12 December 2015

TO: DC3 reprocessing file
FROM: Al Cooper
SUBJECT: vertical wind for DC3

# 1 The problem to address

Review of DC3 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 DC3 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, 1.98 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 $\alpha$, from the Processing Algorithms technical note:

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

where $\Delta p_\alpha$ 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, $\alpha^*$, 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 $\alpha^*$ and $\alpha$.

For DC3 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. 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 DC3 flight 5 of $-0.06 \pm 0.1$ 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 all DC3 research flights, rf01–rf22, but omitting 15 and 18 which had problems in early processing. Some data restrictions are needed, for three 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 DC3, 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°.

3. DC3 flights often encounted significant turbulence, so there were many regions where the assumption of zero vertical wind was not valid. Furthermore, there were many regions of apparently real updrafts and downdrafts that extended for many seconds. Most of these regions had significant standard deviations in the vertical wind, so to exclude them the standard deviation in WIC (based on a preliminary calculation, and averaged over 60 s) was restricted to less than 0.3 m/s.

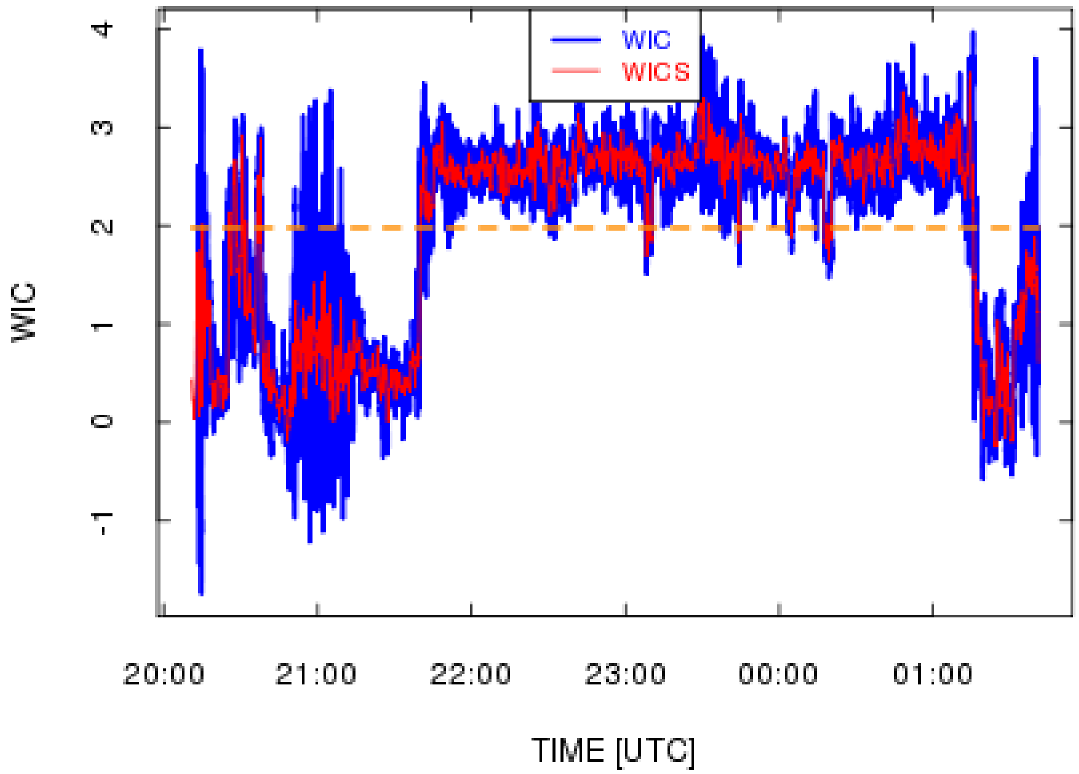


Figure 1: Vertical wind, DC3 flight 5. The blue trace is WIC; the red trace (WICS) is the same measurement after application of 60-s smoothing. The dashed orange line shows the mean value for the flight.

## 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 $\{c_{1--3}\} = \{4.775, 9.099, 13.502\}$. 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.

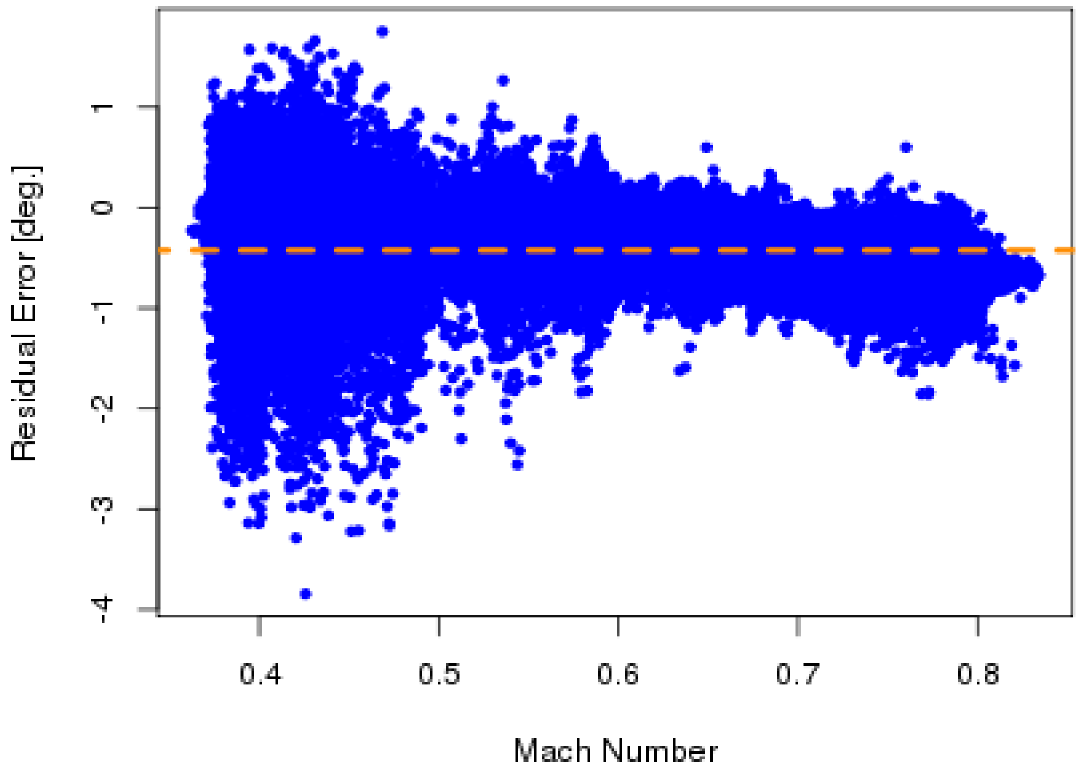


Figure 2: Residual error as defined in (1) as a function of Mach number. The dashed orange line is the mean value, 0.424 deg.

```
## lm(formula = AOAREF ~ QR + I(QR * M), data = DF)
## [1] "Coefficients:"
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)       4.78    0.00142    3368        0
## QR                9.10    0.01973     461        0
## I(QR * M)        13.50    0.02448     552        0
## [1] "Residual standard deviation: 0.131, dof=175169"
## [1] "R-squared 0.949"
```

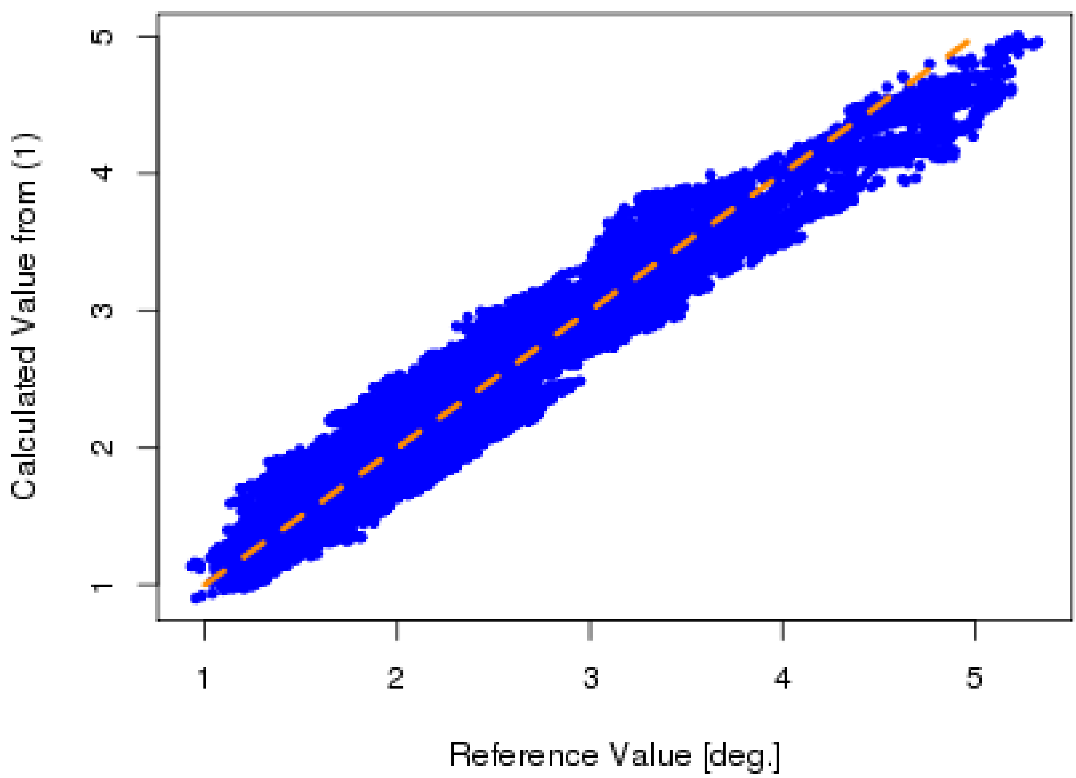


Figure 3: Calculated value of angle of attack vs the reference value used in the fit.

