14 October 2015

TO: HIPPO reprocessing file
FROM: Al Cooper
SUBJECT: vertical wind for HIPPO-1

1 The problem to address

Review of HIPPO-1 measurements shows that, when the "standard" sensitivity coefficients as given in the Processing Algorithms technical note are used, there is often a significant offset in vertical wind and there is much variability from flight to flight and even within flights. For example, for HIPPO-1 flight 5, Fig. 1 shows the measurements of vertical wind. The blue line shows 1-Hz measurements, and the red line is the result after 60-s smoothing. The mean offset, 1.3 m/s, is significant, and the offset varies during the flight. Other flights show similar problems but with some inconsistency, often showing pronounced correlation between rate-of-climb and WIC. Figure 2 shows the difference between the reference angle given by (1) and the angle of attack determined using the standard formula. There is a significant offset in mean angle and an apparent residual dependence on Mach Number, so it appears appropriate to reconsider the sensitivity coefficients representing angle of attack for this project.

2 The standard fit

The first step here will be to re-fit the measurements to the standard formula used to represent angle of attack α, from the Processing Algorithms technical note:

$$\alpha = c_0 + \frac{\Delta p_\alpha}{q}(c_1 + c_2 M) \tag{1}$$

where Δp_α is the pressure difference between upward and downward ports on the radome (ADIFR), q is dynamic pressure (QCF), and M is the Mach number calculated using the uncorrected static and dynamic pressure (PSF and QCF). The three coefficients specified in that document, for projects before 2012, are $\{c\} = \{5.516, 19.07, 2.08\}$ and these are the coefficients used in the initial processing.

The approach used here is described in detail in the Wind Uncertainty technical note. It is to use a reference value for angle of attack, α^*, defined by

$$\alpha^* = \theta - \frac{w_p}{V} \tag{2}$$

which would equal the angle of attack if the vertical wind were zero, and then determine the coefficients in (1) that minimize the difference between α^* and α.

For HIPPO-1 and all projects before SPRITES-II, there is the problem that the highest-quality measurement of the rate of climb of the aircraft, GGVSPD, was not available. The alternatives are

VSPD and VSPD_A, the latter from the avionics-system GPS. The former is updated using the pressure altitude as reference, which can introduce long-distance biases, especially in cases like HIPPO where the flights do not return to the same airport. Such flights may extend through atmospheric regions with important baroclinity or significant departures from the standard atmosphere, so there can be an important gradient in geometric altitude for flight along a surface of constant pressure and hence a false update applied to the vertical motion of the aircraft. See the Algorithm Documentation memo UsingVSPDforWI.pdf for a discussion of this problem.

As a test, the measured altitude GGALT was differentiated to obtain an alternate measurement of rate of climb. This new variable was consistent with VSPD_A, for example with mean difference and standard deviation of the difference for HIPPO-1 flight 5 of $-0.08{\pm}0.15$ m/s. The variance spectra characterizing VSPD_A and the new rate-of-climb variable were hard to distinguish, with coherence above 0.95 and phase shift within about 10° at all frequencies. However, the fit procedure that follows in this memo gave a larger residual standard deviation for the new variable than for VSPD_A, so VSPD_A will be used in the following.

3 Data used

This memo will use measurements from rf01–rf11. Some data restrictions are needed, for two reasons:

1. Near the start and end of flights, there are periods where flaps and/or landing gear are deployed, leading to large potential errors in angle of attack. For HIPPO, there are frequent descents to low level followed by climbs, and in some cases where they are missed approaches flaps may have been deplowed, so it is best to exclude periods of low-speed flight unless at levels well above the surface where they may have arisen in the course of speed runs. It appears that if TASX is required to exceed 130 m/s, this provide a suitable delineation between these two cases, so that will be used to qualify data for this study.

2. A few other regions needed to be excluded because it appeared that ADIFR was questionable, perhaps because there were blockages in the lines or apertures. These regions were identified by significant departures in plots like Fig. 3 below. In addition, because there are additional potential uncertainties for measurements in turns, the data used in the following were restricted to cases where the roll was between -4 and 4°.

Only the flight times listed in the following table were used for those reasons. The composite set of data had more than 250,000 1-s measurements.

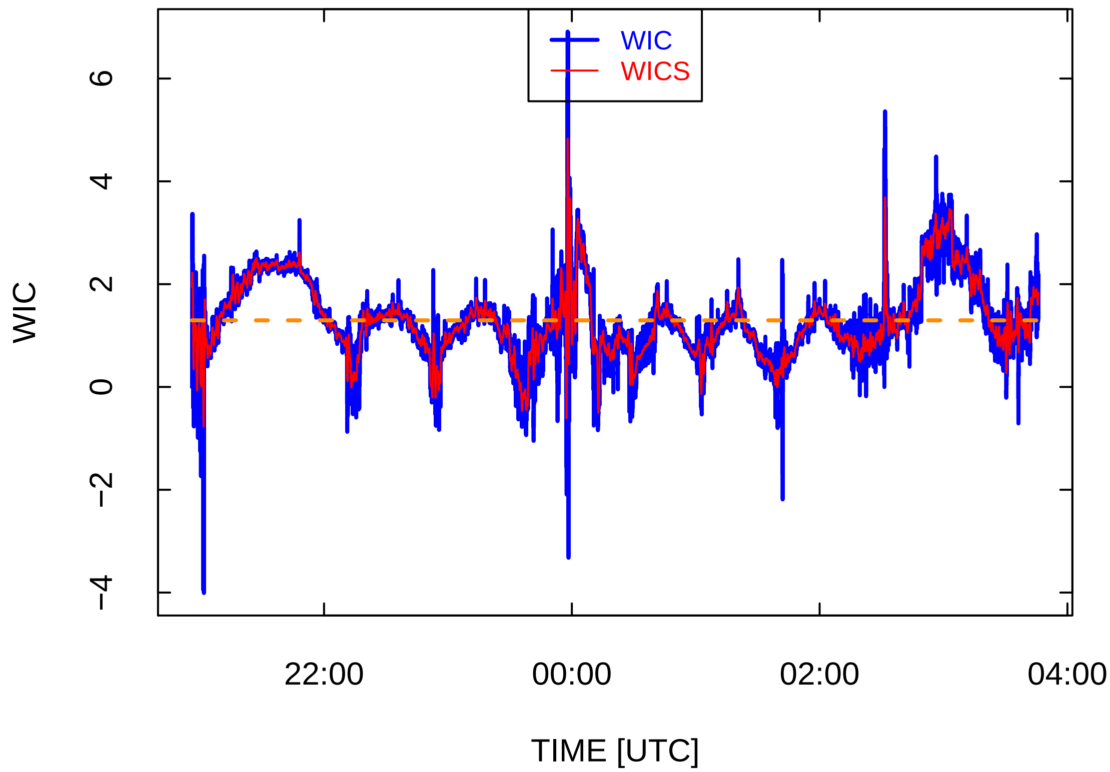

Figure 1: Vertical wind, HIPPO-1 flight 5. The blue trace is WIC; the red trace (WICS) is the same measurement after application of 60-s smoothing. The dashed orange line shows the mean value for the flight.

