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CAESAR (2024) Project Manager Report

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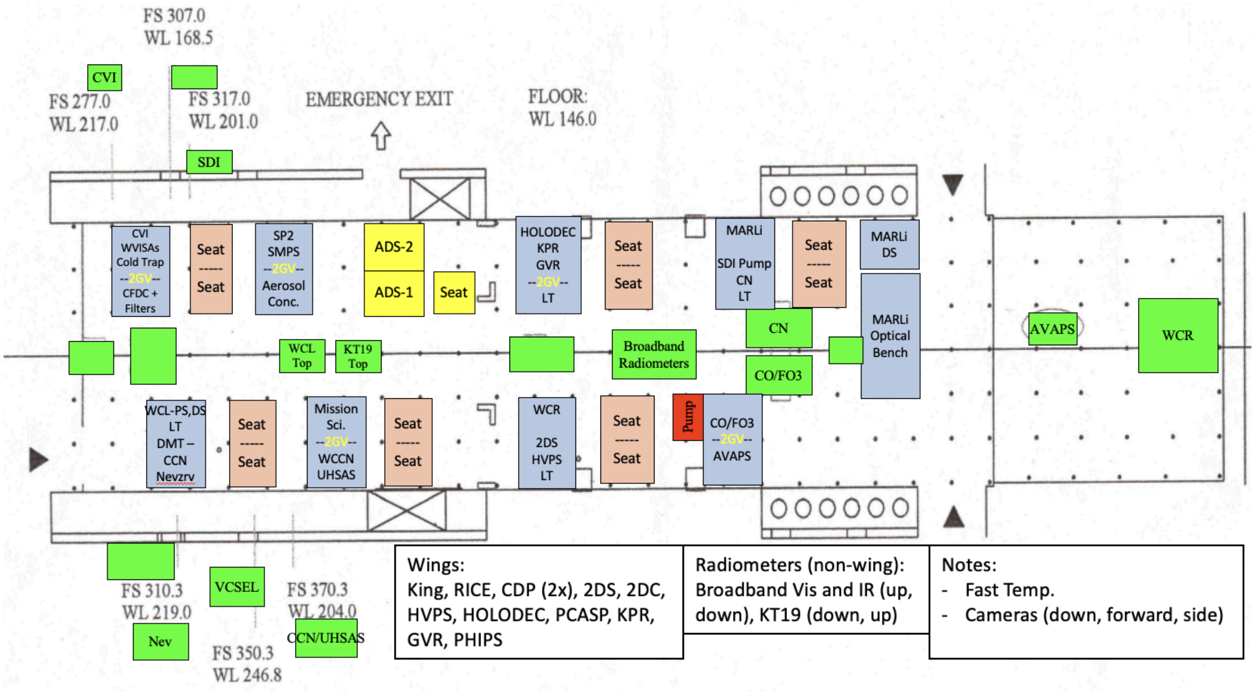
I. Aircraft Payload and Layout



Wings:
King, RICE, CDP (2x), 2DS, 2DC, HVPS, HOLODEC, PCASP, KPR, GVR, PHIPS

Radiometers (non-wing):
Broadband Vis and IR (up, down), KT19 (down, up)

Notes:
- Fast Temp.
- Cameras (down, forward, side)

This summary has been written to outline basic instrumentation problems affecting the quality of the data set and is not intended to point out every bit of questionable data. It is hoped that this information will facilitate use of the data as the research concentrates on specific flights and times.

The report covers only the RAF supplied instrumentation on the NSF/NCAR C-130 and is organized into the following sections. Section II provides a general overview of the data collected and lists recurring problems, general limitations, and systematic biases in the standard RAF measurements. A discussion of the performance of RAF specialized instrumentation will be provided separately, along with the data. Section III describes issues that occurred on a flight-by-flight basis.

Please note that virtually all measurements made on the aircraft require some sort of airspeed correction or the systems simply do not become active while the aircraft remains on the ground. None of the data collected while the aircraft is on the ground should be considered valid.

Information on the processing algorithms used to produce the final dataset can be found at:
https://www.eol.ucar.edu/content/raf-bulletins

II. General Data Notes

RAF staff have reviewed the data set for instrumentation problems. When an instrument has been found to be malfunctioning, specific time intervals are noted. In those instances the bad data intervals have been filled in the netCDF data files with the missing data code of -32767. In some cases a system will be out for an entire flight.