# 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+($\alpha$-AKRD)$\pi$V/180 where $\alpha$ 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 DC3 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.

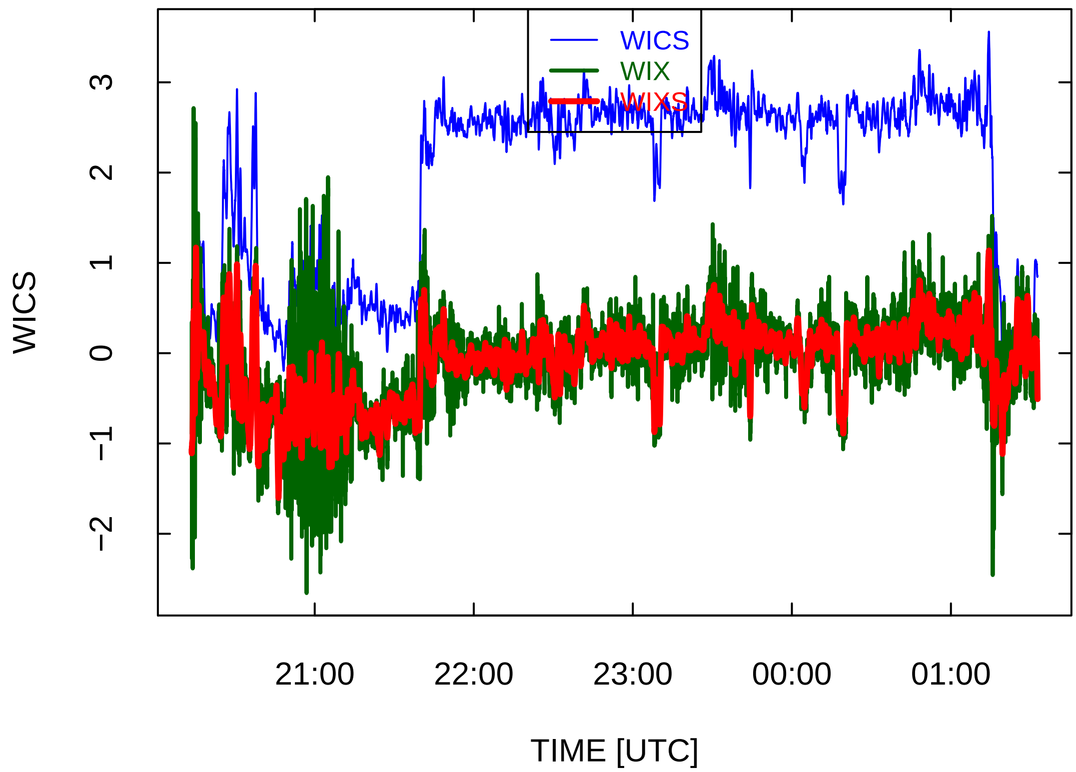


Figure 4: As for Fig. 1 but adding the new variable WIX for the vertical wind.

# 6 Recommendation

Use the sensitivity coefficients {4.775, 9.099, 13.502} for DC3.

– End of Memo –

Reproducibility:

| | |
|---|---|
| PROJECT: | WI-DC3 |
| ARCHIVE PACKAGE: | WI-DC3.zip |
| CONTAINS: | attachment list below |
| PROGRAM: | AKRDforDC3.Rnw |
| THIS DOCUMENT: | AKRDforDC3.pdf |
| WORKFLOW: | WorkflowFindAKRDcal.pdf |
| ORIGINAL DATA: | /scr/raf_data/DC3/DC3rf01.nc, etc |
| DATA ARCHIVE: | NCAR HPSS (not github) |
| GIT: | https://github.com/WilliamCooper/Reprocessing.git |

