*
Honeywell PPT2	*SF*	*Primary*
Rosemount 858	*SOL*	*Secondary*
Rosemount Pitot	*SSB*	*Secondary*
AIMMS20	*SWT*	*Tertiary*
Aeroprobe	*PSB*	*Quaternary*

Dynamic Air Pressure

The NRC Convair was equipped with multiple sensors for measuring the Dynamic Pressure (Table 7).

Table 7. Aircraft dynamic air pressure sensors.

Instrument Name	*Position*	*Reliability Level*
Honeywell PPT2	*SF*	*Primary*
Rosemount 858	*SOL*	*Secondary*
Rosemount Pitot	*SSB*	*Secondary*
Aeroprobe	*PSB*	*Quaternary*

Angle of Attack and Sideslip

The angles of attack and sideslip care calculated from the Convair three independent 5-hole gust probes (Table 8).

Table 8. Aircraft angle of attack and sideslip sensors.

Instrument Name	*Position*	*Reliability Level*
Rosemount 858	*SOL*	*Primary*
AIMMS20	*SWT*	*Secondary*
Aeroprobe	*PSB*	*Tertiary*

4.2.1 Advanced Processing of Pressure and Airflow Angle Data

The pressure parameters comprise of the static pressure P_s, the dynamic pressure P_d, the angle of attack α and the angle of sideslip β. The pressure parameters are simultaneously calibrated in-flight by an NRC-developed technique referred to as SCADS (Simultaneous Calibration of Air Data Systems) [1]. This technique removes the position dependence (or position error) of pressure measurements, thus ensuring that dynamic and static pressures measured at different locations on the aircraft (i.e. wing vs. fuselage), both measure the true static and dynamic pressures. The position error correction for pressures is then used to calibrate the measurements of sideslip and attack angles. This correction is generally only applicable for airflow angles under 10 degrees. At higher degrees, the correction is not as robust.

Figure 5 below shows plots of corrected and uncorrected pressure and airflow angle. As can be seen, the corrected pressures all correlate extremely well with each other. For airflow angle, this correction is more challenging, but even so the agreement is significantly improved.

