Subject: C130 hybrid variables (Kalman filtered)
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Background

The Honeywell IRUs on the C-130 have integrated Kalman filters that provide updating to GPS measurements. This should provide improved measurements in comparison to the standard variables. This note presents my evaluation of those hybrid variables.

For wind measurements, the primary source of uncertainty is the uncertainty in the pitch and heading variables, for respectively the vertical and horizontal wind measurements. The aircraft vertical and horizontal velocities also enter those measurements, but we already have good measurements of those from the GPS units.

The Velocity Components

Despite their lesser importance for our purposes, I will start with the velocity components because that is the case where the Schuler oscillation is easiest to detect.

Figures 1 and 2 show, as the blue thickest lines, the differences VEW-GGVEW and VNS-GGVNS, respectively for the standard INS output. The Schuler oscillation representing the error in Earth-relative motion from the INS is clear in these plots, with magnitudes of the errors that exceed 1 m/s at times and for the flight have RMS errors of about 0.5 m/s. The green traces show that the hybrid output from the INS is much better, with typical RMS errors of about 0.2 m/s. However, the dashed red traces show that the variables resulting from our complementary-filter processing (resulting in VEWC and VNSC) are still better, with RMS errors of about 0.06 m/s. For the motion of the aircraft relative to the ground, the hybrid variables are a significant improvement over the standard variables, but they do not provide any advantage for our wind measurements because our complementary-filter approach already produces still better ground-speed components.[1]

Pitch

Improvement in the measurement of pitch would be valuable, but there does not appear to be a measurement of pitch among the hybrid variables provided by the INS. Pitch can be improved significantly using the "CorrectPitch()" function provided by Ranadu and documented in the Tech Note on the Kalman filter,[2] but that presently uses difference between the INS-provided ground-speed components and those from the GPS to deduce the pitch error. This same approach can't be

[1] There is apparently no vertical-motion variable among the hybrid variables so no improvement over the standard variable (VSPD).

[2] Cooper, W. A., 2017: A Kalman Filter to Improve Measurements of Wind from NSF/NCAR Research Aircraft. NCAR Technical Note NCAR/TN-540+STR, 73 pp, doi:10.5065/D61N7ZTS.