Attachments: AKRDforDC3.Rnw
AKRDforDC3.pdf
WorkflowFindAKRDcal.pdf
SessionInfo

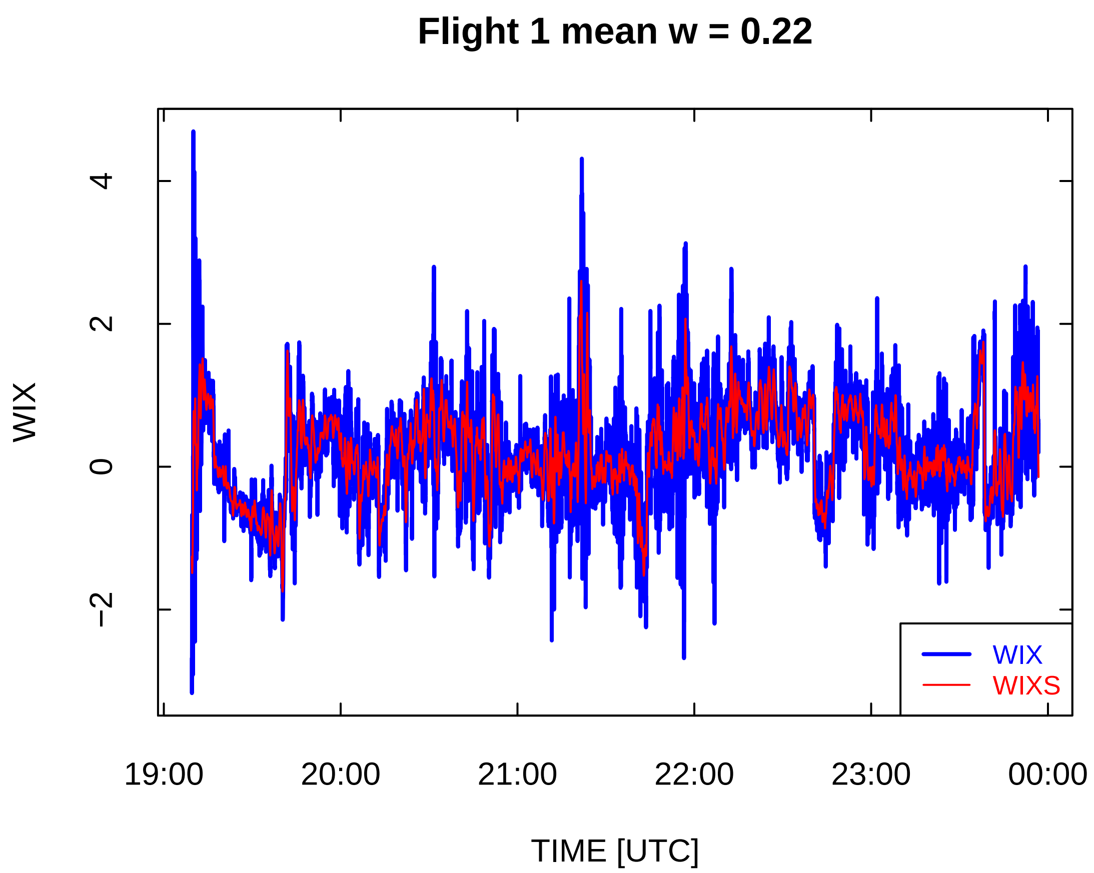


Figure 5: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

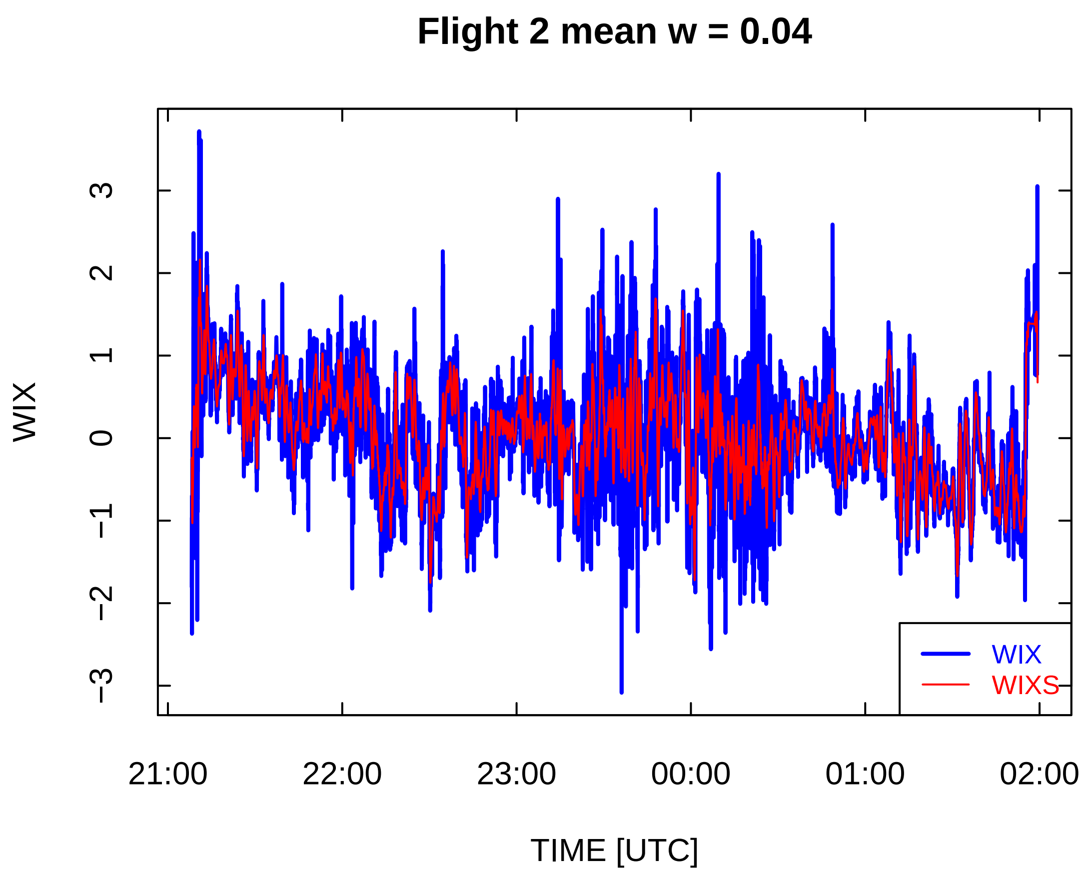


Figure 6: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

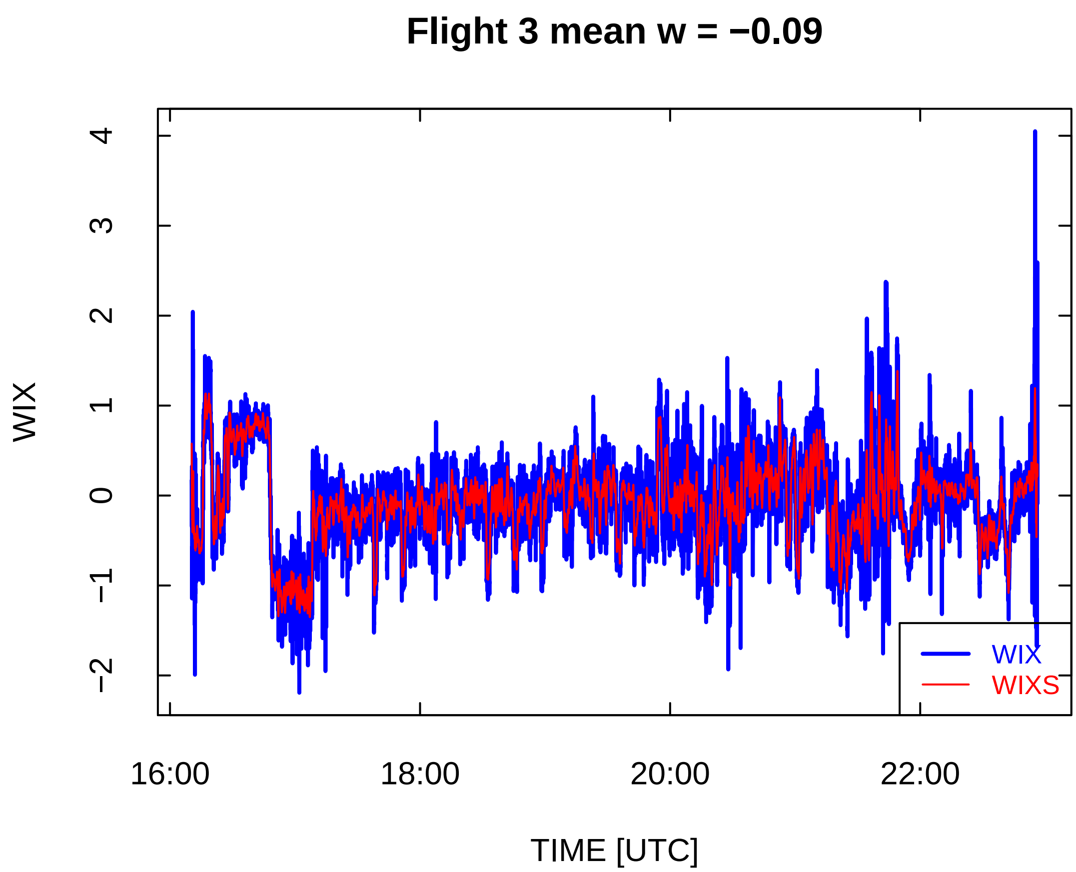


Figure 7: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