Flight	**Start [UTC]**	**End [UTC]**
rf03	18:48:13	24:44:27
rf04	19:28:14	27:42:33
rf05	20:58:19	27:29:24
rf06	21:04:25	28:14:16
rf07	21:16:32	29:41:05
rf09	2:24:13	8:34:49
rf10	17:27:40	25:08:28
rf11	16:04:07	22:01:29

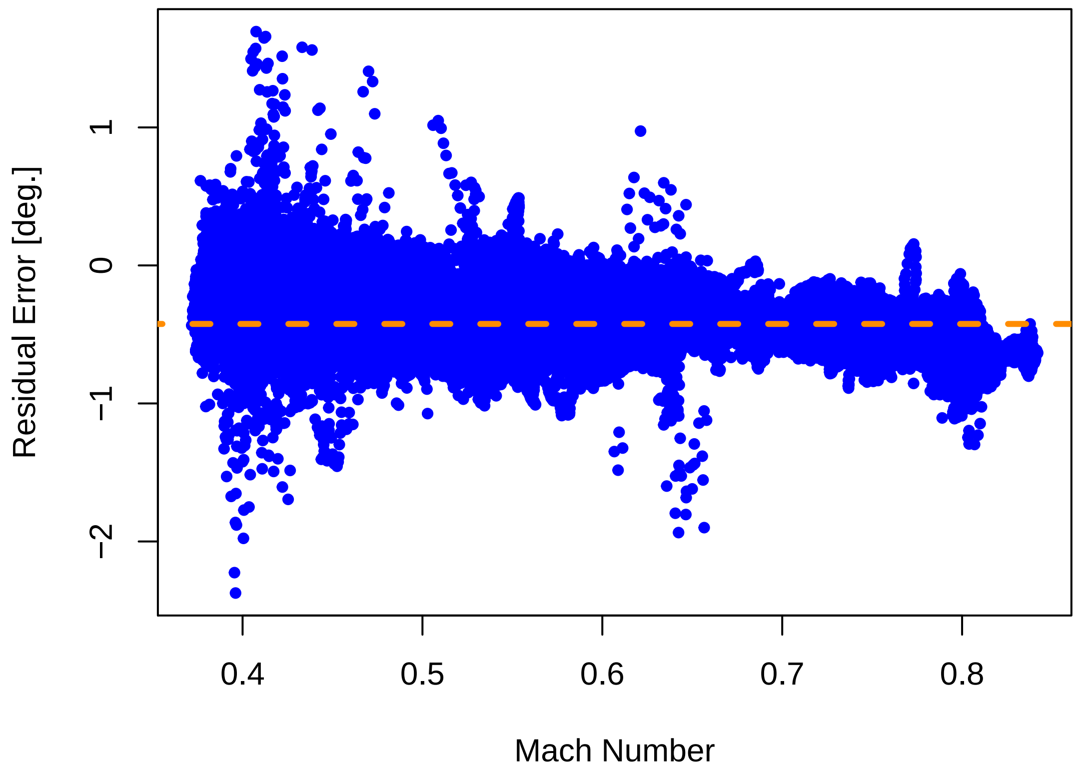

Figure 2: Residual error as defined in (1) as a function of Mach number. The dashed orange line is the mean value, 0.424 deg.

4 New coefficients using the standard formula

A fit of (1) to the composite data, qualified as in Sect. 3, led to best-fit coefficients $\{c_{1--3}\}$ = $\{4.864, 12.429, 9.451\}$. A comparison of the angle of attack produced by (1) with these coefficients to the reference values given by (2) is shown in Fig. 3. The residual standard deviation for this fit was reduced slightly (about 10%) from the fit that used only the first term, so it appears worthwhile to use this three-coefficient fit instead. Several other options were considered, including direct dependence on Mach number, air density, pressure, altitude, and powers and products of these, but none provided significant (>0.01) further reduction in the standard deviation of the residuals so it does not appear useful to include more complex terms in the fit.

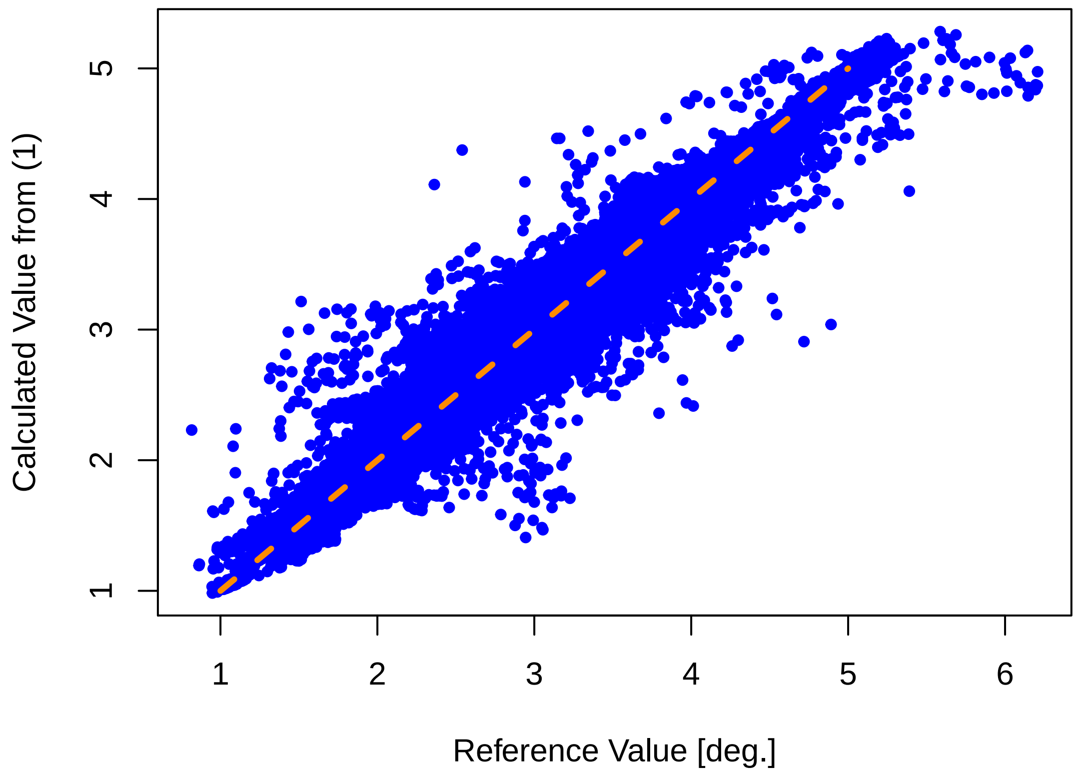

Figure 3: Calculated value of angle of attack vs the reference value used in the fit.

```
## lm(formula = AOAREF ~ QR + I(QR * M), data = DF)
## [1] "Coefficients:"
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)       4.86   0.000879    5532        0
## QR               12.43   0.013818     899        0
## I(QR * M)         9.45   0.018546     510        0
## [1] "Residual standard deviation: 0.115, dof=175068"
## [1] "R-squared 0.968"
```

