Subject: Dew point correction for pressure in housing
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Background

The external dew point sensors have housings exposed to the airstream by a special inlet, shown in Fig. 1 below. The inlet is supposed to be rotated so that the pressure in the housing matches the ambient pressure. On the GV especially, this is difficult because of the high speed and large range in angle of attack. Without measurement of the pressure in the housing, a large uncertainty would be introduced in the measurement. Since May 2011 there have been transducers for pressure in each of the external dew point sensors, recorded as a new variable PSDPx (x=L or R). This pressure, however, is not yet incorporated into the processing code, so this note describes how that should be done.

Present Processing Code

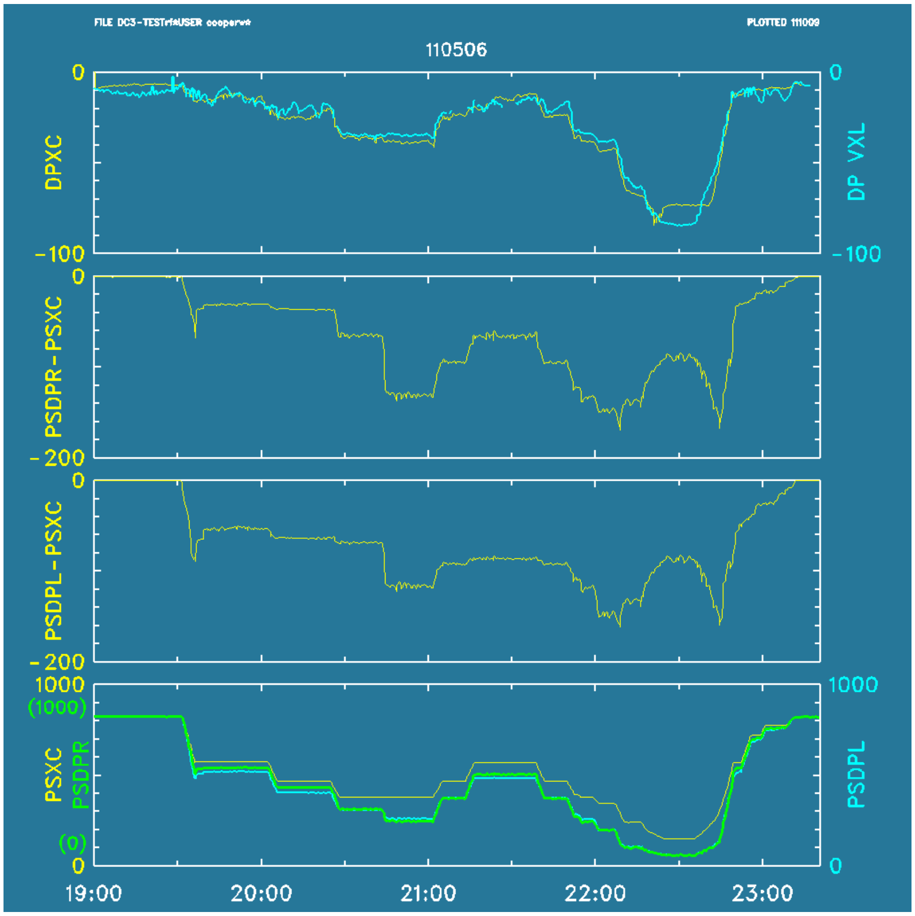
Processing of the dew point measurements to obtain vapor pressure was described in the earlier note on vapor pressure, where a change to Murphy-Koop was recommended. A relationship between vapor pressure and dew point was recommended for use there, because that is necessary to remove the effect of the "enhancement factor" that requires an enhanced water vapor pressure for equilibrium in the presence of dry air. The latter relationship can also be used to correct the dew point for the error arising from the pressure in the housing, so that will be the approach taken in this note.

