16 August 2015

TO: Algorithm Documentation File
FROM: Al Cooper
SUBJECT: Argument against using VSPD for vertical wind

1 Summary

This memo documents the reasons why VSPD should not be used for vertical wind and why the variable WI, conventionally based on VSPD, should be retired.

2 Weaknesses of VSPD

VSPD is the vertical aircraft speed, or rate of climb, provided by the IRU. The IRUs in use on both aircraft use updating to the pressure altitude to control the known instability that arises from integrating vertical acceleration to get rate-of-climb. As a result, the rate-of-climb represented by VSPD is adjusted to match a standard atmosphere, and if the atmospheric stratification differs from the standard atmosphere the resulting rate-of-climb will not be the geometric-altitude rate of climb, as needed for the calculation of vertical wind.

This can be seen best from the hydrostatic equation, expressed as

$$\frac{dz}{dp} = -\frac{R_a T}{pg}$$

Then

$$w = \frac{dz}{dt} = -\frac{R_d T}{pg}\frac{dp}{dt}$$

dz/dt is the rate of climb in terms of geometric altitude. For given climb conditions (T, p, and dp/dt), this only matches the climb rate in a standard atmosphere if the temperature equals that of a standard atmosphere, T_s. Otherwise, the error in rate-of-climb w is:

$$\frac{\delta w}{w} = \frac{R_d}{wpg}(T - T_s)\frac{dp}{dt} = (\frac{T - T_s}{T}) \ .$$

As an extreme example, if the temperature is 20°C different from a standard atmosphere and the climb rate is 10 m/s where the flight temperature is about -70°C, the error is about 1 m/s. This error enters directly into WI when calculated from VSPD.