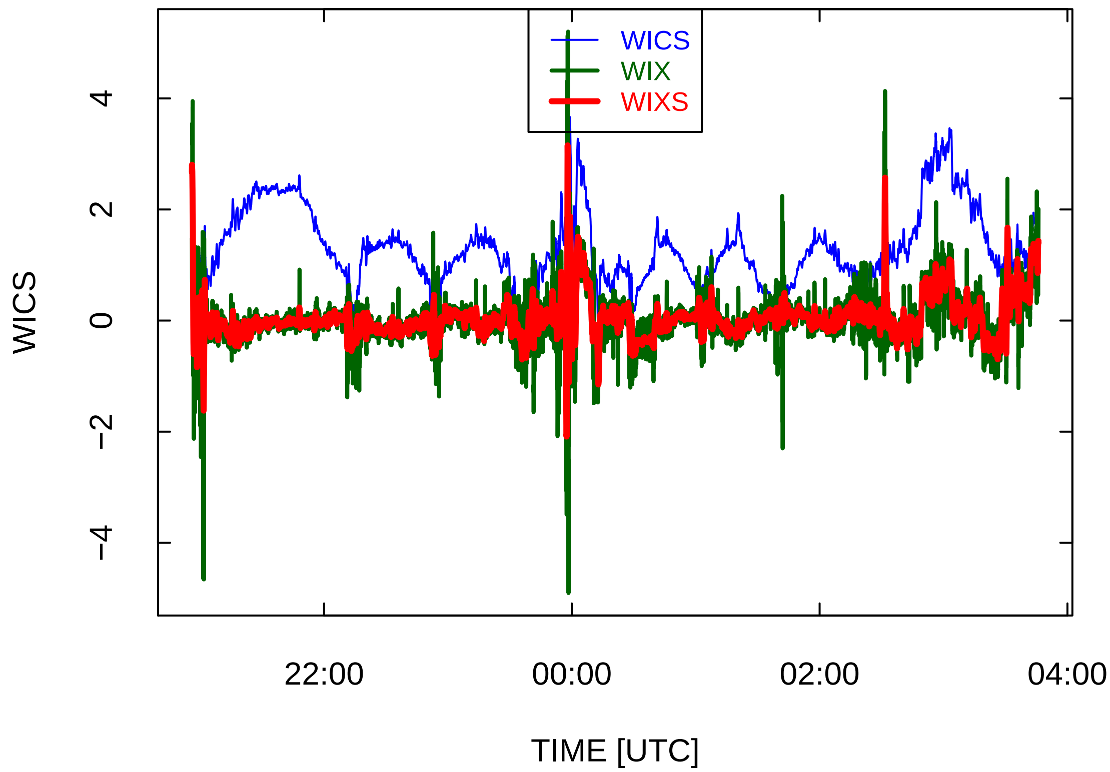

Figure 4: As for Fig. 1 but adding the new variable WIX for the vertical wind.

5 New values of the vertical wind

The revised vertical wind based on the new coefficients can be estmated from the previous value (WIC) modified to be WIX=WIC+(α-AKRD)πV/180 where α is given by (1), V is the airspeed and $\pi/180$ is needed to convert from degrees to radians. Figure 4 repeats Fig. 1 for flight 3 with the addition of this new measurement of the vertical wind. The red trace (WIXS, WIX with 60-s smoothing) represents the new variable, which shows mean values close to zero for most of the flight and is a significant improvement over WIC.

For reference, the plots of new vertical wind WIX for each of the HIPPO-2 research flights are appended to this memo, beginning with Fig. 5. Gaps in these plots often arise because the radome pressure ports were obstructed and ADIFR or BDIFR was affected, so the measurements during these periods were flagged as erroneous. There are some regions in flights 1, 2, and 8 that remain questionable, so those flights were not used when obtaining the fit that led to the recommended sensitivity coefficients.

6 Recommendation

Use the sensitivity coefficients {4.864, 12.429, 9.451} for HIPPO-2.

– End of Memo –

Reproducibility:

PROJECT:	WI-HIPPO1
ARCHIVE PACKAGE:	WI-HIPPO1.zip
CONTAINS:	attachment list below
PROGRAM:	AKRDforHIPPO1.Rnw
THIS DOCUMENT:	AKRDforHIPPO1.pdf
WORKFLOW:	WorkflowFindAKRDcal.pdf
ORIGINAL DATA:	/scr/raf_data/HIPPO/HIPPO-1rf01.nc, etc
DATA ARCHIVE:	NCAR HPSS (not github)
GIT:	https://github.com/WilliamCooper/Reprocessing.git

Attachments: AKRDforHIPPO1.Rnw
AKRDforHIPPO1.pdf
WorkflowFindAKRDcal.pdf
SessionInfo

