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

David J. Delene

Department of Atmospheric Sciences
University of North Dakota

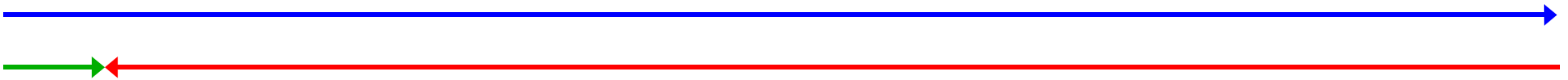
Why Measure Winds During Flight?

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

Wind Velocity Measurement from an Aircraft

$$\vec{V} = \vec{V}_p + \vec{V}_a$$

$\vec{V}_p$ – Velocity of the aircraft with respect to the earth



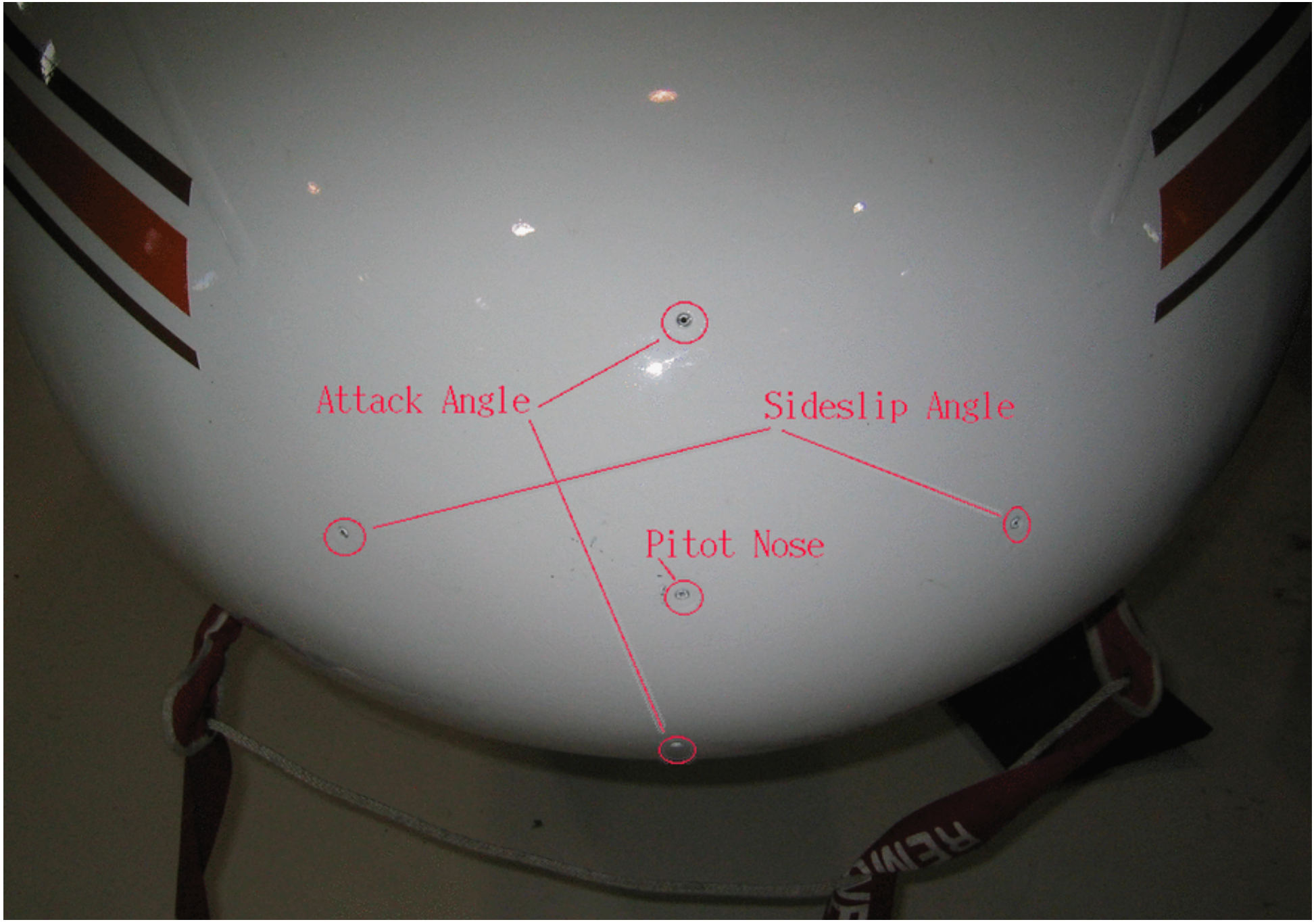
$\vec{V}_a$ – Velocity of the air with respect to the aircraft