1. NetCDF File Changes

Particle probe histograms and size-distributions have changed some. For CAESAR this change applies to the CDP, 2DC, 2DS, HVPS, and PCASP. Up until 2022 the histograms and size-distributions had a legacy unused bin added at the small end. For example, the CDP is a 30 channel probe, but the data was stored as 31 bins. This has been removed, and now the 30 channel probe will have 30 bins in the NetCDF file. The bin sizing is still in the NetCDF file as an attribute to the size-distribution, called CellSizes, and remains as 31 end point elements (for the CDP). For more information on this change, plus general information on RAF NetCDF conventions, please visit: https://field.eol.ucar.edu/docs/raf/software/netCDF.html

2. Position and Altitude Data

The GPS operated as expected during CAESAR. Terrastar corrections dropped to lesser accuracy during spirals and at high latitudes (north of 75°N) where signals are more difficult to obtain. Data were collected at 20 Hz. Where Terrastar is active (GGQUAL = 5) the horizontal standard deviation was below 0.1 m in most cases and is often below 0.05 m. Vertical standard deviation in these cases is less than 0.2 m. Outside of those cases position accuracy can be expected to be near 1 m. These variables are represented in the GGxxx variables in the dataset.

3. Three Dimensional Winds

Wind data are of highest quality when the aircraft is in straight-and-level flight. These data are still good quality in level climb and descent, with evidence of a negative wind bias of -20 cm/s in descent over all CAESAR data including test and ferry flights. Caution should be exercised when using winds in turns. Straight-and-level legs should be used for sensitive calculations.

During CAESAR, radome icing frequently influenced angle-of-attack (AoA) measurements and once influenced angle-of-sideslip (AoS) measurements. Both measurements are required for deriving full-quality 3-D winds at high frequencies. Icing resulted in periods where

1) AoA, AoS are bad (drifted to Inf/NaN)
2) AoA, AoS are degraded (shifted until icing cleared by anti-icing, maneuvers)

Bad AoA, AoS:
When AoS was bad, full 3-D winds were still produced assuming a constant AoS, roughly accounting for the C130's p-factor in typical straight-and-level flight. When the aircraft is level, the vertical winds (WIX) are considered full quality, while the high-frequency information in horizontal wind components (UIC, VIC) is highly degraded as no high-frequency AoS measurement is available. Low-frequency components of horizontal winds should be reasonably accurate, with wind direction errors typically less than 0.5 deg in straight-and-level flight.

When AoA was bad, vertical wind estimates were set to NaN. Horizontal winds were still computed, which can be considered full quality when the aircraft is nearly level.

If either AoA or AoS were bad and |ROLL| > 2.5 degrees, all wind components were set to NaN.
Degraded AoA, AoS:
There were numerous periods where the radome-measured AoA and a reference AoA (often equivalent to pitch angle) suddenly differed significantly after an observed icing event. In these situations, AoA tends to shift and become biased, eventually snapping back after, presumably, radome anti-icing removes the ice. Despite AoA being biased during these periods, high-frequency turbulence information is still present in the measurement. As this information might still be useful in flux calculations, at least qualitatively, full 3-D winds were still produced. In these periods, when the aircraft is level, horizontal winds can be considered full quality, while vertical winds (WIX) can be considered strongly biased but still potentially useful for flux estimates.

On RF02, RF07, and RF09, a negative drift in AoA and WIX were noted after numerous icing events. In RF02 and RF07, liquid was noted in the radome pressure port drains. Presumably this drift was due to water in the pressure lines between the port and the sensor. On the ends of these flights, high-frequency information may be additionally damped.

Degraded AoS periods were not noted in CAESAR.

In total, ~24% of CAESAR research flight time was flagged as bad or iced AoA or AoS.

Wind Quality Flag
A wind quality flag, "WINDSFLG", is being provided for convenience where
0 = Full quality winds
1 = Bad AoA
- Horizontal winds are full quality when aircraft is level
- Vertical winds set to NaN
- All winds set to NaN when |ROLL| > 2.5 deg

2 = Bad AoS
- Vertical winds are full-quality when aircraft is level
- High-frequency information in horizontal winds is not useful, but low-frequency information is still reasonably accurate when aircraft is level

- All winds set to NaN when |ROLL| > 2.5 deg

3 = Bad AoA and AoS
- Horizontal winds are degraded, with high-frequency information not useful, but low-frequency information still usable when aircraft is level
- Vertical winds cannot be used.
- Vertical winds set to NaN, all winds set to NaN when |ROLL| > 2.5 deg

4 = Iced AoA
- Vertical winds biased, but high-frequency information exists, potentially useful for fluxes
- Horizontal winds are full quality when aircraft is level

5 = Iced AoS
- Horizontal winds biased, so low-frequency information not useful, but high-frequency information exists, potentially useful for fluxes
- Vertical winds are full quality when aircraft is level

6 = Iced AoA and AoS

Times where icing impacted the wind measurements can be found in the individual flight summary section below.