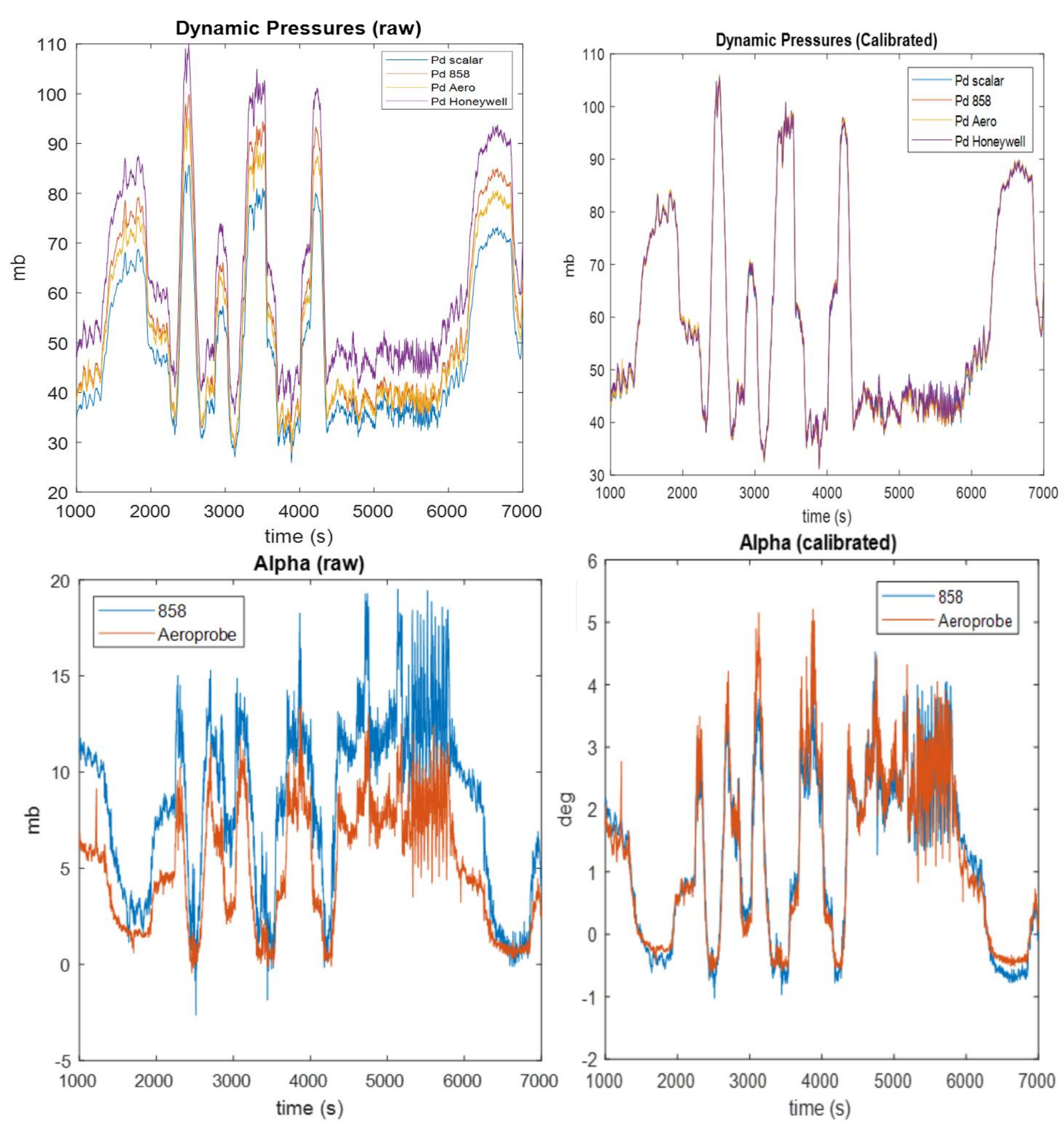


Figure 5. An example of pressure and airflow angle correction using the SCADS calibration technique.

4.2.2 Summary of Pressure and Airflow Angle Data Products

- In this release, there are numerous sources of both pressure and airflow angles. For dynamic and static pressure, this amounts to five independent sources, and three independent sources for the airflow angles.
- While all the sources are reliable, except in instances where they are flagged, there is a hierarchy in terms of accuracy.
- The most reliable sources for dynamic and static pressures will come from the HG fuselage transducer. For airflow angles, the most reliable source is the Rosemount 0858 probe.
- The AIMMS20 is also highly reliable for any uses. The best use of the data for airflow angles will come as a combination of the two. In terms of priority, the Rosemount takes precedence. However, the AIMMS is very useful as a second source, and can be used to validate Rosemount data.

4.3 Temperatures

Total Air Temperature

The total air temperature (TAT) is the maximum air temperature that can be attained by 100 % conversion of the kinetic energy of the flight. The NRC Convair was equipped with 4 Rosemount TAT Probes and an ECCC Reverse Flow Temperature Probe at different underwing locations during ICICLE (Table 9).

Table 9. Total air temperature sensors.

Instrument Name	*Position*	*Reliability Level*
Rosemount 102	*PUW*	*Primary*
Rosemount 102	*SSB*	*Secondary*
Rosemount 102	*PSB*	*Tertiary*
Rosemount 105	*PSB*	*Quaternary*
Reverse Flow TAT Probe	*PUW*	*Not assessed*

Static Air Temperature

The static air temperature is the temperature of the undisturbed air estimated from the TAT probes.

Table 10. Static air temperature sensors.

Instrument Name	Position	Reliability Level
Rosemount 102	*PUW*	*Primary*
Rosemount 102	*SSB*	*Secondary*
Rosemount 102	*PSB*	*Tertiary*
Rosemount 105	*PSB*	*Quaternary*
AIMMS20	*SWT*	*Quaternary*
Reverse Flow TAT Probe	*PUW*	*Not assessed*

4.3.1 Summary of Temperature Data Products

- The static temperature data is highly consistent and reliable. The highest quality data were acquired at the PUW location, followed closely by the SSB source (Table 1). The plot in Figure 6 shows an example of the total air temperature and recovery-corrected static air temperature, depicting the agreement to be expected in data analysis.
- The AIMMS20 generally has a -1 ^{o}C bias compared to the other probes. This bias varies from flight to flight, and as a result, processing will need to be done on a flight-by-flight basis if AIMMS20 static temperature data is to be used. As a result, no offset and scaling has been applied on the AIMMS20 temperature. Thus, this will need to be done on an individual basis by the end user.
- The Rosemount 105 probe is a newer model which requires revisions in calibration and recovery corrections. This may be seen in Figure 6, where an offset and minor nonlinearity may be seen in the Rosemount 105 temperature. Thus, it should be used only qualitatively.

- The reverse flow probe data processing from the NRC is still preliminary, and its use should be held off until a more revised dataset is provided.