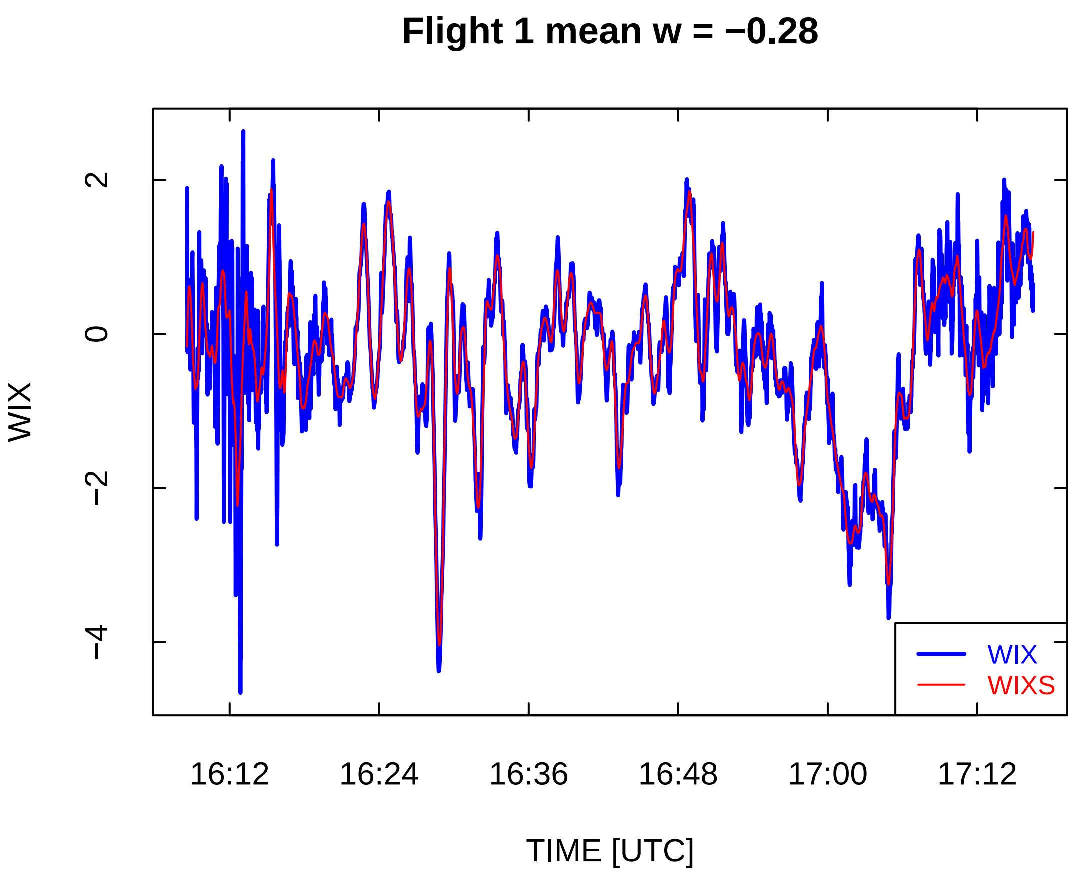

Figure 5: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

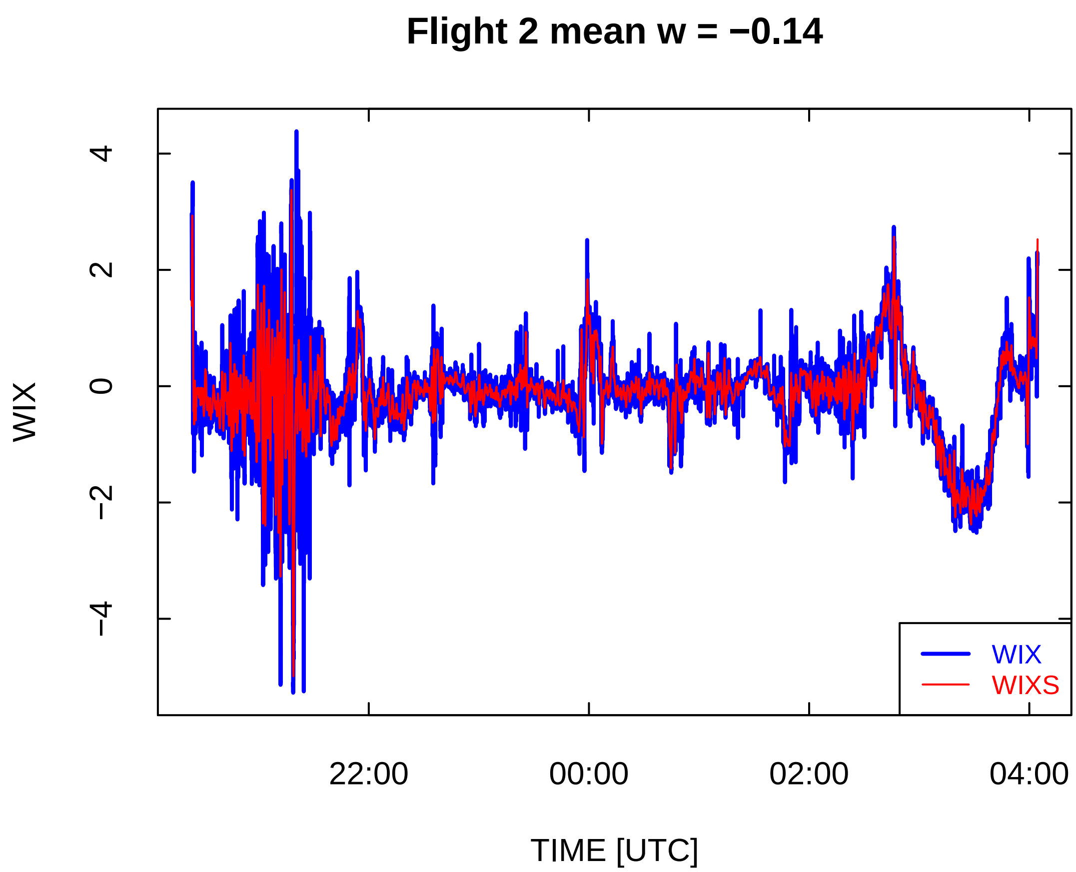

Figure 6: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

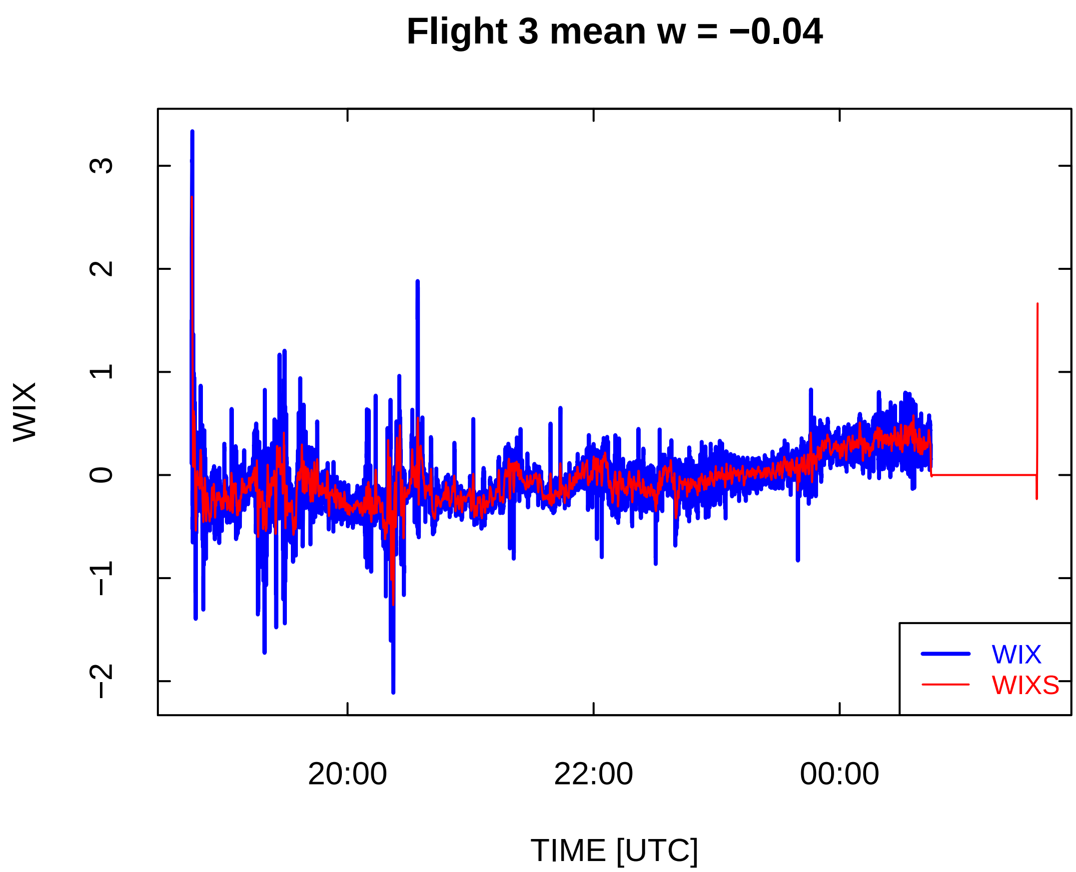