A final note: The special processing mentioned here, when AoA and AoS are bad, was not performed in the initial data release on 8 October 2024. In this release, wind data were set to NaN in these periods. In the 2nd data release on 29 October 2024, this processing was performed, adding data when AoA or AoS were bad (e.g. adding vertical winds for ~57% of RF05). The wind quality flag, consistent with the periods provided above, was also added in the 2nd data release for data user convenience.

4. Pressure

Static pressure (PSFRD) on the C-130 is measured using a static port on the fuselage and then corrected (PSFC) using the angle of attack and dynamic pressure. This sensor worked well through the entire project and its measurements are the reference for CAESAR (PSX, PSXC). There are two traditional measurements for dynamic pressure: a heated pitot tube on the fuselage (QCF) and the forward hole on the radome (QCFR), which is unheated. Both are also then corrected (QCFC and QCRC) using the static pressure and angle of attack. Water can sometimes get into the radome tubing and cause poor measurements. QCFR and QCFRC are chosen as the reference raw and corrected dynamic pressures (QCX, QCXC), respectively, for CAESAR.

5. Ambient Temperature

Temperature measurements were made using two heated sensors (ATH1 & ATH2) and and unheated fast response sensor (ATF1). The temperature sensors generally tracked well throughout the project. There were occurrences where ATF1 cooled up to 0.5 degrees in clouds with large drops, precipitation, or high liquid water content due to wetting and evaporative cooling on the sensor. This causes what appears to be large areas of supersaturation and may result in the appearance of instability in a well mixed cloud. The probe recovered after every instance, but users should use caution when interpreting the fast response temperature data when in cloud. ATF1 is also susceptible to icing, which can result in data drift and in the worst case, damage to the wire. There were instances in CAESAR where icing impacted this measurement, but the probe recovered each time. These instances are listed in the individual flight notes below.

ATH1 is chosen as the reference temperature (ATX) for CAESAR.

6. Humidity

Humidity is measured by two thermoelectric (chilled mirror) dew point sensors and the VCSEL hygrometer. The chilled mirror sensors (DP_DPT, DP_DPB) may perform poorly during ascents and descents as they can flood and take time to restabilize. There are also non-physical oscillations that occur occasionally in these sensors. DPT and DPB should only be used when VCSEL data (DP_VXL) are missing and even in these situations, should be used with caution.

In general, the VCSEL performed well during CAESAR flights and is set to the reference dewpoint (DPXC). There are a couple of caveats. At low humidities, the VCSEL data may have a low bias, on the order of ~10% in some cases. Caution is also advised for flux analyses when the instrument undergoes frequent mode switching (MODE_VXL) as different mode data have different measurement variance. The Aerodyne instrument also has a water vapor channel (H2O_ARI). It can be used as a comparison with the other humidity measurements or as a backup measurement but should not be relied on as a reference value.

7. Aerosols

EOL/RAF supplied a wing-mounted PCASP and cabin-mounted CN Counter for CAESAR. The Solid Diffuser Inlet (SDI) was also installed and used for PI team aerosol instruments.

PCASP: The PCASP collected data reliably during CAESAR. However, laser instability, mainly on the high-altitude ferry legs, produced spurious counts requiring that the smallest-diameter size bin (0.097 - 0.105 micron) be discarded. And following the project, the sample flow calibration was found to be substantially in error due to electronics changes by the manufacturer. With the corrected calibration, concentrations are reduced to about two-thirds of those reported in the field.

The PCASP size distributions are of dry aerosol at ambient number concentration. Drying results from ram heating of sample air in the diffusing intake, and heating by deiced components on the way to the laser cavity.

Data have not been filtered for clouds. Cloud particles may shatter on the leading edge of the inlet, producing elevated particle counts over the aerosol background, and possibly skewing the size distribution too.

