Background

The processing code for the calculation of wind has included a correction for the difference between the position of the relative-wind measurement (now the radome) and that of the INS, because when the aircraft is rotating that causes a false component to be present in the measurement of relative wind that is not present at the location of the INS. A variable named boomln[] in gust.c, the relevant routine in nimbus, represents this displacement, and the correction is made to the horizontal as well as vertical wind on the basis of this length. This is done in a fully three-dimensional calculation that is valid for any orientation of the aircraft. Because nimbus is single-pass, the needed rotation rates are determined by saving previous values of the pitch and heading and then using the difference between measurements to find the rotation rates.

As originally formulated, this was valid because the reference values for the motion of the aircraft were provided by the INS, so correction of the relative wind to the reference frame of the INS allowed calculation of the Earth-relative wind. However, since that original formulation, a change has been made that incorporates information from GPS receivers. The antenna for the GPS receiver is not located at the position of the INS, so a similar correction is needed. The correction differs for the vertical and horizontal components, however, because those are calculated in slightly different ways. For the vertical speed of the aircraft, the variable GGVSPD is usually used as a direct representation of the rate of climb. However, in the horizontal components, measurements GGVEW and GGVNS are used in a complementary filter with VEW and VNS from the INS. The latter contain the high-frequency components, and combining with the low-frequency components of GGVEW and GGVNS produce the final ground-speed components used in the wind calculation. Therefore, making a rotation-caused correction to GGVEW and GGVNS is likely to have little effect, although it does not introduce any error, while an appropriate correction to GGVSPD is approximately as important as that currently in use for the radome because, for the GV, the radome-to-INS distance (4.42 m) is approximately the same as the GPS-to-INS distance (-4.3 m).[1]

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[1] At the time of this memo, I hadn't learned the corresponding GPS-to-INS distance for the C-130.

Present Processing Code

The code in use now is in the nimbus routine "gust.c". A relevant section of that subroutine is included below (with some omissions to focus on the critical parts):

```
thedot = (pitch - pitch0[probeCnt][FeedBack]) / DELT[FeedBack];
 ...
psidot = (thdg - thdg0[probeCnt][FeedBack]) / DELT[FeedBack];
bvns  = boomln[probeCnt] * (psidot * ss * ch + thedot * cs * sh);
bvew  = boomln[probeCnt] * (thedot * sh * ss - psidot * cs * ch);
 ...
t = wp3 + boomln[probeCnt] * thedot * ch;
ui[probeCnt] = tas_dab * r + (vew - bvew);
vi[probeCnt] = tas_dab * s + (vns - bvns);
 ...
wi = tas_dab * ab + t;
```

The pitch and heading derivatives are thedot and psidot, and ss, sh, cs, ch are the sines and cosines of the heading and pitch (respectively and sic). The variables vew, vns, and wp3 are respectively the eastward and northward components (VEWC, VNSC) of the aircraft groundspeed (from the INS after complementary filtering to match the GPS) and the rate of climb (usually now GGVSPD from the GPS). The results {ui, vi, wi} are the Earth-relative components of the wind.

Proposed Change

Consider the vertical component first because it is simplest. In addition to the aircraft-characteristic "boomln" another length is needed to characterize the displacement of the GPS antenna from the INS, here called boomgps. The above equations have a positive boomln, so it is simplest to define a negative value for boomgps because the antenna is behind the INS as installed on the GV. A variable "boomgps[]" will need to be initialized with appropriate values, as for "boomln[]". The needed correction is then to replace the present line starting with "t =" with the following line:

```
t = wp3 + (boomln[probeCnt] + boomgps[probeCnt]) * thedot * ch
```

If the aircraft is rotating so that pitch increases, the radome is moving upward faster than the INS so the relative wind it measures is too low and needs to be increased by the rotation factor to give the relative wind with respect to the INS. Similarly, the GPS antenna is moving upward more slowly than the INS and so a negative correction is needed to wp3 (representing GGVSPD) to get the INS rate-of-climb. *tas_dab* is the airspeed adjusted downward for the effects of flow angle to get the longitudinal component, and *ab* is the combination of functions of angles that resolves this into the

vertical direction and, for level flight, is approximately the difference between the tangent of the pitch and the tangent of the angle of attack.

If we retain the complementary filter for the horizontal wind, it does not seem necessary to make any further change. However, in case that filter is changed or discarded in the future, it may be desirable to apply a similar change to the horizontal wind. An effect of "boomgps[]" might arise in a turn that extends longer than the filter update period. It would not be correct, though, to apply a correction similar to that for wp3 to bvns and bvew because the GPS-based part of the variable here represented as vns or vew has already been filtered. Instead, one would need to correct GGVEW and GGVNS for the rotations before they enter the complementary filter.

