Calibration of the University of North Dakota's Citation Aircraft Wind System

David J. Delene

Department of Atmospheric Sciences
University of North Dakota

Where it all Started

A long, long, time ago ..... May

In an office, not too far way ...

What? You have to move the IMU!

It shouldn't be a problem.
Just redo the calibration.

Why Measure Winds During Flight

- Basic Atmospheric Parameter
- Transport Studies
- Vertical Velocity (updrafts, downdrafts)
- Air Parcel Tracking

Wind Velocity Measurement from an Aircraft

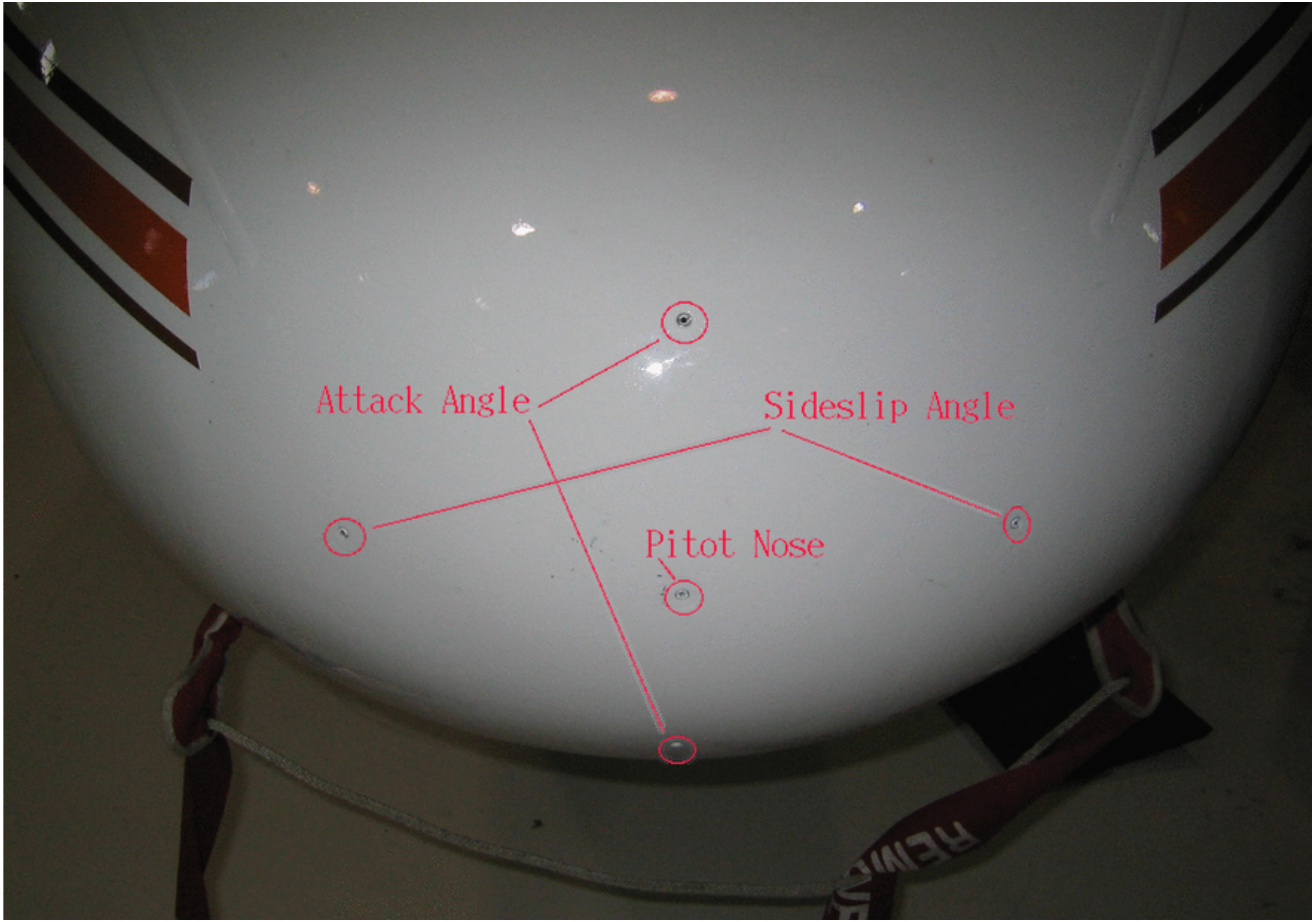
$$\mathbf{V = V_p + V_a}$$

Velocity of the aircraft with respect to the earth - V_p

Velocity of the air with respect to the air

Vp – Measured with the Position and Orientation System
Va – Measured with pressures transducers on the aircraft nose

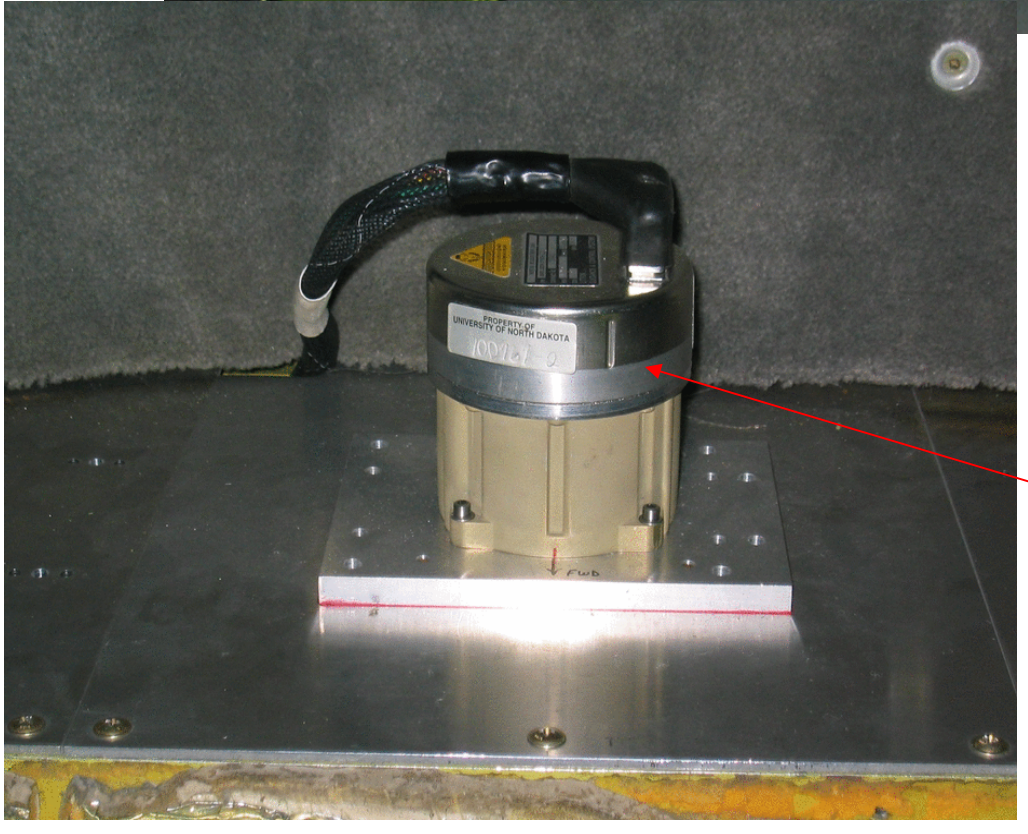
Pitot Pressure Ports on Aircraft Nose



Inside of the Citation's Radome

Position and Orientation System

Rack Mount Computer System



Inertial Measurement Unit

Air Velocity with Respect to the Earth

$$U = -U_a * D^{-1}[\sin\Psi\cos\Theta + \tan\beta\,(\cos\Psi\cos\phi + \sin\Psi\sin\Theta\sin\phi) + \tan\alpha\,(\sin\Psi\sin\Theta\cos\phi - \cos\Psi\sin\phi)] + U_p - L(DIV(\Theta)\sin\theta\sin\Psi - DIV(\Psi)\cos\Psi\cos\theta)$$

$$V = -U_a * D^{-1}[\cos\Psi\cos\Theta - \tan\beta\,(\sin\Psi\cos\phi - \cos\Psi\sin\Theta\sin\phi) + \tan\alpha\,(\cos\Psi\sin\Theta\cos\phi + \sin\Psi\sin\phi)] + V_p - L(DIV(\Psi)\sin\Psi\sin\Theta + DIV(\Theta)\cos\Psi\sin\theta)$$

$$W = -U_a * D^{-1}(\sin\Theta - \tan\beta\cos\Theta\sin\phi - \tan\alpha\cos\Theta\cos\phi) + W_p + LDIV(\Theta)\cos\Theta$$