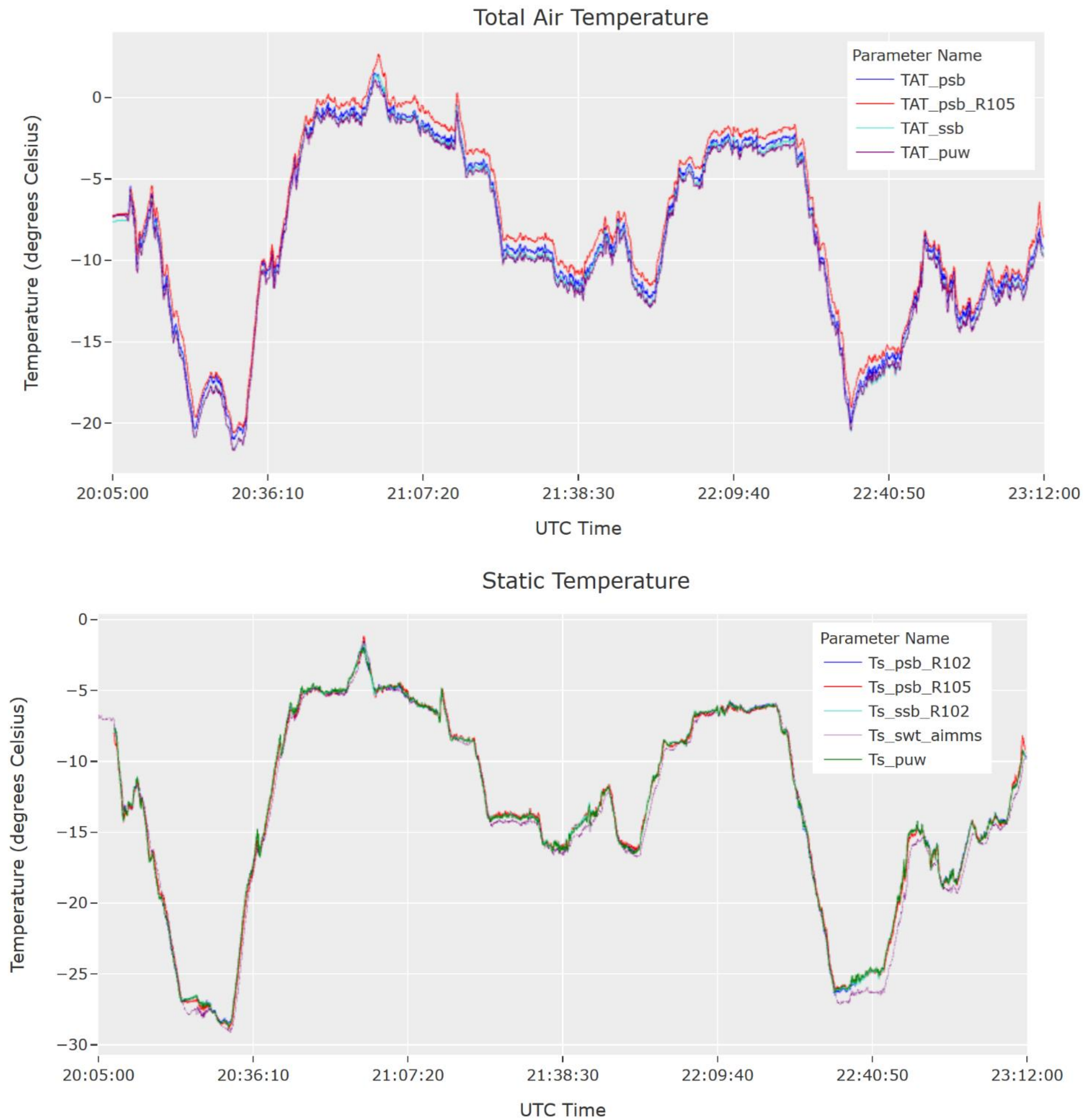


Figure 6. The recovery correction of total air temperature (top), and subsequent agreement of static air temperature (bottom).

4.3.2 Temperature Data Processing Details

The temperatures are taken as a total air temperature from a probe. The air temperature measurements have a Mach Number dependency, which is removed via a recovery factor correction. With the recovery factor correction, we obtain the static air temperature.

Given a Mach Number M, the recovery correction ν is calculated as:

$$\nu = C_0 + C_1 \cdot M + C_2 \cdot M^2 + C_3 \cdot M^3 \qquad \text{(Eq. 1)}$$

Where the constants $C_0 \ldots C_3$ are manufacturer-provided calibration constants.

Then the recovery factor is calculated as:

$$r = 1 - \nu \cdot \left(1 + \frac{2}{(\gamma - 1) \cdot M^2}\right) \qquad \text{(Eq. 2)}$$

where $\gamma = 1.4$ is the isentropic expansion factor. This leads to the final calculation of static temperature:

$$T_s = \frac{TAT}{1 + \left(\frac{\gamma - 1}{2}\right) \cdot r \cdot M^2} \qquad \text{(Eq. 3)}$$

4.4 True Airspeed

The true airspeed (TAS) is the speed of the aircraft relative to the air in which the aircraft is flying. Table 11 list the basic pressure probe used in calculating the TAS.

Table 11. True air speed sensors.

Instrument Name	Position	Reliability Level
Honeywell PPT2	*SF*	*Primary*
Rosemount 858	*SOL*	*Secondary*
Rosemount Pitot	*SSB*	*Secondary*
AIMMS20	*SWT*	*Tertiary*
Aeroprobe	*PSB*	*Quaternary*

4.4.1 Summary of True Airspeed Data Products

- The TAS is all highly consistent, and generally the SF and SOL are the best sources.
- The AIMMS reading of TAS is reliable, but due to a slight bias in static temperature (see Section 4.3.1.), the TAS is also biased.
- The PSB TAS should be used primarily for qualitative analysis. However, unless flagged, the data can still be used if necessary.

4.4.2 True Airspeed

True airspeed is calculated from the pressure measurements, temperature and humidity [1].