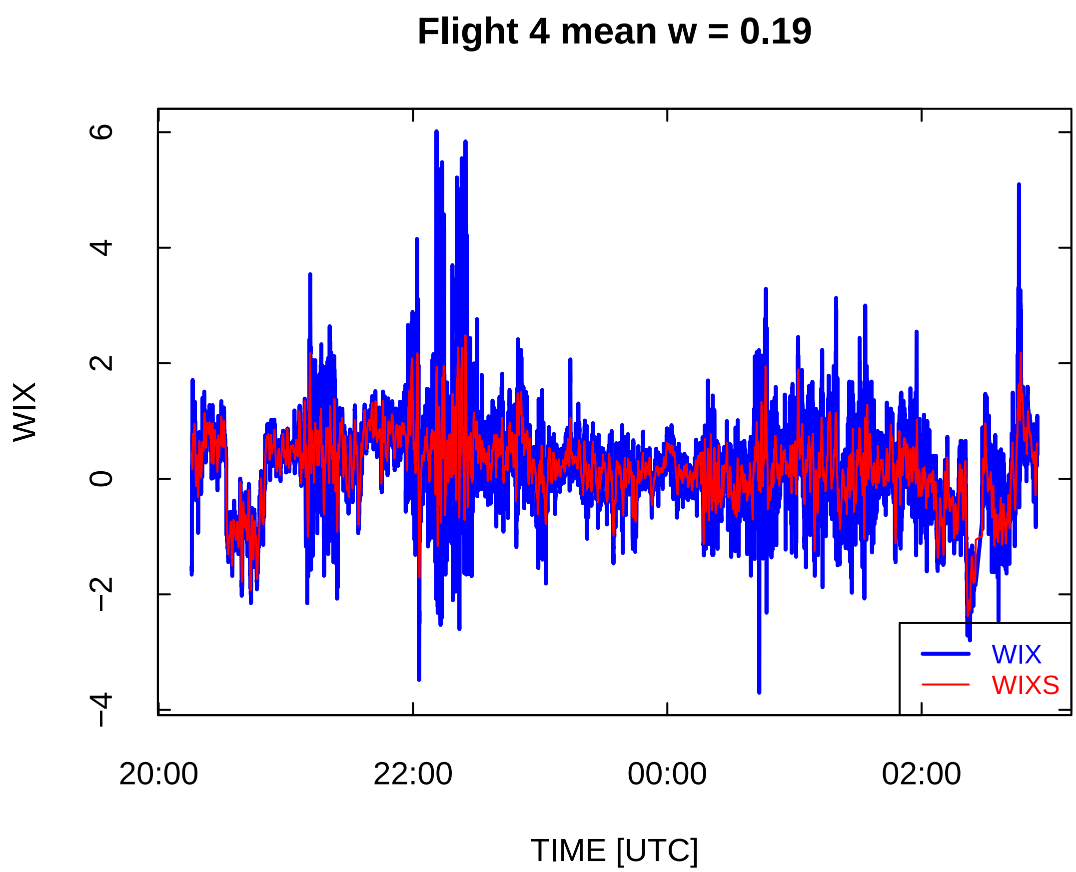


Figure 8: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

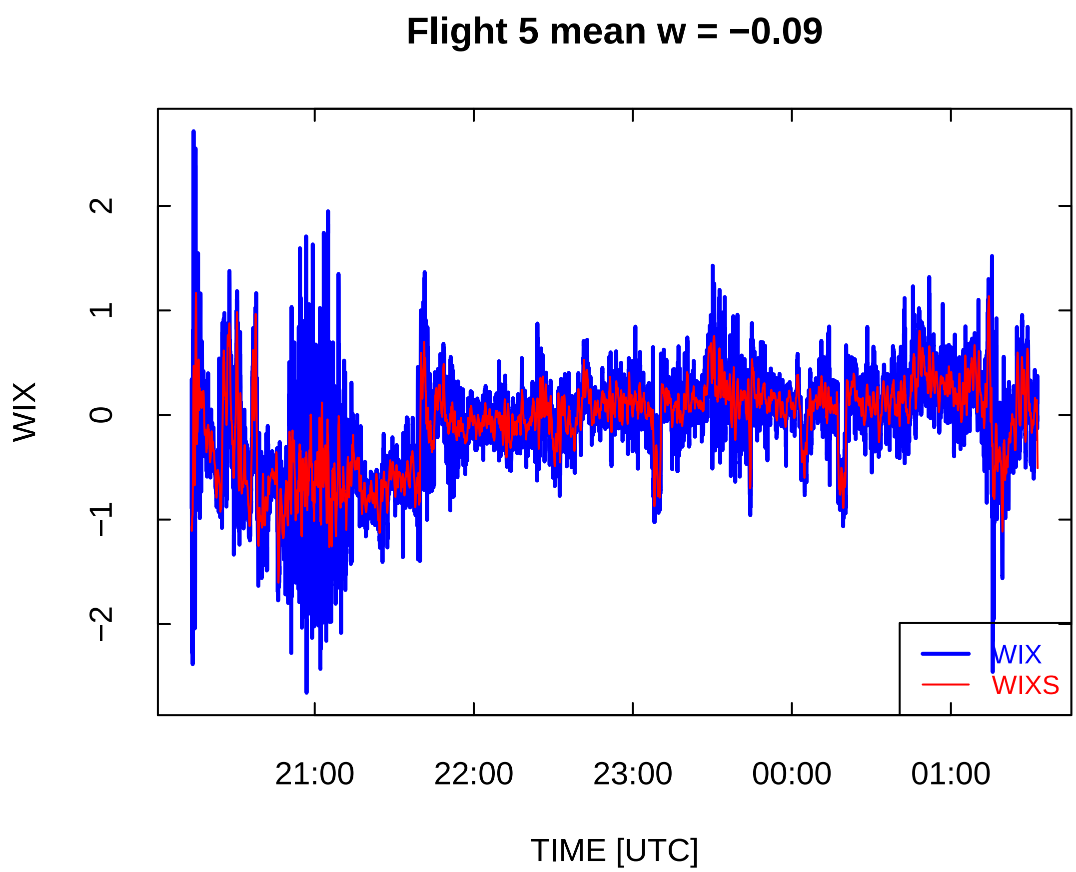


Figure 9: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

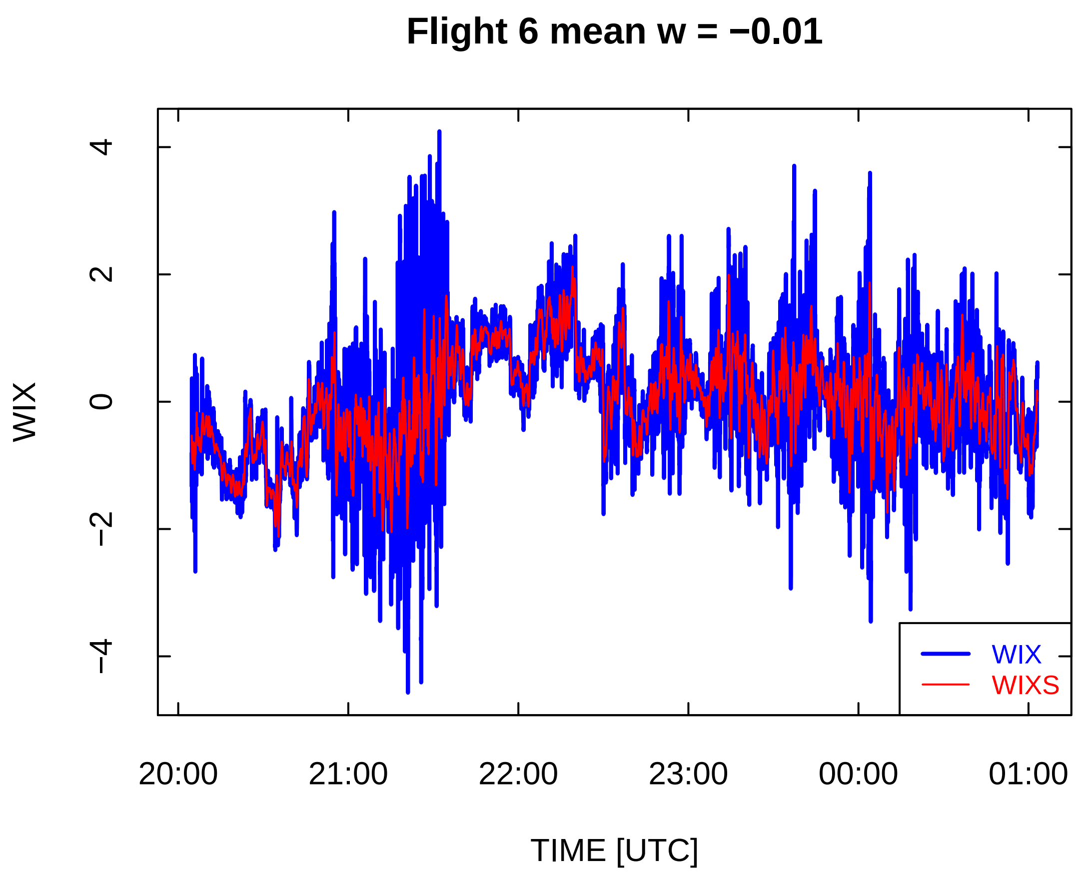


Figure 10: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

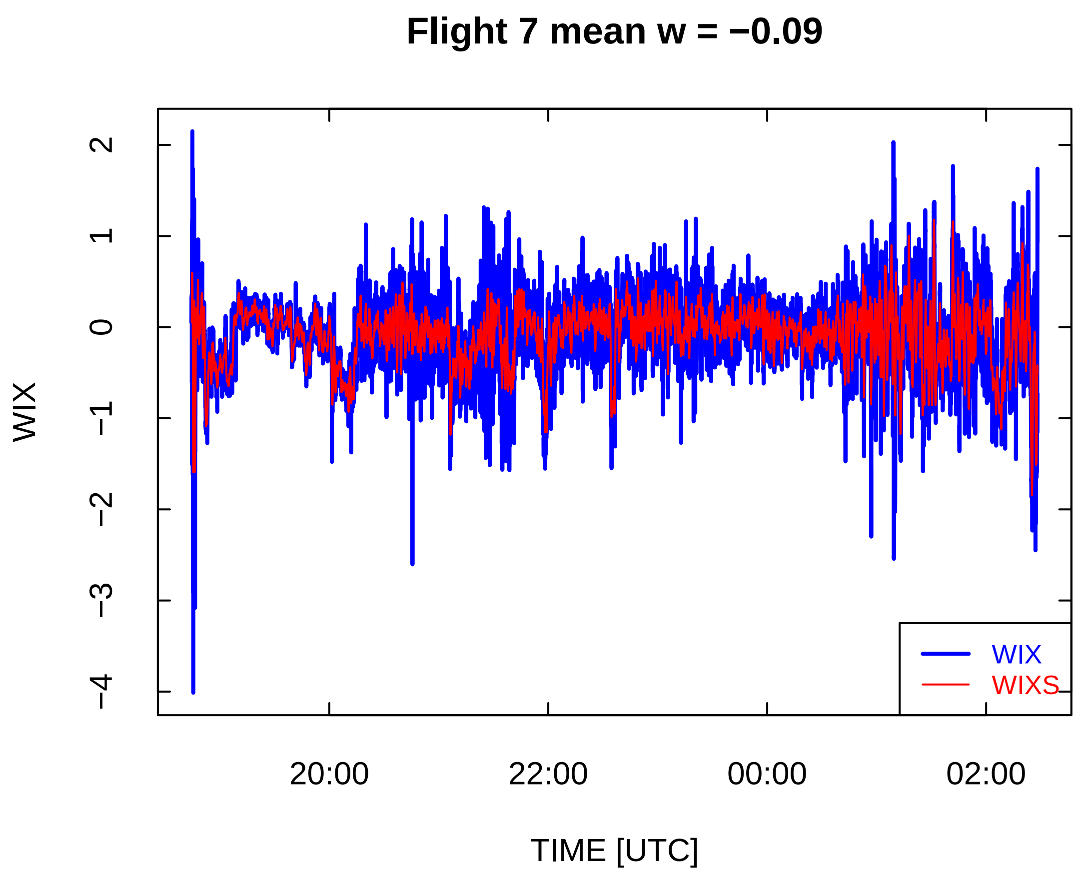


