# Project managers quality report, Jorgen Jensen – ICE-L

## Information on ICE-L:

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## Acknowledgments:

Thanks are due to RAF's technical, mechanical and operational staff for making ICE-L a success. Special thanks are due to Allen Schanot for examining the quality of wind measurements during ICE-L. Teresa Campos provided processed chemistry data (TDL water vapor, CO and ozone), and Pavel Romashkin processed the differential GPS data. Ron Ruth directed me to issues with documentation that materially improved the data set, and many others within RAF provided invaluable help with instrument calibration.


## Background:

The C-130 carried a heavy aerosol, cloud physics and trace gas instrumentation payload in ICE-L. A number of new instruments and installations were implemented for ICE-L, and the vast majority of the instruments onboard the C-130 for ICE-L functioned extremely well, but a few required special handling in generating the data for ICE-L. Installation of upgraded user equipment led to some noise issues in the data, particular for anti-iced temperature, but redundant sensors meant that this is not a problem for analysis of the data.

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 purpose is to serve as a guide for users unfamiliar with the C-130 sensors, variable names etc. In particular, the purpose of Section 1 is:

> To describe the instruments installed onboard C-130 in ICE-L in some detail. Many instruments and variable names differ from those used on the GV. The following description covers the most commonly used variables in the ICE-L C-130 data set.
>
> To describe the data logging procedures, including how data are filtered and averaged.

Section 2 lists isolated problems occurring on a flight-by-flight basis. Documents describing the detail performance of the ACD ozone sensor will be provided separately.

Note that this description only includes the NCAR/EOL and NCAR/ACD data that is distributed as part of the main data set. Individual instrument providers provided many instruments that they provide as independent data sets for ICE-L. The individual instrument provider measurements will not be discussed here.

At present (28 Aug 2008) the corrected chemistry data has not been merged in. This will be done in the final data set.

The following description refers to the low-rate (1 sample per second) data. A high-rate data set (mostly 25 samples per second, some particle probes at lower rates) will also be released. The high-rate files contains data that in some cases has been interpolated to 25 sps, whereas most of the analog data (temperature, most pressures, etc) was sampled at higher rates than 25 sps and therefore sampled down to 25 sps. Users should be aware that time constants in some sensors (e.g. cooled mirror dewpoint sensors) are of order seconds, yet they are given in the data set as 25 sps variables. It is left to the users to use caution when examining the frequency response of individual sensors.

## Section 1: General discussion of sensors and measurements

### Pressure:

Static pressure is available using two different systems:

Static pressure is measured with a highly accurate Paroscientific (MODEL 1000) with a stated accuracy of 0.01% of full scale.

| | |
|---|---|
| PSFD/PSX | Static pressure as measured using the fuselage holes |
| PSFDC/PSXC | Static pressure corrected for airflow effects (pcorr) |

A second, independent static pressure system uses the same type sensors, but the location of the static port makes the measurement from this second system more difficult to correct for air flow effects, in particular during climbs and descents:

| | |
|---|---|
| PSFRD | Static pressure as measured using the fuselage holes |
| PSFC | Static pressure corrected for airflow effects (pcorr) |

Use PSXC for the normal measure of pressure (e.g. in equation of state or hydrostatic equation).

### Temperature:

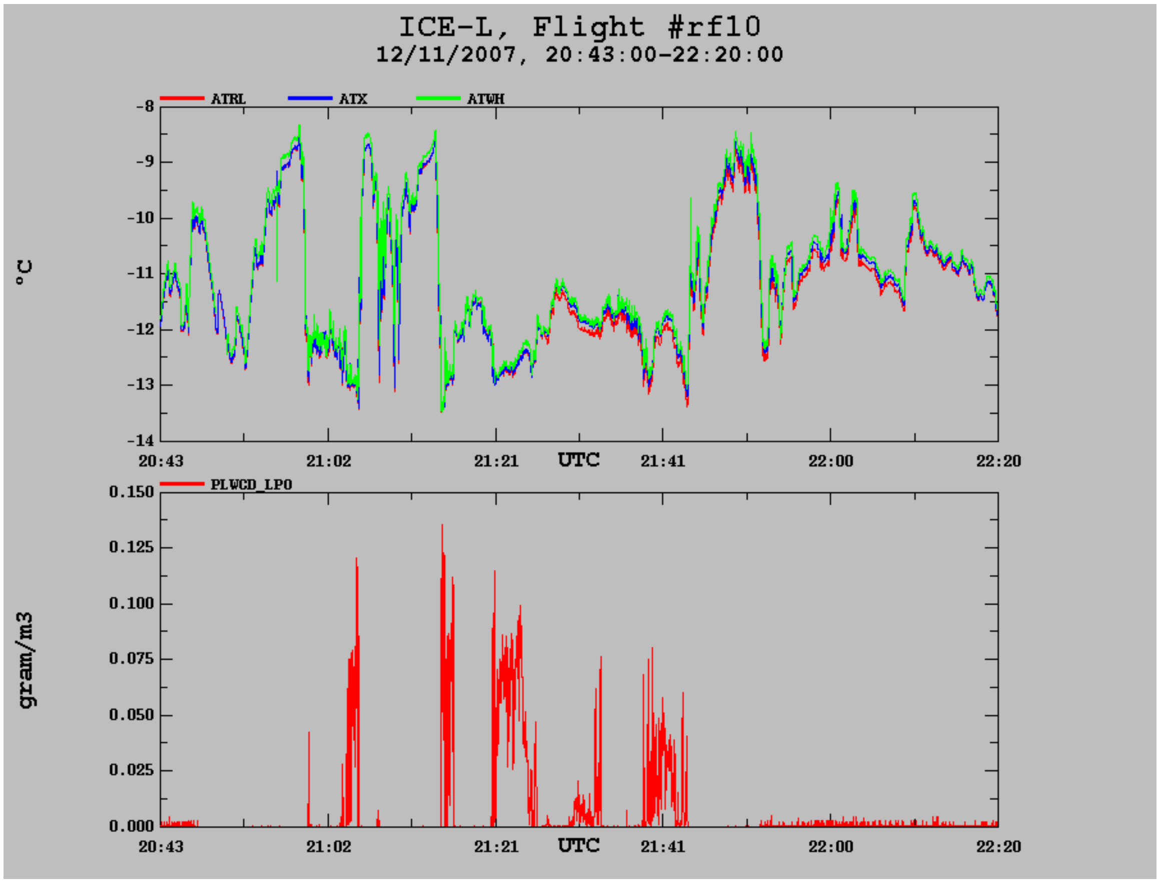
Temperature was measured using three different sensors on the C-130:

Two unheated Rosemount sensors were used for fast-response measurements. These sensors can be affected by icing, and this was a problem during parts of a problem in ICE-L.
A heated Rosemount sensor was used to give a slower response temperature, that would also be adequate in icing conditions; however, the previously mentioned electrical noise interference meant that the heated Rosemount temperature sensor was too noisy during flights RF01 to RF08.

RAF recommends using the un-heated temperature, ATX, see below, for the ICE-L data set, but users are advised to examine the comparison between the traces of ATRL and ATX for individual time segments.

| | |
|---|---|
| TTRL | Total air temperature from fast Rosemount sensor, left side of the fuselage. |
| TTRR | Total air temperature from fast Rosemount sensor, right side of the fuselage. |
| TTWH | Total air temperature from the heated Rosemount system. |
| ATRL | Ambient air temperature from the Rosemount system, left side of the fuselage. |
| ATRR/ATX | Ambient air temperature from the Rosemount system, right side of the fuselage. |

RAF recommends using the un-heated temperature, ATX, for the ICE-L data set, but users are advised to examine the comparison between the traces of ATRL and ATX for individual time segments as a means to detect if the temperature measurement is affected by icing.