The expression for TAS in this dataset is:

$$TAS = \sqrt{7.0 \cdot R_{gas} \cdot T_s \cdot \left(1 - \frac{P_s}{P_s + P_d}\right)^{\frac{2}{7}}} \qquad \text{(Eq. 4)}$$

Where R_{gas} is the gas constant, and P_s, P_d are the static and dynamic pressures respectively.

4.5 Winds

Winds

The 3D winds (Vertical Wind, Horizontal Wind Speed and Horizontal Wind Direction) are calculated from five-hole gust/Air Data probes and the IMU measurements. During the ICICLE campaign, the NRC Convair had three independent gust probes installed at various location under wing and wing tip (Table 12). The dataset also includes the north-south and east-west components which are used to calculate the horizontal wind and direction and speed.

Table 12. NRC Convair gust probes.

Instrument Name	*Position*	*Reliability Level*
Rosemount 858	*SOL*	*Primary*
AIMMS20	*SWT*	*Secondary*
Aeroprobe	*PSB*	*Tertiary*

4.5.1 Summary of Winds Data Products

- The most reliable source for all winds is the Rosemount SOL winds. This should be the first source to be used unless otherwise indicated by flagging.
- The AIMMS winds are also reliable, and almost on par with the Rosemount.
- The Aeroprobe had numerous issues during the flight campaign time period, and thus should be used with high scrutiny. Even though unusable data is flagged, Aeroprobe wind data should only be used in the limited cases where the much higher quality wind data from the AIMMS and Rosemount are unavailable. This is only the case for 2-3 flights.

In spite of a dedicated calibration flight to remove biases due to flow distortion caused by sensor location, the data for some flights had some small (<+-0.5 m/s) bias in the vertical wind. Those biases were removed and are also indicated in the "comments" field of the vertical wind variable attributes.

4.5.2 Winds Data Processing Details

For a full detailing of the wind processing method, please consult [1]. The process for deriving winds essentially boils down to getting the aircraft-relative velocities u, v, w followed by a lever arm correction to transform them to the aircraft center of gravity. Finally, an Euler angle transformation is applied to get the airspeed velocity to an Earth-relative frame. Then the airspeed velocities and ground velocities are subtracted to finally obtain wind measurements.

4.6 Atmospheric Gas

H_2O and CO_2 Concentrations

Table 13. Water vapor and carbon dioxide measuring instruments.

Instrument Name	*Position*	*Reliability Level*
Licor 840a	*Cabin*	*Primary*
Licor 7000	*Cabin*	*Secondary*

4.6.1 Dew Point and Frost Point

Table 14. Dew/Frost point measuring instruments.

Instrument Name	*Position*	*Reliability Level*
Licor 840a	*Cabin*	*Primary*
Licor 7000	*Cabin*	*Secondary*
Edgetech Chilled Mirror Hygrometer	*Cabin*	*Tertiary*

4.6.2 Relative Humidity with respect to Water and Ice

Table 15. RH instruments.

Instrument Name	*Position*	*Reliability Level*
Licor 840a	*Cabin*	*Primary*
Licor 7000	*Cabin*	*Secondary*
Edgetech Chilled Mirror Hygrometer	*Cabin*	*Tertiary*
AIMMS20	*SWT*	*Quaternary*

4.6.3 Summary of Atmospheric Gas Phase Data Products

- Figure 7 below demonstrates an analysis of **F14** flight included in the dataset. Top plot shows the measured H_2O and CO_2 concentrations (Fig. 6a). These concentrations are then used to derive the dew and frost points, seen in the succeeding plots (Fig. 6 b,c). In the frost and dew point figures the static air temperature is also provided for comparison. The ice water content and liquid water content (IWC, LWC) measurements are provided in the final plot for reference (Fig. 6e).
- As can be seen, the dew point from the Licor 840 and 7000 and the chilled mirror hygrometer agree quite well. Keep in mind however, that this is not always the case.
- The agreement between relative humidity calculations and the dew/frost point may also be observed (Fig. 6 b,c,d). During periods where the static air temperature is above the frost and dew point, relative humidity drops along with IWC and TWC. Additionally, during periods where the static air temperature drops below the frost or dew point, we observe saturation in the relative humidity.
- The in-flight Licor calibration cycle may also be seen in this figure. You can observe a drop-off to zero concentration during the calibration cycle, occurring due to the flushing of NO_2 into the Licor cells [2]. This may be used as a 'figure of merit' for gauging the reliability of water concentration measurements.
- The atmospheric gas measurements and derived quantities are included without including a flag. Users are encouraged to scrutinize the data by comparing other complimentary measurements such as static temperature and cloud phase.