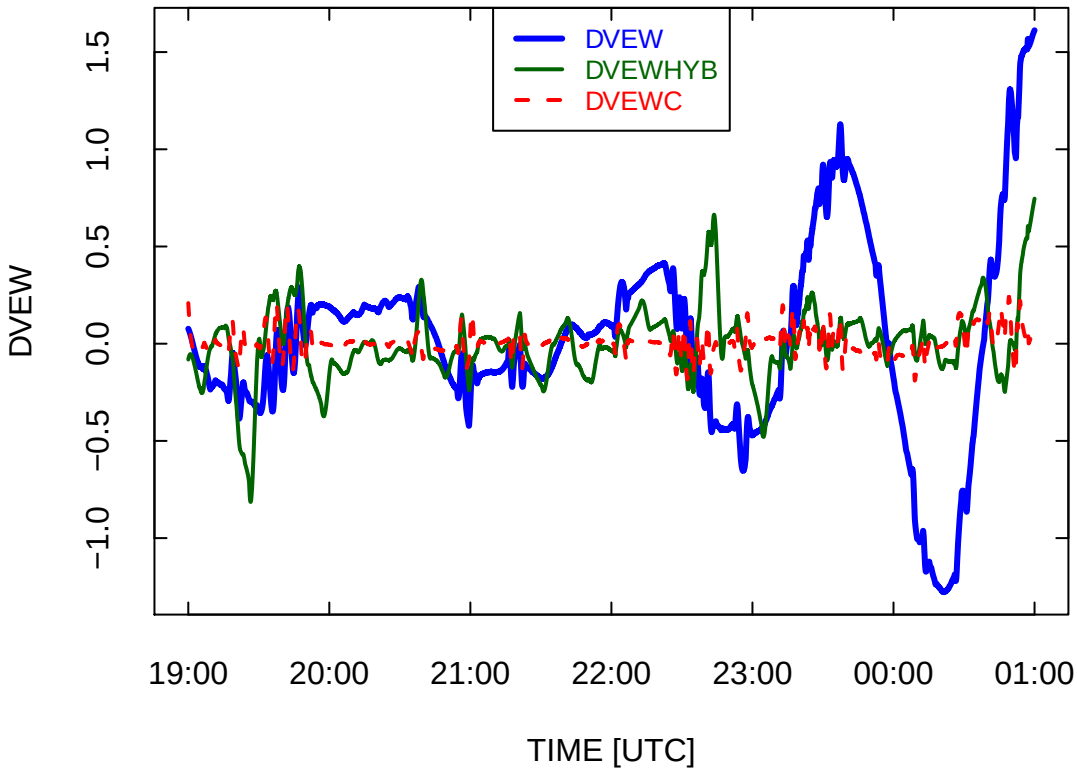

Figure 1: Differences in eastward components of aircraft ground speed in comparison to the ground speed from GPS, for WECAN research flight 5. DVEW=VEW-GGVEW, DVEWHYB=VEWHYB-GGVEW, DVEWC=VEWC-GGVEW.

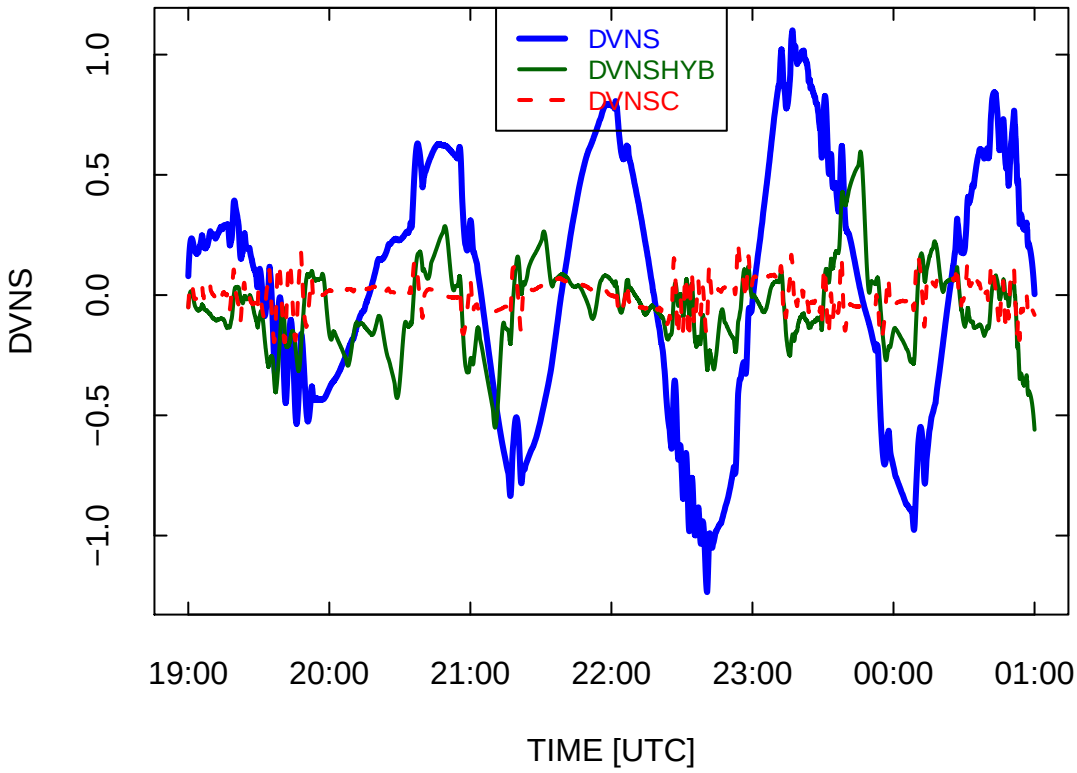

Figure 2: As in the preceding figure but for the northward component of aircraft ground speed.