Because any change would be small and limited to periods of extended turns, it seems preferable to make no changes for the horizontal component. However, it should be kept in mind that if there is ever a related change in the wind calculation, e.g. by eliminating the complementary filter and using the GGVEW/GGVNS measurements directly without reference to the INS, then there may need to be changes to the "gust.c" routine also. In that specific case, the same replacement as for the vertical wind (replacing "boomln[]" with "boomln[]+boomgps[]" would make the required correction.

Analysis

Figure 1 shows that the change in vertical wind introduced by this modification is quite small and could well be ignored. This is good because it suggests that corrections to previous data archives are not necessary. However, the magnitude is not completely negligible in comparison to the claimed uncertainty in vertical wind (around 0.05 m/s for fluctuations), so it is probably worth including. Other cases, perhaps including flight in the boundary layer, might have larger effects. In any case, it is worth making the change to remove a weakness and inconsistency in the processing.

In the case of the lateral component of the horizontal wind, Fig. 2 shows the difference between including or excluding the correction. (To construct this plot, the heading-rate-of-change correction was applied to the GPS measurements GGVEW and GGVNS before they were used in the normal complementary filter and otherwise the calculation proceeded as normal, with the normal correction for the radome-to-INS distance included in both.) There are some spikes in this plot, always associated with the end-of-leg turns to reverse course during this flight, so this confirms that the persistent turning during those maneuvers can have some effect on the measured horizontal