$$D = (1 + \tan^2\alpha + \tan^2\beta)^{1/2}$$

U – East Wind Velocity
V – North Wind Velocity
W – Upward Wind Velocity

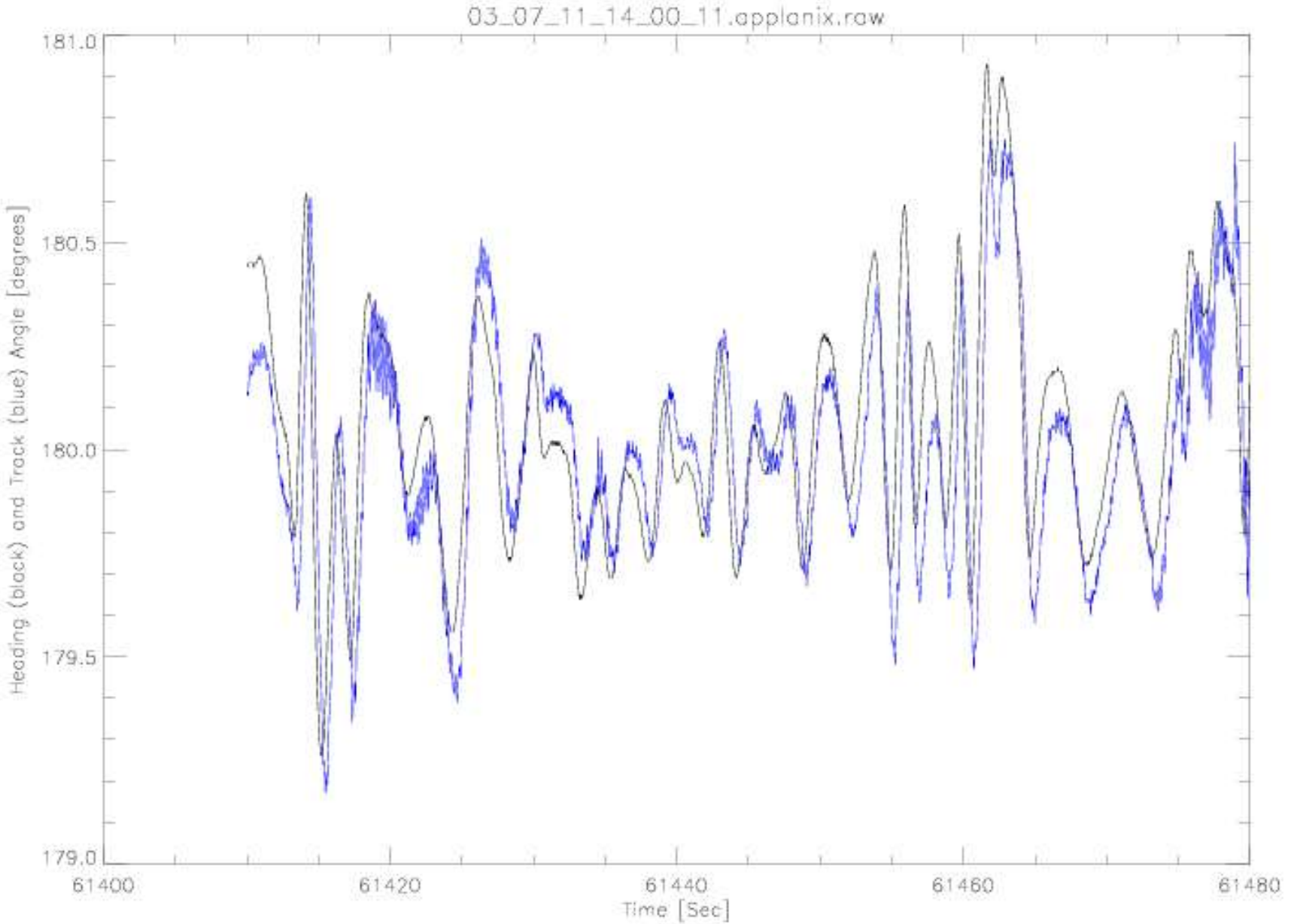
U_p – East Aircraft Velocity
V_p – North Aircraft Velocity
W_p – Upward Aircraft Velocity

Ψ – True Heading, measured clockwise (looking down) from north
Θ – Pitch Angle
ϕ – Roll Angle
α – Alpha Angle
β – Beta Angle
L – Distance between the inertial navigation system and the air-sensing platform along the x-axis of the aircraft

Calibration Procedure

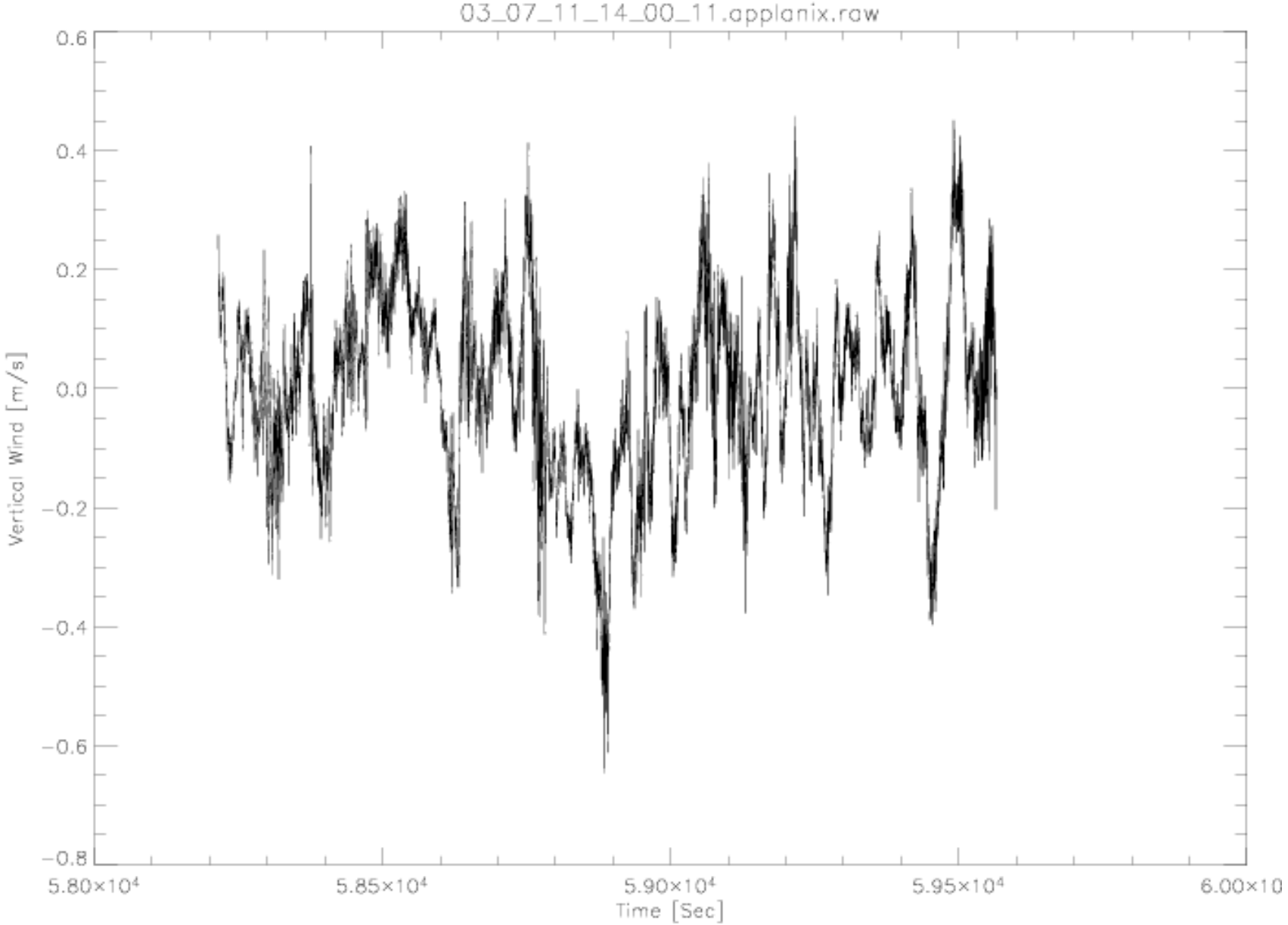
- Heading Angle Offset
- Alpha Angle Calibration
- Beta Angle Calibration
- Pitot Pressure Calbiration