Figure 7: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

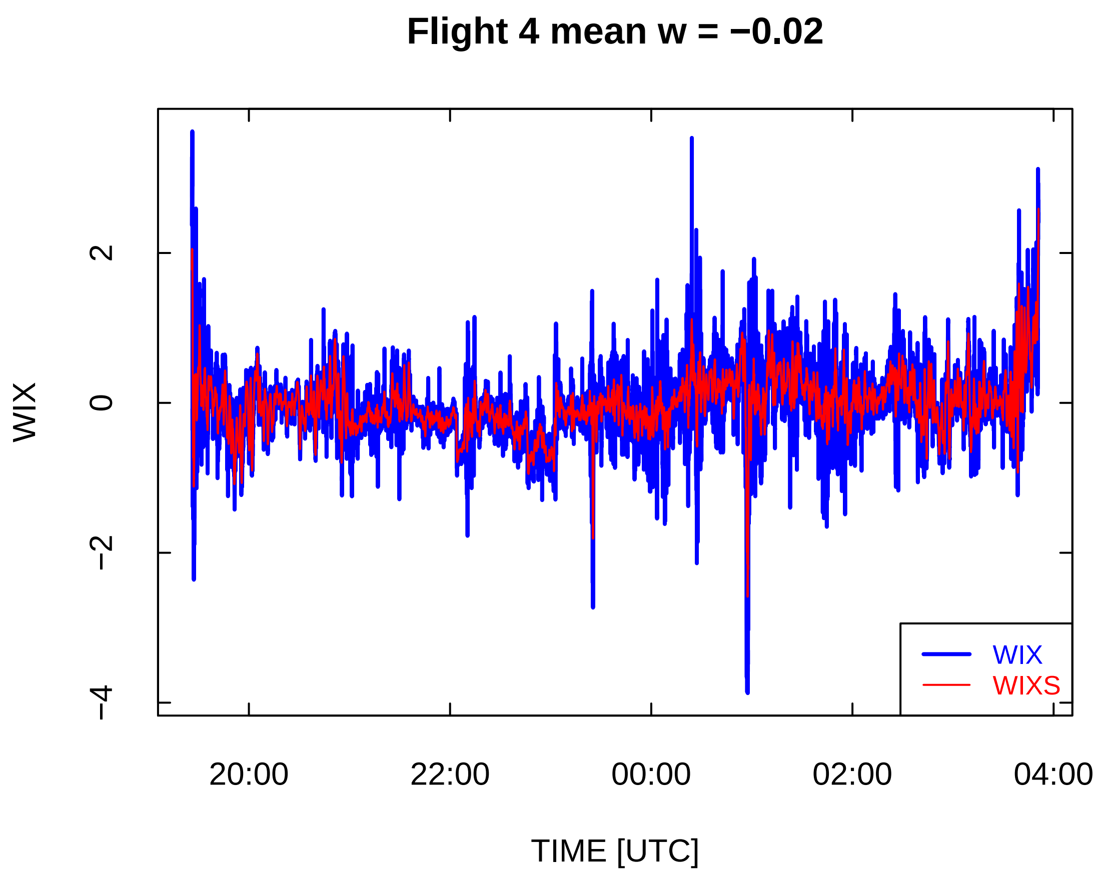

Figure 8: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

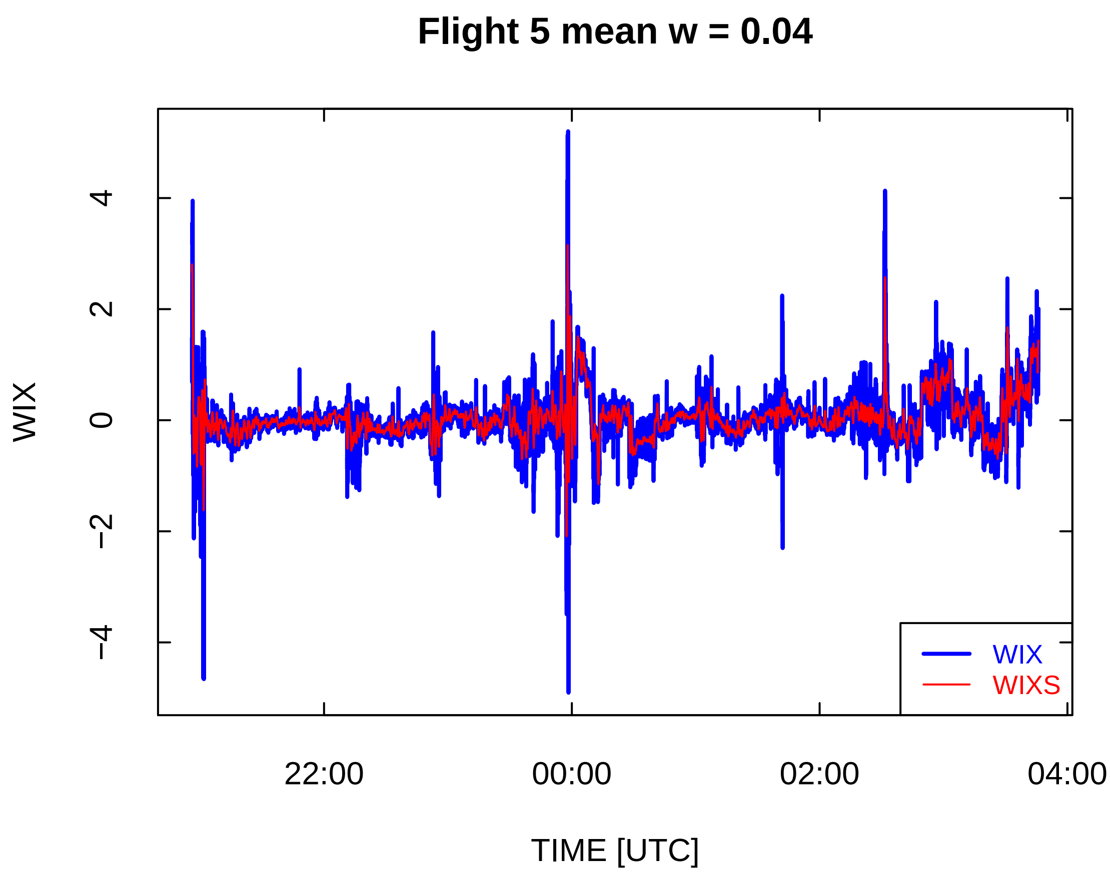