CN Counter: The CN performed well during CAESAR. The SMAI particle inlet from which it sampled is designed to reject splash and shatter artifacts from cloud particles, and the CN data are believed to be largely free of contamination. Nevertheless, concentrations in cloud may still be affected in severe cases.

The length of the sample line for the CN introduces a delay of about 3 seconds in its measurement time series, as determined by comparisons with the wing-mounted PCASP. Although this delay time varies somewhat with changes in altitude and airspeed, the CN data have been shifted by a constant 3 seconds.

SDI: The SDI generally performed well during CAESAR, maintaining isokinetic flow in nearly all flight conditions. The exceptions were a number of icing events in which the inlet became partially occluded by ice. In these cases the SDI appeared to go subisokinetic, then briefly superisokinetic when the obstructing ice cleared, before returning to normal operation. But because the reduced inlet diameter is unknown, it is not possible to determine the actual departure from isokinetic flow. Ice typically cleared within a minute or two, but durations ranged from several seconds to nearly 22 minutes in one case. To identify such events, a quality flag (SDIQUAL_SDI) was added to the netCDF files after the project. The flag is a boolean value with 1 = 'OK' and 0 = 'CAUTION.' The criterion for 'OK' is that actual SDI flow (MFLOW_SDI) is within +-2% of the isokinetic set point (SETPT_SDI), with the limits roughly corresponding to a 5% change in transmission efficiency to the sample manifold for 3 micron particles. Larger particles are most sensitive to departures from isokinetic flow, and particularly to superisokinetic flow (when MFLOW_SDI > SETPT_SDI). Due to noise in the pressure, temperature, and true air speed measurements used in the real-time calculation of the isokinetic set point, and pressure fluctuations in the inlet itself especially during low-altitude flight segments, there are many instances of brief zero flags during each flight. These momentary departures from the set point may be safely ignored.

Note that SDIQUAL_SDI = 0 ('CAUTION') does not necessarily mean all measurements should be discarded. Anisokinetic effects are size-dependent, with the greatest influence on transport efficiency for larger particles, so users are encouraged to consider their size range of interest, keeping in mind that submicron particles are much less affected by small departures from isokinetic sampling. Note also that further inertial loss of larger particles, and diffusional loss of smaller particles, occur within each instrument's sample line from the SDI manifold regardless of the SDI's isokinetic state.

8. Cloud Particle Size

Two 1D particle probes (CDPs), three 2D cloud/precipitation probes (2DC, 2DS, HVPS), and one holographic probe, HOLODEC-II, were used for CAESAR. It should be noted that the RAF in-house processing of the Optical Array Probes (OAPs), which are included in the CAESAR GV

Flight-Level NetCDF files (processed through nimbus/process2d), is sufficient for initial assessment of cloud observations, but is not intended for full cloud microphysical analysis. More sophisticated processing of the 2DC, 2DS, and HVPS that includes such features as mask bit filling, better noise removal, and other improvements from software such as SODA2, UIOPS, or OAPview should be utilized. Such products will be made available and submitted to the data archive as a separate dataset. Similarly, a separate set of products will be archived for the HOLODEC-II data (anticipated final data 1 year post-project completion). For questions or guidance on which products to use, please contact the RAF Science and Instrumentation Group, specifically Sarah Woods.

CDPs: Two CDPs were flown on the left wing during CAESAR. Variables from the inboard CDP are denoted with _LWI while those from the outboard CDP contain the string _LWO.

After analyzing bead calibrations conducted during CAESAR, bin edges for the CDP in the LWI location (S/N016), were adjusted from the factory default to the following (microns):
1.93 2.91 3.89 4.87 5.85 6.83 7.81 8.79 9.77 10.75 11.73 12.71 13.69
15.65 17.61 19.57 21.53 23.49 25.45 27.41 29.37 31.34 33.3 35.26 37.22 39.18
41.14 43.1 45.06 47.02 48.98

Similarly, after analyzing bead calibrations conducted during CAESAR, bin edges for the CDP in the LWO location (S/N058), were adjusted from the factory default to the following (microns):
1.32 2.35 3.38 4.41 5.44 6.47 7.51 8.54 9.57 10.6 11.63 12.66 13.69
15.75 17.81 19.87 21.93 24 26.06 28.12 30.18 32.24 34.3 36.36 38.43 40.49
42.55 44.61 46.67 48.73 50.79

2DC: The 2DC was susceptible to intermittent communication dropouts throughout the project, ranging from a few seconds to 30+ minutes. It was also susceptible to optical fogging during rapid descents on several flights. 2DC data should be utilized with caution, and in companion with other cloud probes (CDP, 2DS, HVPS, King Probe, etc.).