*Measurements of temperature using the two fast-response Rosemount sensors (ATRL and ATX), and the anti-iced temperature (ATWH). Also shown is the cloud liquid water content from the CDP probe (PLWCD). It can be seen that the ATRL sensor shows some deviation from the other two sensors, probably caused by icing build-up on the sensor. Towards the end of the time period, the ATRL sensor appears to recover.*

**Dewpoint temperature and vapor density:**

Humidity was measured using three different sensors:

Two Buck Research 1011C cooled mirror hygrometers are used for tropospheric humidity. They have a sandwich of three Peltier elements to cool the mirror, and in comparison to earlier generations of cooled mirror hygrometers, they have a much-improved capability to measure at low temperatures. These sensors are assumed to measure dewpoint above 0C and frostpoint below 0C. The instrument has a quoted accuracy of 0.1 degC over the -75 to + 50 degC; however, based on examination of the measurements RAF is not comfortable with accuracies better 0.5 degC for dewpoint and 1 degC for frostpoint. The cooled mirror sensors are slow, in particular at lower temperatures, and this may give considerable differences between the measurements from the two units. Their cooling rates depend in part on the airflow through the sensor, and this may depend on the angle of the external stub relative to the airflow. The angle may differ between the two sensors, and this may contribute to response-time differences between the sensors. The sensors are set to different response times; where sharp gradients in dewpoint are encountered, there may be different levels of overshooting between the two sensors. In general DPBC (DPXC) is more steady and less oscillatory.

At very low temperatures the sensors may jump ("rail") to even lower temperatures. The cooled mirror temperatures are included when they are outside the sensor operating range; this is caused by the need to use values of water vapor in other calculations (e.g. true air speed). We do not believe that this was a problem in ICE-L.

Humidity was also measured using a MayComm Open-Path Laser Hygrometer. This dual-channel hygrometer detects optical absorption of water vapor at 1.37 um with a 20 samples/sec resolution. The sensor has an estimated accuracy of 5-10% of ambient humidity (units of ppbv). The sensor has two spectral channels that are used to determine high and low values of humidity, and they are combined to give a single value of humidity, see below. For the ICE-L project, only the long-path channel was operational, and only these variables are shown below.

| | |
|---|---|
| DPB | Dewpoint/frostpoint for bottom fuselage cooled mirror sensor. |
| DPBC/DPXC | Dewpoint for bottom fuselage cooled mirror sensor. |
| DPT | Dewpoint/frostpoint for top fuselage cooled mirror sensor. |
| DPTC | Dewpoint for top cooled mirror sensor. |
| MR | Mixing ratio (g/kg) based on DPXC. |
| MRTDL | Mixing ratio (g/kg) based on TDL sensor. |
| MRTDL_MC | Mixing ratio (ppmv) based on TDL sensor. |

RAF recommends using DPXC as a slow 'tropospheric' variable, and RAF recommends using MRTDL as a fast-response 'tropospheric' humidity measurement.

**Attack and sideslip angles:**
Measurements of attack and sideslip were done using the 5-hole nose cone pressure sensors, primarily ADIFR and BDIFR.

| | |
|---|---|
| ADIFR | Attack angle pressure sensor |
| ATTACK | Attack angle |
| BDIFR | Sideslip angle pressure sensor |
| SSLIP | Sideslip angle |

Both ATTACK and SSLIP were corrected using in-flight maneuvers. Both these two measurements were made used the radome 5-hole system, and this system is subject to icing. Attack and sideslip enters into the calculation of the 3-dimensional wind, and it is thus critical that users try to determine if the measurements of the attack and sideslip angles are affected by icing. One means of doing this is to compare the measurements of differential pressure, QCRC and QCFC, from the radome and heated fuselage systems. If they start to deviate significantly, then the likely cause is icing on the radome. If radome icing is suspected for QCRC, then it is also likely that ADIFR, ATTACK, BDIFR, SSLIP and thus winds are affected by aircraft icing. In general RAF recommends that users during their analysis critically assess if the winds are physically sensible.

**True air speed:**

True air speed was also measured using both a radome 5-hole system and two conventional pitot-static tubes on the side of the fuselage. The radome system has minimal anti-ice heating capability, thus for ICE-L the reference system is one of the heated pitot-static systems on the fuselage of the aircraft. Measurements using the radome and fuselage pitot systems were corrected using in-flight maneuvers.

| | |
|---|---|
| TASR | True air speed using the radome system |
| TASF/TASX | True air speed from the fuselage pitot system |
| TASHC | True air speed using the fuselage pitot system and adding humidity corrections to the calculations; this is mainly of benefit in tropical low-altitude flight. |

RAF recommends using TASX as the aircraft true air speed.

**Position and ground speed:**

The measurement of aircraft position (latitude, longitude and geometric altitude) and aircraft velocities relative to the ground are done using five different sensors onboard the C-130:

Garmin GPS (Reference): These data are sampled at 10 sps and averaged to 1 sps. This is a simple GPS unit with a serial output, and the measurements are available in real-time. The values from this sensor start with a “G”; e.g.:

| | |
|---|---|
| GGLAT | Latitude |
| GGLON | Lognitude |
| GGALT | Geometric altitude |
| GGSPD | Ground speed |
| GGVNS | Ground speed in north direction |
| GGVEW | Ground speed in east direction |

These are good values to use for cases where the highest accuracy is not needed. These variables are subsequently used to constrain the INS drift for the calculations of the GV winds; more about this below.

Novatel differential GPS: This is an extremely accurate Novatel OEM-4 GPS system providing accuracies estimated to be in the range of better than 0.2 m for most of ICE-L. These data are post-processed with data from ground stations in order to obtain the high accuracy. The differential GPS data are given relative to the NAD83 geoid. The data is logged on dedicated data logger and later merged with the main aircraft data.

| | |
|---|---|
| LAT_DGPS | Latitude of the GPS antenna |
| LON_DGPS | Longitude of the GPS antenna |
| ALT_DGPS | Altitude of the GPS antenna |
| ALT_DGPSP | Altitude of the static pressure transducer. This altitude is preferred for high-precision work on pressure perturbations. |
| VEWDG | Ground speed, east direction |
| VNSDG | Ground speed, north direction |
| VSPDDG | Vertical aircraft speed |

Honeywell inertial reference system: The C-130 has Lasernav 2SM inertial systems on the flight deck. Data from this is logged on the main aircraft data logger. The advantage of the IRS values is that they typically have very high sample rates and very little noise from measurement to measurement. However, since they are based on accelerometers and gyroscopes, their values may drift with time. The drift is corrected for by filtering the INS positions towards the GPS positions with a long time constant filter; the filtered values have a “C” added to the end:

| | |
|---|---|
| LAT | Latitude from the IRS, no GPS filtering |
| LATC | Latitude from the IRS, filtered towards GPS values |
| LON | Longitude from the IRS, no GPS filtering |
| LONC | Longitude from the IRS, filtered towards GPS values |
| GSF | Ground speed from the IRS, no GPS filtering |

The choice of parameters for position analysis depends on the type of analysis; in general the Garmin GPS is sufficiently accurate. However, for very precise analysis we recommend using the differential GPS data. For instance, in the ICE-L area, the Garmin data have an accuracy of aircraft altitude of +/-3 m, whereas the differential GPS is estimated to be accurate to better than +/-0.3 m for 95% of the time. Before ICE-L work involving satellite communication necessitated moving the antenna locations, and as a consequence the Novatel dGPS measurements were somewhat degraded, but still relatively very accurate, during ICE-L.