Heading Angle Offset



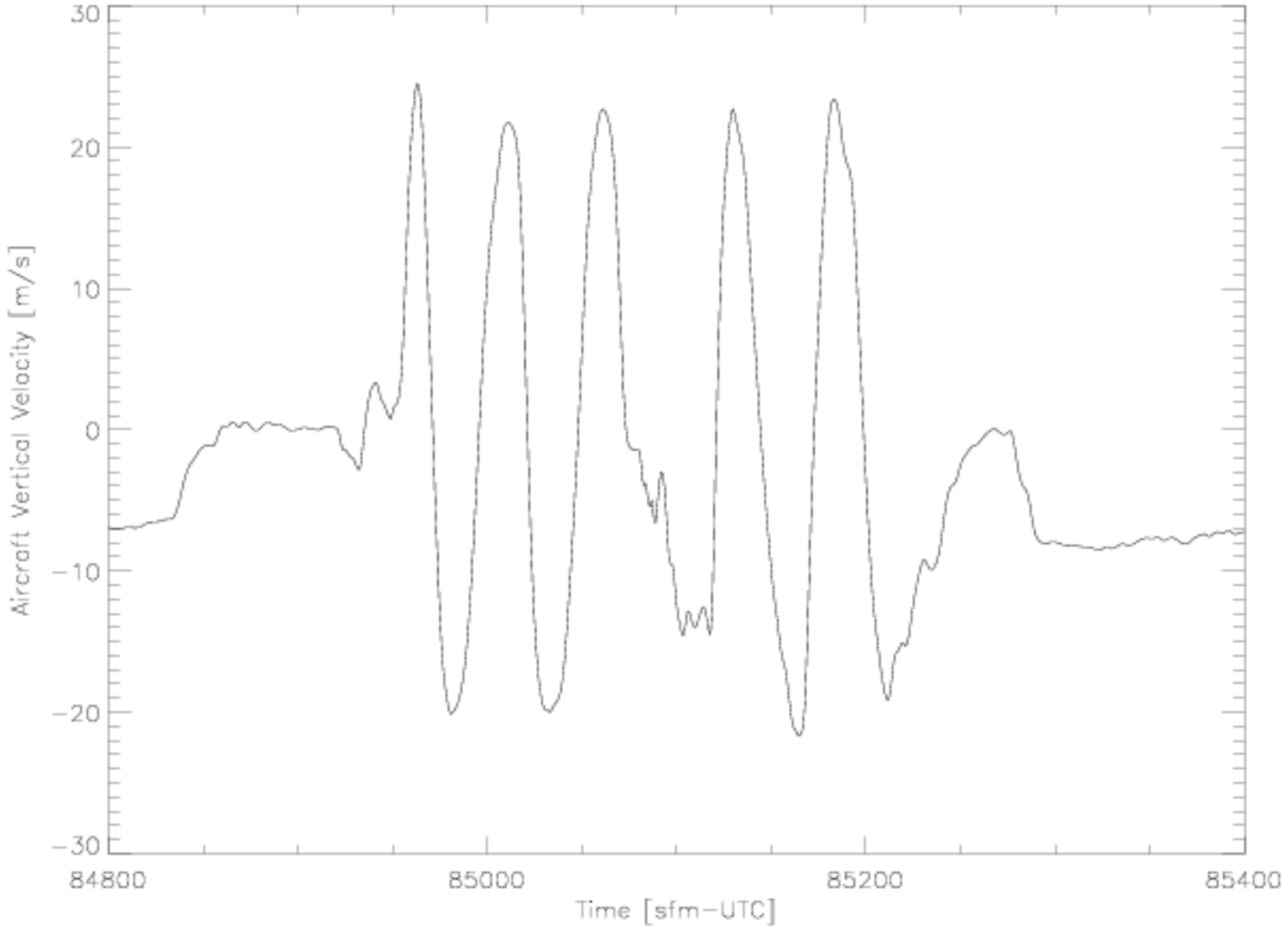
The aircraft's heading (black line) and track angle (blue line) versus time for taxies segment 3 on July 11, 2003 using the real time data files.

Alpha Angle Calibration



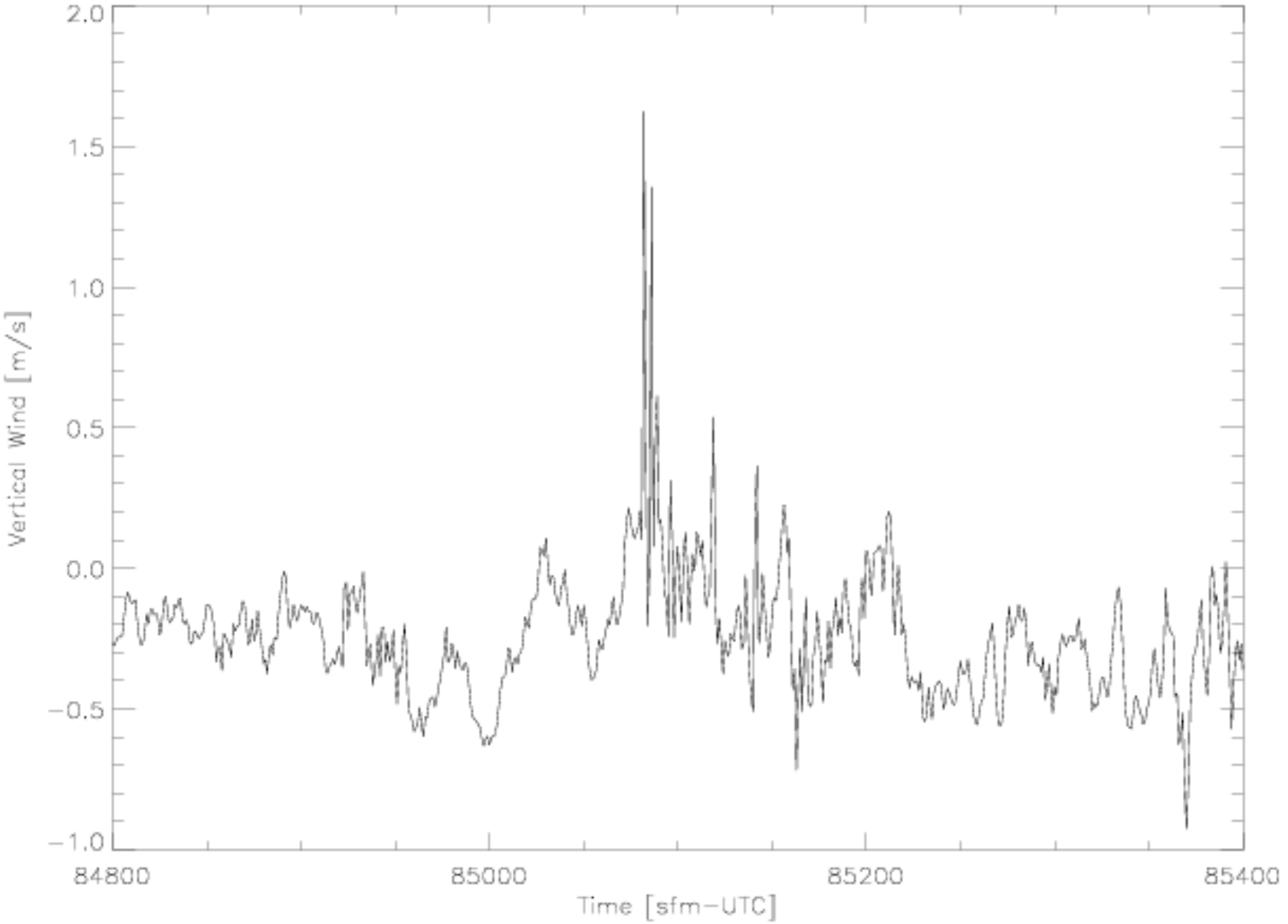
The vertical wind versus time for the time period of the alpha angle calibration on July 11, 2003.

Alpha Angle Check



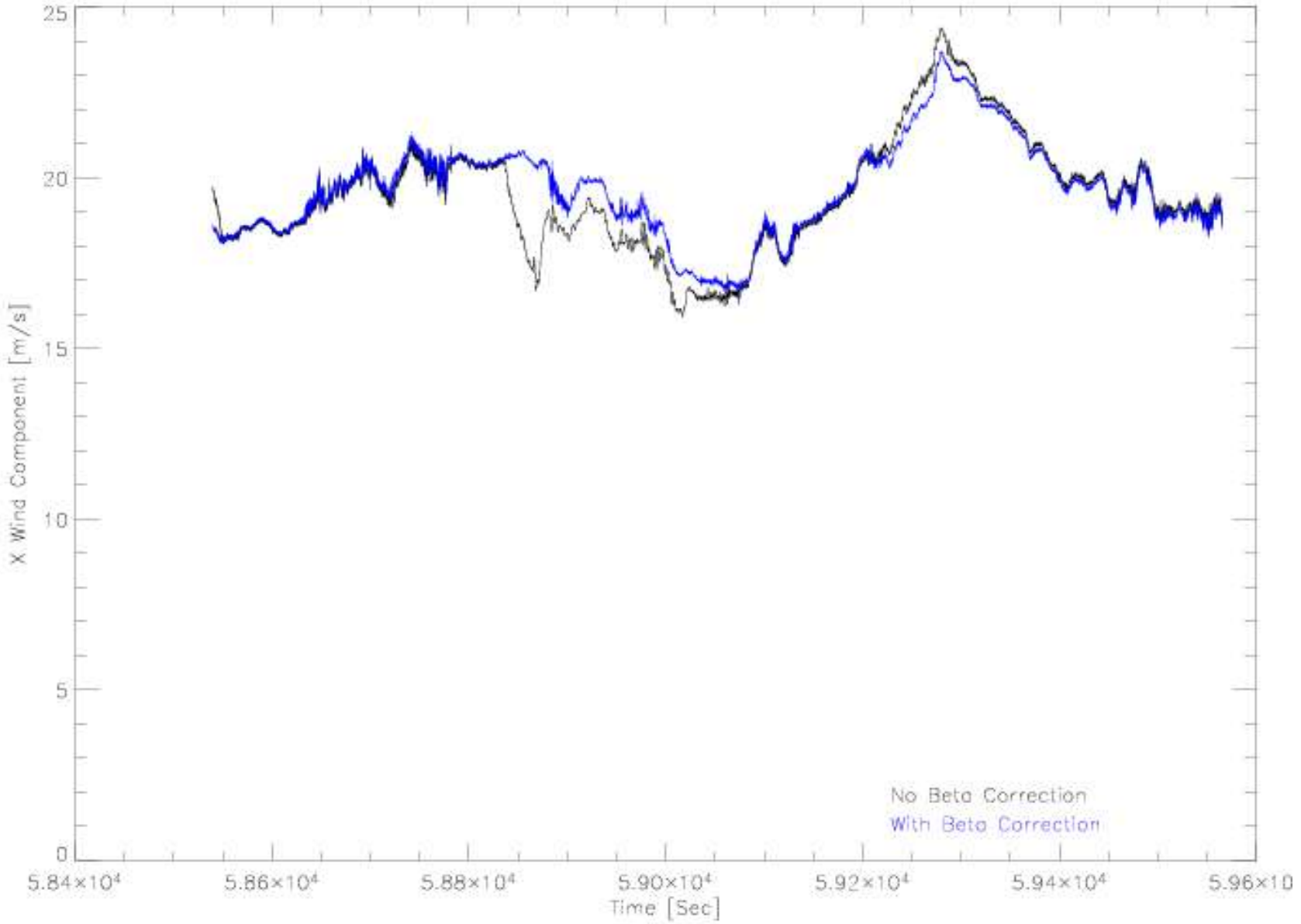
The aircraft's vertical velocity during the October 8, 2003 flight.