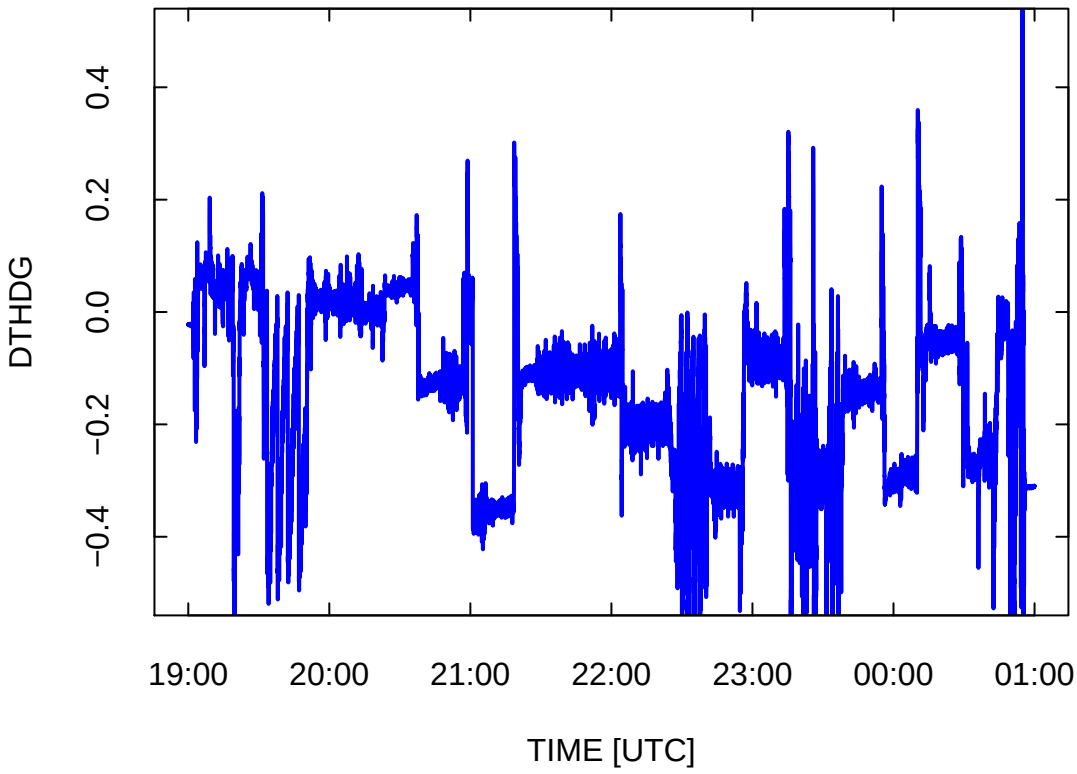

Figure 3: The difference between the standard heading measurement (THDG) and the hygrid measurement (THDGHYB), for WECAN research flight 5.

used with the hybrid variables because the error has been removed partially from the ground-speed components, so the hybrid variables do not provide any advantage for measurements of pitch and hence for vertical wind.

Heading

The hybrid variables include a measurement of heading (THDGHYB), and that variable differs from the standard variable (THDG), as shown in Fig. 3. The period from a spiral descent, 19:31:00 – 19:52:00, is shown in Fig. 4. Figure 5 shows that there is a peculiar variation in the difference between heading measurements as a function of heading, with the difference varying from ≈ 0 for heading just above 180 and decreasing to $\approx -0.47^\circ$ for a heading just below 180. This is a large difference in heading, more than the uncertainty expected in either value, and such a vari-