$\vec{V}$ – Air Velocity with respect to the earth (Wind)

V_p is measured with the Position and Orientation System.

V_a is measured with pressure transductors.

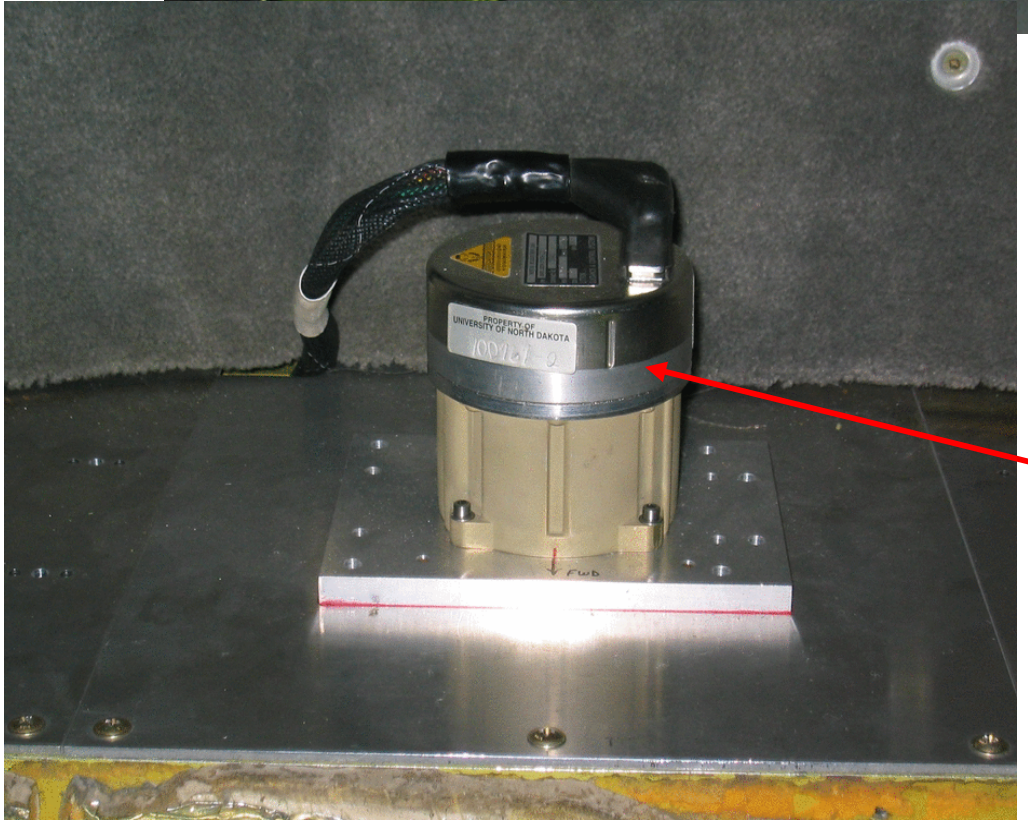
Pitot Pressure Ports on Aircraft Nose



Inside of the Citation's Radome

Position and Orientation System (POS)

19” Rack Mount Computer System

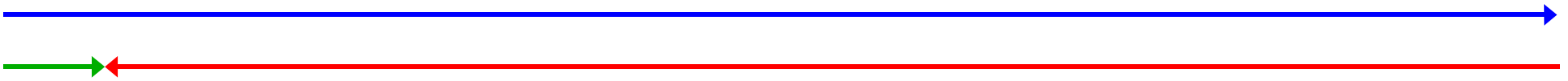


Inertial Measurement Unit (IMU)

Wind Velocity Measurement from an Aircraft

$$\vec{V} = \vec{V}_p + \vec{V}_a$$

$\vec{V}_p$ – Velocity of the aircraft with respect to the earth



$\vec{V}_a$ – Velocity of the air with respecty to the aircraft.