Figure 9: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

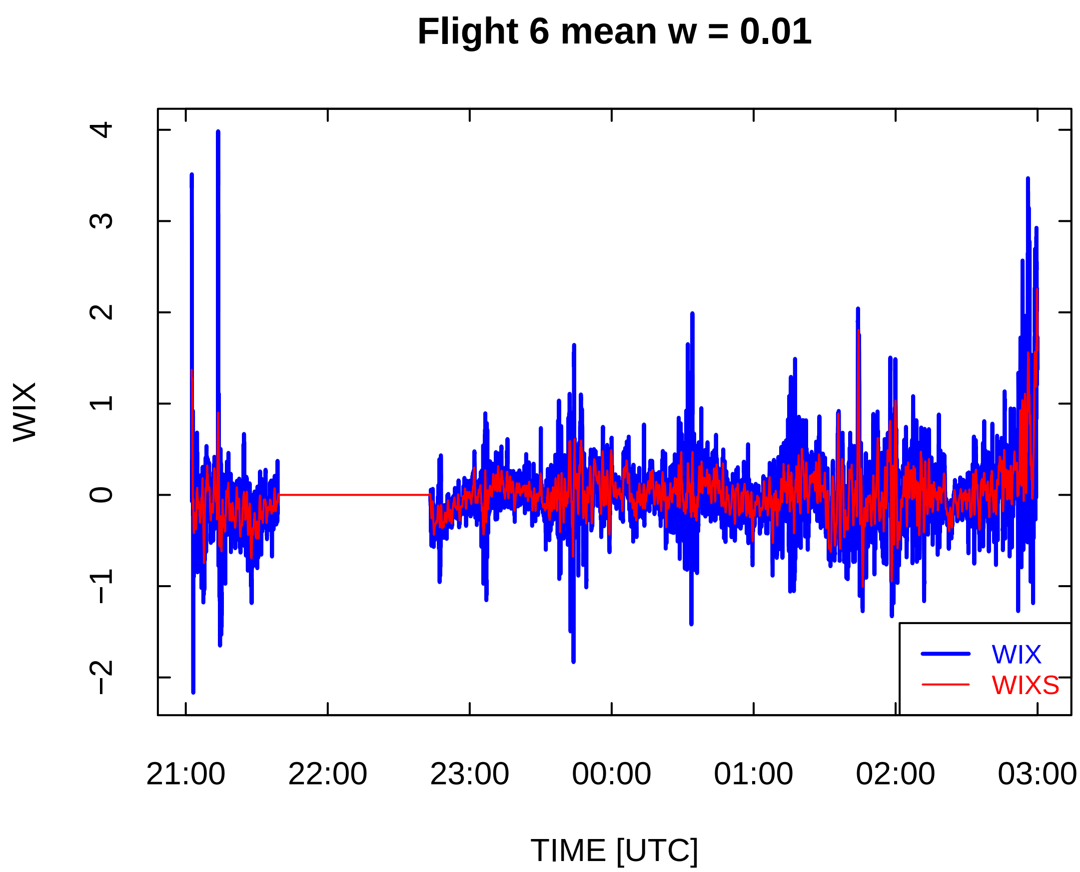

Figure 10: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

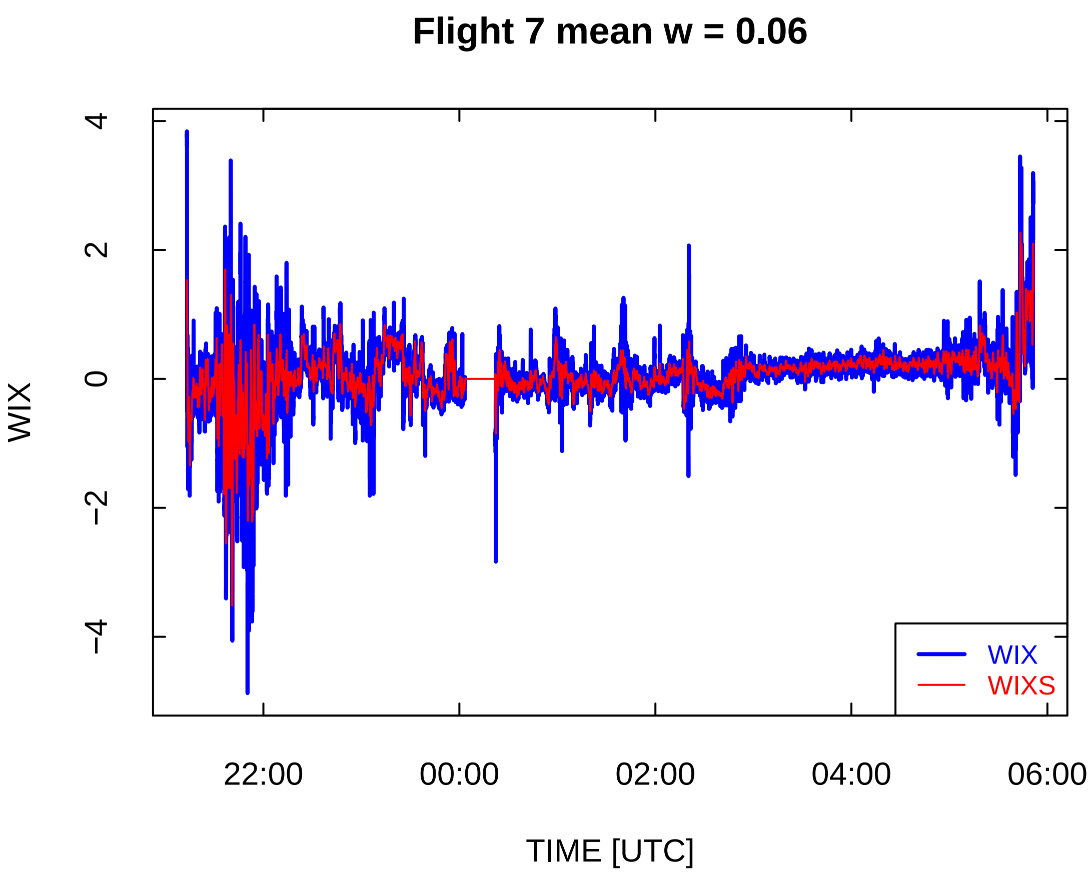