Alpha Angle Check



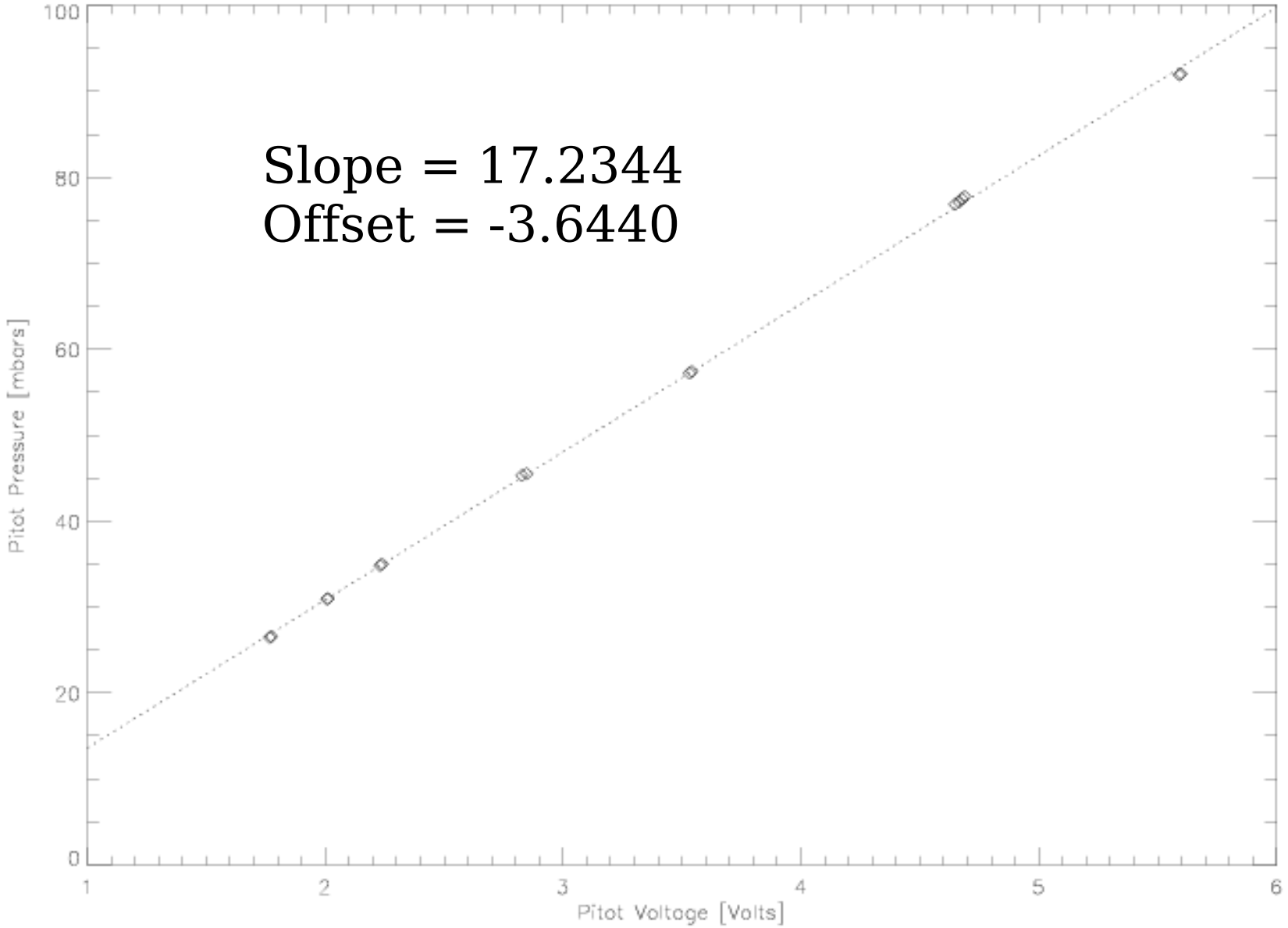
The vertical wind versus time during the October 8, 2003 flight.

Beta Angle Calibration



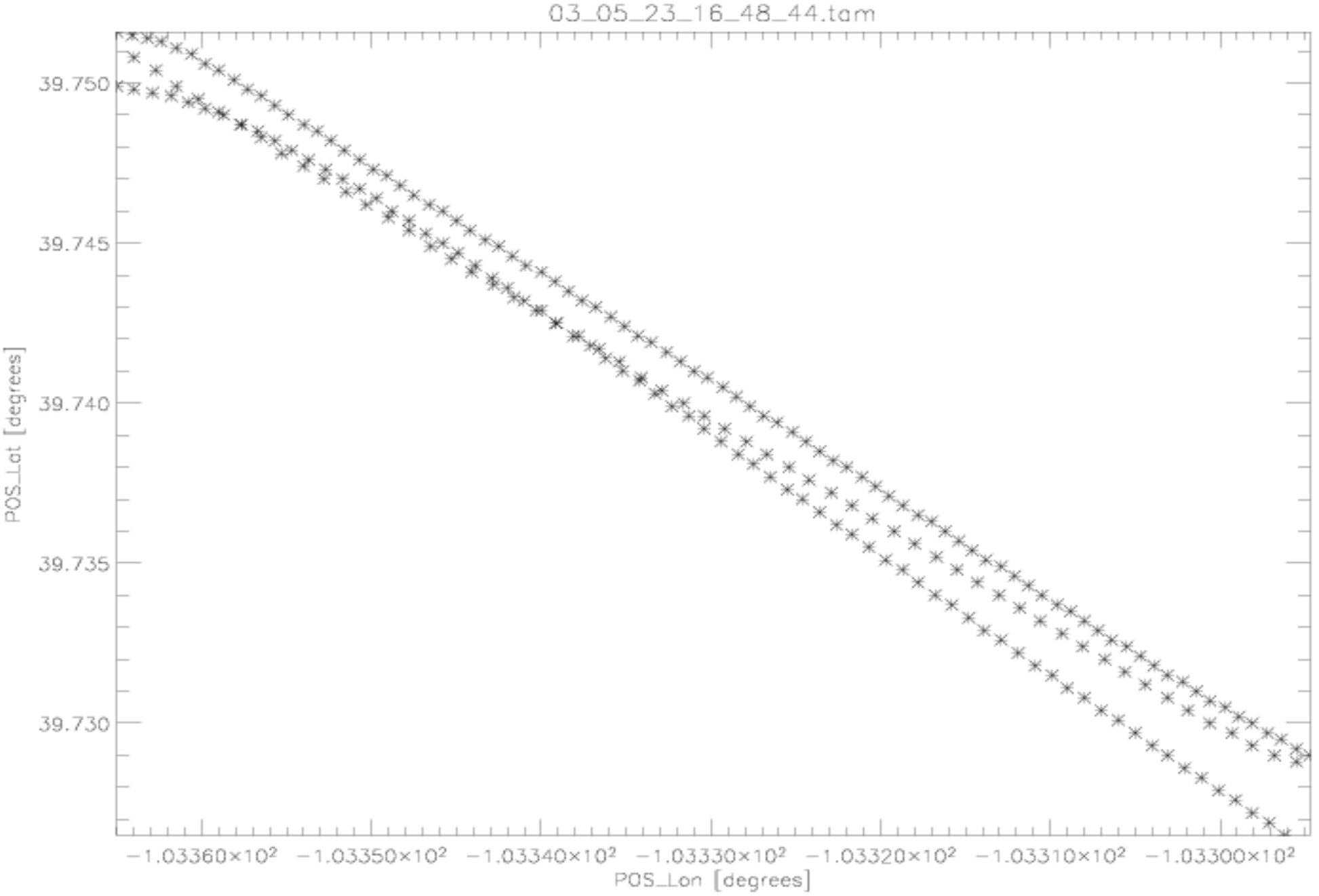
The X (East) component of the wind versus time for the time period of the beta angle calibration on July 11, 2003.