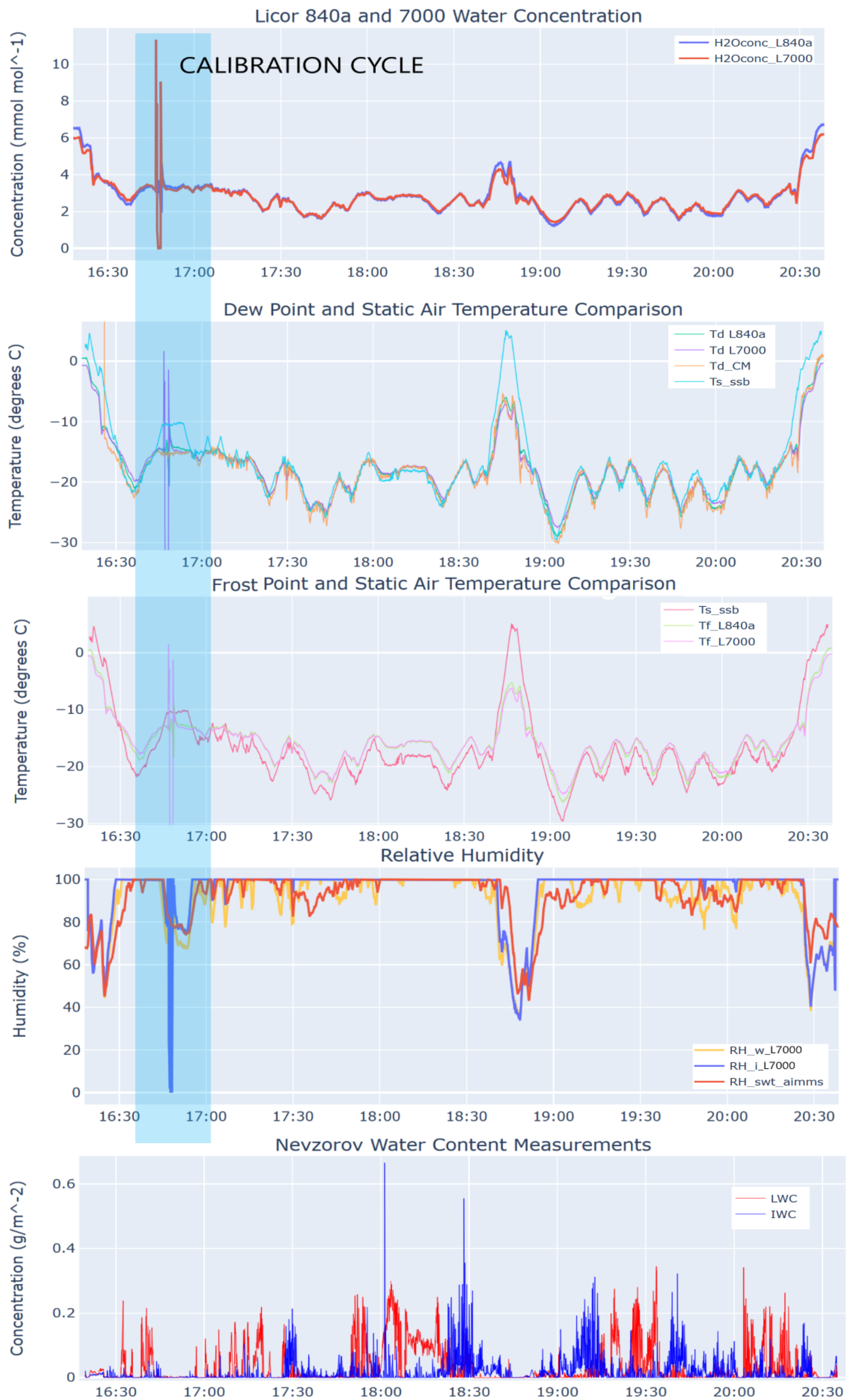


Figure 7. A Cross-Comparison of Water Concentration, Water Content, T_d, T_s and Humidity.

4.6.4 Atmospheric Gas Processing Details

Concentrations

The initial processing begins by obtaining the H_2O and CO_2 concentrations, which is described in detail in the LICOR 7000 and Licor 840a operating manuals [2]. For each flight, calibration cycles are performed in order to ensure the concentration is properly measured. This involves "zeroing" the concentration measurements by flushing the Licor cells with NO_2, and ensuring the instruments measure zero concentration of H_2O or CO_2. In the case where the calibration cycle demonstrates a static offset (i.e. the Licor measures 5 ppm even with only NO_2 present and no H_2O), this is used to recalculate all the water-related atmospheric quantities by adding or removing this offset. This period is blue-shaded in Figure 7 and labeled as a calibration cycle.

Dew Points

With proper H_2O concentration, the dew point is calculated by both Licor instruments. The Licor 840a calculates it automatically in flight. For the Licor 7000, this is done during data processing step. This step is described in the operating manual [2]:

$$z = \ln\left(\frac{P_w}{0.61365}\right) \rightarrow T_d = 240.97 \cdot \frac{z}{17.502 - z} \qquad \text{(Eq. 5)}$$

Where P_w is the partial pressure of water in kPa.

Frost Point

The frost point is derived from [3], calculated as:

$$T_f = \frac{1.814625 \cdot \ln(P_w) + 6190.134}{29.12 - \ln(P_w)}; \quad T > 115K$$

where P_w is the ambient partial pressure of water, calculated from the Licor water concentration.