Figure 11: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

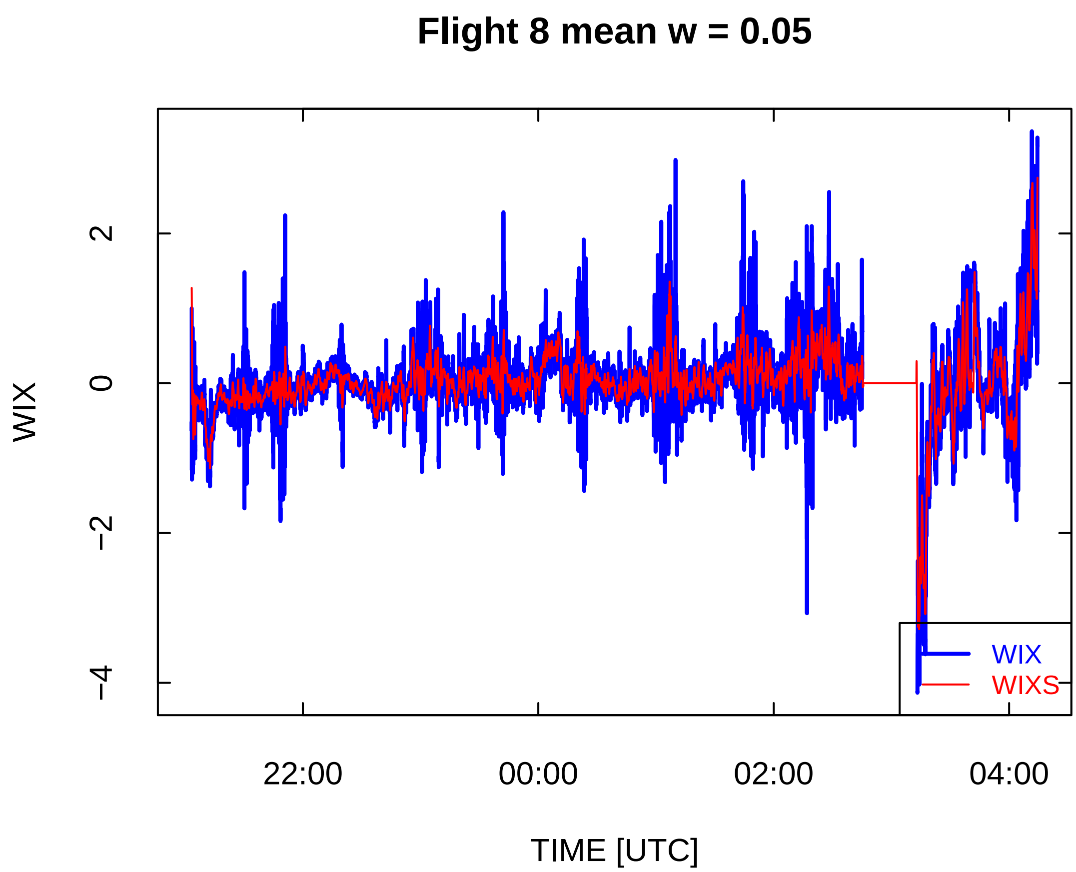

Figure 12: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

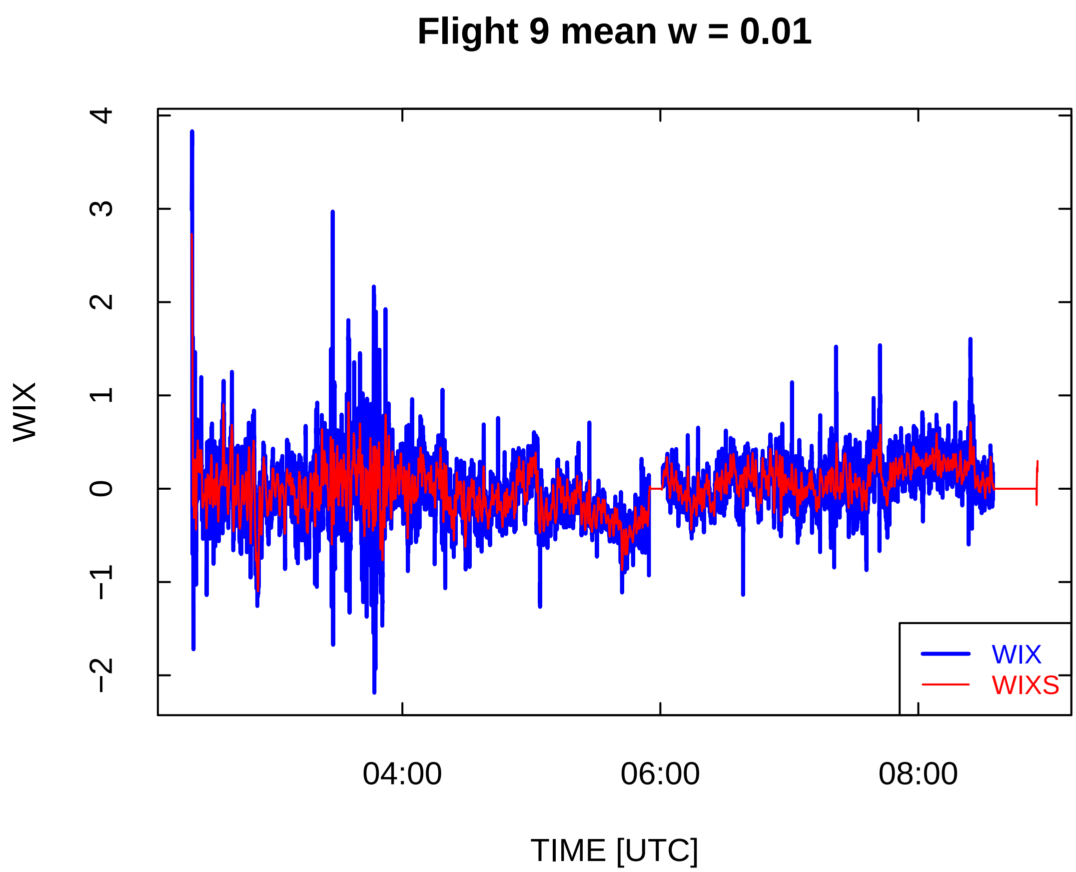

Figure 13: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