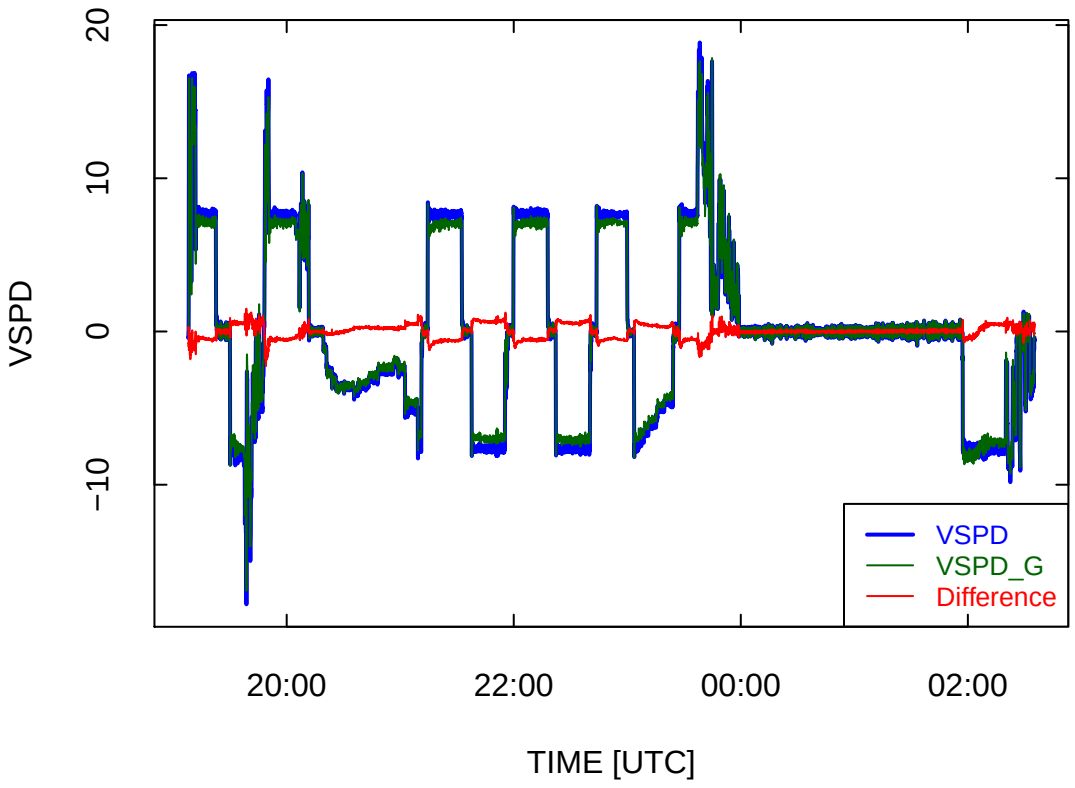

Figure 1: Comparison of VSPD and VSPD_G for HIPPO-2 flight 10.

3 Illustration of the problem

Figure 1 shows the two measurements VSPD and VSPD_G and also the difference between them. The difference is negatively correlated with VSPD and has a magnitude of around 1 m/s. As shown also in Fig. 2, the magnitudes of VSPD and VSPD_G are about 8% different through the region from 21:00:00 to 24:00:00. This difference then is reflected in WI, as shown by the blue line in Fig. 3. In that figure, the red trace is VSPD/10 to provide a reference for changes in rate-of-climb, and errors in WI are clearly correlated with errors in VSPD. Because HIPPO flights encountered such a wide range of atmospheric soundings, other HIPPO flights show similar errors but sometimes with positive correlation and sometimes with negative correlation between WI and VSPD depending on the atmospheric stratification. WIC, based on VSPD_G (the green line in Fig. 3), does not show this error. The reason for this error is evident from Fig. 4, which shows the atmospheric sounding for the period of climbs and descents in this flight. This was a far-north leg in a cold atmosphere, as shown by the blue trace in that plot. The temperatures are far below