2DS and HVPS: Both of these probes worked very well during CAESAR with no major problems or issues highlighted. Note: there is no 2DS or HVPS data for RF03, which was a very short flight with very minimal cloud passes. The 2D-S flown was a Fast 2D-S model (raw data format will vary from that of a standard 2D-S probe, but processed data will be comparable).

All bin edges are stored in the netCDF file as an attribute to the corresponding size-distribution variable (CCDP_LW?, C2DC*, C2DS*, C2DH*).

9. Liquid Water Content

LWC is measured by the King probe (PLWCC) and the CDP (PLWCD_LWI and PLWCD_LWO). PLWCC should not be used for a few minutes after takeoff as it often has spurious, high values during that time. PLWCC also often shows non-zero values on descent after high-altitude ferry and sometimes during descents in dry air while profiling. At times these values reach up to 0.05 g m^{-3}. PLWCC should be compared with the LWC measurement from one of the CDP probes (PLWCD_LWX) for all liquid cloud penetrations.

10. Supercooled Liquid Water Indicator

Measurements from the Rosemount Icing Detector (RICE) should be used only as a qualitative indicator of the presence of icing. It functioned well during CAESAR.

11. Radiometers

Pyranometers and Pyrgeometers: These measurements (VISTC, VISBC, IRTC, IRBC) are most reliable when the sensors are level with respect to the surface. They are mounted on stabilized platforms which rotate through two axes to compensate for pitch and roll variations of the aircraft. The stabilized platforms are designed to correct for aircraft attitude variations over a limited range (i.e., +/- 10 degrees for roll and -2.1 to +7.9 degrees for pitch). When aircraft attitude changes exceed these limits, data from the Kipp and Zonen radiometers (VISTC, VISBC, IRTC, IRBC) is less reliable and has been removed from the production data files. Data missing from these files can be obtained by contacting the RAF.

Radiation Pyrometers: Measurements from three Wintronics KT19.85 sensors (one upward-looking, two downward-looking; RSTT, RSTB, RSTB1) are generally very good. Radiometric temperature values appear to be physically realistic and respond appropriately to clouds in the field of view, changes in surface characteristics (land, water, ice), etc. Trends in these variables align well with infrared measurements from the Kipp and Zonen CGR4 sensors (IRTC, IRBC).

Although they are mounted very close to each other on the bottom of the aircraft, measurements from the two downward-looking units (RSTB, RSTB1) show a consistent bias on the order of 0.5 degrees C. The bias is larger at higher altitudes/colder temperatures, so may be related to differential heating/cooling of the instrument housings. Note that RAF did not heat the sensors during CAESAR, nor monitor the temperature of the instrument housing, but in any case, the bias is generally within the accuracy specifications provided by the manufacturer.

12. Camera Images

The C-130 flew forward (color) and downward (monochrome) facing digital cameras for in-flight image capture. For both cameras, images were acquired once per second and stored as

JPEG-compressed files. No image processing was performed beyond converting the raw pixel data from the color camera to 24 bit/pixel color images. Applying a sharpening filter as is ordinarily done by consumer digital cameras will considerably improve the appearance. The UTC date and time are encoded in the filename as YYMMDD-HHMMSS.jpg.

III. Individual Flight Summary

RF01
28 February 2024
Takeoff: 11:39:00
Landing: 18:37:00
Winds: Iced AoA period (WINDSFLG=4) 16:09:31 - 16:36:16.
RSTT: No power was applied to the upward-looking KT-19 sensor for this flight so RSTT is missing.
Radiometers: Top and bottom VIS and IR sensors are blanked out 14:56:00 - 15:20:44, 16:25:53 - 16:26:00, and 16:28:02 - 16:28:26.
2DC: Fogging event. All 2DC variables are missing 18:30:45 - 18:36:44.

RF02
29 February 2024
Takeoff: 11:07:00
Landing: 18:16:00
Winds: Bad AoA period (WINDSFLG=1) 17:54:50 - 17:58:32. Iced AoA period (WINDSFLG=4) 15:56:30 - 16:02:12 and 17:58:32 - 18:16:00.