wind. However, away from such turns, the difference between the two solutions was much smaller than for vertical wind and can be neglected. The reason is that the added effect only appears in the GPS ground-speed components and the complementary-filter approach smooths any high-frequency component of the correction while retaining true fluctuations in the high-frequency component from the INS. This provides support for the approach that neglects this correction in the case of the horizontal wind.
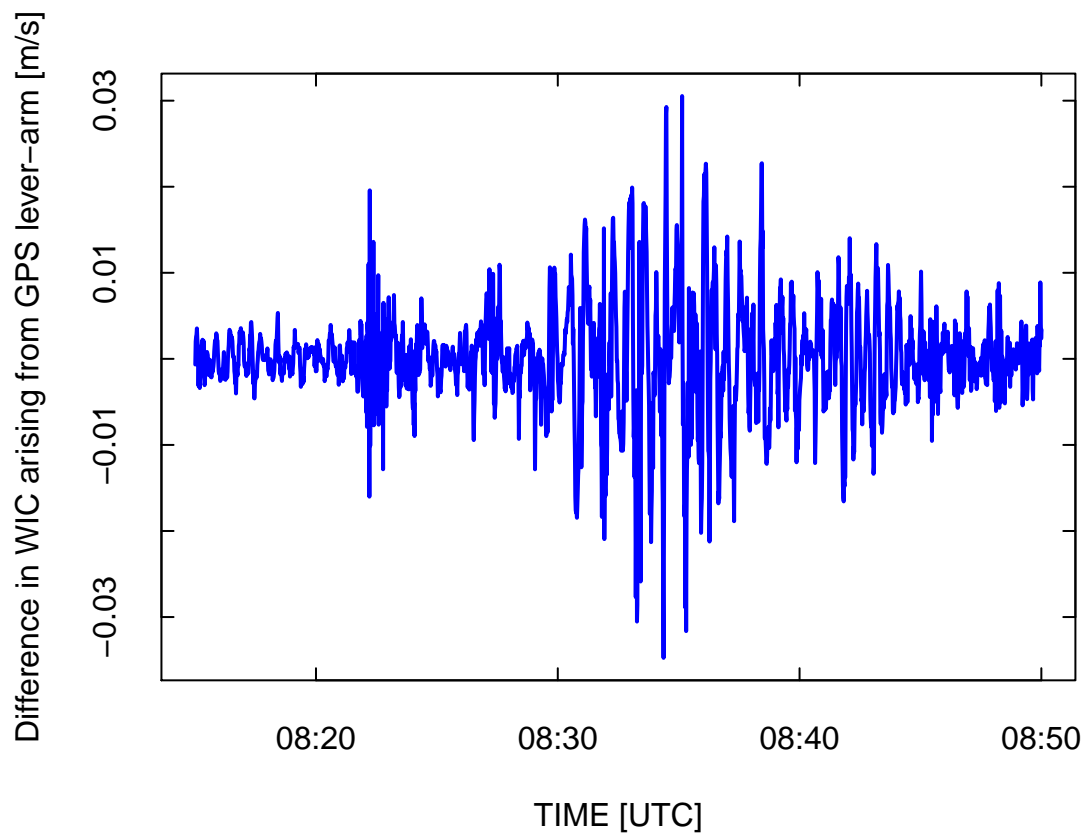
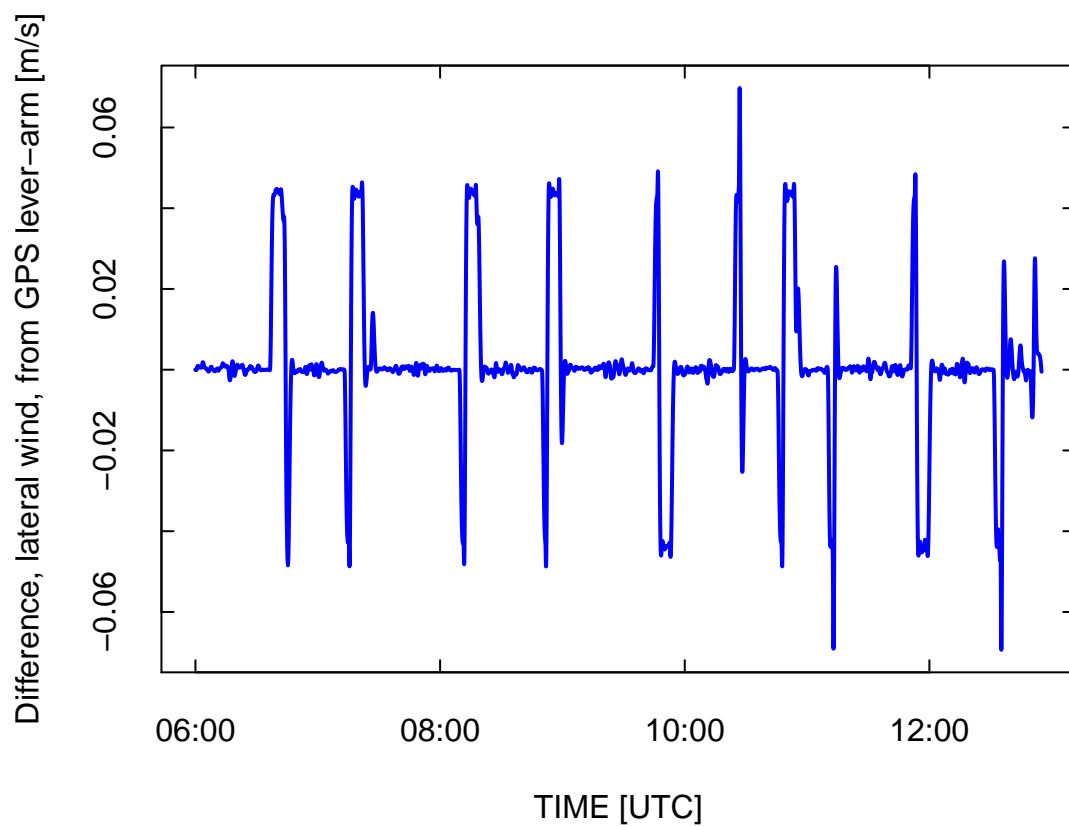Figure 1: Difference from including or excluding GPS lever-arm correction, DEEPWAVE flight 16 (4 July 2012)

Figure 2: Difference in lateral horizontal wind including vs. excluding the GPS lever-arm correction. DEEPWAVE flight 16.

Recommendations

Incorporate a correction only for the vertical wind, and for now retain the horizontal-wind calculation with the complementary filter. For the vertical wind:

1. Define a new aircraft characteristic, similar to "boomln[]", that has the value -4.3 for the GV. (Note the minus sign.) Find what the corresponding distance is for the C-130.

2. Make the single-line change listed in red above to "gust.c".[2]

If it becomes desirable to make this correction also to the horizontal wind, the Ranadu function "WindProcessor()" has appropriate code and can serve as a reference for how this should be incorporated. A special version of this function, NWindProcessor(), is included in the code used in the routine generating this memo, but with the GPS-to-INS distance set to zero, to calculate the comparisons shown here.

—- END —-

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[2]Because the two "boom" lengths are approximately equal and opposite, this has the effect of nearly eliminating the correction for vertical wind.