**Attitude angles:**

Aircraft attitude angles are measured by the Honeywell IRS unit.

| | |
|---|---|
| PITCH | pitch angle from IRS (nose up is positive) |
| ROLL | roll angle from IRS 1 (right wing up is positive) |
| THDG | true heading from IRS 1 |

The values of pitch angle (PITCH) have been corrected using in-flight measurements to give approximately the same values as the aircraft attack angle (ATTACK) for long parts of each flight; this correction is done on a flight-by-flight basis to give a near-zero mean updraft over extended flight legs. The variation from flight to flight of this offset is caused by small differences in the pre-flight alignment of the inertial navigation system.

**Wind speeds:**

Wind speeds are derived based on the 5-hole nose cone, other pressure measurements, temperature and inertial measurements supported by GPS data. The use of the Mensor 6100 pressure sensors for ADIFR, BDIFR, QCF and QCF results in the following limitations on the wind data: These pressure measurements were sampled at 50 sps or higher, and thus resulting power spectra is limited to 25 Hz and slower. Tubing lengths and diameters in the nosecone may also limit the frequency response further, and it is known that the C-130 power spectra for vertical wind (in particular) does not completely follow the theoretical -5/3 law. This may be caused by flow deformation around fuselage and wings of the C-130. Users of wind data should be aware that contributions to covariances and dissipation calculations will be affected at and above high frequencies.

The following lists the most commonly used wind parameters:

| | |
|---|---|
| UI | Wind vector, east component |
| UIC | Wind vector, east component, GPS corrected for INS drift |
| VI | Wind vector, north component |
| VIC | Wind vector, north component, GPS corrected |
| | |
| UX | Wind vector, longitudinal component |
| UXC | Wind vector, longitudinal component, GPS corrected |
| VY | Wind vector, lateral component |
| VYC | Wind vector, lateral component, GPS corrected |
| | |
| WI | Wind vector, vertical gust component |
| WIC | Wind vector, vertical gust component, GPS corrected |
| | |
| WS | Wind speed, horizontal component |
| WSC | Wind speed, horizontal component, GPS corrected |
| WD | Horizontal wind direction |
| WDC | Horizontal wind direction, GPS corrected |

RAF recommends using the GPS corrected wind components, i.e. the variables ending in “C”.

**CN:**

Condensation nuclei (CN) were measured using a TSI 3760 instrument that uses butanol. The minimum detectable particle size is nominally 7 nm.

| | |
|---|---|
| CONCN | CN concentration |

The CN concentration is given in units of #/cm3 inside the sensor growth tube. CHECK! For more information users are encouraged to contact Dr. Dave Rogers, 303-497-1054.

The CN is subject to increased counts as a result of splash artifacts in cloud and precipitation.

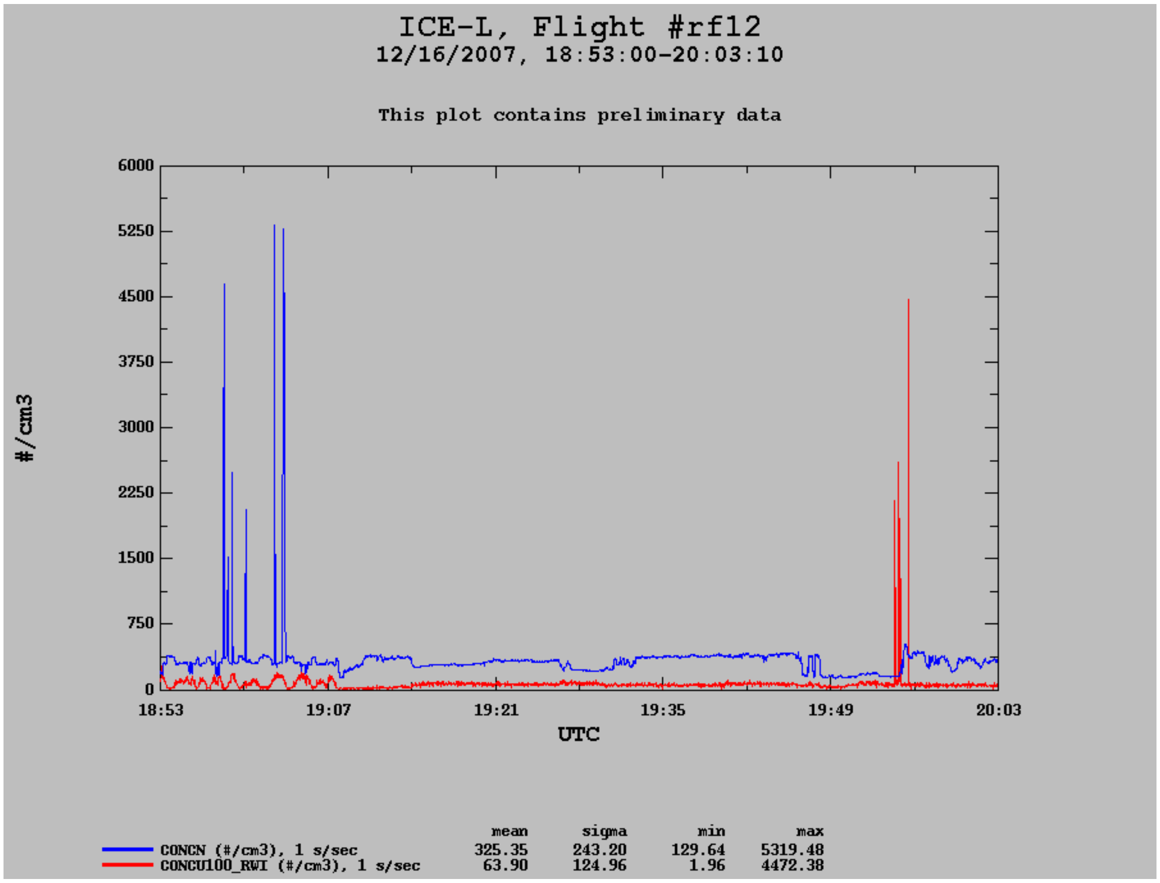
**Aerosol spectra:**

Aerosol particle spectra were measured using a PMI UHSAS probe, operating with a 100-bin resolution and covering the approximate size range of 0.05-1 um diameter. The probe operates with 4 amplifier stages, and it produces nice continuous particle spectra on the ground. Unfortunately, at high altitudes (and cold temperatures) the stages do not overlap smoothly, and the spectra thus look somewhat jagged. The manufacturer states that the particle concentration is correct, thus the probe does not miss any particles or create any artifacts. RAF has processed the spectra based on the counts and bins as per the manual. RAF recommends that users create wider bins, thus producing smoother spectra; the choice of how to define wider bins is left to the individual user.