RF03
2 March 2024
Takeoff: 09:26:00
Landing: 11:01:00
Dewpoint: Flooding issues on chilled mirror dewpointers. All variables ending in _DPB or _DPT are bad for this flight.
2DS and HVPS: No data from either probe are available on this flight.

RF04
5 March 2024
Takeoff: 06:02:00
Landing: 12:40:00
Winds: Iced AoA period (WINDSFLG=4) 09:45:00 - 09:48:40.

RF05
11 March 2024
Takeoff: 06:54:00
Landing: 12:51:00
Winds: Bad AoS period (WINDSFLG=2) 06:53:00 - 10:14:21. Iced AoA period (WINDSFLG=4) 09:45:09 - 10:16:58, 10:19:27 - 10:35:08, 10:47:26 - 11:22:03.
VISTC: There was an unexplained drop in the value of VISTC from 0912 to 0921 UTC. The aircraft track was straight and level, so it was not due to aircraft attitude change. Also there was no change in signal from the companion IR measurement (IRTC), so it's not clear there was a change in the sky condition.
2DS: Partial fogging event on two descents. Some particle images were collected, so this time period is NOT blanked out to allow assessment of particle imagery, but computed variables (concentration, water content, sizing, etc) may not be fully representative during these times and should be used with caution. The event times are 10:49:57 - 10:51:42 and 11:13:50 - 11:15:13.
ATF1: There is a larger than usual offset due to icing 10:55 - 12:00. The probe recovered.

RF06
12 March 2024
Takeoff: 06:06:00
Landing: 12:29:00
Winds: Iced AoA period (WINDSFLG=4) 07:45:16 - 07:50:12, 07:56:55 - 08:05:06, 10:15:13 - 10:21:58, 10:26:10 - 11:02:31.
RSTT: No power was applied to the upward-looking KT-19 sensor for this flight so RSTT is missing.
Radiometers: Top and bottom VIS and IR sensors are blanked out 07:28:00 - 07:40:00.
ATF1: There is a larger than usual offset due to icing 10:45 - 11:30 and also during the descent. The probe recovered in both cases.

RF07
16 March 2024
Takeoff: 09:45:00
Landing: 17:35:00
Winds: Bad AoA period (WINDSFLG=1) 15:56:17 - 16:02:53 and 16:10:50 - 16:19:10. Iced AoA period (WINDSFLG=4) 14:43:57 - 15:26:56, 15:39:29 - 15:56:17, 16:19:10 - 17:35:00.
Radiometers: Top and bottom VIS and IR sensors are blanked out 13:26:00 - 13:43:00.

RF08
25 March 2024
Takeoff: 08:51:00
Landing: 09:31:02
This flight was aborted after an overheating issue with an underfloor power supply. No quality-controlled data from this flight are released.

RF09
2 April 2024
Takeoff: 08:00:00
Landing: 16:02:00
Winds: Iced AoA period (WINDSFLG=4) 10:10:50 - 10:52:10, 13:13:49 - 14:23:30, 14:29:46 - 14:45:54, 14:45:54 - 16:02:00.
2DC: Fogging event. All 2DC variables are missing 10:15:25 - 10:26:45, 10:28:45 - 11:43:45, 12:00:00 - 12:13:35, 12:29:45 - 12:34:45, 14:19:30 - 14:31:40, 14:50:25 - 14:57:30, and 15:51:30 - 15:57:10.
Radiometers: Top and bottom VIS and IR sensors are blanked out 10:07:27 - 10:07:31, 10:40:17 - 10:42:50, 11:23:00 - 11:40:00, 12:17:56 - 12:17:59, 14:10:52 - 14:10:55, 15:48:00 - 15:48:04, 15:50:57 - 15:51:05, 15:55:33 - 15:55:43, 15:57:10 - 15:57:14.

RF10
4 April 2024
Takeoff: 08:22:00
Landing: 15:57:00
Winds: Iced AoA period (WINDSFLG=4) 11:12:56 - 11:20:58, 11:22:37 - 11:27:59, 13:36:38 - 13:40:27, 14:16:56 -14:30:50.
Radiometers: Top and bottom VIS and IR sensors are blanked out 10:07:23 - 10:07:26, 11:49:00 - 11:50:00, 11:53:00 - 11:54:00, 15:33:02 - 15:33:06.
2DC: Fogging event. All 2DC variables are missing 09:40:50 - 09:47:00, 12:13:55 - 12:18:30, 13:40:20 - 13:42:15, and 15:44:35 - 15:54:12.