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Intercomparison of wind speed, temperature, and humidity data between dropsondes and aircraft in situ measurements

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S1. Uncertainty Analysis and Calibration Details

a. Dropsonde Data Uncertainties

Dropsonde data from the Vaisala NRD41 sensors have the following conservative uncertainty estimates for various parameters:

-Pressure: ±0.4 hPa (repeatability)

-Temperature: ±0.1 K (repeatability), response time 0.5 s under standard conditions

-Relative Humidity: ±2% (repeatability), with response times of <0.3 s at +20°C and <10 s at -40°C

The repeatability of the sensors refers to the statistical variability in successive calibrations (confidence level: k=2). Given the higher ventilation speed in dropsonde applications compared to radiosonde use, response times are likely faster than the stated values. The response time of the humidity sensor varies exponentially with temperature. Since all relative humidity comparisons in this study were conducted within the temperature range of -20°C to +25°C, the response time correction for relative humidity was deemed negligible.

To ensure high data quality, all humidity sensors were reconditioned prior to deployment, mitigating potential dry bias caused by contaminants. Wind speed accuracy, directly estimated by the GPS receiver module, is typically better than ±0.4 m s^{-1}. Data points with uncertainties exceeding ±0.6 m s^{-1} were excluded as part of the quality control process (Vömel et al., 2023).

b. HU-25 Falcon In-Situ Wind Calibration

As ACTIVATE was the first time the HU-25 Falcon was used for measurement of flight level winds, extensive calibrations needed to be performed to precisely determine the slope and offsets for the angles of attack and sideslip, the heading offset, and the pressure defect (example results in Figure S1). To accomplish this dedicated calibration, flights were conducted during each of ACTIVATE’s six deployments to make enough repeated maneuvers above the boundary layer to build up the statistics and confidence in the values obtained while also minimizing the influence of the natural variability in the atmosphere. Most of the statistics built up were from these flights as the atmosphere desired for wind measurement calibrations (cloud-free, homogenous, and above the boundary layer) are diametrically opposed to those desired for ACTIVATE science flights.

To determine the angle of attack slope and offset, speed variations were performed at multiple altitudes varying the airspeed from near minimum to near maximum holding constant at four speeds for two minutes each (Figure S1c). The coefficients for the sideslip angle were determined through crabbing the aircraft side-to-side while holding the wings level (Figure S1b). The results of these maneuvers were repeatable from flight to flight and year to year with no unexpected outliers or results. The heading offset was determined though cross-wind reverse headings repeated at a couple of altitudes each year. Even though the heading offset is not dependent on altitude, it was done at multiple altitudes for a sanity check and to help offset any unintended influence of natural variability. The pressure defect was determined via multiple along-track reverse headings from just above the boundary layer up to about 20 kft with enough made to be able to determine the offset as a function of Mach number very well (Figure S1a). Our calibration maneuvers separated the along track and cross track reverse headings in order to minimize the influence of natural variability on the results.

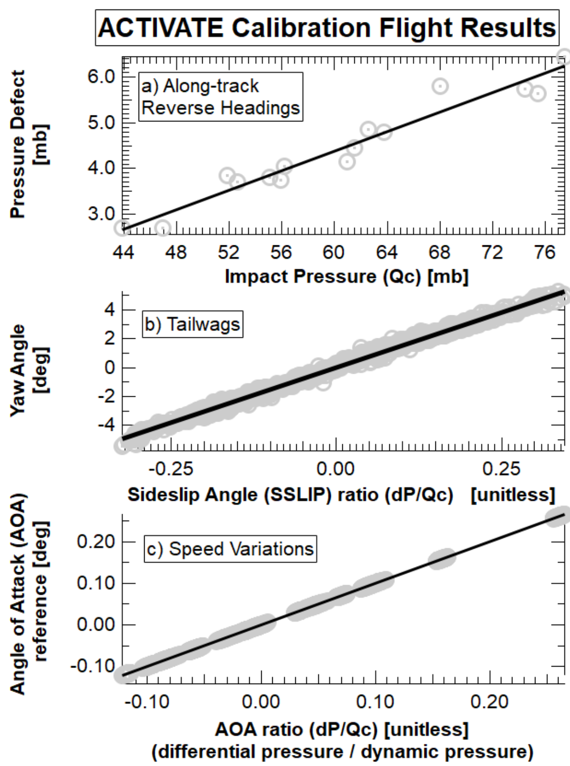

Figure S1. Results of the dedicated calibration flights for the TAMMS winds system on the NASA HU-25 Falcon during the ACTIVATE field campaign. Data are for multiple years and show the repeatability in the results from year-to-year. Starting from the top, a) is from the along-track reverse headings to determine the pressure defect term, b) is the results of the tailwags (crabbing) to determine the coefficients for the sideslip angle, and c) is the results from the speed variations that provide the coefficients necessary to compute the angle of attack.

Table S1: Summary table of all TAMMS – dropsonde wind speed (u component) intercomparison metrics. The first row uses all data points following the Fig. 1 method excluding the last step, which allows for vastly increased statistics by allowing all pairs to be used that were within 25 m vertical distance. The second row includes the final step of Fig. 1 using only the data points with minimized vertical separation (i.e., one pair per dropsonde launch). Remaining rows examine all the data from the second row but in various categories. SE = standard error; STD = standard deviation.