The UHSAS was also affected by noise in the first 9 channels of the instrument. The cause of the noise is not apparent. As a consequence, RAF has omitted the first 9 bins from the UHSAS size spectra in the production data set. The implication is that the probe data is given for the approximate size range of 0.1-1 um.

| | |
|---|---|
| UHSAS_RWI | UHSAS aerosol particle spectrum |
| CONCU | UHSAS particle spectrum, all bins |
| CONCU100 | UHSAS particle spectrum, particles with diameters above 100 um only |
| CONCU500 | UHSAS particle spectrum, particles with diameters above 500 um only |

Both the CN counter and the UHSAS are subject to increased counts due to splash artifacts in cloud and precipitation, and particle concentrations in cloud should generally be higher then CONCN (see below); this would indicate periods of faulty data in one of the instruments, typically the UHSAS.




**Cloud droplet spectra and concentrations:**
Cloud droplet spectra were measured using a Particle Measurement Systems (PMS) FSSP-100 upgraded with Droplet Measurement Technologies (DMT) SPP-100 electronics. In addition a DMT CDP probe was also flown. These instruments provided drop-size spectra using 30 bins to cover the approximate range 2-47 um diameter.

| | |
|---|---|
| S100_RWO | FSSP/SPP-100 dropsize spectrum |
| CDP_LWO | DMT CDP dropsize spectrum |

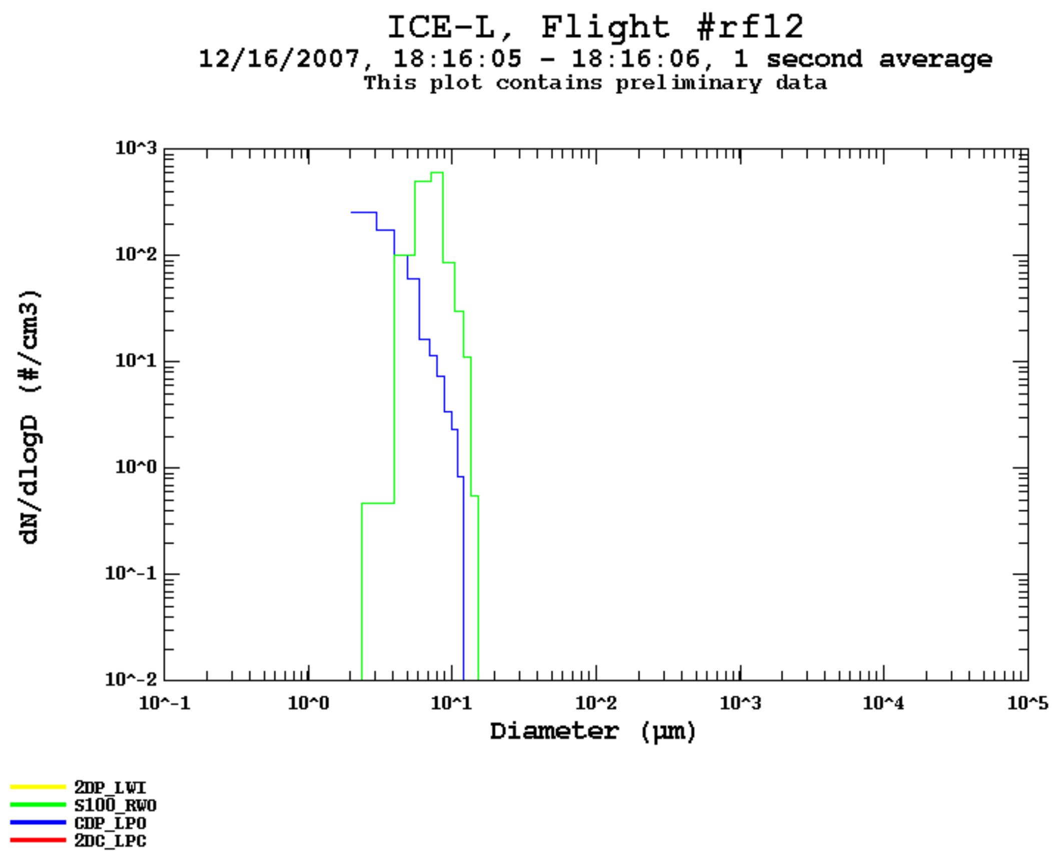
The FSSP was a tube-less version. This was done to minimize the amount of bouncing precipitation particles that fragment and are detected as cloud droplets. The FSSP suffered from a set-up issue early in the ICE-L period, which results in the probe having twice the bin width (and thus a wider size range for cloud droplets) during TF01-TF03 and RF01-RF04.

The CDP uses polarized light. It is suspected that the CDP is reporting lower concentrations of frozen drops (Heymsfield, personal communication) than does the FSSP.

| | |
|---|---|
| CONCF | Particle concentration from the FSSP |

CONCD Particle concentration from the CDP

The mean diameter as measured by the FSSP/SPP-100 is typically 3 micron larger than that measured by the CDP probe. Typically, when sampling small droplets, the FSSP shows the classical peaked spectral size distribution, whereas the CDP may only show a “shoulder”, see below.




*Drop spectra for a cloud with no 2D-C or 2D-P particles.*

**Ice and precipitation particles:**

During ICE-L an upgraded fast-2D-C probe was flown. This probe has twice the sample volume (64 diodes as opposed to 32 diodes) and its electronics circuitry has been made much faster, thereby allowing for the measurement of much smaller particles than what is common with a normal PMS 2D-C probe. The probe was in fact so sensitive that it was able to record giant aerosols in the boundary layer. The fast-2D-C has the same resolution (25 micron, nominally) as does a conventional 2D-C, and this fast-2D-C is a major improvement over prior data sets.

An un-modified 2D-P probe was flown on most flights. On some wave flights, the 2D-P was removed, and a SPEC Fast-FSSP was flown instead. The 2D-P operates with a 200-um resolution and a 32-bin spectrum.

In the second release of the ICE-L data set, size spectra from the 2D-C and 2D-P probes are given only for 'entire in' (see 1D in names below. RAF has reviewed current processing methods, and decided that until improved algorithms are implemented, RAF will only release the 1-D data. RAF will working on rejection of shattered particles, on images that are partially in and out of the viewing volume, and on better determination of the particle depth-of-field calculations. This will take some time to implement; in the mean-time users that desire to do their own 2-D processing can have access to the raw 2D-C and 2D-P image data. Users should also be aware that the current particle concentrations are calculated using the entire distance between the probe arms as the depth of field, regardless of particle size.

| | |
|---|---|
| 1DC_LPC | 'Entire in' particle spectrum from the 2D-C probe; the size is determined from the two shaded pixels furthest towards the edge of the diode array during the particle passing through the beam (260-x emulation). |
| 1DP_LPC<br>the | 'Entire in' particle spectrum from the 2D-P probe; size is determined from the two shaded pixels furthest towards the edge of the diode array during the particle passing through the beam (260-x emulation). |
| CONC1DC | 'Entire in' concentration sum of all bins from the 2D-C probe |
| CONC1DP | 'Entire in' concentration sum of all bins from the 2D-P probe |
| CONC2C | 2D-C probe particle concentration based on the shadow-or counter (includes very small particles that do not result in a recorded image). |
| CONC2P | 2D-P probe particle concentration based on the shadow-or counter (includes very small particles that do not result in a recorded image). |

For the 2D-C concentrations, we recommend using CONC1DC for the best compatibility with previous measurements with original (slow) 2D-C probes.