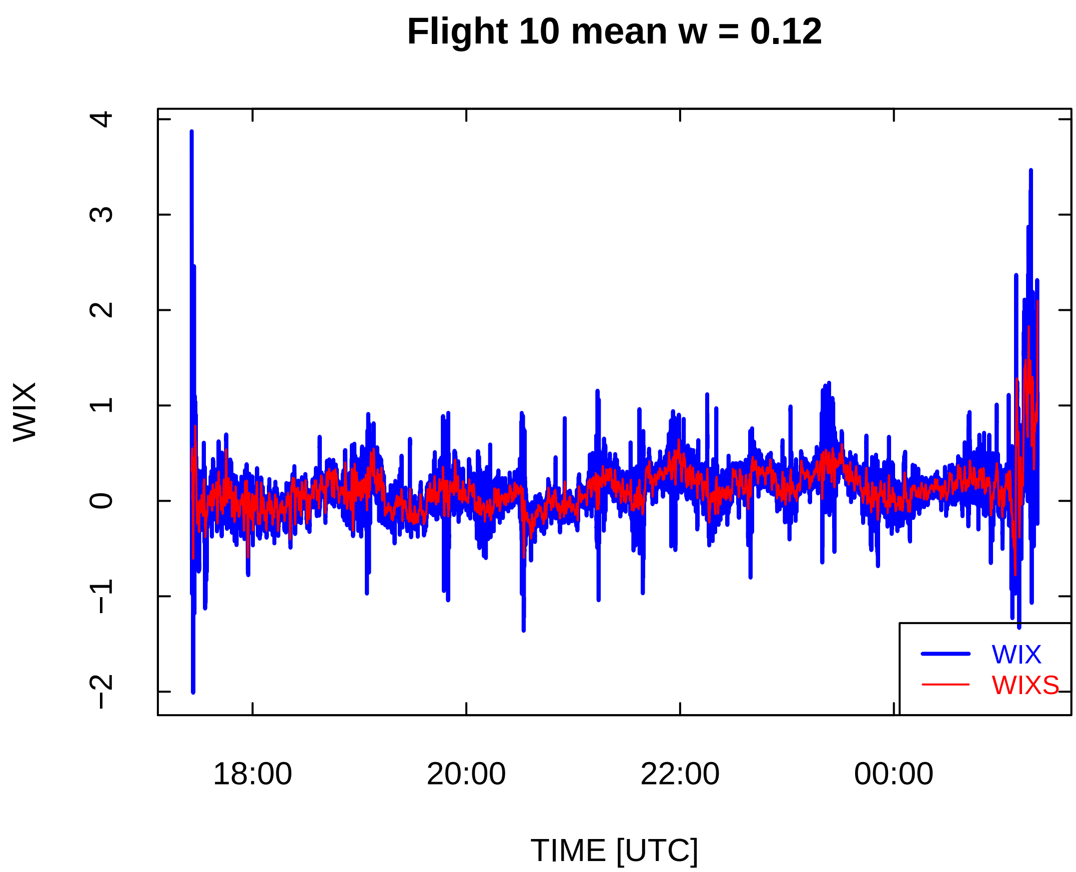

Figure 14: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

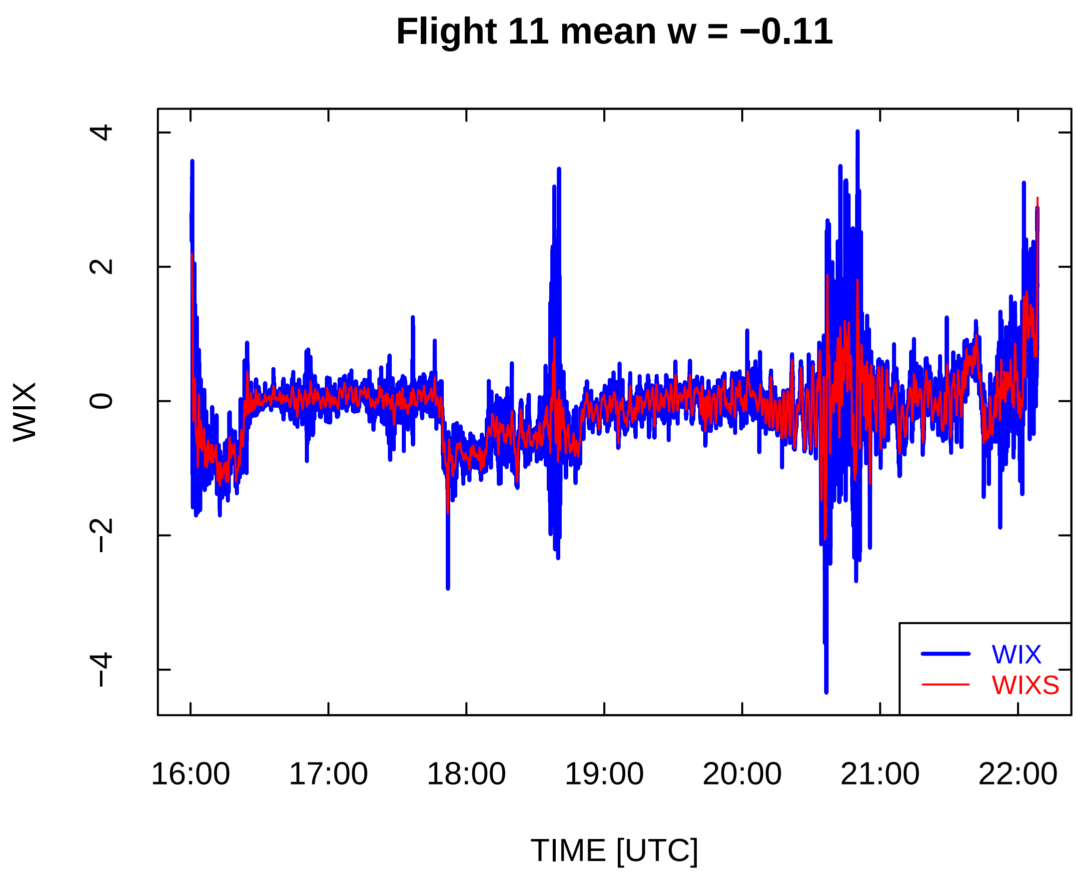

Figure 15: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.