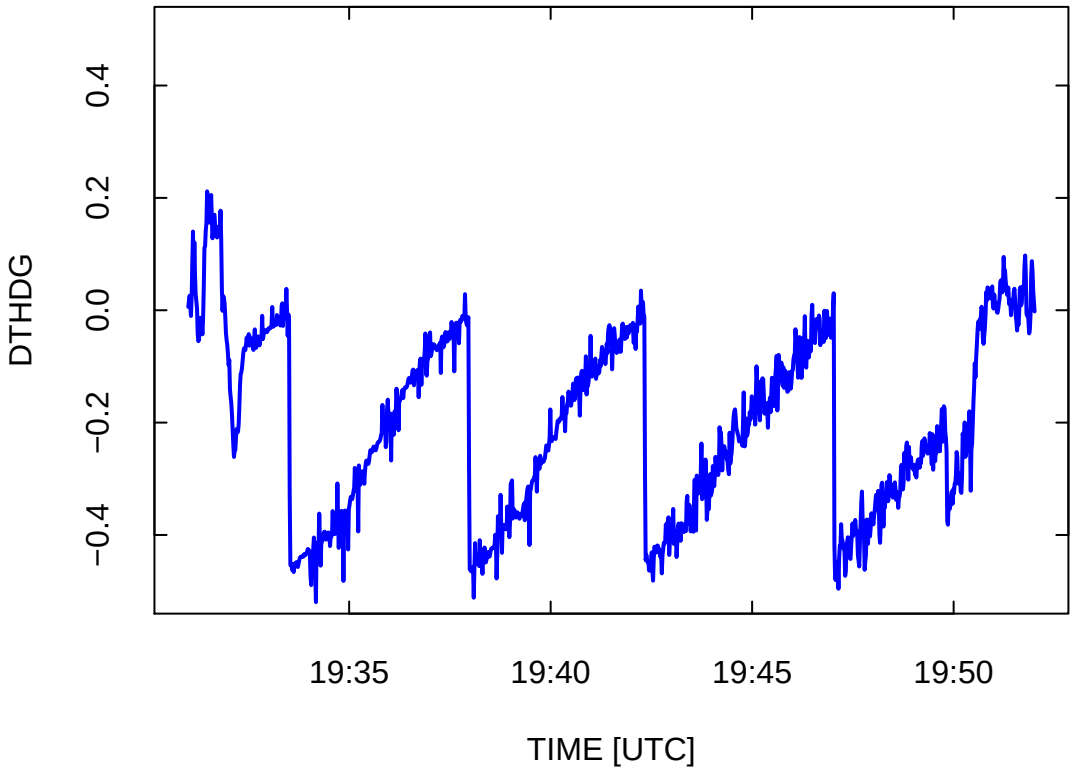

Figure 4: As in the preceding figure but for the period during a spiral descent featuring several circles.