Figure 11: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

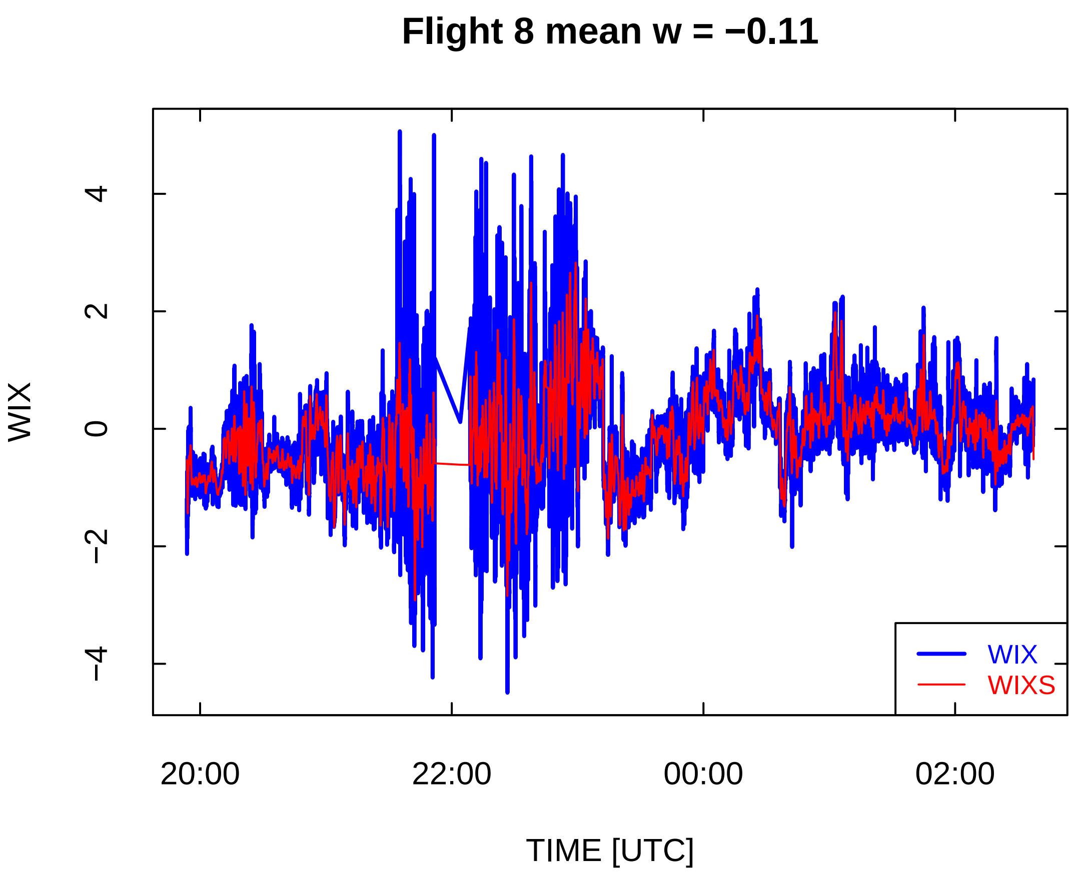


Figure 12: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

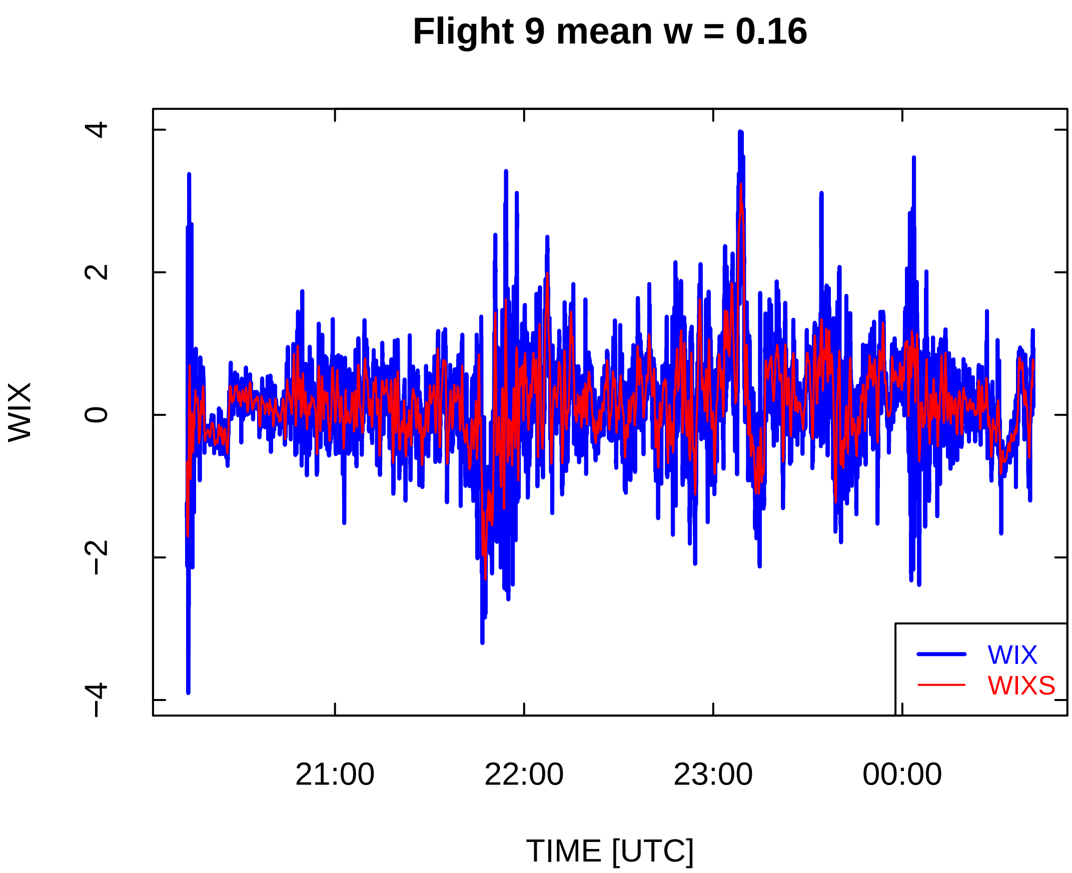


Figure 13: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

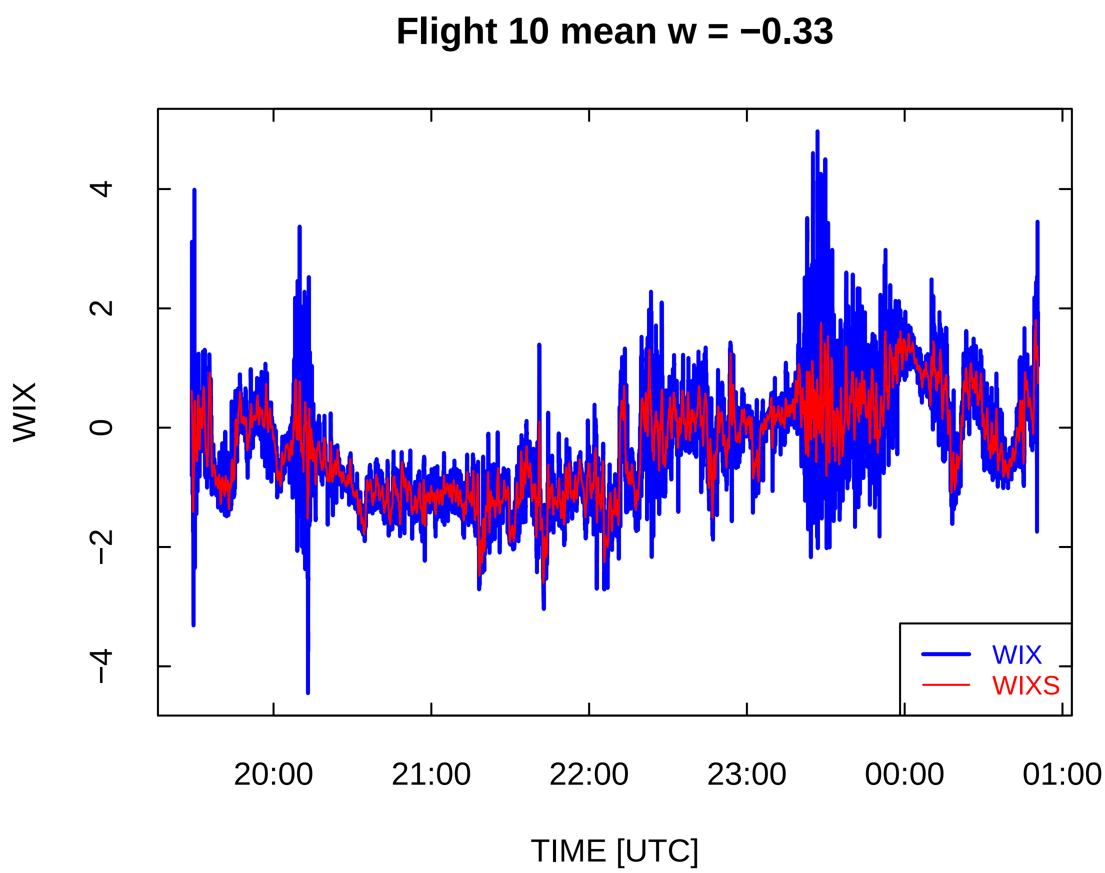