Relative Humidity with respect to Ice and Water

In order to calculate relative humidity, the vapor pressure over water P_{v_w} and saturation vapor pressure $P_{w_{sat}}$ are calculated using expressions for vapor pressure derived from [3]. Then, the relative humidity over water is simply calculated as a ratio: $H_w = 100 \times \frac{P_{v_w}(T_d)}{P_{w_{sat}}}$. Likewise, the relative humidity over ice is calculated as $RH_i = 100 \times \frac{P_{v_i}(T_f)}{P_{i_{sat}}}$.

4.7 Icing

4.7.1 MSO Frequency

During ICICLE, the NRC Convair was equipped with three Rosemount/Goodrich Icing Detector (Table 16). The MSO Frequency parameter from the two NRC sensors are included in this dataset.

Table 16. Icing detectors list.

Instrument Name	*Position*	*Reliability Level*
Rosemount 0871ND5FT Icing Detector	*SUW*	*Primary*
Rosemount 0871LM5 Icing Detector	*PUW*	*Secondary*
Rosemount 0871ND5FT Icing Detector	*SIL*	*Not included*

4.7.2 Summary of Icing Detector Data Products

No processing was applied to the icing detector data and it is provided “as-is”. Changes in MSO frequency may be used to qualitatively identify icing periods.

4.7.3 Icing Detector Data Processing Details

The icing detector data is not processed beyond the data acquisition stage.

5.0 DATA COLLECTION AND PROCESSING

5.1 Description of data collection

The data described in this document are all collected through a real-time *Data Acquisition System (DAS)*. In this case, it was collected by a custom-made DAS designed at the FRL. Transmitted packets are all collected into one file and then preprocessed before moving on to derivation of parameters. Below are the steps taken to arrive at data that is uniformly spaced in time and free of time anomalies.

1. **Conversion to NetCDF:** The data is converted to NetCDF from the raw network packets recorded on the DAS
2. **Time Anomaly Correction:** Timing errors may sometimes arise. This includes issues of timing resets, a midnight transition from 11:59:59PM to 12:00:00AM and more
3. **Resampling:** The time spacing of all parameters is made uniform. This entails interpolation to make the time spacing intervals equal for the whole time series. Resampling in this case is resolved to 1 Hz.

5.2 Description of Quality Assurance and Control Procedures

In addition to ensuring that each parameter is well optimized for reliability, the data has also been thoroughly flagged for any problematic sections. There are two places to look for flagging information. First, there is a flagging variable for every parameter, which is named as the same variable it provides flagging information for, but with the **FLAG** suffix added. In this variable, every data point has an associated flag value indicating how usable it is. Additionally, the **data_quality** attribute provided for each variable gives a more qualitative assessment of the data. Finally, an attribute containing relevant comments is also provided when applicable.

There are six flags provided in this dataset, described below.

5.2.1 GOOD

The data is usable for quantitative analysis and sufficiently accurate.

5.2.2 CALIBRATION_CYCLE

The sensor is undergoing a calibration cycle. Not usable for calculations except for analyzing calibration accuracy. The primary use of this flag is for the Licor sensors (shown in Figure 7 where a calibration cycle is highlighted), which can be checked for accuracy by looking at these flight segments. Please note however, that the Licors are not flagged for this release. However, the highlighted plot section is the kind of event that the CALIBRATION_CYCLE flag is meant to highlight.

5.2.3 MINOR_ISSUE

Data has a minor issue present, meaning it will reduce the accuracy of data wherever this flag is present. However, the effect is minimal, and therefore the data might still be usable.

An example of this may be seen below, where the AIMMS has a slight offset of 1 degree in Static Temperature. It may still be used and even possibly corrected, but if left as-is, it will add some inaccuracy to calculations, e.g. calculations of TAS.