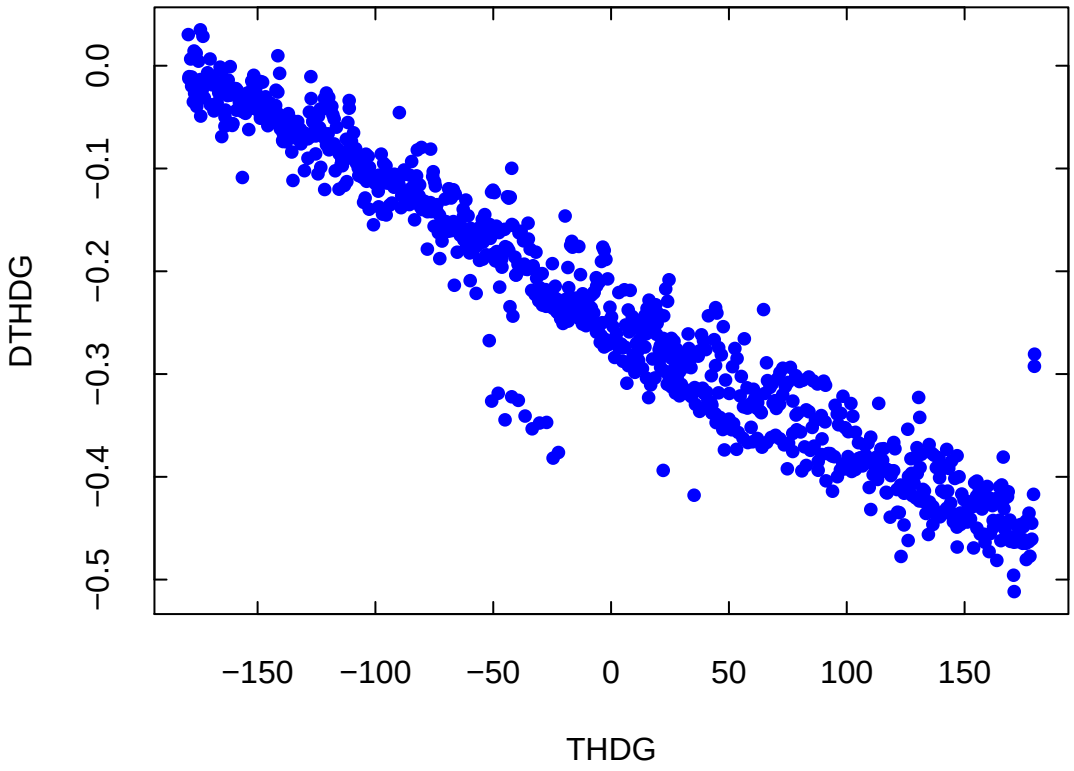

Figure 5: The difference shown in the preceding figure for the period 19:35:00 – 19:50:00, plotted as a function of the heading where, to emphasize the linear trend and the discontinuity at 180 degrees, 360 has been subtracted from the values of THDG larger than 180.

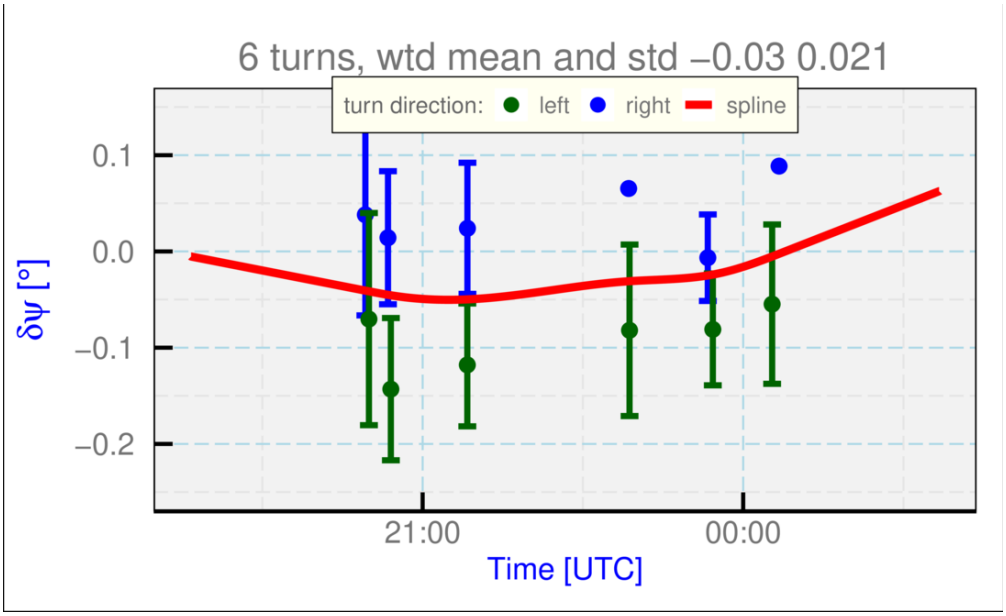

Figure 6: The estimated error in heading for WECAN flight rf09.

ation should not occur systematically over a short period as in this case. It would introduce a fluctuation of about 1 m/s around the circles, larger than the normally expected uncertainty in wind measurements.

A method of estimating the error in heading using the measured body accelerations in comparison to those deduced from GPS measurements was developed in the Kalman filter Tech Note. This method needs turns to constrain the fit, and only four of the WECAN flights had enough qualifying turns to produce reliable correction estimates. For all four, the estimated errors were below 0.1°, usually significantly below. The best example was from WECAN research flight 9, for which the heading-correction estimate is shown as the red line in Fig. 6.

This result conflicts with the much larger differences between THDG and THDGHYB, shown in Fig. 7. These differences are not reasonable estimates of the errors in THDG, and as in Fig. 5 a strong heading dependence is present in the indicated error, although the estimated errors here span a much larger range. Figure 6 indicates that the estimated errors from the heading-correction algorithm developed in connection with the Kalman filter Tech Note are much smaller than those shown in Fig. 7