Pitot Pressure Calibration

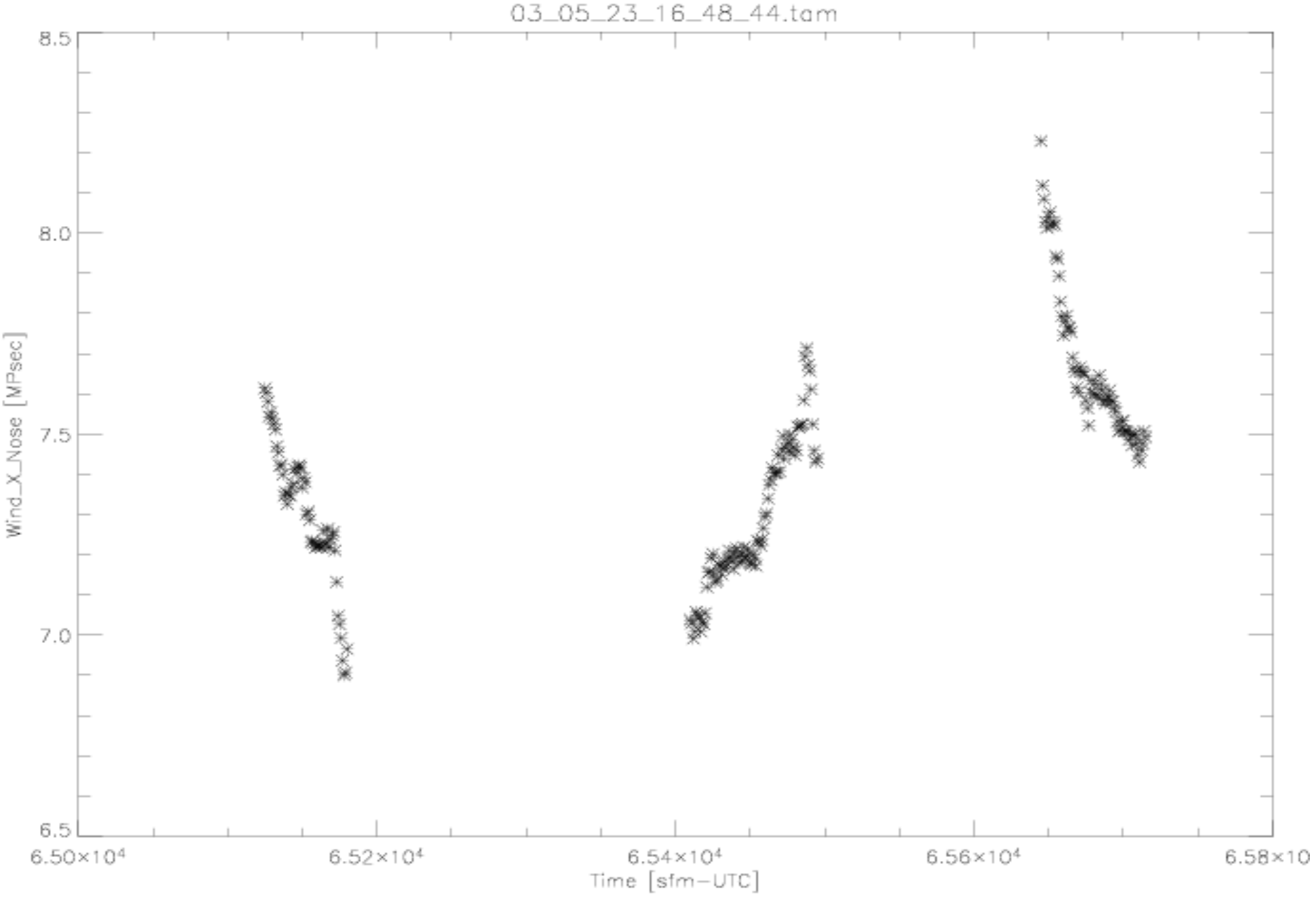


The nose pitot pressure versus the measured pressure transducer voltage for the July 11, 2003 reverse track flight.