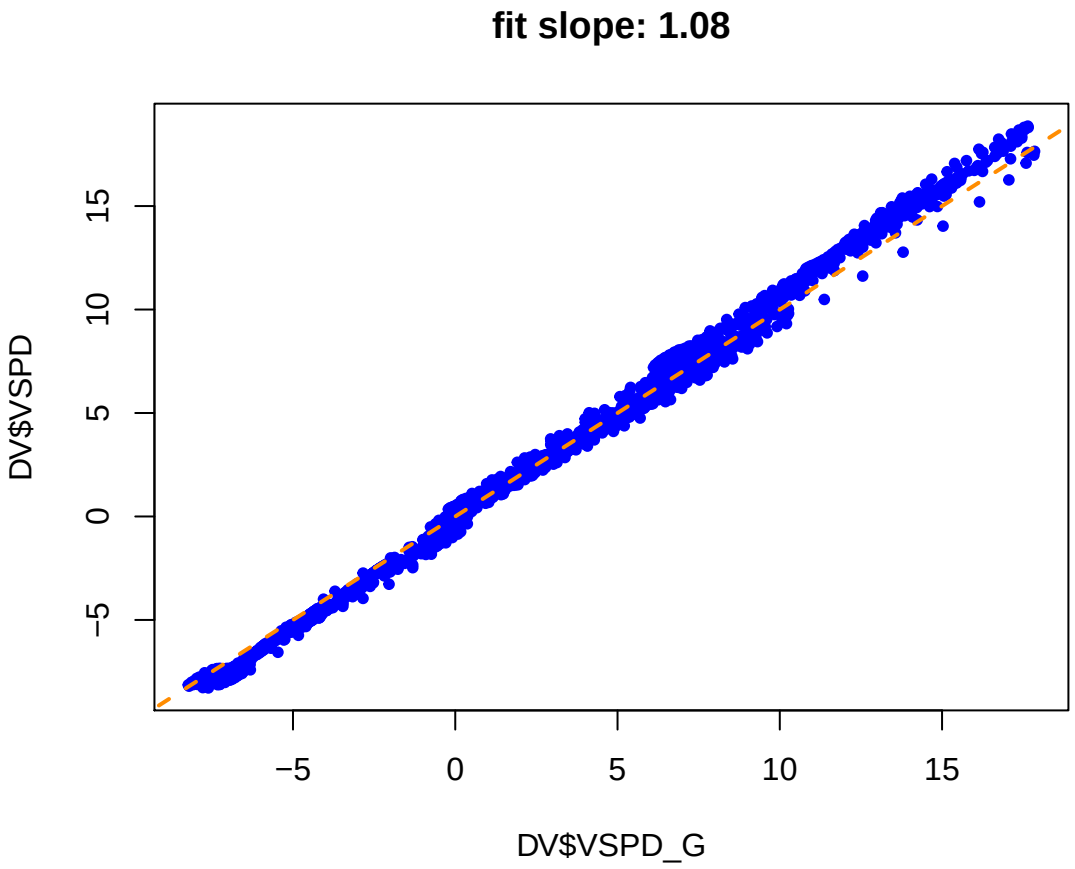

Figure 2: VSPD vs. VSPD_G for the segment of flight 2, HIPPO-2, from 21:00:00 to 24:00:00 UTC

the standard-atmosphere temperatures, shown as the red line, so that is the reason that VSPD is significantly different from VSPD_G.