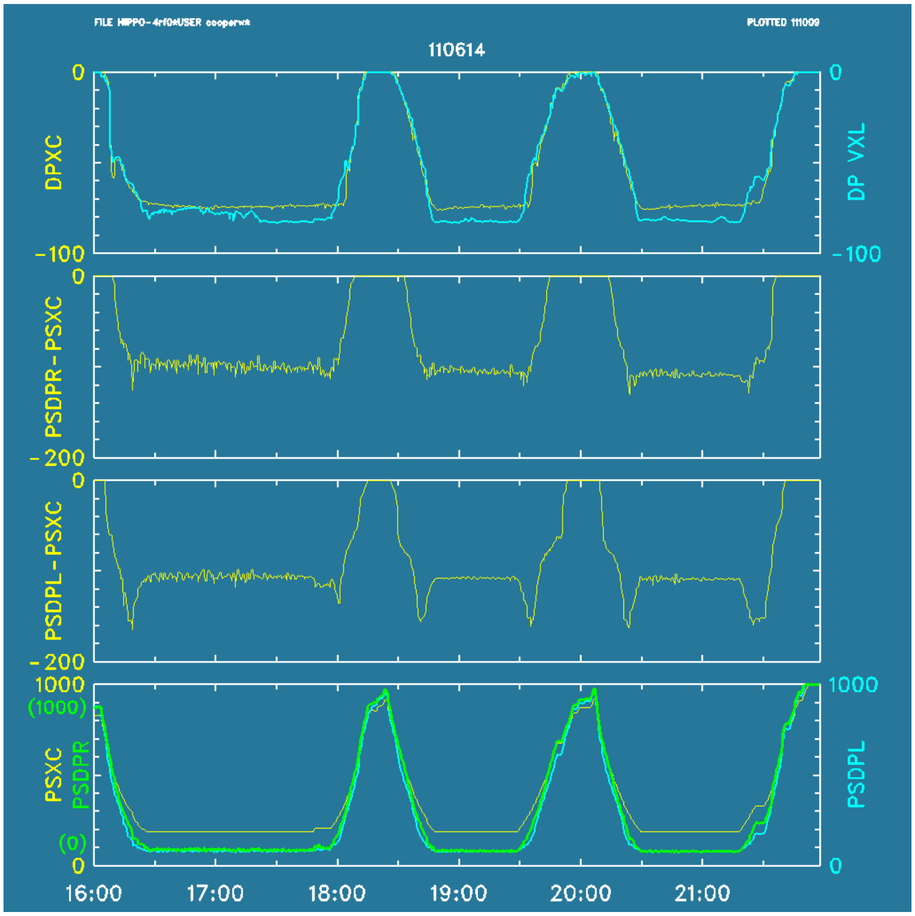
Reasons For Proposing Changes

It is important not only to incorporate the measurement of housing pressure into the processing but also to correct, as far as possible, the past measurements. The reason is that otherwise the error can be significant. An approximate estimate of the error can be obtained from the typical dependence of vapor pressure on dew point, for which the vapor pressure changes approximately a factor of 2 for each 10° change in dewpoint. If the pressure in the housing is only 50% of the ambient pressure, for example, the vapor pressure deduced from this measurement will also be 50% of the correct value, and the dew point will be about 10°C too low. The initial measurements suggest that this value is not as extreme as expected before this measurement was added.

Analysis

The following two plots show examples of the pressure measurements, the first from DC3-TEST rf03, the second from HIPPO-4 rf01:


FILE DC3-TESTrf#USER cooperw*
PLOTTED 111009
110506
DPXC
DP VXL
PSDPR-PSXC
PSDPL-PSXC
PSXC
PSDPR
PSDPL
0
-100
-200
1000
(1000)
(0)
19:00
20:00
21:00
22:00
23:00