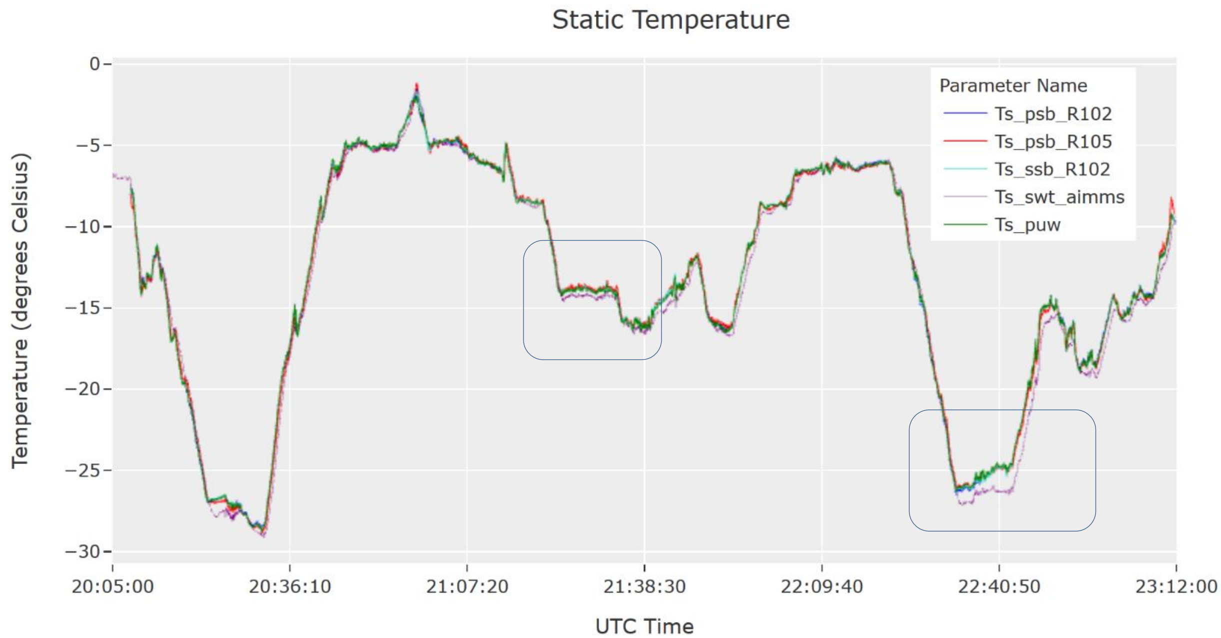


Figure 8. An example of static temperature minor-issue flagging case for AIMMS-20.

5.2.4 MAJOR_ISSUE

The accuracy of the data is very questionable. It might still be usable qualitatively, but any quantitative analysis should not include this data. An example of this may be seen in the vertical velocity data from F13 (Figure 9), where the measurement from the AIMMS probe started to deviate from the other two measurement starting ~185350 hence it is flagged 'major issue' in the segments where it deviates from the other two independent measurement.

Figure 9: An example of the MAJOR_ISSUE section, where the vertical wind data from the aimms probe (blue) is flagged as Major_Issue after ~18:53:50.

5.2.5 UNUSABLE

The data is unusable for any analysis. An example is provided below, where the Aeroprobe-derived wind measurements are unusable for any analysis, even qualitatively, and cannot be systematically corrected.

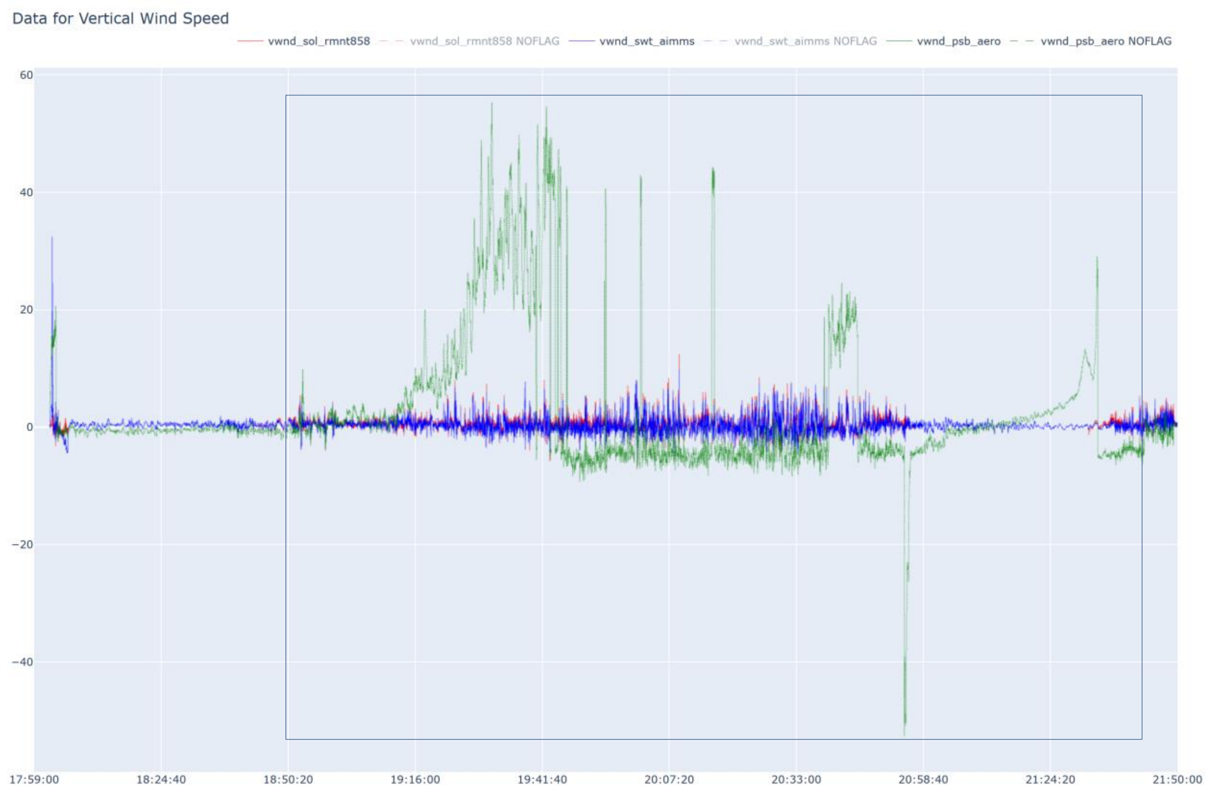


Figure 10 - An example of unusable data from the Aeroprobe winds

5.2.6 MISSING

No data available, either due to sensor malfunction, human factor, or the flagging period not being a segment where data is being collected.