$\vec{V}$ – Air Velocity with respect to the earth (Wind)

V_p is measured with the Position and Orientation System.

V_a is measured with pressure transductors.

Air Velocity with Respect to the Earth (Small Angle Approximation Version)

$$U = -U_a * \sin(\Psi + \beta) + U_p$$

$$V = -U_a * \cos(\Psi + \beta) + V_p$$

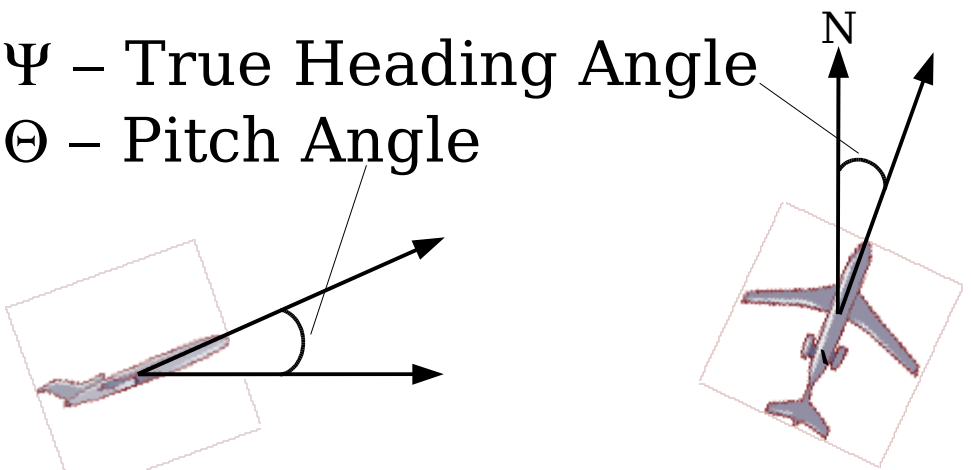
$$W = -U_a * \sin(\Theta + \alpha) + W_p$$

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

U_a – True Air Speed (Pitot Pressure, Temperature, Pressure)

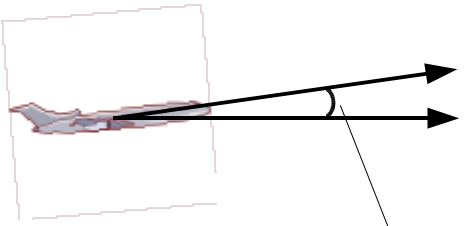
Angles Relative to the Earth

Ψ – True Heading Angle
Θ – Pitch Angle

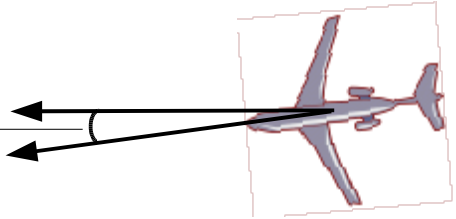


Measured with POS System

Angles Relative to the Air Flow



α – Alpha Angle
β – Beta Angle



Measured with Nose Pressure Ports

Air Velocity with Respect to the Earth (Full Version)

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

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

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

U_a – True Air Speed

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

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 Angle measured clockwise from North

Θ – Pitch Angle

ϕ – Roll Angle

α – Alpha Angle

β – Beta Angle

L – X-axis Distance between the inertial navigation system and air sensing platform

Calibration Procedure

- Heading Angle Offset (hoffset_cal)
- Alpha Angle Calibration (alpha_cal)
- Beta Angle Calibration (beta_cal)
- Pitot Pressure Calbiration (wind_cal)

The wind calibration procedure involves first determining the heading angle offset and then iterating on the alpha, beta, and pitot pressure calibration steps until the calibration coefficients converge.

The calibration constants defined in the “citation_constants.pro” file need to be updated after do each calibration step.