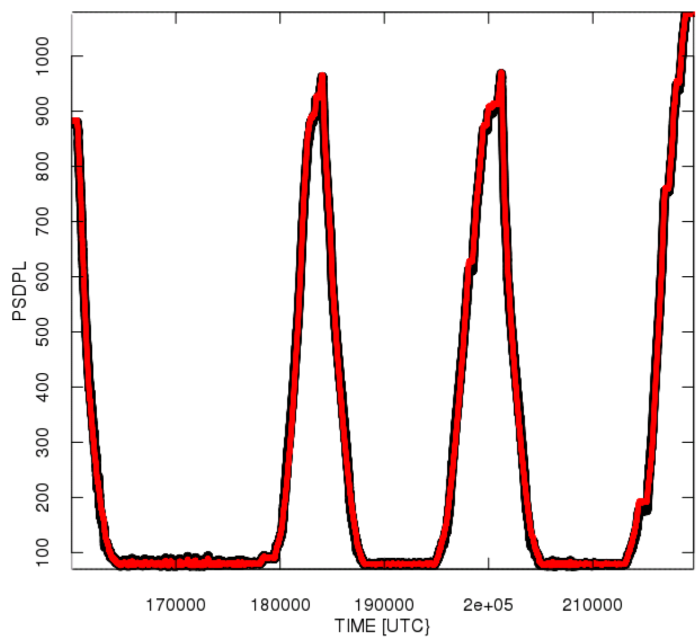
In both cases the pressure in the housing is almost 100 mb less than the ambient pressure at the upper levels, although the pressure agrees with the ambient on the ground. For example, at 170000 in HIPPO-4 rf01, the measured pressure is about 188 mb but the pressure in the housing of the DPR sensor is 90 mb. This is surprising because the dynamic pressure here is only 98 mb, so the pressure deficit in the housing is the same as the full dynamic pressure. The airspeed is Mach 0.80 and the dew point sensors are in a region of possibly accelerated flow around the nose of the aircraft, so perhaps some extreme effects can arise at near-sonic speed. (The effect seems so large that further consideration of the calibration of the sensor is indicated, but the rest of this note will assume that these pressure measurements are valid.) It is curious that the pressure difference for PSDPL shows periods of extra deviation in both climbs and descents, as shown by the dips in the second panel of the HIPPO-4 flight, but the similar deviations do not occur for PSDPR. These deviations occur where the angle of attack is lower than in level flight, by about 1 degree, both for climbs and descents. so they suggest a dependence on angle of attack as well as on airspeed and pressure. Plots of QCRC and MACH1 in these regions show that there are significant deviations in QCRC, but not in MACH1, associated with the deviations in housing pressure at the start of climbs and descents. These suggest looking for correlations between the pressure deficit and QCRC and/or angle of attack, in addition to a dominating correlation with Mach Number or airspeed.

A fit to the data of RF01, HIPPO-4, found significant dependence on PSXC, Mach Number, and

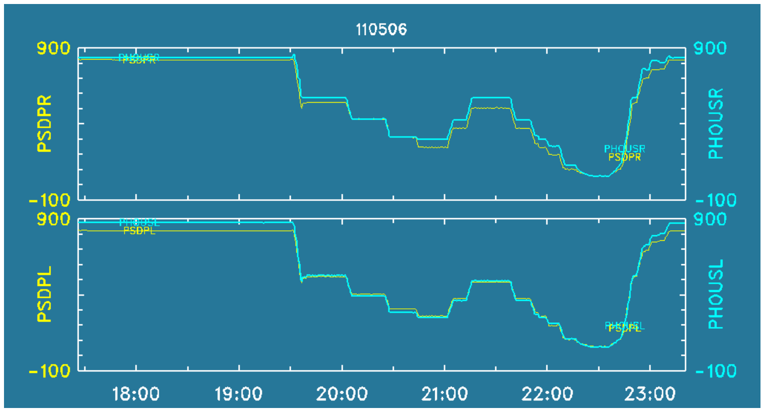
QCRC. The following fit gave a residual RMS of 7.9 mb and extreme deviations all less than ±30 mb:

$$\{\mathrm{PSDPL}\} = \mathrm{PSXC}\,(a_0 + a_1\{\mathrm{QCXC}\} + a_2\{\mathrm{XMACH2}\}) \qquad (1)$$

where a_0=1.064737656, a_1=0.001574938 mb^{-1}, $a_2 = -1.249778256$. For the right dew point sensor, the coefficients were slightly different: 1.016216249, 0.003024151 mb^{-1}, and -1.345207603. In this case, the fit had a higher RMS error, about 12 mb, and maximum errors of about ±45 mb. The following plot shows the measured pressure in the housing, PSDPL, as the thick black line, and the fit from the equation above, as the thin red line, for flight RF01 of HIPPO-4:

