Project managers quality report, Jorgen Jensen – T-PARC

Information on T-PARC:

PI for the P3: Dave Raymond, New Mexico Institute of Mining and Technology.
Main web site: www.eol.ucar.edu/deployment/field-deployments/field-projects/t-parc
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Acknowledgments:

Thanks are due to EOL's technical, mechanical and operational staff for making T-PARC a success; many staff worked extremely hard in both the preparation and execution phase of T-PARC. Thanks are also due to the NRL for expertly flying the aircraft in a very challenging environment and for their flexibility in the operations involving airports in both Guam and Japan.

Background:

The NRL P-3 carried the ELDORA radar as its main instrument. In addition the aircraft carried thermodynamics, inertial and wind sensors from RAF and a wind Doppler-lidar from Simpson Weather Associates. The present report only refers to the RAF instruments. These instruments functioned in general well, although the measurement of attack is only of low quality. There were some issues with icing that affected the un-heated radome measurements of flow angles but this was mostly limited to high-altitude ferry legs that were not a critical part of T-PARC sampling of tropical cyclones and depressions. There were also several instances of icing formation on the two un-heated temperature sensors; in several cases this lead to damage of the wires. However, having two temperature sensors meant that good measurements of temperature is available for almost all flights.

This summary has been written to provide users with guidance understanding the instruments and data set as a whole. The following outlines basic instrumentation issues affecting the quality of the data set and it 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 P-3 sensors, variable names etc. In particular, the purpose of Section 1 is:

> To describe the instruments installed onboard P-3 in T-PARC in some detail. Many instruments and variable names differ from those used on the C-130 and the GV. The following description covers the most commonly used variables in the T-PARC P-3 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

The following description refers to the low-rate (1 sample per second) data. 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 1 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 using a fuselage-mounted pitot tube connected to a Rosemount sensor:

PSF/PSX	Static pressure as measured using the fuselage pitot tube
PSFC/PSXC	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 two sensors on the P-3, and both are un-heated Rosemount sensors. These sensors can be affected by icing, and this was a problem during parts of T-PARC. The sensors may also be affected by wetting when the aircraft is flying in cloud or precipitation; this may cause the calculated temperatures to be lower than the dewpoint temperature when flying in cloud and precipitation. A method for calculating the cooling of a fully wetted temperature element is given by e.g. Lenschow and Pennell (1974, Monthly Weather Review, **102**, 447-454). The P-3 was not equipped with a liquid water sensor, so it is not possible to independently pinpoint the times when the aircraft was flying in cloud or precipitation.

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.
ATRL	Ambient air temperature from the Rosemount system, left side of the fuselage.
ATRR	Ambient air temperature from the Rosemount system, left side of

the fuselage.

ATX   Ambient air temperature from the best of the two Rosemount systems (set to either ATRL or ATRR).

RAF recommends using temperature, ATX, for the T-PARC data set, but users are advised to examine the comparison between the traces of ATRL and ATRR for individual time segments as a means to detect if either of the temperature measurements are affected by icing, wetting and/or radio interference.

Indications are that ATRL is more affected by radio interference during the brief times of pilot communication with Air Traffic Control. Thus when ATRR is well functioning, then RAF has used this sensor for ATX. An example of radio interference is shown below.

Example of radio interference on the ATRL measurements. This interference is rare when the P-3 is in the middle of its mission.

Although icing buildup on the temperature sensors was rare, it was a problem for two reasons. Firstly, icing buildup changes the airflow through the temperature sensors, thus changing the ventilation of the temperature element. Secondly, the wires are very fragile due to their design for measurement of rapid temperature fluctuations. Icing buildup may stretch the wires, thus changing the resistance and calibration of the sensor. In a worst-case scenario, the temperature wires may break, thus rendering the sensor unserviceable. Two examples of icing impact on the temperature sensors are given below.

Measurements of temperature using the two fast-response Rosemount sensors (ATRL and ATRR) during an icing encounter. ATRL appears to be icing affected from 00:32:30 and ATRR from approx. 00:36:00. ATRL would appear to recover at about 00:51:00 and ATRR about 4 minutes later.

After review, most obvious periods affected by icing have had the temperature variable set to the missing data flag (-32767) in the final data set.