Applanix POS Data

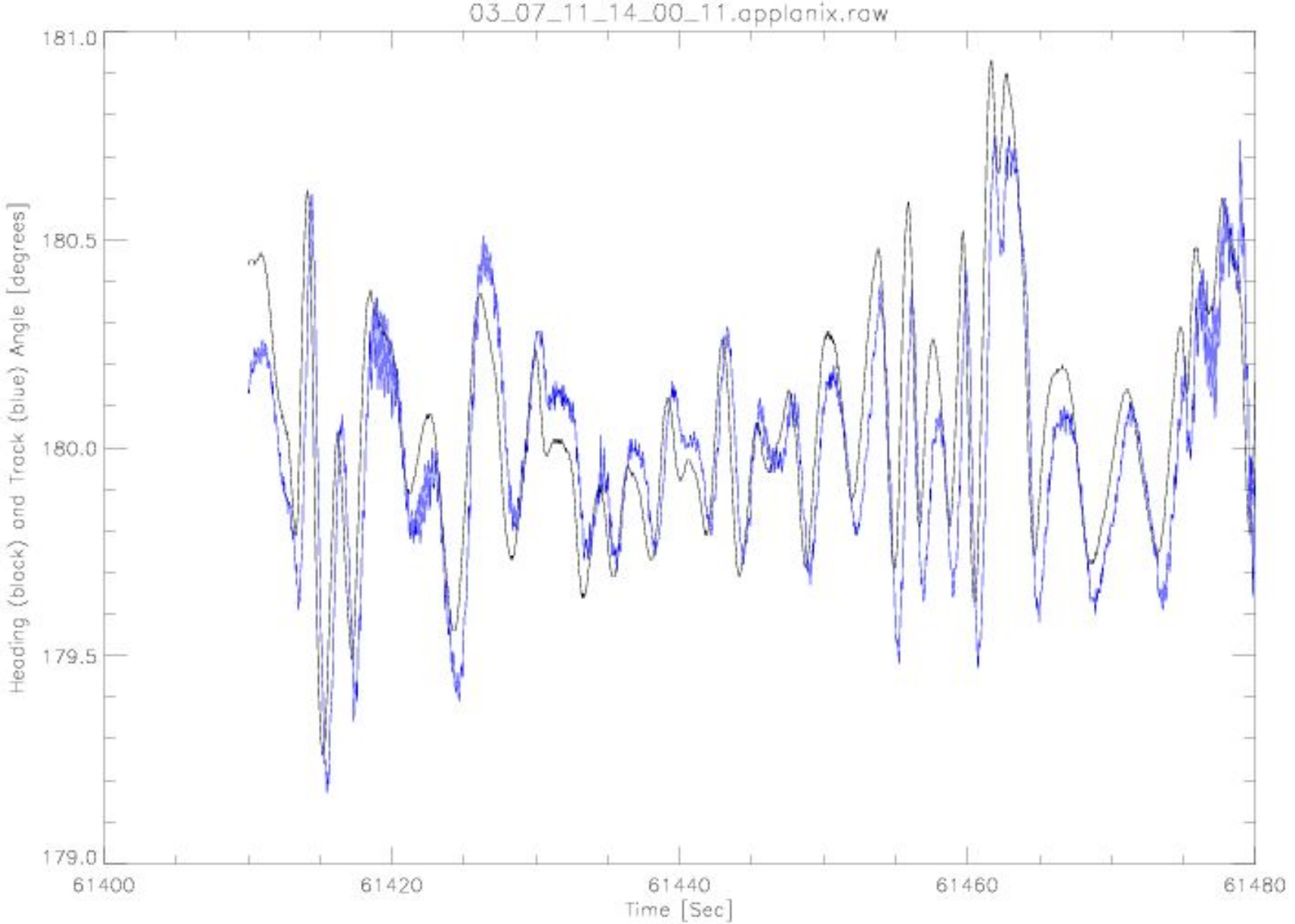
Aircraft position information for the calibration procedure can be based on either the real time 25 Hz applanix (REAL file) data or on the 25 Hz post processed (SBET file) applanix data.

The calibration software module's accept either a real time or post processed Applanix data file.