4 Possible solutions

- If we want to retain VSPD as a representation of the rate-of-climb, it should be multiplied by T/T_s where T_s is the temperature in a standard atmosphere at the same pressure and both are expressed in absolute units (K). In that case we might want to introduce a new variable called ROC for rate-of-climb and calculate it from VSPD, ATX and PSXC from

```
ROC = VSPD * (ATX + 273.15) /
             (StandardAtmosphereTemperature (PSXC) + 273.15)
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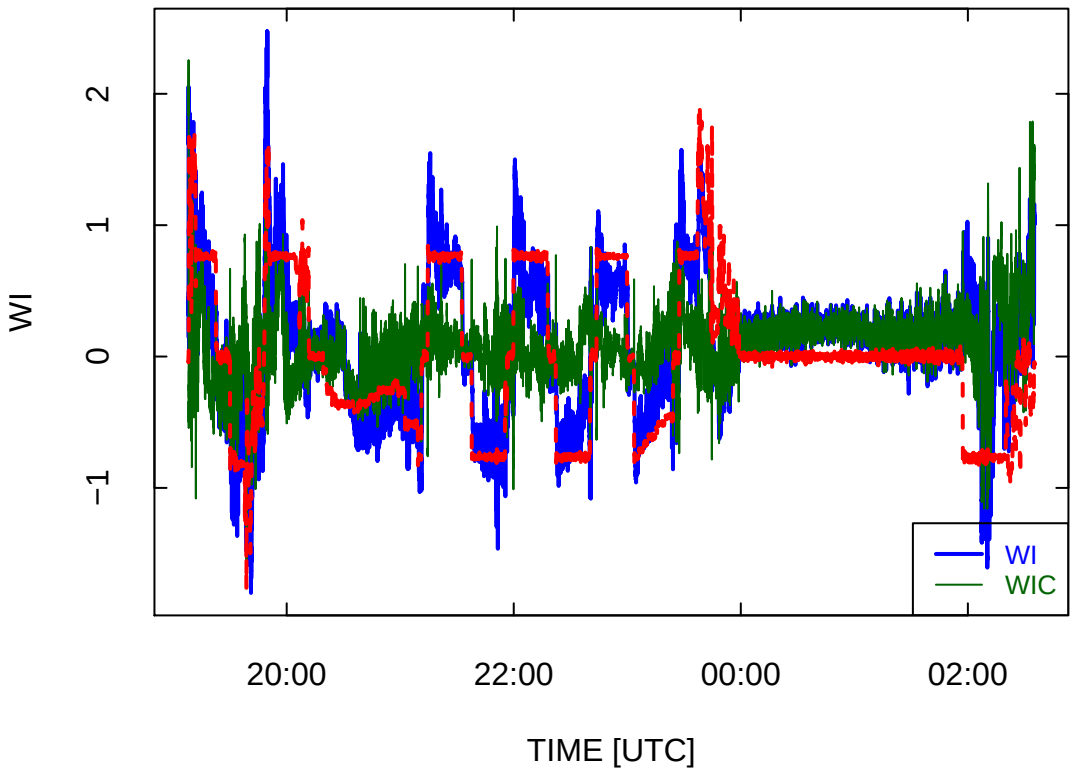

Figure 3: WI for HIPPO-2 flight 10.

`Figure 5 shows that ROC calculated in this way matches VSPD_G well.`

- Alternately we could drop WI and use only WIC based on a GPS-provided rate-of-climb. Because changing the definition of WI may be