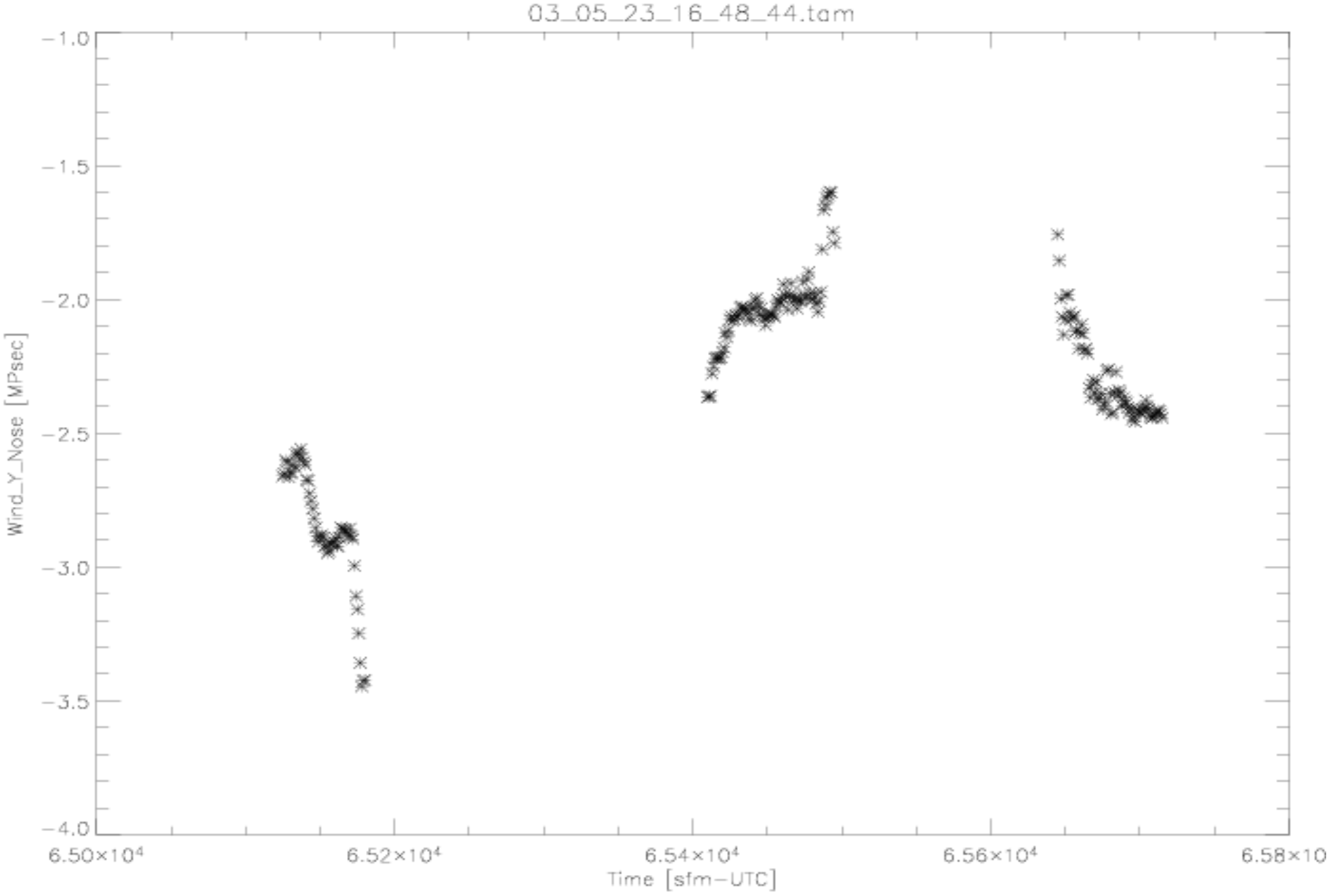
Reverse Track Flight: May 23, 2003



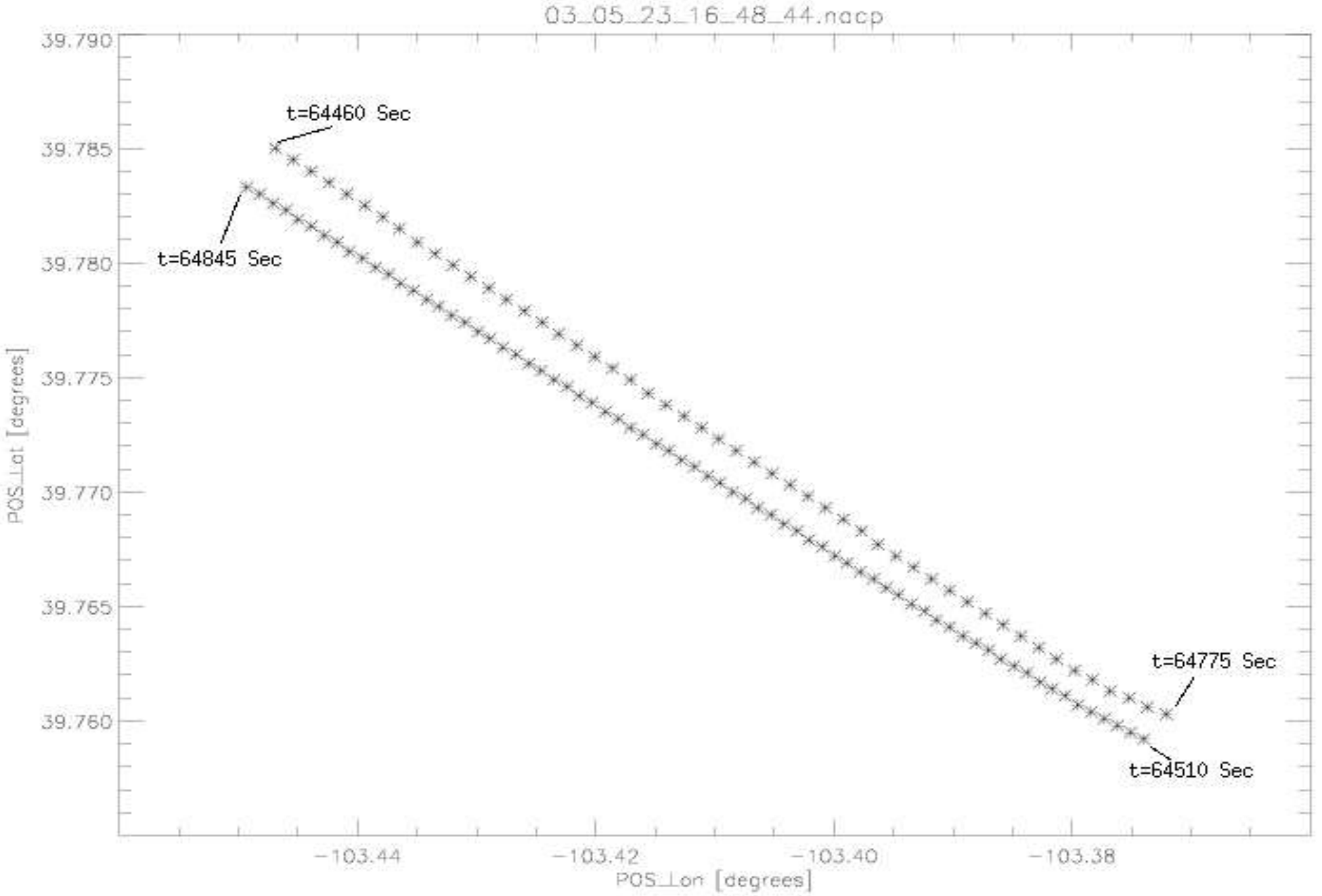
Reverse Track Flight: May 23, 2003



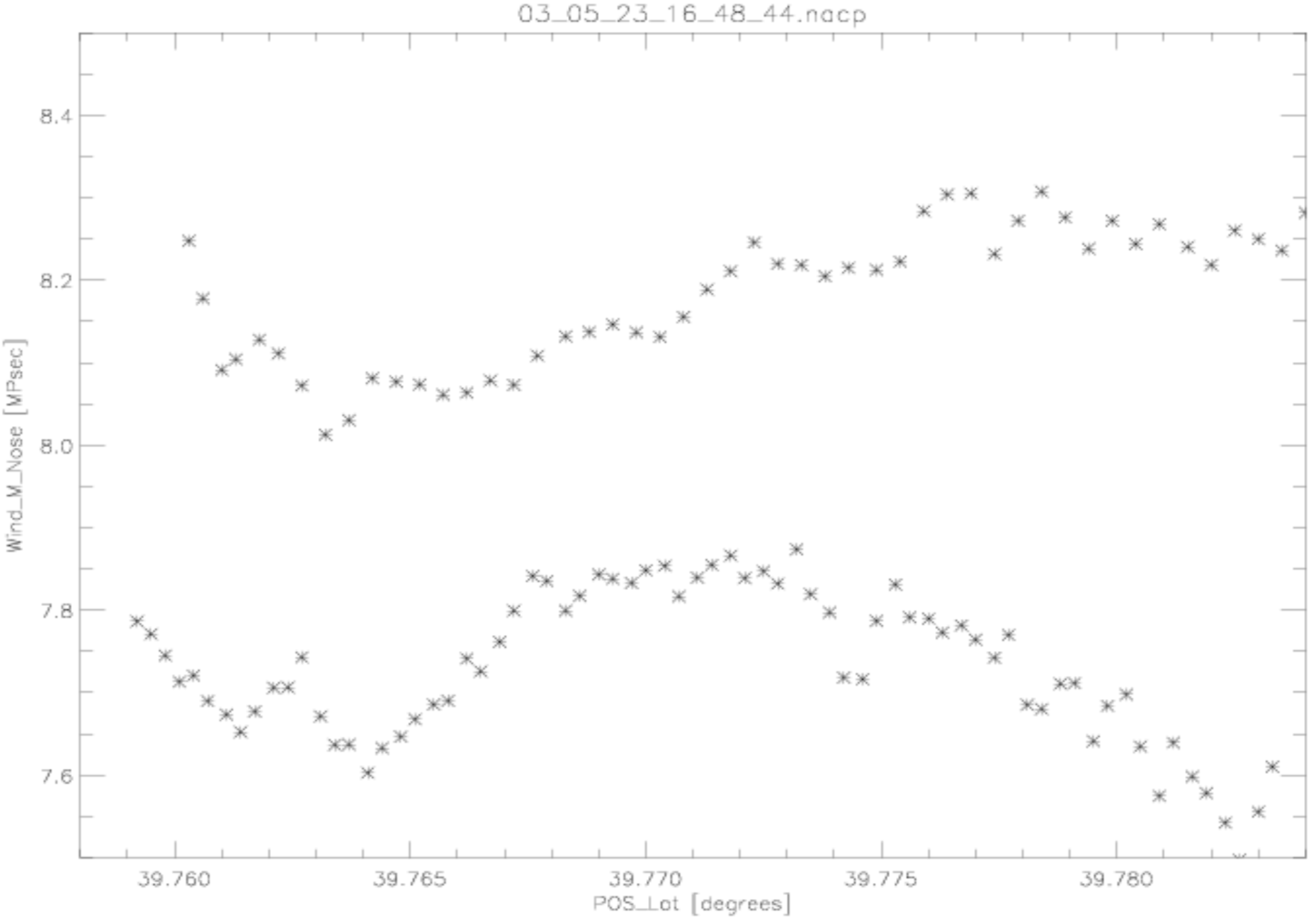
Reverse Track Flight: May 23, 2003



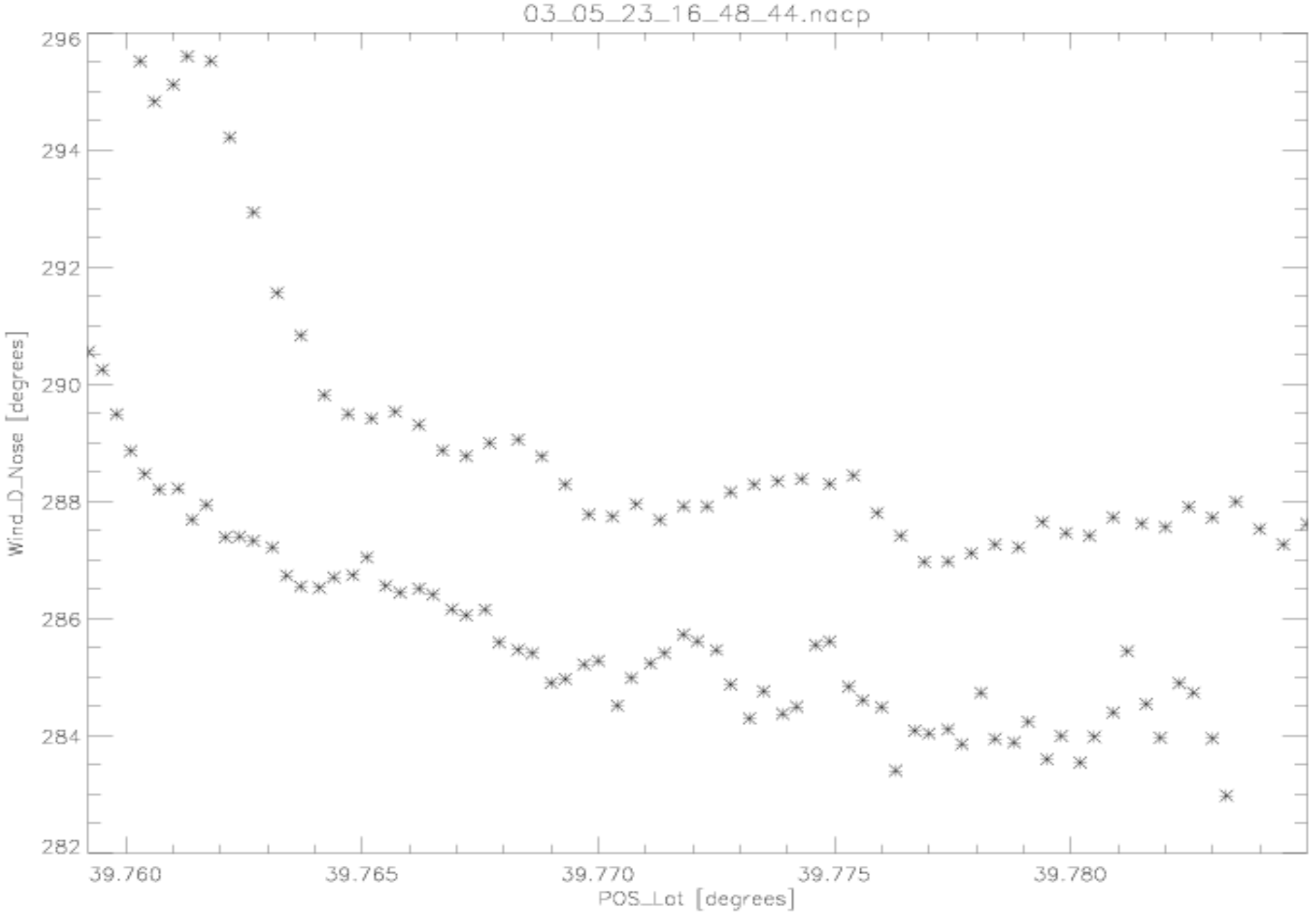
Reverse Track Flight: May 23, 2003



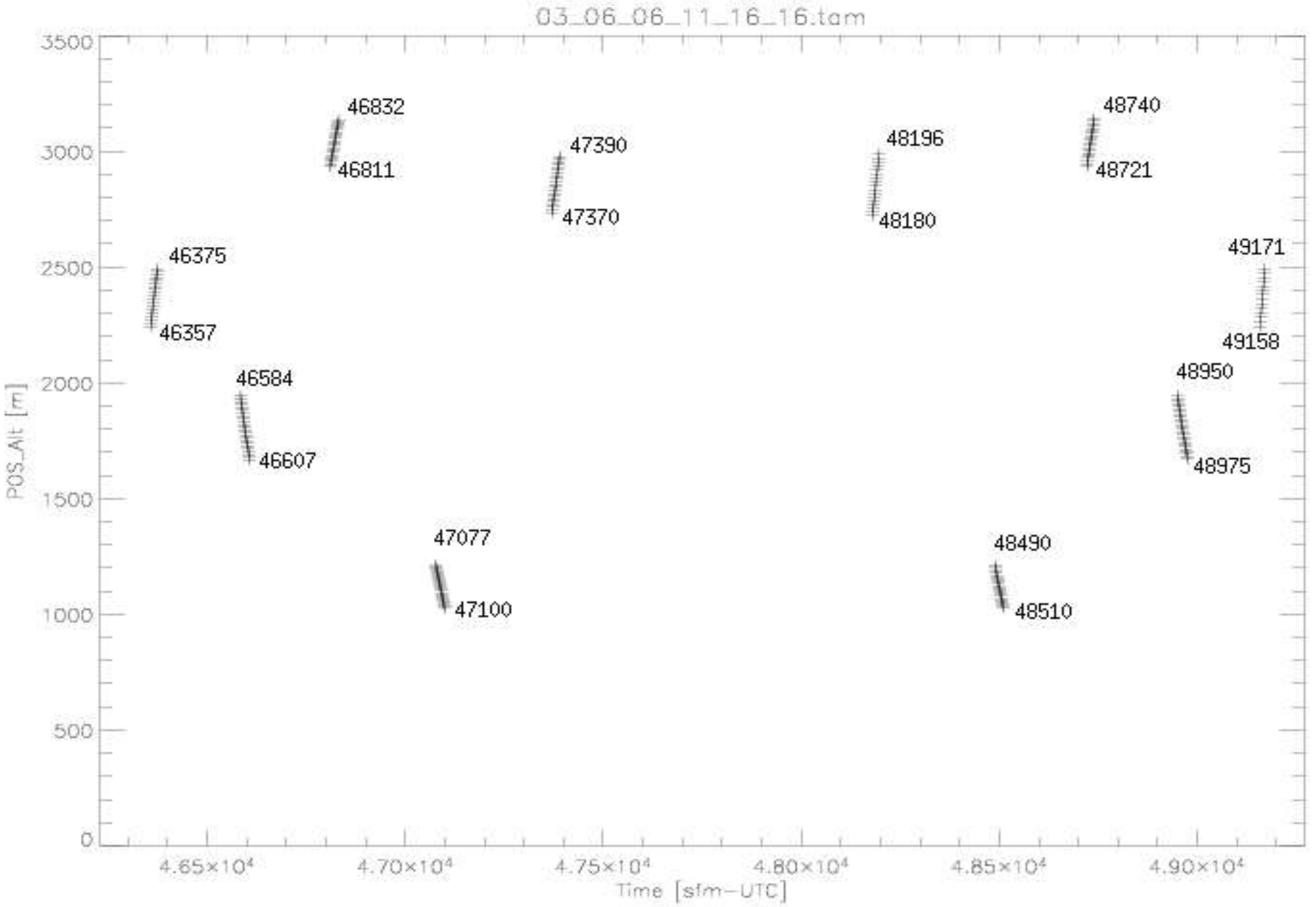
Reverse Track Flight: May 23, 2003



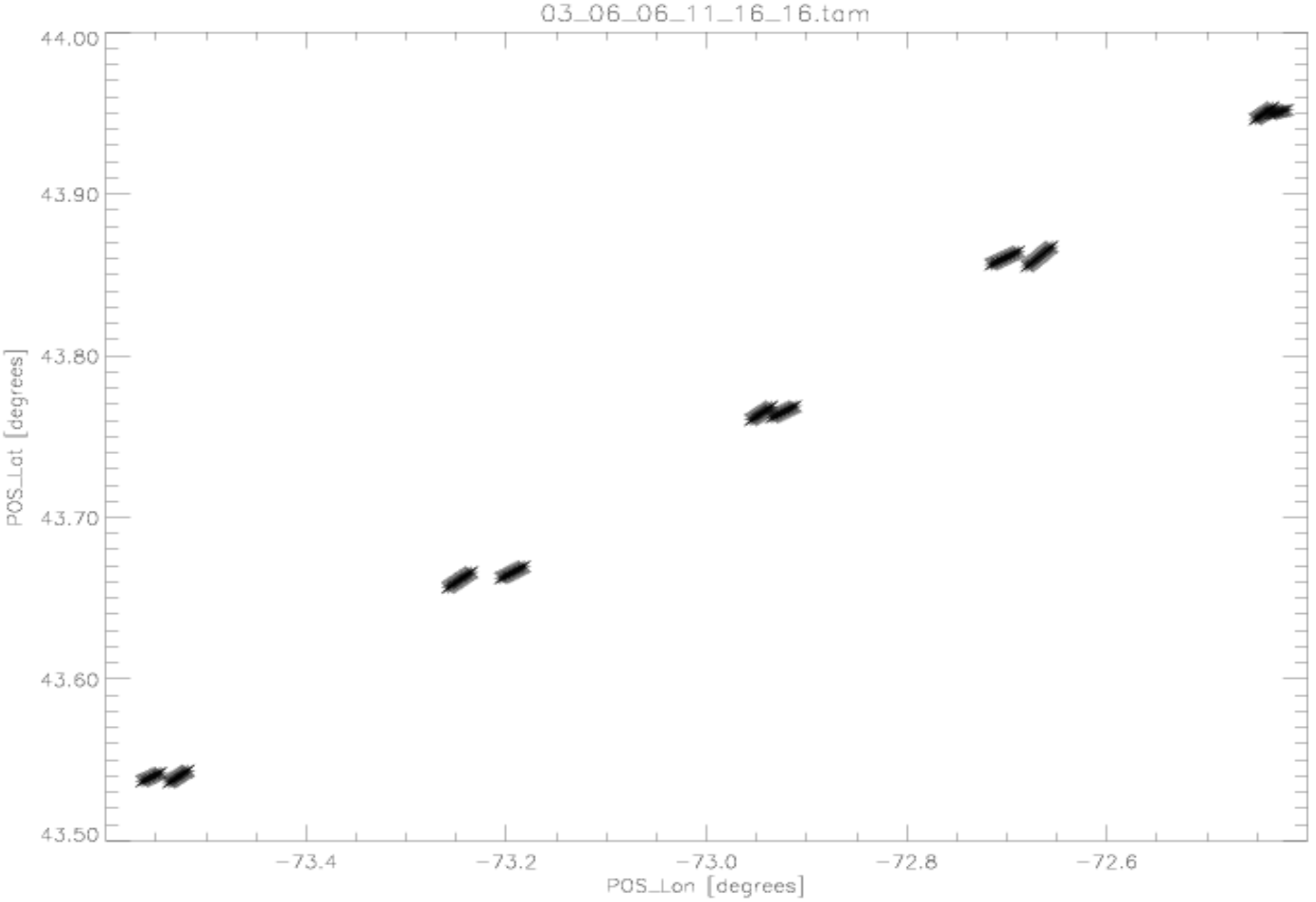
Reverse Track Flight: May 23, 2003



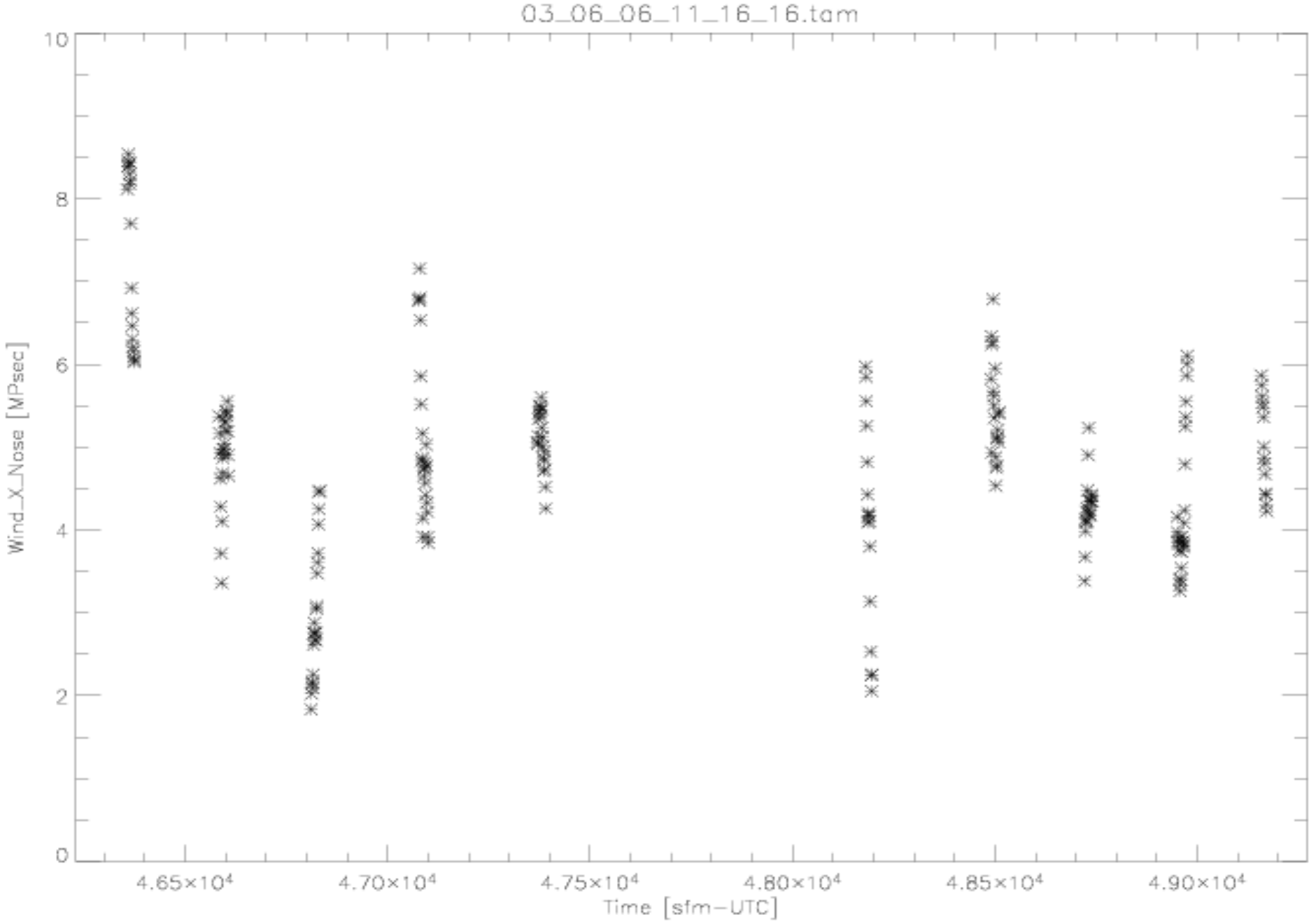
COBRA Flight: June 6, 2003