**Remote temperature sensing:**

A Heimann KT19.85 unit was mounted in the bottom of the C-130, looking downwards. Calibration data for this sensor show it to be within a tolerance of 1 degC, and for recordings at temperatures between 0 and 100 degC it has an accuracy of better than 0.5 degC. During ICE-L most cloud penetrations were much colder than 0degC, sometimes even as cold as -35 degC, thus the Heimann units were operated far outside their normal range.

Examination of penetrations of liquid, supercooled cloud showed occasionally large differences between the Heimann temperature and the Rosemount immersion temperature sensors. A large part of this may be due to optically thin clouds, and difference between immersion temperature sensors and the Heimann sensor is thus not an error under these circumstances.

We have used selected cloud penetrations in an attempt to extend the calibration for the Heimann units to cover the entire ICE-L temperature range. These corrected values are given in the variables ending in C below:

| | |
|---|---|
| RSTB | Remote temperature corrected to low temperatures |
| RSTBC | Remote temperature corrected to low temperatures |

Given that the Heimann unit was operated outside its calibration range, and given what appeared to be a systematic bias, the Heimann temperatures have been reduced by 2 degC to make them match with the in-cloud immersion temperatures; users should be cautioned about this.

**Radar altitude:**

The HGM232 radar altimeter is useful for determining topography below clouds, in particular wave clouds. ICE-L was flown with a new data system, and a consequence of the faster electronics was that some spikes occur in the data. The RAF NIMBUS data processor has removed most of these, but there are still occasional spikes present in the production data set.

The radar altimeter is sometimes not turned on until immediately after takeoff and it may also be turned off prior to landing.

| | |
|---|---|
| HGM232 | Radar altitude above ground level |

**Ozone:**

An ozone chemiluminescence instrument (provided by PIs Dr. Teresa Campos and Dr. Ilana Pollack, NCAR/ACD/CARI) was flown on the C-130 during ICE-L. This instrument relies on a reaction between NO and ambient ozone. The instrument has a sub-ppbv detection limit and a 3-5 Hz frequency response.  Time synchronization was obtained by calculation of inlet delays, and the data was interpolated to facilitate comparison with other aircraft measurements. The ozone mixing ratio was merged into standard RAF data files:

| | |
|---|---|
| XO3MR | Corrected ozone mixing ratio. |

If interest develops in faster-response data, the native 25-Hz data files can be produced upon request to Dr. Campos.

**CO:**

In-situ carbon monoxide was provided by Drs. Campos and Pollack using a commercial vacuum ultraviolet resonance fluorescence instrument, the Aero-Laser AL5002. The AL5002 has a lower detection limit of 3 ppbv with an accuracy of +/- (3ppbv + 5%):

| | |
|---|---|
| XCOMR | CO mixing ratio (ppbv) |

Quality assured data were obtained for 11 of 12 ICE-L flights; the instrument was not functional during research flight 1. Processed data have been synchronized before being merged into the final release of RAF netcdf data files. The CO instrument needed calibration every 30-60 minutes and this is apparent as missing data and flagged accordingly.

**Liquid water content:**

A PMS-King type liquid water content sensor was installed on the C-130 for the ICE-L flights:

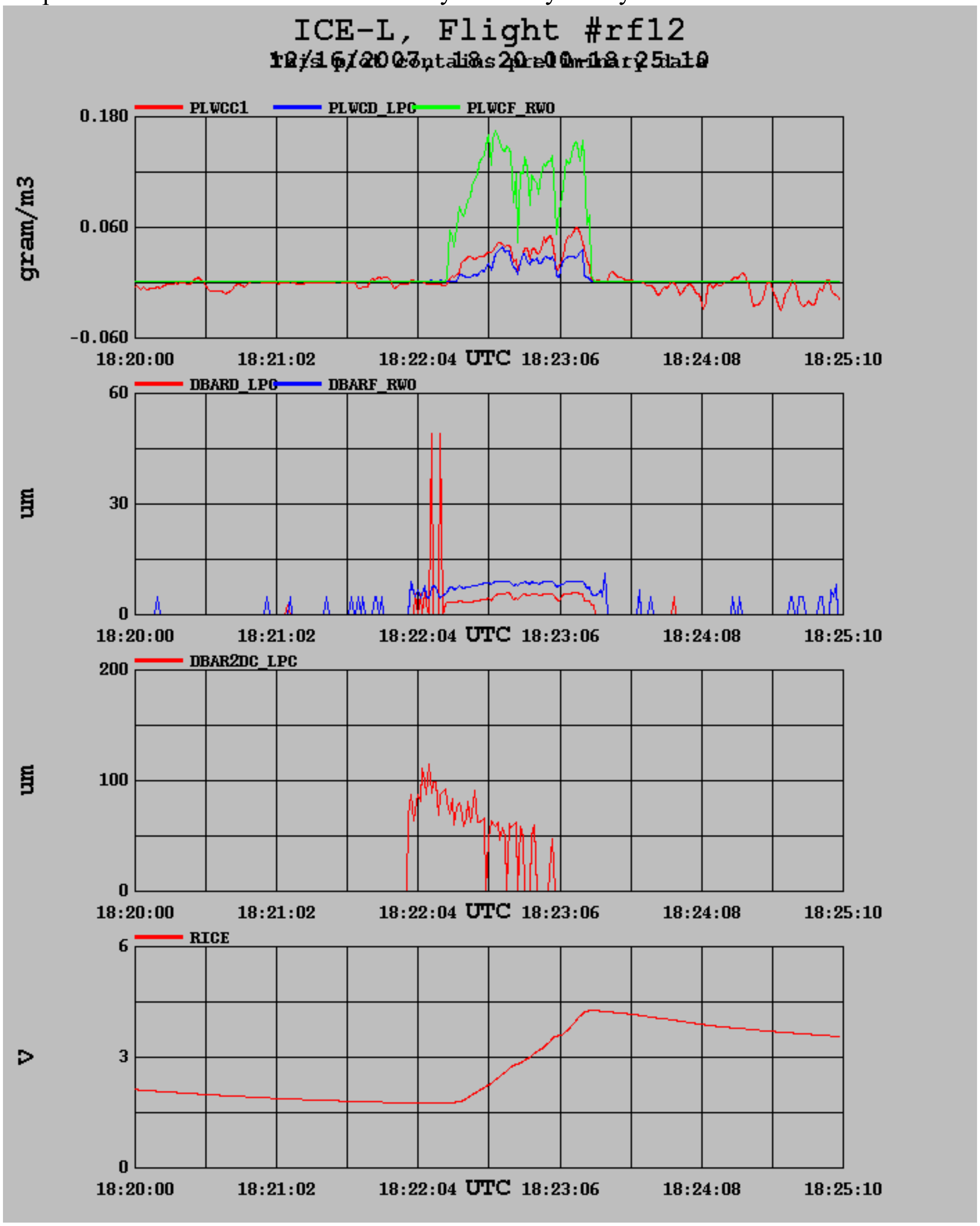
| | |
|---|---|
| PLWC1 | Dissipated power (wet + dry terms) for the King probe. |
| PLWCC1 | Cloud liquid water content ($g/m^3$) |

In addition the cloud liquid water content can be calculated from both the FSSP and CDP probes:

| | |
|---|---|
| PLWCF | FSSP cloud droplet liquid water content |
| PLWCD | CDP cloud droplet liquid water content |