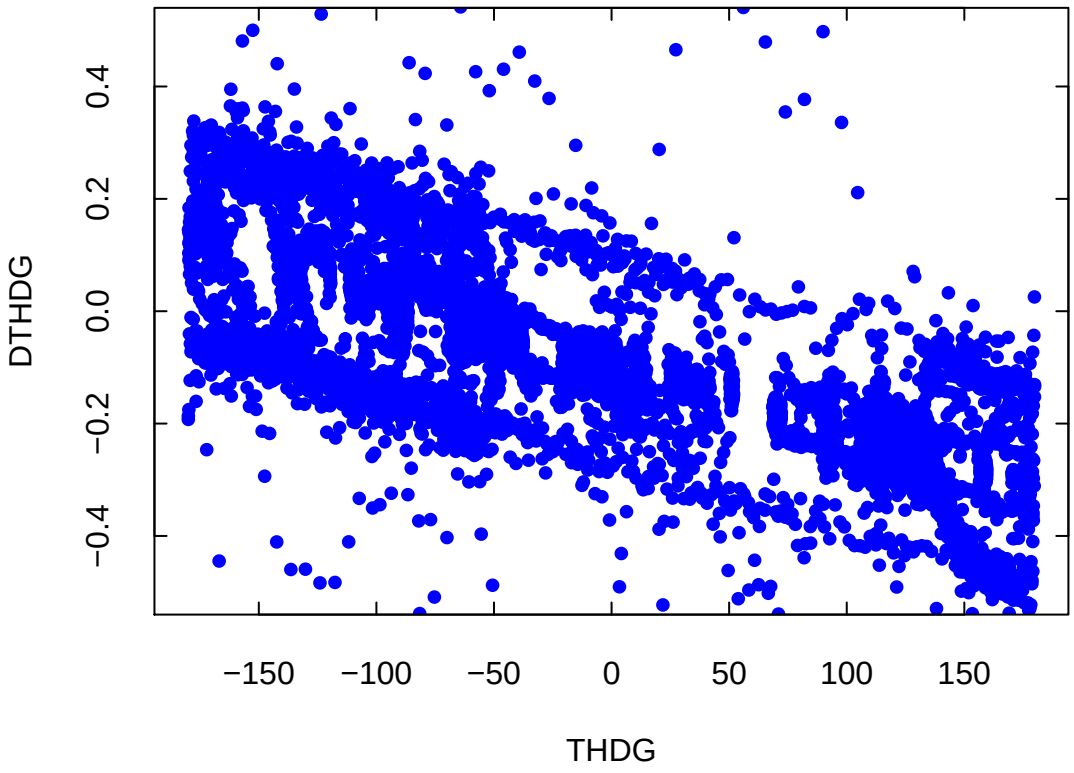

Figure 7: The difference between THDG and THDGHYB for WECAN flight rf09.

Conclusions

It appears that the hybrid variables produced by the integral Kalman filter in the C-130 INS are not usable for our wind calculation and do not offer any improvement over the standard output variables. The problems are these:

1. There is no hybrid PITCH variable. For measurements of the vertical wind, this would be the most useful measurement to improve. The hybrid variables provide no advantage for the calculation of vertical wind.

2. The measurements of horizontal aircraft ground speed are indeed improved and the hybrid variables remove a large part of the Schuler oscillation that is present in the standard variables (VEW, VNS). However, our current complementary filter removes this oscillation better and produces variables (VEWC, VNSC) that are in better agreement with the GPS variables (GGVEW, GGVNS). Therefore, using the hybrid variables does not offer an advantage over the standard variables.

3. The hybrid heading variable THDGHYB has a strange dependence on heading even for short-term flight segments like a spiral descent, and the indicated errors from THDG-THDGHYB are much larger than is reasonable from expected uncertainty in the standard heading and from estimates developed using a heading-correction algorithm documented in the Kalman filter Tech Note. Using this heading variable would degrade the wind measurements significantly. It is not clear why the hybrid heading variable is so bad, so there may be some unresolved problem that might be correctable, and improvement to the heading to the specs of the hybrid system would be valuable, but unless some change can be made to improve this hybrid heading measurement it should not be used for wind calculations.

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Reproducibility

PROJECT:	C130INS
ARCHIVE PACKAGE:	C130INS.zip
CONTAINS:	attachment list below
PROGRAM:	C130INS.Rnw
ORIGINAL DATA:	/scr/raf_data/WECAN
GIT:	https://github.com:WilliamCooper/C130INS.git

Attachments: C130INS.Rnw
C130INS.pdf
SessionInfo