Time series of temperature (ATRL, ATRR) and dewpoint (DPXC). In this case ATRL suffers from icing at 02:16 and ATRR about a minute later. ATRL shows sudden temperature drops of about 30 degrees; this is typically caused by sensor element winding being stretched and touching one another, sometimes for extended periods, see e.g. the period from 02:31 to 02:37. The two temperature *sensors appear to recover from icing effects at 02:41, the damage the ATRR element is so severe that it completely malfunctions after 02:44. The damage to ATRL can bee seen to persist during three brief periods after 03:02.*

The temperature measurements affect the calculation of true air speed and thus the calculated 3-dimensional winds. In Appendix 1 is a flight-by-flight list of issues, including notes on the temperature measurements. Icing problems are almost exclusively confined to the second part of T-PARC (RF13 and beyond); mostly there is at least one good temperature sensor but users should carefully examine the temperature measurements when analyzing thermodynamics and winds for the part of T-PARC. When in doubt, please contact Jorgen Jensen (303-444-0469, jbj@ucar.edu).

Dewpoint temperature and vapor density:

Humidity was measured using an EG&G Model 1011B cooled mirror hygrometer. This sensor is 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 at steady state conditions. The cooled mirror sensor is slow, in particular at lower temperatures, and this may give considerable differences measured and actual dewpoint in regions of rapidly varying humidity fields. 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. Where sharp gradients in dewpoint are encountered, there may be overshooting of the actual dewpoint value. In some cases there appears to be some oscillations in the dewpointer signal; this may be caused by liquid water ingestion into the sensor or by dirt accumulating on the mirror.

At very low temperatures the sensor may not be able to track the actual dewpoint due to the units inability to operate in air with large dewpoint depressions.

DPT	Dewpoint/frostpoint as directly measuredby the cooled mirror sensors (assumed dewpoint for DPT>0 C and frostpoint for DPT< 0 C).
DPTC/DPXC	Dewpoint as measured or calculated for the cooled mirror sensor.

RAF recommends using DPXC as the variable for dewpoint.

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

The ADIFR sensor suffered from multiple malfunctions during T-PARC, beginning with ferry flight RF02. Although the units in other cases and on other aircraft have been very stable, this was not the case for the T-PARC deployment. Multiple units very rushed as spares into the field, but the ADIFR measurements is nevertheless of very low quality for T-PARC. It is not clear if the issue was caused by power supply problems, signal wire problems, small tubing leaks or unstable sensors. The measurement of ADIFR also impacts the calculated vertical velocity, see later.

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. Careful review has been used to flag periods with suspect icing of the radome, and the differential pressure and angle values are flagged with the missing data flag, -32767. Periods with problems will have the missing data flag propagated to the wind measurements. 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	True air speed from the fuselage pitot system
TASHC/TASX	True air speed using the fuselage pitot system and adding humidity corrections to the calculations; this is essential for tropical environments such as T-PARC.

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 P-3:

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.

Honeywell inertial reference system: The P-3 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. RAF recommends using the filtered IRS/GPS data.

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 primarily caused by the aforementioned instability in the attack-angle pressure system, ADIFR, with only a small contribution from 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 P-3 wind system is not suited to turbulence (flux) studies.

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”. RAF has a high confidence in the horizontal winds, and less confidence in the vertical measurement of winds (WI and WIC).

Radar altitude:

The HGM232 radar altimeter is useful for determining aircraft altitude; the Garmin GPS can also be used for this purpose. The HGM232 system has some spikes in the data, but these are readily apparent in comparison with the GGALT parameter from the Garmin sensor. The RAF NIMBUS data processor has removed most of HGM232 spikes, 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

Other
Data logging and averaging:

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.

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.

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:

ATRL shows occasional radio-interference spikes; ATRR (ATX) does not show this.

RF02:

A number of small radio spikes in ATRL.

RF03:

A number of small radio spikes in ATRL.

RF04:

A number of small radio spikes in ATRL.

RF05:

A number of small radio spikes in ATRL.

RF06:

A number of small radio spikes in ATRL.

RF07:

A number of small radio spikes in ATRL.

RF08:

A number of small radio spikes in ATRL.

RF09:

A number of small radio spikes in ATRL.

RF10:

A number of small radio spikes in ATRL.

RF11:

ATRL slightly warmer than ATRR at warm temperatures (~ 0.3 degC at 24 degC).

ATRL has many small radio spikes.

RF12:

ATRL has many radio spikes.

RF13:

Several cases of icing impacting the recording of temperature; the ice build-up ventilation leads to lower temperature recordings (compare to DPXC)
Both ATRL and ATRR suffer from severe ice buildup at 26:16 and for the rest of RF13a; measurements of many derived parameters (incl. wind) are suspect for this period. ATRR malfunctions after 02:44.