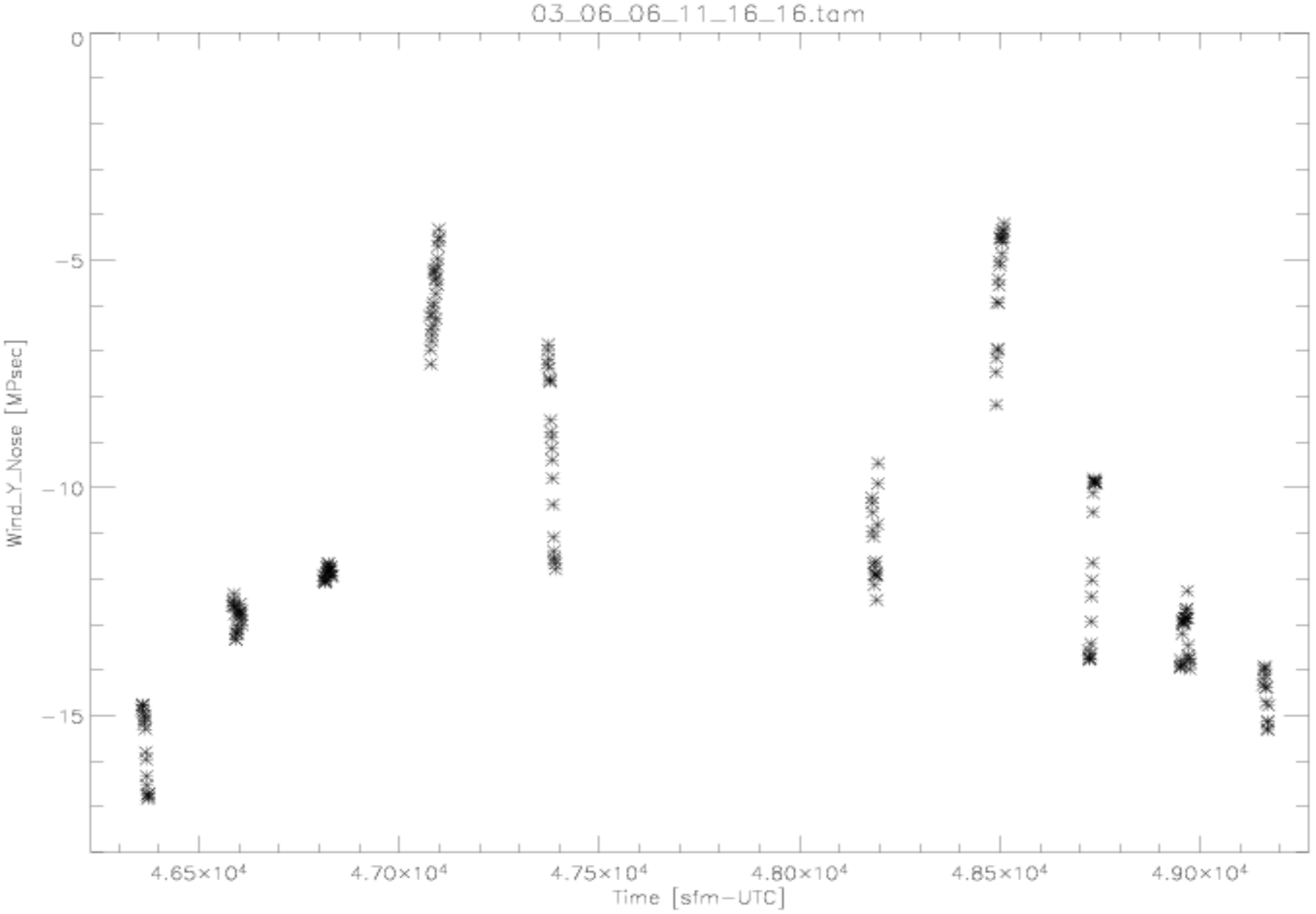
COBRA Flight: June 6, 2003



COBRA Flight: June 6, 2003



COBRA Flight: June 6, 2003



Bismarck Rawinsonde Sounding: July 25, 2003

Start Time [sec]	End Time [sec]	Heading [degrees]	Pressure [hPa]	Wind Speed [m/s]		Wind Direction [degrees]	
				Citation	Sounding	Citation	Sounding
83287	83483	143	591	15.14 ± 0.80	14.5	272.6 ± 3.6	268
83576	83748	321		15.29 ± 0.56		272.0 ± 3.1	
84176	84362	317	466	19.92 ± 0.67	20.2	269.3 ± 2.7	266
84460	84650	143		19.15 ± 0.63		270.9 ± 2.9	
85202	85391	145	376	23.22 ± 1.11	23.7	268.4 ± 1.1	270
85494	85726	321		25.43 ± 1.33		269.3 ± 1.3	
85977	86170	143	330	21.87 ± 0.70	20.9	269.2 ± 3.3	270
86283	86606	320		21.44 ± 0.90		267.3 ± 3.7	

Conclusions

The wind calibration procedure has been validated using independent flight data and by comparison with a rawinsonda sounding.

The wind components have an accuracy of 1 Meter/second.

Robust software routines are available so recalibration of the Wind System is not a “problem”.

More information and further calibration documentation is available at http://cumulus.atmos.und.edu/citation/winds