The post processing incorportes base line GSP data to improve accuracy of the real time GSP data.

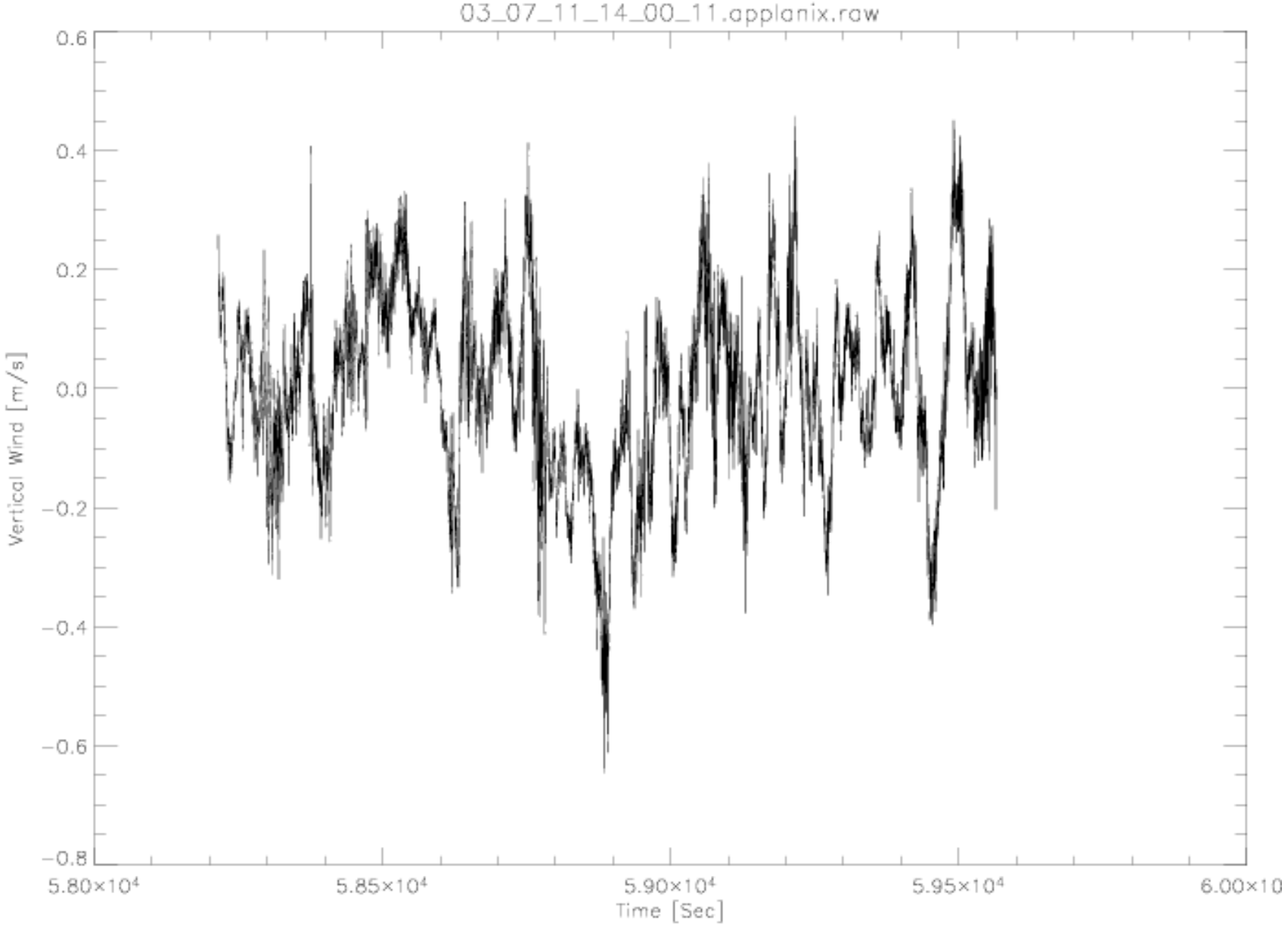
The SBET data file is the result of filtering the GPS and IMU data, reconciling discrepancies, eliminating errors and computing an optimally accurate, blended navigational solution.