Figure 14: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

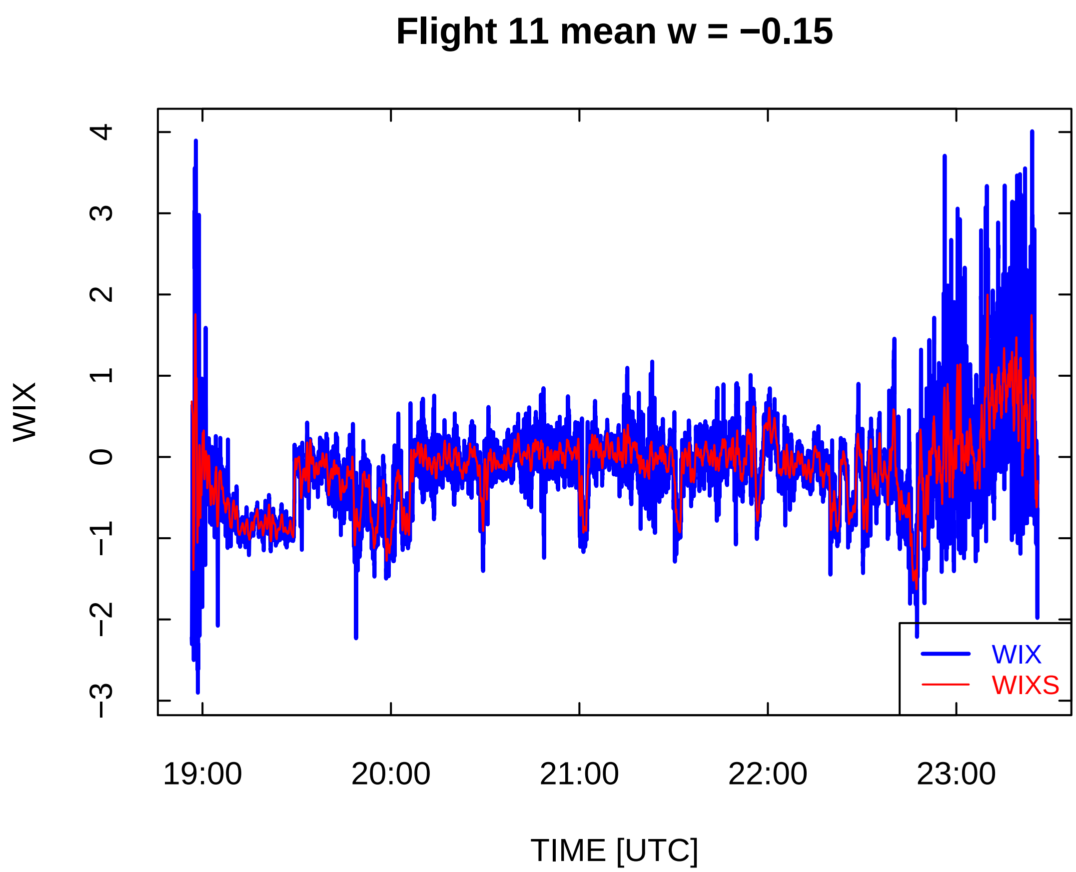


Figure 15: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

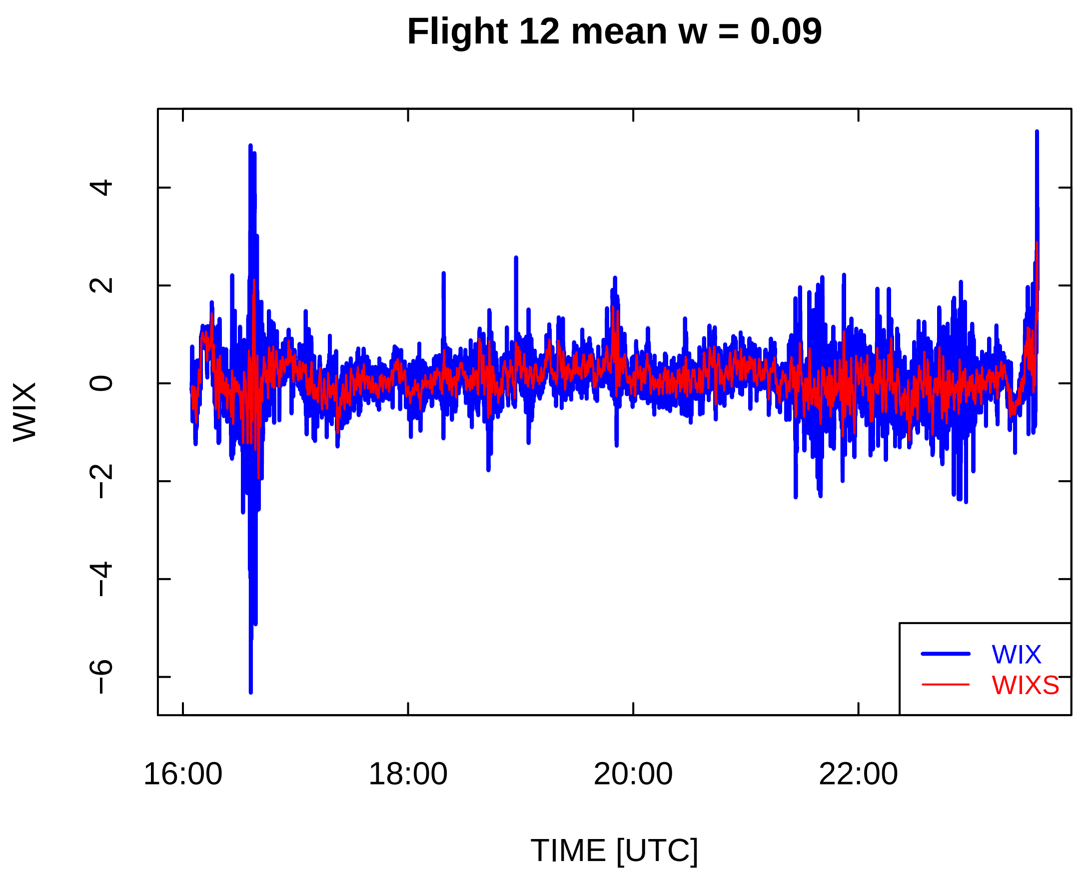


Figure 16: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

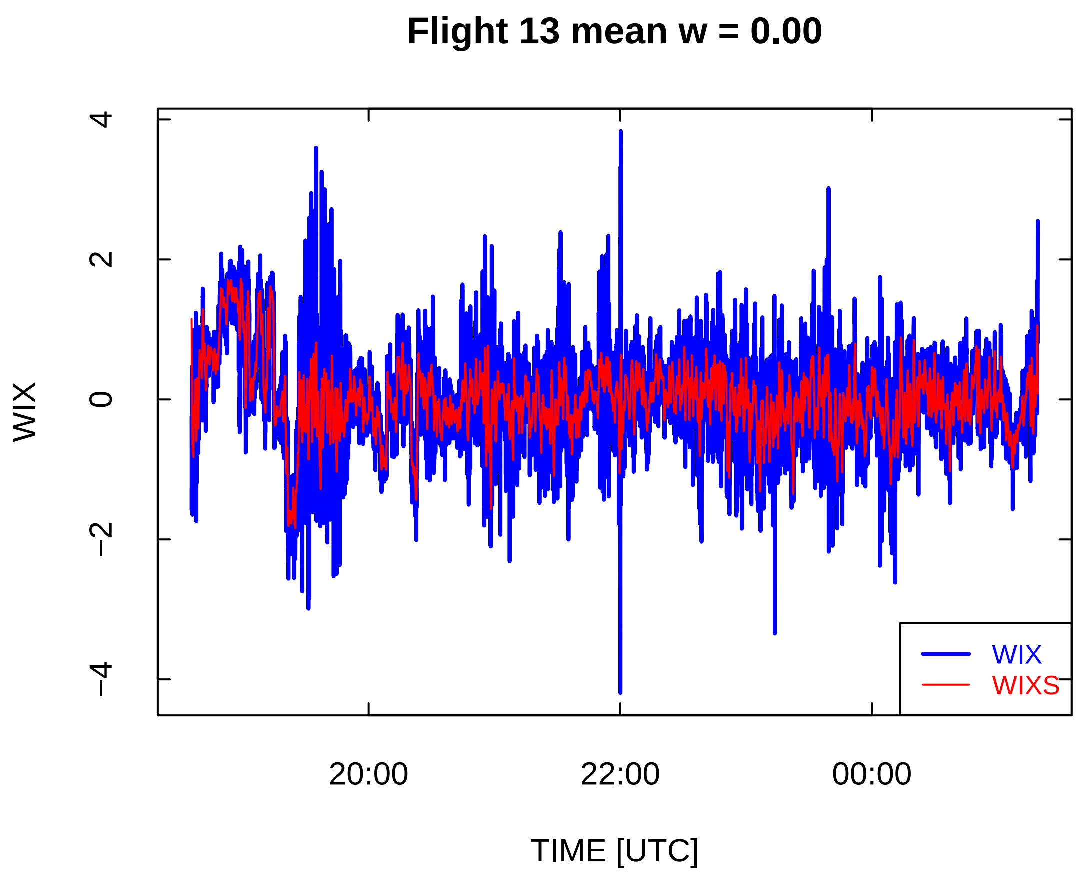


Figure 17: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