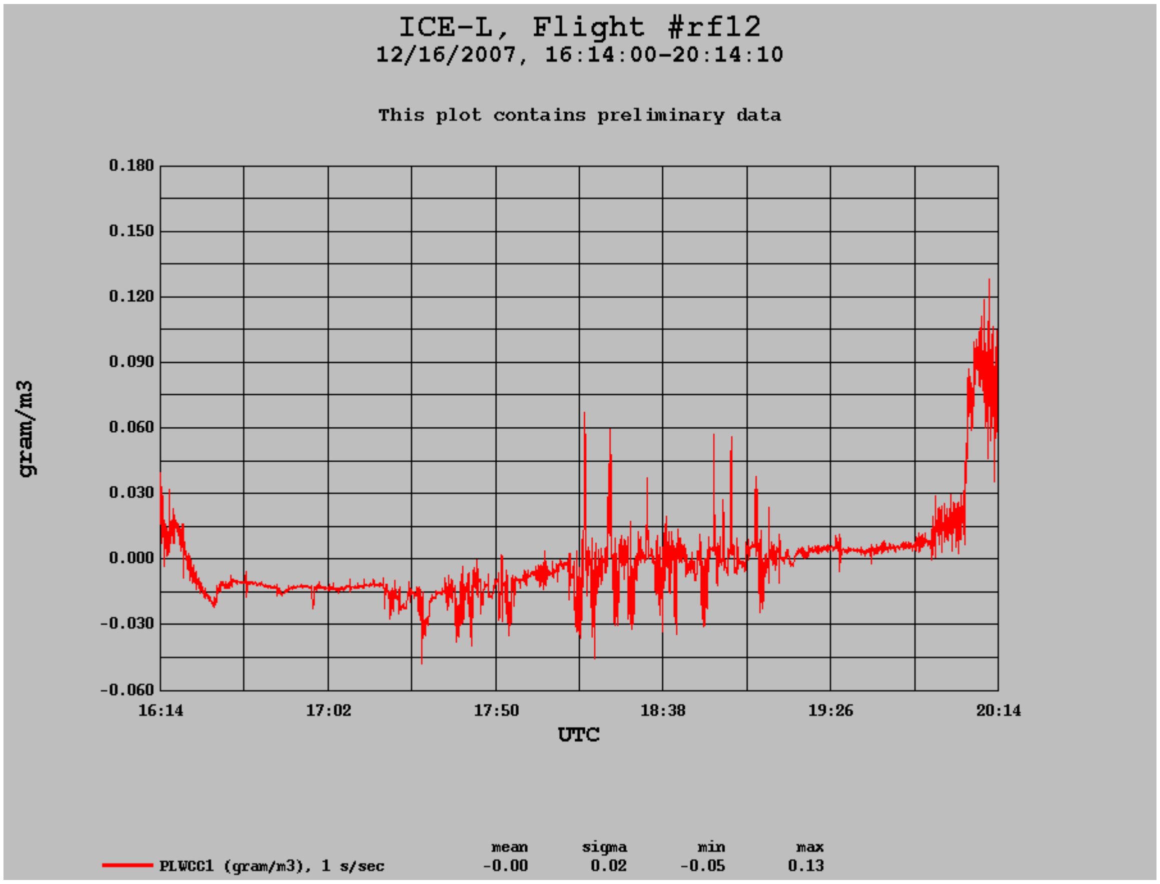
Care should be taken in interpretation of the liquid water content when drops are frozen or when small ice particle scattering is sized as liquid water drops.

Both the FSSP and CDP probes behaved very well in the DMT particle size calibration. Nevertheless, the FSSP (DBARF) normally has mean sizes of 3 micron higher than the CDP (DBARD) during flight conditions. The sample volumes of the two probes were also determined by DMT. The FSSP sample volume was measured, whereas the sample volume for the CDP is determined from theoretical considerations. It should be noted that the FSSP concentrations (CONCF) are often 50% higher than the CDP concentrations (CONCD). The net result is that the FSSP liquid water content commonly exceeds the CDP and King liquid water contents in cases of small drops, see the example below. In higher liquid water content situations, the CDP and King liquid waters are often in closer agreement, with the FSSP showing a larger difference from the other probes; however, the pattern shows considerable variability from day to day.



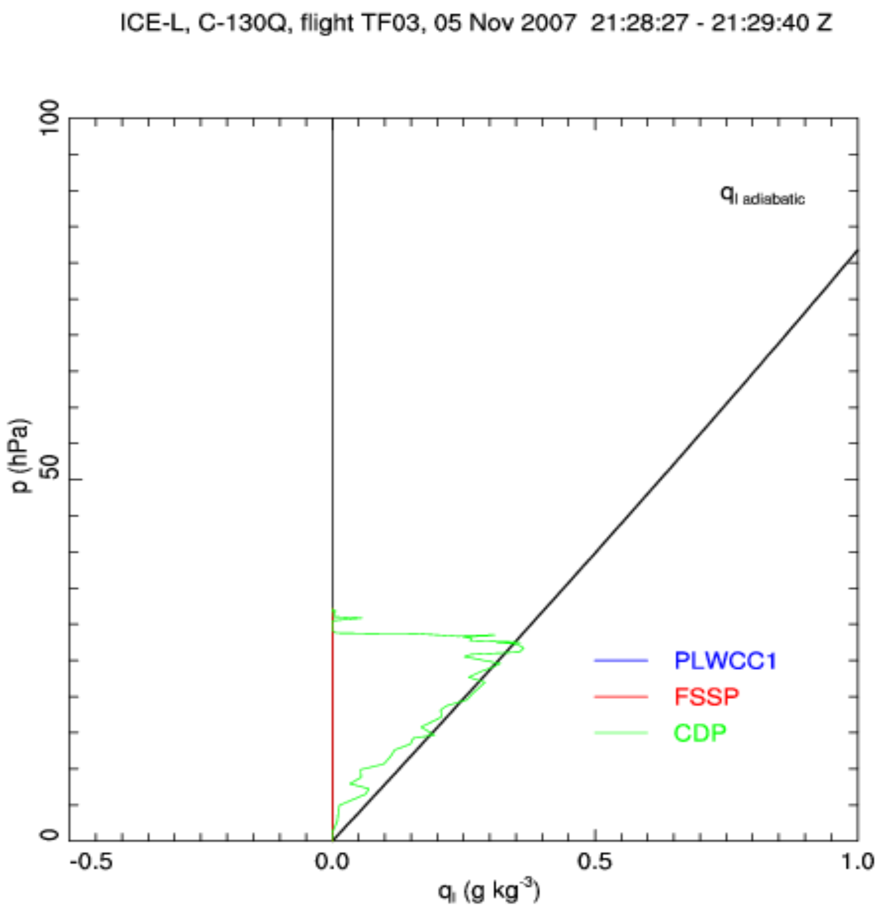

*Comparison of the three cloud liquid water probes (PLWCC1, PLWCD and PLWCF) for a situation of mostly water cloud with small average particle sizes.*

The King liquid water sensor is mounted under the wing of the aircraft. Thus as fuel burn changes the average pitch of the aircraft, there may be a small change (typically 0.02 g/m3 drift) in the liquid water reading offset; i.e. the value out of clouds. An example is given below. The figure also shows considerable changes in the King liquid water reading during initial climb and final descent when the flaps are set.