confusing, especially with differing definitions in use, I favor this. Maybe a compromise between these solutions is to define a new variable (WIR?) based on rate-of-climb represented by ROC.

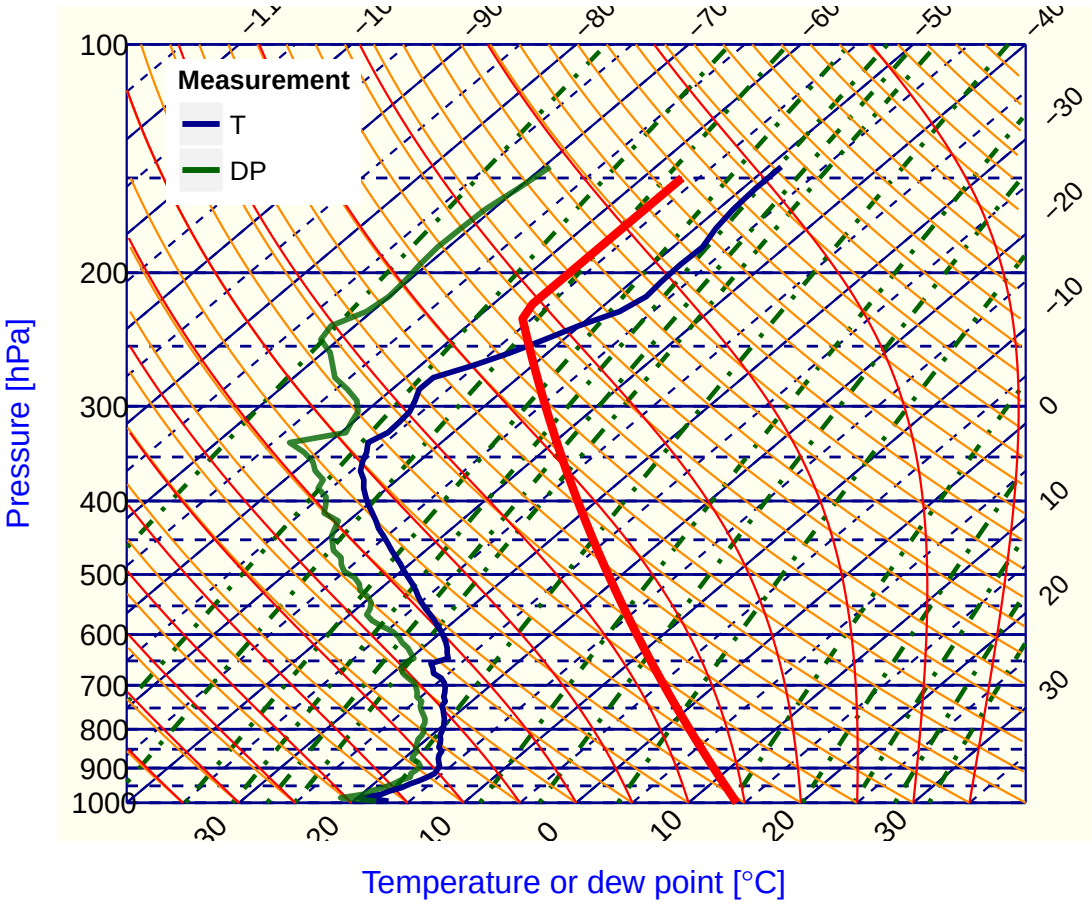

Figure 4: Sounding for the period from 21:00:00 to 24:00:00 on HIPPO-2 flight 10. The red line is the temperature of a standard atmosphere.

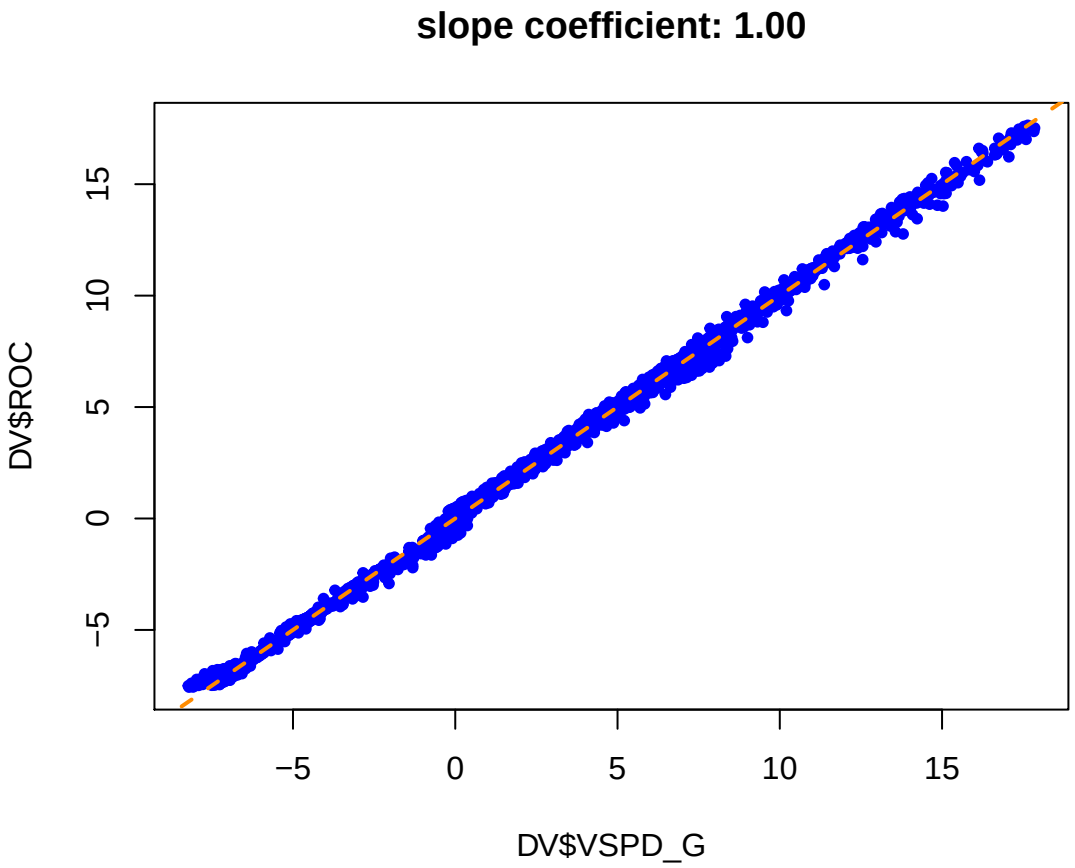

Figure 5: Same as for Fig. 2 but for ROC vs VSPD_G.

– End of Memo –

Reproducibility:

PROJECT:	UsingVSPDforWI
ARCHIVE PACKAGE:	UsingVSPDforWI.zip
CONTAINS:	attachment list below
PROGRAM:	UsingVSPDforWI.Rnw
ORIGINAL DATA:	/scr/raf_data/HIPPO/HIPPO-2rf10.nc
GIT:	git@github.com:WilliamCooper/UsingVSPDforWI.git

Attachments: UsingVSPDforWI.Rnw
UsingVSPDforWI.pdf
UsingVSPDforWI.Rdata
SessionInfo