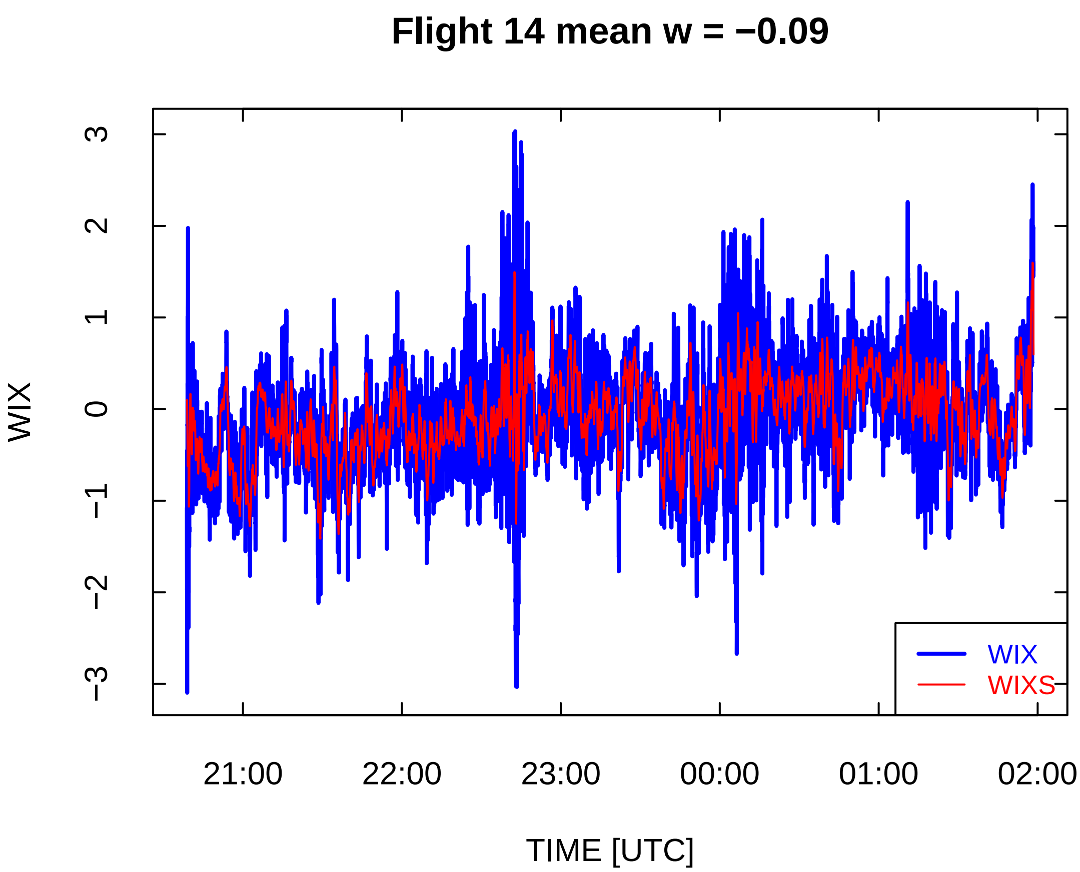


Figure 18: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

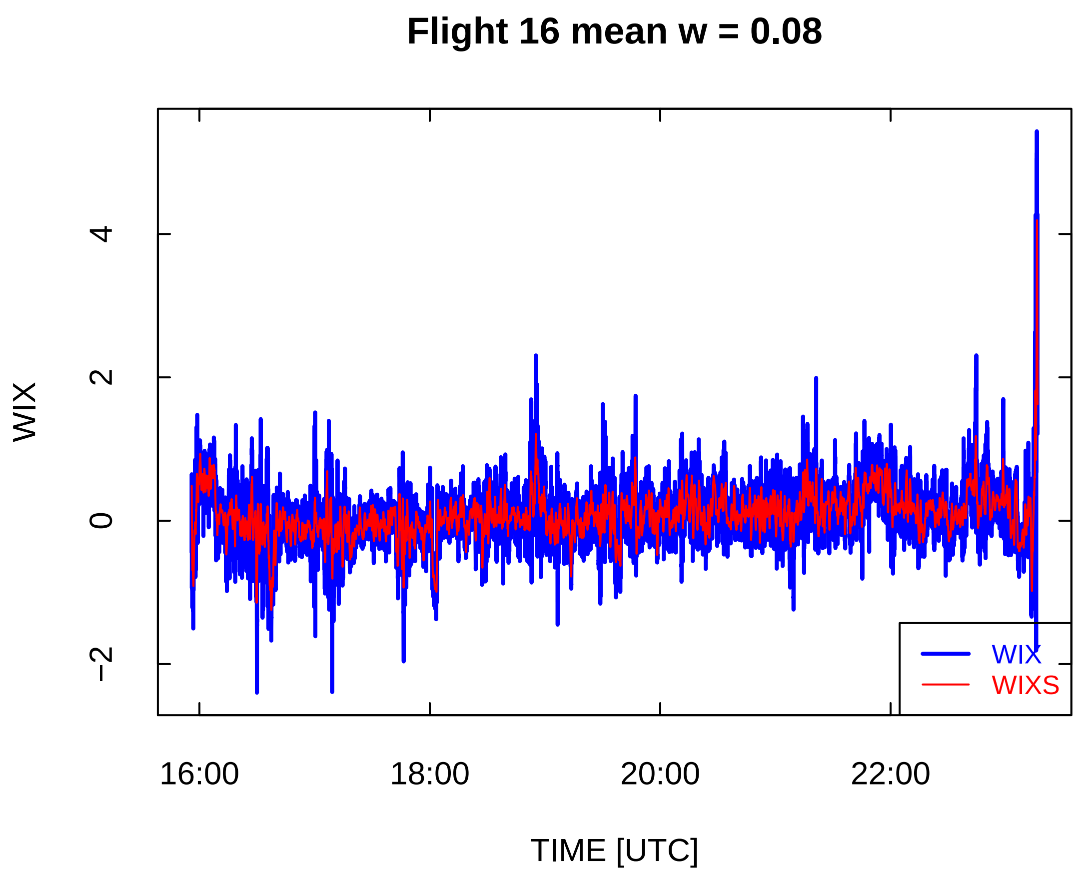


Figure 19: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

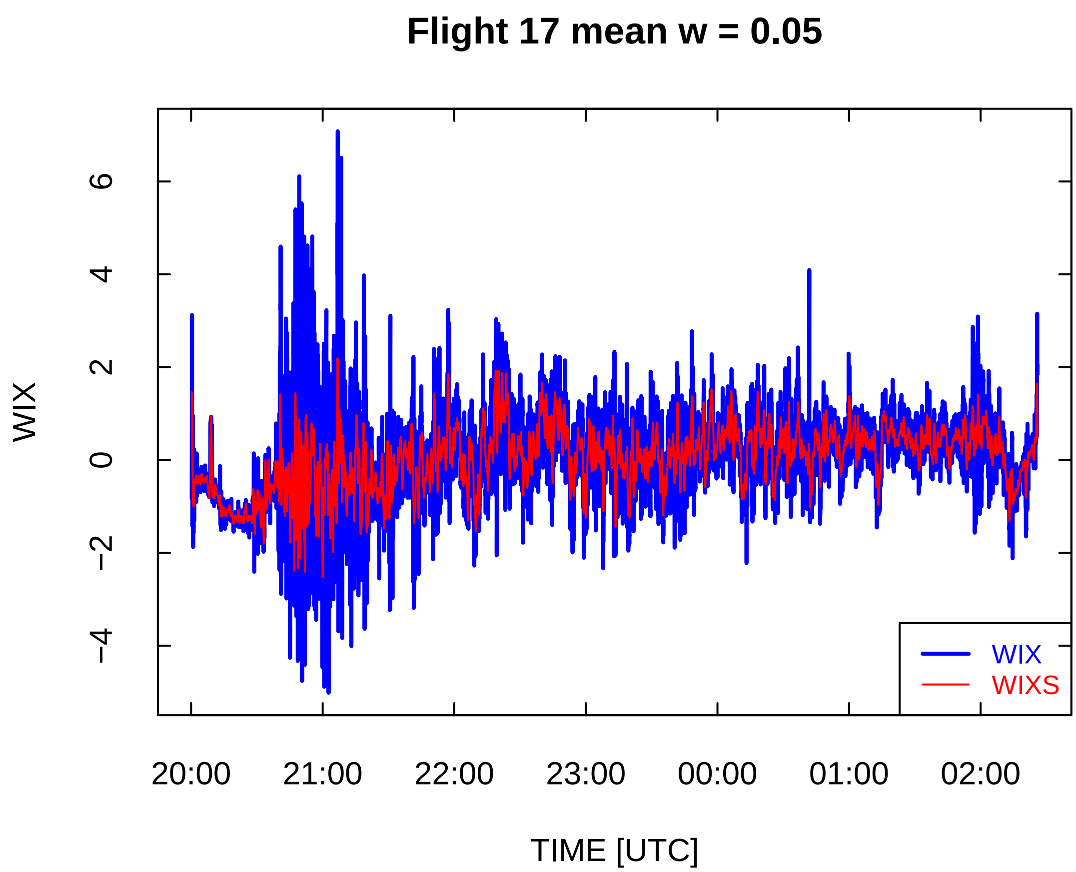


Figure 20: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

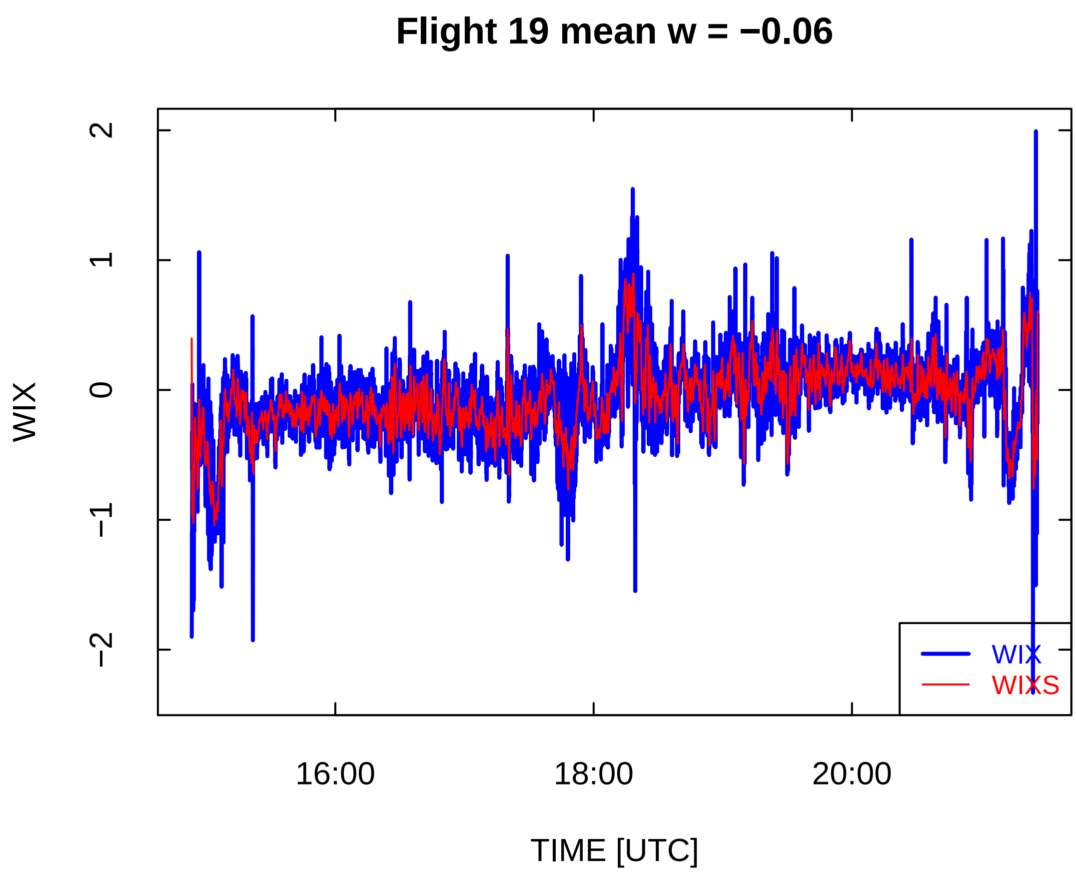