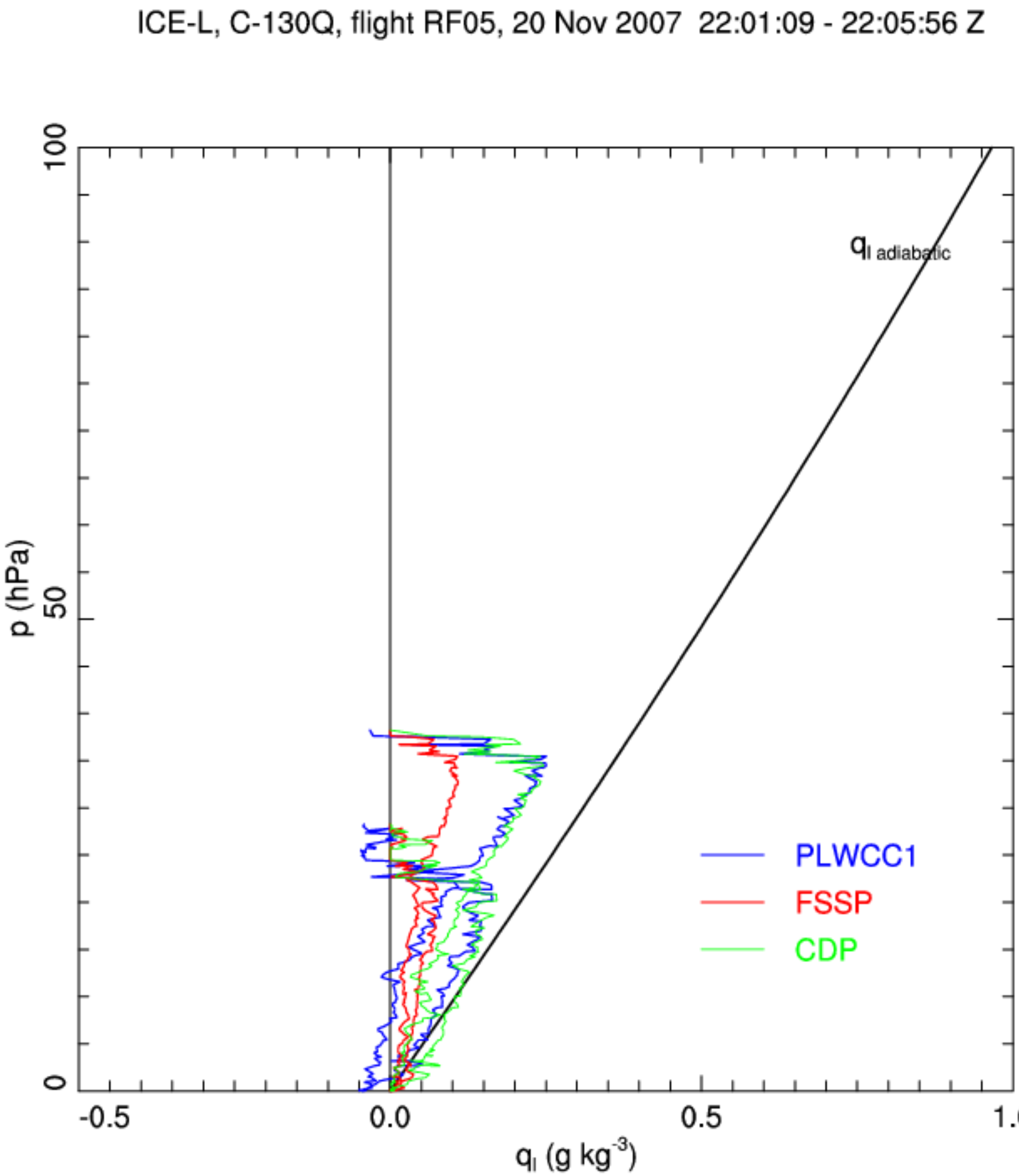



*Example of PLWCC1 drift over a flight (about 0.02 g/m3). Also notice the vastly higher values early and late with wing flaps extended.*

The measurement of liquid water content has been checked against adiabatic predictions for a number of different cases. The figure below shows the measurement of PLWCD and the calculated adiabatic water content for a vertical profile through an apparently well-mixed stratocumulus cloud with considerable liquid water content as observed during a touch-and-go in Wyoming during TF03. The figure shows that the CDP probe apparently closely matches the adiabatic prediction; if anything the CDP probe may provide a slight underestimate (compare the slopes of the black and red curves). The cloud base is not always well defined, so a constant offset between the two curves is not a serious issue.




*Variation of calculated adiabatic liquid water mixing ratio and observed values for the CDP probes against altitude. The King (PLWCC1) and FSSP probes were not functioning on this test flight. The results from the CDP probe is fairly close to the predicted water mixing ratio; if anything the suggestion is that the CDP may be slightly overestimating the actual liquid water mixing ratio.*




*Variation of calculated adiabatic liquid water mixing ratio and observed values for the King, FSSP and CDP probes, all against altitude. The aircraft moved a considerable horizontal distance during the descent and ascent through a stratiform layer, and the cloud base would appear to have some variation along the flight track; this is evident from the offset apparent for each of the three observed profiles. Nevertheless, for extensive parts of the profiles, the slope from both the King probe (PLWCC1) and the CDP probes are fairly close to the predicted adiabatic slope*

Liquid water contents are also calculated from the PMS 2D-C and 2D-P probes. These two probes are described in the section titled "Ice and precipitation particles". Two liquid water contents are calculated:

| | |
|---|---|
| PLWC1DC_LWO | Liquid water content for “entire in” particles (i.e. end diodes are not shaded) for the 2D-C probe |
| PLWC1DP_LWO | Liquid water content for “entire in” for the 2D-P probe |
| PLWC2DC_LWO | Liquid water content for particles using image reconstruction for the 2D-C probe |
| PLWC2DP_LWO | Liquid water content for particles using image reconstruction for the 2D-P probe |

Again, care should be taken with the interpretation of liquid water content measurement if the particles are ice.