ATRL has several cases of up to 30-degrees reduction due to wire wounds shorting out.

As a consequence of the temperature sensor problems, the netCDF files has been broken into two files, 305rf13a.nc and 305rf13b.nc. The sensor used for ATX was swapped between the end of the first file and the start of the second file.

RF14:

ATRR faulty.

DPTC faulty in small time segments.

Occasional GPS track-angle (GGTRK) drop out during 29:24 – 30:20 (implications for wind measurements?)

RF15:

ATRR faulty.

Occasional GPS track-angle (GGTRK) drop out during 00:14 – 00:54 (implications for wind measurements?)

Data system re-boot 01:14:50 – 01:15:20.

RF16:

ATRR faulty.

Occasional GPS track-angle (GGTRK) drop out during 02:47 – 03:53 (implications for wind measurements?)

ATRL faults during the following periods. (Note that many derived parameters are also affected, e.g. winds):

07:08:30 – 07:12:30
07:19:00 – 07:19:30
07:26:00 - 07:29:00
09:34:20 – 10:02:30
11:42:10 – 11:50:00

QCR develops a permanent offset during the flight, probably due to icing. Use QCXC.

RF17:

ATRR faulty.

ATRL faults during the following periods. (Note that many derived parameters are also affected, e.g. winds):

26:16:50 – 28:18:30
26:27:50 - 26:32:10
27:02:50 – 27:19:00
27:20:00 – 30:27:00
30:31:00 – 30:38:30
30:39:30 – 30:40:10

30:41:40 – 30:45:30

Occasional GPS track-angle (GGTRK) drop out during 24:18 – 25:06 (implications for wind measurements?)

RF18:

ATRR faulty.

Occasional GPS track-angle (GGTRK) drop out during 00:10 – 00:47 (implications for wind measurements?)

ATRL faults during the following periods. (Note that many derived parameters are also affected, e.g. winds):

04:06:50 – 04:07:40
05:06:40 – 05:08:50
05:10:10 – 05:11:00
05:26:50 – 05:30:20
05:36:00 – 05:37:00
05:38:20 – 05:40:00
05:41:40 - 05:48:30
06:39:00 – 06:46:40
06:51:00 – 06:56:30
07:01:20 – 07:01:40
07:08:40 – 07:10:00

Unstable dewpointer during 03:43 – 05:58.

Dewpointer re-balanced during 05:58:30 – 06:04:40

ADIFR (and thus ATTACK angle) error during 06:32 – 06:37:30.

RF19:

Occasional GPS track-angle (GGTRK) drop out during 20:29 - 20:46 (implications for wind measurements?)

Evidence of temperature sensor wetting during 21:05 – 21:08. Aircraft must be in cloud or precipitation.

Many spikes in ATRL temperature data.

RF20:

Occasional GPS track-angle (GGTRK) drop out during 22:20 – 23:13 (implications for wind measurements?)

RF21:

60-second auto-pilot oscillations affect static pressure and wind measurements during 21:08 – 21:27.

Electronic noise in temperature and dewpoint measurements during 21:00 – 21:04.

Occasional GPS track-angle (GGTRK) drop out after 24:59 (implications for wind measurements?)

RF22:

Extended flight times were made at temperatures of -3 to -15 with ensuing icing build-up. This affects wind measurements and temperatures during the flight.

QCR hole froze over during 21:41 – 21:59 and to a lesser extent on many subsequent occasions. AKRD (and thus attack angle) affected by freezing during 21:52 – 21:59:10. BDIFR (and thus sideslip angle) affected by freezing during 21:52 – 21:59:00. There may have a number of other smaller periods affected by icing of the radome holes.

Occasional GPS track-angle (GGTRK) drop out from 23:08 – 23:35 (implications for wind measurements?)

Temperature sensors and radome measurements impacted by icing during 24:14 -24:26a and 24:41 - 24:52:10; state parameters and wind measurements are unreliable during these periods.

Radome affected by icing during 26:05 – 26:07, winds impacted.

RF23:

Where is the end of the file? File ends at 28:35:40. Yet, timeseries implies at 10-hour flight???

ATRL offset of 0.4 degrees – correct.

Occasional GPS track-angle (GGTRK) drop out from 23:15 – 23:47 (implications for wind measurements?)