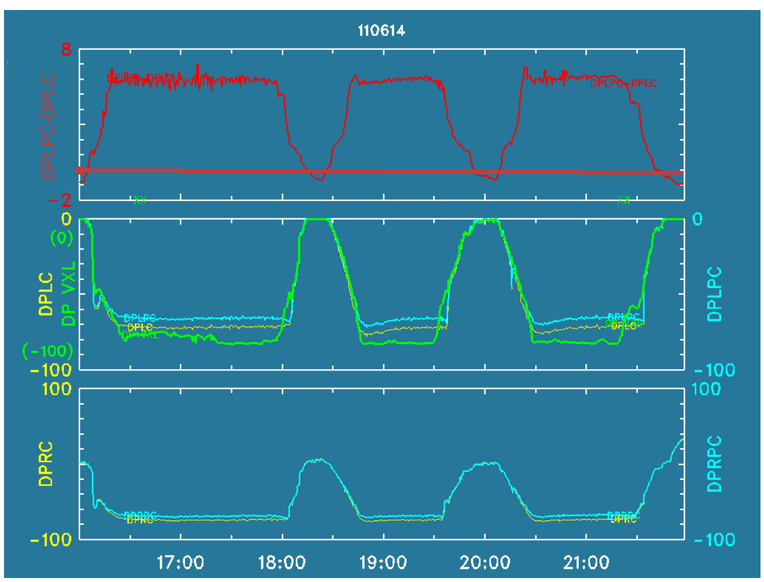


The importance of this fit is that, if it applies to flights prior to installation of the pressure sensor, it can be used to correct archived values. At least for the HIPPO flights, this seems reasonable because the flight profiles were reasonably similar to this one. To test how well this might apply to other projects, flights from DC3-TEST were used to compare the predictions of this formula to the measured values. The results are shown in the next figure:



In this figure, the yellow lines show the measured pressures and the blue lines the predicted pressure on the basis of the fit determined from HIPPO-4 flight RF01. The predicted pressure is significantly better for the left dew point sensor (PSDPL) than for the right sensor, giving a standard deviation (for the portion from 1940 to 2250) of 11 mb vs 25 mb for the right sensor. An error of 11 mb at a pressure of 400 mb, or an error of about 3% in vapor pressure, leads to an uncertainty in dew point of approximately 0.4°C, while a 25 mb error corresponds to an error in dew point of about 1 °C.

The following plot shows an example of the magnitude of the difference between the corrected and original dew point measurements:



In this plot, the yellow traces in the bottom two plots are the original measurements, and the values corrected for housing pressure are shown in blue. The green trace in the second panel is the dew point from the VCSEL for the same time. The difference between the values of dew point for the left sensor is shown as the red trace in the top panel. The differences are often around 6°C and vary from -1 to +6 during the climbs and descents.

Recommendations

1. Add processing to include the effect of the measured pressure, as follows:
   (a) Calculate the pressure ratio PSXC/PSDPx =Rx
   (b) In the new processing sequence for dew point, as described in the memo discussing vapor pressure and recommending use of the Murphy-Koop equations, multiply the vapor pressure by Rx after converting from dew point to vapor pressure.
   (c) Use this modified vapor pressure as the output variable, and also as input to the interpolation table to find the dew point temperature.
2. For old GV data, consider reprocessing with the pressure determined from (1) to correct for rather large errors in the dew point measurements, which can be 5-10°C.

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