	N	Linear (SE)/Bisector Slope (SE)	Linear/Bisector Y-Intercept	r	Mean Error ± STD (m s^{-1})
All: Relaxed vertical criteria	369677	1.01 (0.00)/1.03 (0.00)	0.05 / -0.06	0.97	0.10 ± 1.68
All: Strict vertical criteria	555	1.02 (0.01)/1.04 (0.01)	0.09/-0.02	0.97	0.16 ± 1.62
Summer	293	1.01 (0.01)/1.04 (0.02)	0.07/0.02	0.97	0.09 ± 1.25
Winter	262	1.02 (0.02)/1.05 (0.02)	0.11/-0.08	0.97	0.22 ± 1.95
Cloudy	81	1.01 (0.03)/1.05 (0.04)	-0.41/-0.55	0.97	-0.37 ± 1.73
Clear	465	1.01 (0.01)/1.04 (0.01)	0.18/0.08	0.97	0.24 ± 1.57
u component ≤ 1.26 m s^{-1}	185	0.97 (0.03)/1.05 (0.04)	-0.09/0.17	0.92	-0.01 ± 1.39
1.26 < u component ≤ 6.30 m s^{-1}	185	0.99 (0.08)/1.46 (0.10)	0.29/-2.55	0.68	0.27 ± 1.51
u component > 6.30 m s^{-1}	185	1.05 (0.03)/1.13 (0.04)	-0.41/-1.34	0.93	0.20 ± 1.89
Altitude ≤ 673 m	185	0.99 (0.02)/1.02 (0.02)	-0.01/-0.06	0.98	-0.03 ± 1.37
673 < Altitude ≤ 1304 m	185	0.99 (0.02)/1.02 (0.03)	0.07/-0.08	0.96	0.01 ± 1.64
Altitude > 1304 m	185	1.04 (0.02)/1.06 (0.02)	0.27/0.10	0.98	0.49 ± 1.76
Horiz. distance ≤ 13616 m	185	1.01 (0.02)/1.03 (0.02)	0.06/-0.02	0.98	0.08 ± 1.33
13616 < Horiz. dist. ≤ 22955 m	185	1.01 (0.02)/1.04 (0.02)	-0.11/-0.23	0.97	-0.08 ± 1.57
Horiz. distance > 22955 m	185	1.03 (0.02)/1.06 (0.03)	0.34/0.20	0.97	0.47 ± 1.85
5 TAMMS Pts/3 Dropsonde Pts	485	1.00 (0.01)/0.97 (0.02)	0.10/0.23	0.97	0.14 ± 1.54
11 TAMMS Pts/3 Dropsonde Pts	467	1.01 (0.01)/0.97 (0.02)	0.09/0.21	0.97	0.13 ± 1.46
21 TAMMS Pts/3 Dropsonde Pts	448	1.00 (0.01)/0.98 (0.01)	0.06/0.17	0.98	0.09 ± 1.40

Table S2. Same as Table S1 but for the v component of wind speed.

	N	Linear (SE)/Bisector Slope (SE)	Linear/Bisector Y-Intercept	r	Mean Error ± STD (m s^{-1})
All: Relaxed vertical criteria	369677	0.96 (0.00)/1.00 (0.00)	-0.13/ -0.06	0.96	-0.05 ± 1.72
All: Strict vertical criteria	555	0.96 (0.01)/1.00 (0.02)	-0.01/0.03	0.96	0.03 ± 1.67
Summer	293	0.98 (0.02)/1.02 (0.02)	-0.05/-0.06	0.97	-0.05 ± 1.35
Winter	262	0.94 (0.02)/0.99 (0.03)	0.01/0.10	0.95	0.12 ± 2.00
Cloudy	81	0.92 (0.04)/0.97 (0.06)	0.06/0.27	0.94	0.37 ± 2.09
Clear	465	0.97 (0.04)/1.01 (0.06)	-0.02/-0.01	0.96	-0.01 ± 1.56
v component ≤ -3.42 m s^{-1}	185	0.81 (0.04)/0.98 (0.06)	-1.20/0.00	0.83	0.19 ± 1.72
-3.42 < v component ≤ 2.20 m s^{-1}	185	1.00 (0.06)/1.32 (0.08)	0.13/0.31	0.76	0.13 ± 1.43
v component > 2.20 m s^{-1}	185	1.05 (0.05)/1.27 (0.07)	-0.49/-2.12	0.82	-0.24 ± 1.76
Altitude ≤ 673 m	185	0.97 (0.02)/1.00 (0.02)	0.01/0.03	0.97	0.03 ± 1.46
673 < Altitude ≤ 1304 m	185	0.93 (0.02)/0.98 (0.03)	0.07/0.12	0.95	0.15 ± 1.65
Altitude > 1304 m	185	0.97 (0.02)/1.02 (0.03)	-0.11/-0.08	0.95	-0.09 ± 1.87
Horiz. distance ≤ 13616 m	185	0.95 (0.02)/0.99 (0.03)	0.00/0.05	0.96	0.06 ± 1.47
13616 < Horiz. dist. ≤ 22955 m	185	0.96 (0.02)/1.00 (0.03)	0.00/0.06	0.96	0.06 ± 1.71
Horiz. distance > 22955 m	185	0.97 (0.02)/1.01 (0.03)	-0.03/-0.04	0.96	-0.04 ± 1.82
5 TAMMS Pts/3 Dropsonde Pts	485	0.95 (0.02)/0.96 (0.03)	0.02/0.02	0.96	0.05 ± 1.62
11 TAMMS Pts/3 Dropsonde Pts	467	0.95 (0.01)/0.96 (0.02)	0.01/0.01	0.96	0.04 ± 1.59
21 TAMMS Pts/3 Dropsonde Pts	448	0.96 (0.01)/0.96 (0.02)	0.00/0.00	0.96	0.03 ± 1.59

References

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