Figure 21: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

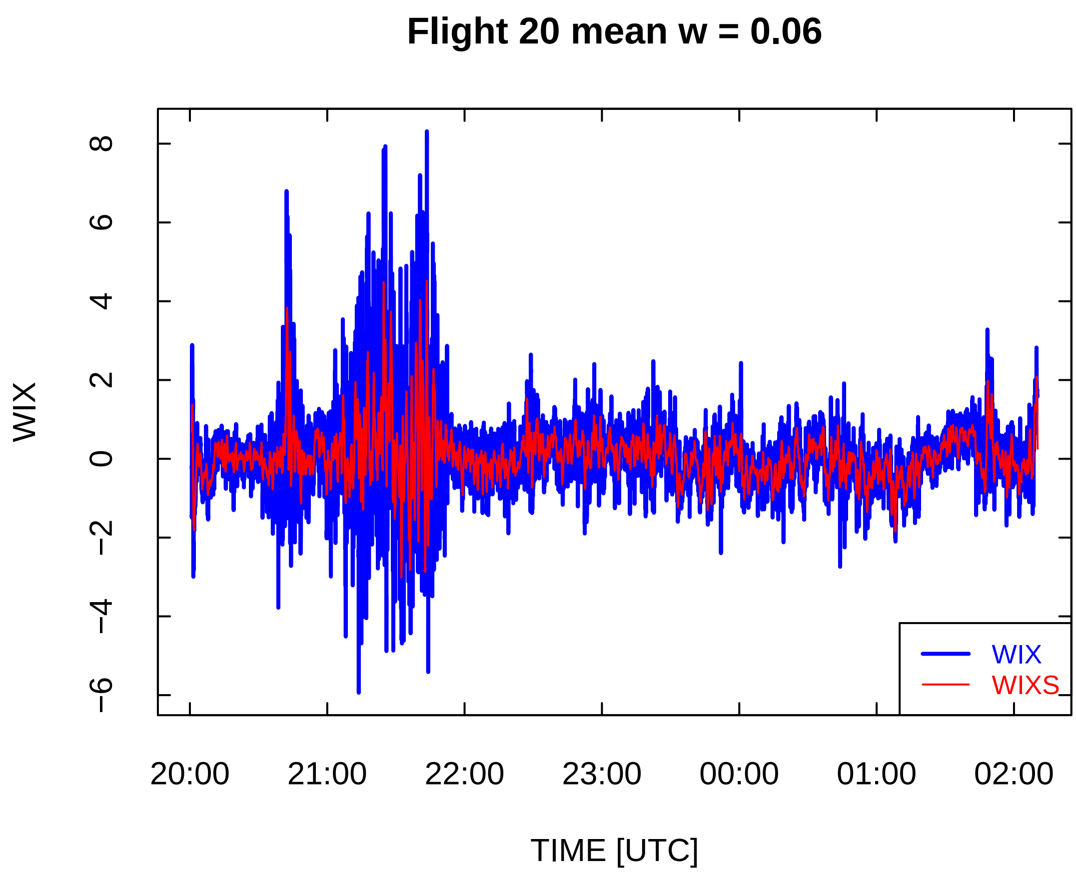


Figure 22: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

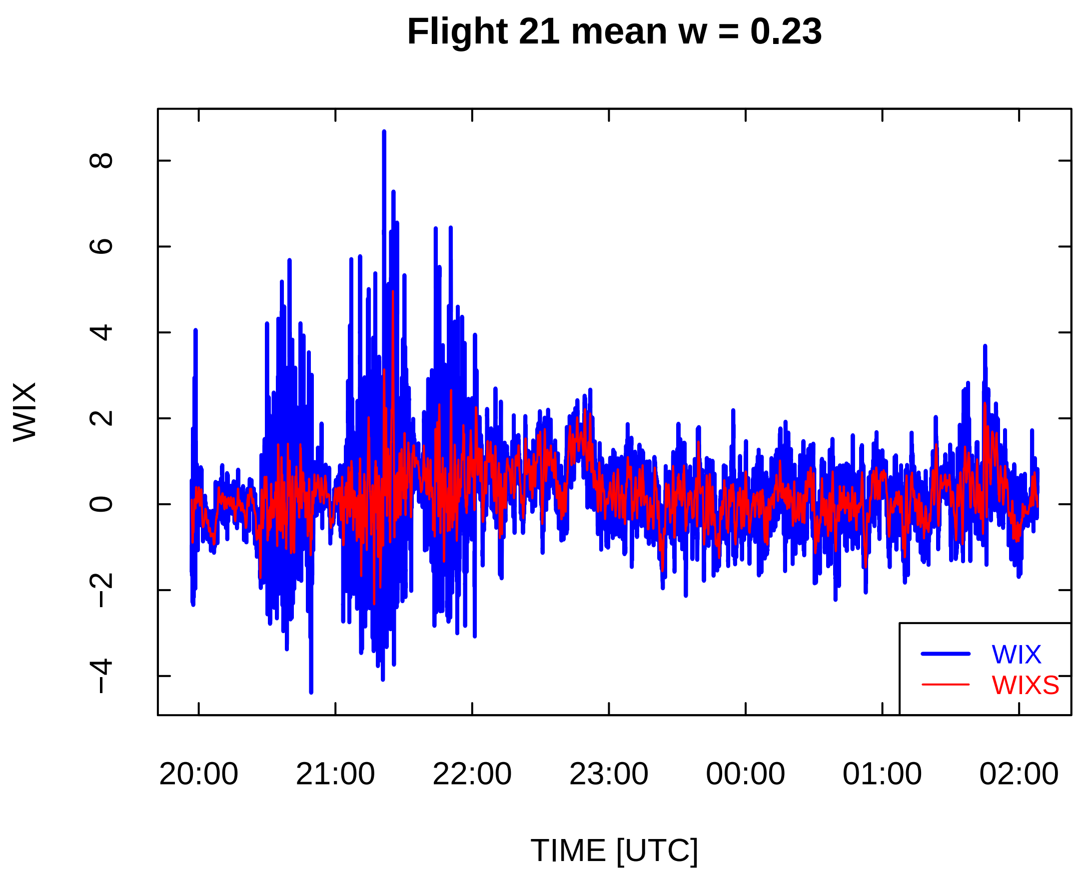


Figure 23: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.

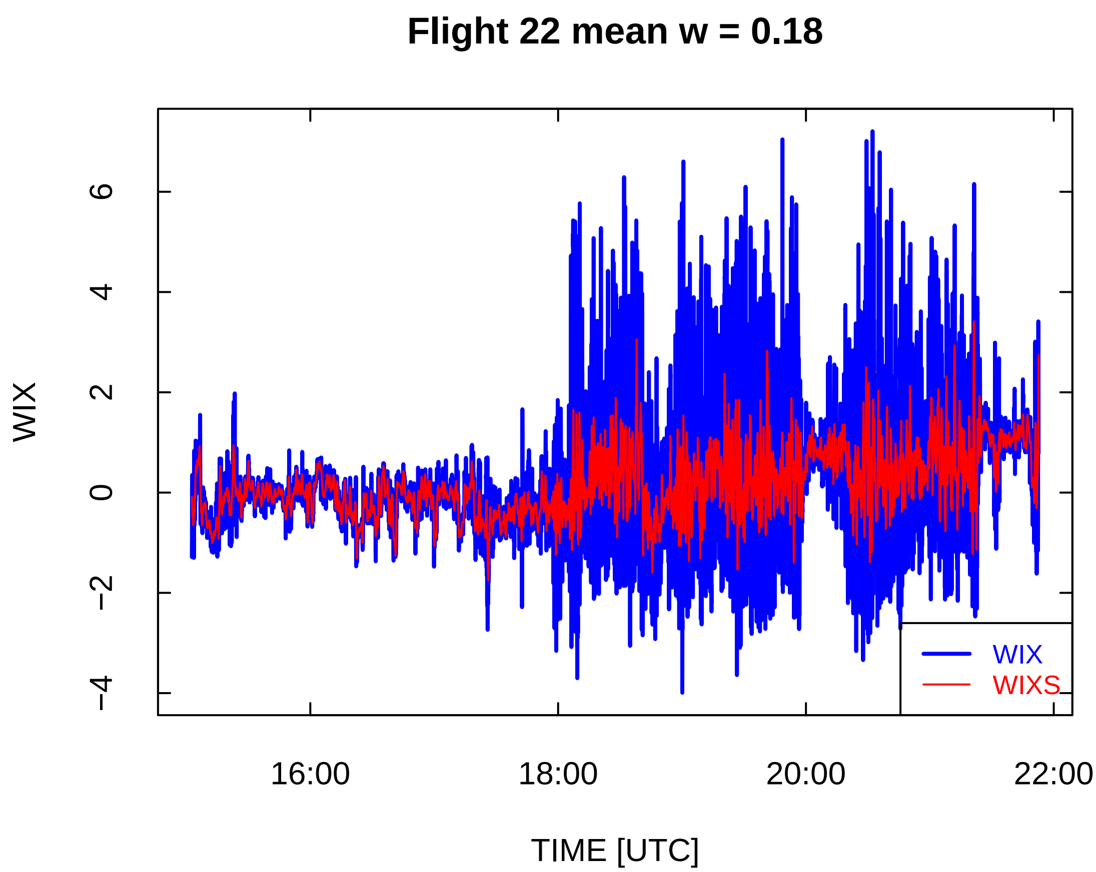


Figure 24: Recalculated vertical wind WIX and, with 60-s smoothing, WIXS.