**Icing rate:**

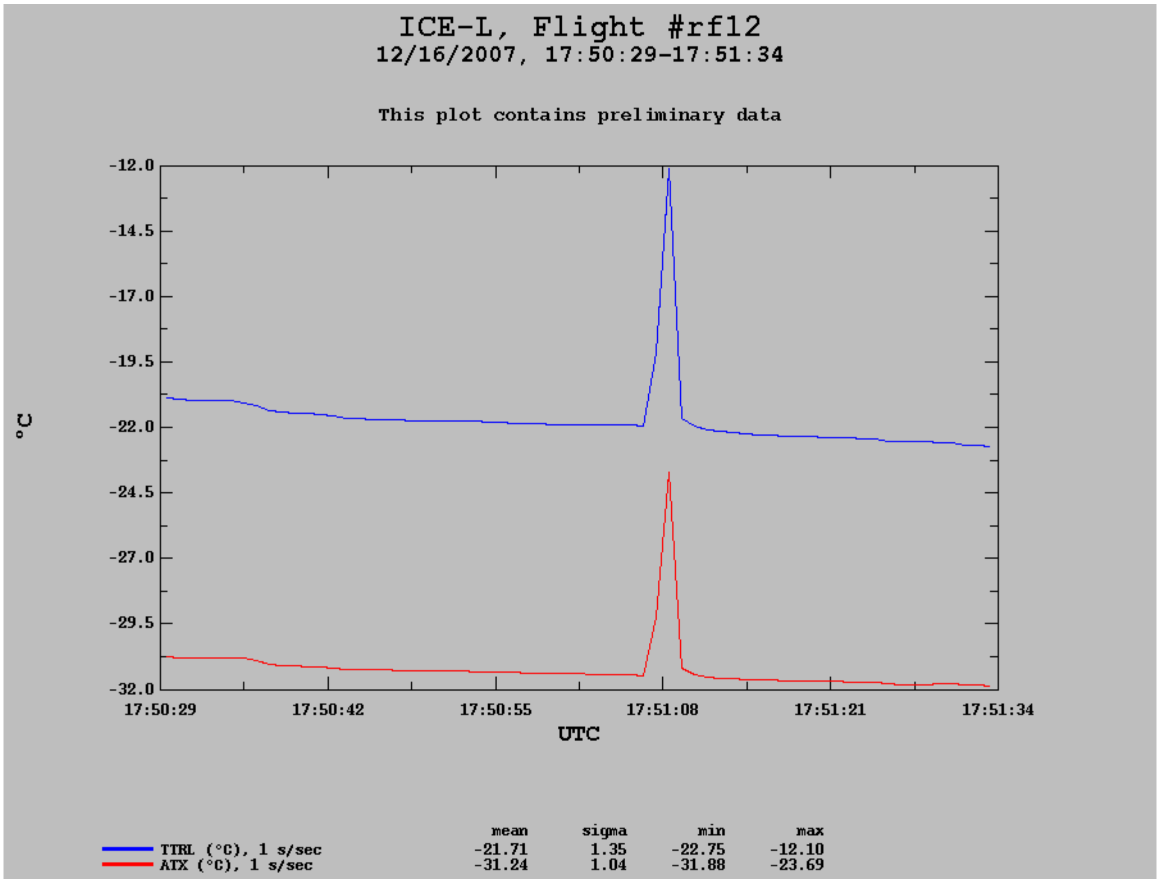
A standard Rosemount Icing rate meter was operated in ICE-L. This measurement is highly valuable in discriminating between supercooled water and completely glaciated cloud. Once ice builds up by freezing of supercooled water drops, the output voltage increases to a maximum near +10V. At this point the sensor circuitry heats the sensor to melt the accumulated ice, and the output voltage drops to 0V. Renewed ice accumulation will then increase the sensor output again.

| | |
|---|---|
| RICE | Rosemount icing rate |

**Other**
**Data logging and averaging:**

Analog data were logged at 500 sps and averaged to 1 sps. Most of the remainder of the data was recorded as serial data (e.g. RS-232), ARINC data (IRS units), etc.

The analog cards shows occasional spikes as apparent from spikes in multiple variables at the same time, and the cause of the spikes is currently under investigation. Most spikes are readily removed by the NIMBUS de-spiker, but spikes with duration longer than about 1 second cannot be removed. These remaining spikes are very few, typically only about two per flight. We have chosen not to blank out the variables with these ‘long spikes’ as it may affect derived parameters that only depend very weakly on the data with spikes.




*Example of a spike of duration 3 seconds. This cannot be removed by the processor de-spiker. Derived variables are thus also affected.*

The recordings listed for a given second contains measurements logged at e.g. 12:00:00 and until 12:00:01. The value of "Time" corresponding to this interval is given a 12:00:00 in the released data set.

All measurements are "time-tagged" at the time of logging. Subsequently these measurements are interpolated onto a regular grid and averaged.

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.

**Measurements on the ground**

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 as valid.

**Recommendation for variable names:**

In general RAF recommends using the 'reference' variables (those ending in "X"), where several exist.

**CPI instrument:**

The RAF CPI instrument data is not part of the netCDF files. Instead separate files are provided. The following flight-by-flight summary also contains comments on the availability of CPI data from ICE-L.

## Section 2: Flight-by-flight summary

**TF01:**

Test data only. Due to the nature of testing, the data quality may be spotty for many sensors.

**TF02:**

Test data only. Due to the nature of testing, the data quality may be spotty for many sensors.

**TF03:**

Test data only. Due to the nature of testing, the data quality may be spotty for many sensors.

**RF01:**

Heated temperature sensor faulty (ATWH).
Laser hygrometer not installed (MRTDL and MRTDLS).
King probe faulty (PLWCC1).
CDP faulty (CONCD and PLWCD).
No CPI data.
No 2D-P data.

**RF02:**

Heated temperature sensor faulty (ATWH).
Brief differences between TTRL and TTRR indicate brief periods of ice build-up.

**RF03:**

Heated temperature sensor faulty (ATWH).
Brief differences between TTRL and TTRR indicate brief periods of ice build-up.
FSSP faulty (CONCF and PLWCF).

**RF04:**

Heated temperature sensor faulty (ATWH).

FSSP faulty in latter part of the flight, after 22:12.
2D-P faulty.

**RF05:**

Severe icing affecting numerous sensors. In fact, the C-130 had to land to melt ice off sensors to regain performance. Users should carefully examine all measurements before usage.
Lots of differences between ATX and ATRL, often +/- 1 deg. In general not possible to say which one is correct, if any.
No ATWH data for the entire flight.
GPS dropout 2125:30 - 21:26:50.
UHSAS out during 21:25:10 - 21:27:20.
PLWCC1 has extensive periods where it is over iced, and not giving good results. This is clear from PLWCD vs. PLWCC1 plot.
PLWCC1 would appear to be bad after 17:40 and for the remainder of the first flight.
PLWCC1 freezes over at 23:55 during second flight.
Fast-2D-C shows occasionally some images with stuck bits, but it should not be a problem for analysis.
2D-P faulty.

**RF06:**

FSSP not installed (CONCF and PLWCF).
2D-P not installed; (SPEC FSSP installed instead).

**RF07:**

This flight had many descents to low altitude. The flaps were set, and there may be jumps in both static and differential pressure. These will work their way into the temperatures, winds and King liquid water content. There may be small errors in measurements of temperature and winds at low altitude.
No ATWH data for the entire flight.
FSSP not installed (CONCF and PLWCF).
DPTC goes bad after 19:36. Later values are blanked out.
2D-P not installed; (SPEC FSSP installed instead).

**RF08:**

No ATWH data for the entire flight.
FSSP not installed (CONCF and PLWCF).
2D-P not installed; (SPEC FSSP installed instead).

**TF04:**

Flight dedicated to state parameter and wind calibration maneuvers.

**RF09:**

**RF10:**

**RF11:**

**RF12:**

CDP may be faulty after 17:25 (approx). Smaller particles appear too small compared to FSSP probe.

## Section 3: Particular changes due to in-flight calibration maneuvers

**QCF:** Five pairs of reverse heading legs on TF04 gave a much better average along-track wind results (UXC) using and increased offset of QCF of +1.1 mb. This change improved measurements covering the entire true air speed range (TASX) of 110 – 150 m/s. This change was applied to all flights.

For the five pairs of reverse legs, the results of the correction are:

| Pair | TASX (m/s) | $\Delta$UXC (m/s) |
|---|---|---|
| 1 | 132.6 | 0.55 |
| 2 | 111.5 | 0.36 |
| 3 | 131.7 | 0.61 |
| 4 | 151.4 | 0.10 |
| 5 | 131.5 | 0.29 |

These results are well within RAF's normal requirements.

**QCR:** A comparison with QCF resulted in an offset of +0.5 mb being applied to all flights.

**QCFR:** A comparison with QCF resulted in an offset of +0.7 mb being applied to all flights.

**PLWC1:** The wire temperature has been changed to give approximately zero PLWCC1 liquid water content out of cloud. The optimum wire temperature varies from day to day, which may be a result of changes to the varnish coating on the wire element.