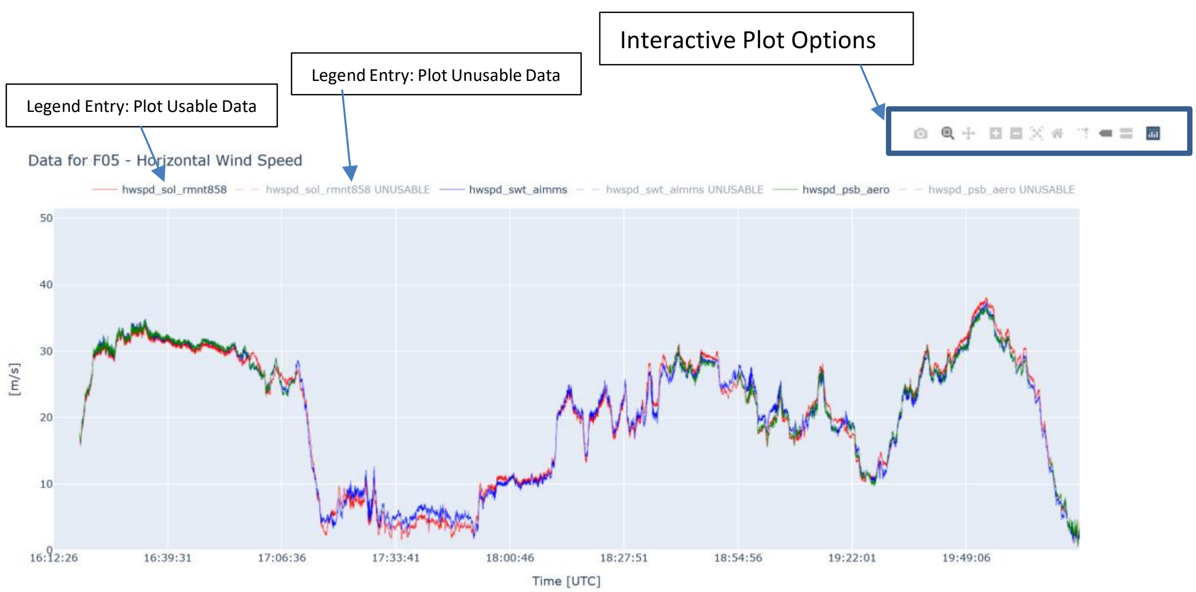
5.3 Listing of Missing Data

For the atmospheric state, any missing data in flight is found via flags. However, there are two flights with very large missing time segments. For F02, there is a significant portion of time where data is missing for all sources. This is also the case in F27, where all the data recording had to be shut off due to a safety check. For additional clarification on any issues or flagged data, end-users may consult the PLANET chat logs.

6.0 GUIDE TO PLOTTING NETCDF FILES AND USING THE PROVIDED QUICKLOOKS

The provided dataset also comes with quicklooks. These are interactive, and generated using the **Plotly**[1] graphing library. Both the data and the associated flags are plotted. A quick guide of using the data may be seen below. Here, you can use the interactive plot options to modify the plot. Simply hovering over the picture will activate the display of these options. In addition, hovering over each of these buttons will tell the end user what function the button serves.

Additionally, each figure has a few extra features. For each line plot, you can select or deselect the display on the legend by left-clicking once. Additionally, each line plot has two display options. One option will plot the data that is flagged as GOOD, MAJOR_ISSUE, MINOR_ISSUE, and CALIBRATION_CYCLE. This is all data that can be usable for analysis, and is therefore plotted. Each line plot also has an option to display the data that has been flagged UNUSABLE for reasons of transparency, so that end users may see what has been indicated as not usable for analysis. This is indicated in the figure below.



[1] More information available at: https://plotly.com/python/

The quicklooks have also been subdivided into 5 different classes. That is, for each flight there are 5 separate **.html** files containing different quicklooks among them. These files are differentiated by an extra suffix at the end of each quicklook file name. These are **_position**(an animated lat/lon plot and altitude), **_acstate**(roll/pitch/headings and velocities), **_pressures**(static/dynamic pressures and airflow angles), **_thermo**(temperatures and TAS), **_gas**(Atmospheric Gases data) and **_winds(**wind data).

7.0 REFERENCES

[1] B. Leach and K. Hui, "In-Flight Technique for Calibrating Air Data Systems Using Kalman Filtering And Smoothing," *AIAA Atmospheric Flight Mechanics*, 2001.

[2] Li-Cor Biosciences, "LI-7000 CO2/H2O Gas Analyzer: Instruction Manual," Li-Cor Inc., Lincoln, Nebraska, 2007.

[3] T. Koop and D. M. Murphy, "Review Of The Vapour Pressures Of Ice And Supercooled Water For Atmospheric Applications," *Quarterly Journal of the Royal Meteorological Society*, 2005.