Heading Angle Offset



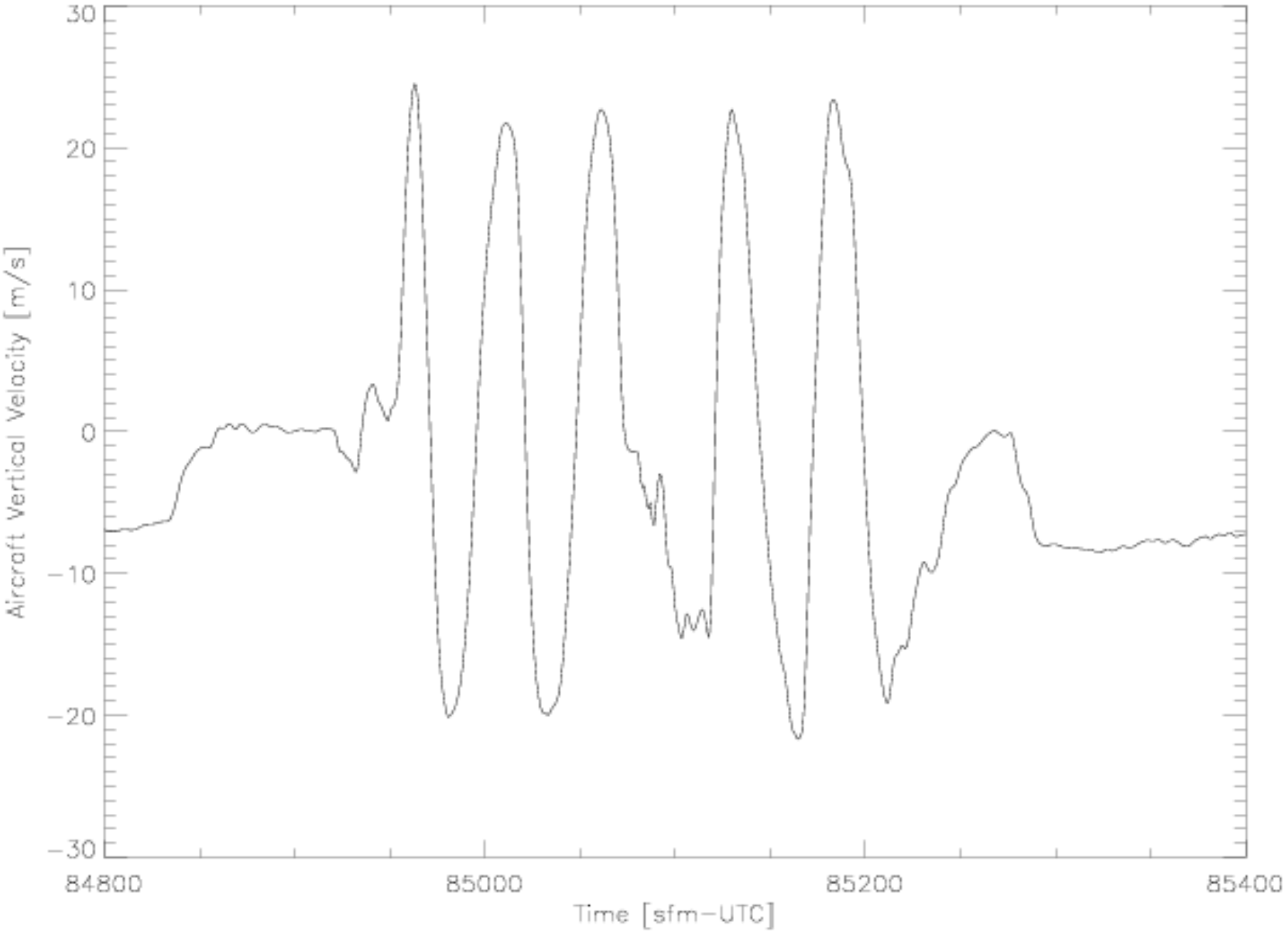
The aircraft's heading (black line) and track angle (blue line) versus time for taxies segment 3 on July 11, 2003 using the real time data files.

Alpha Angle Calibration



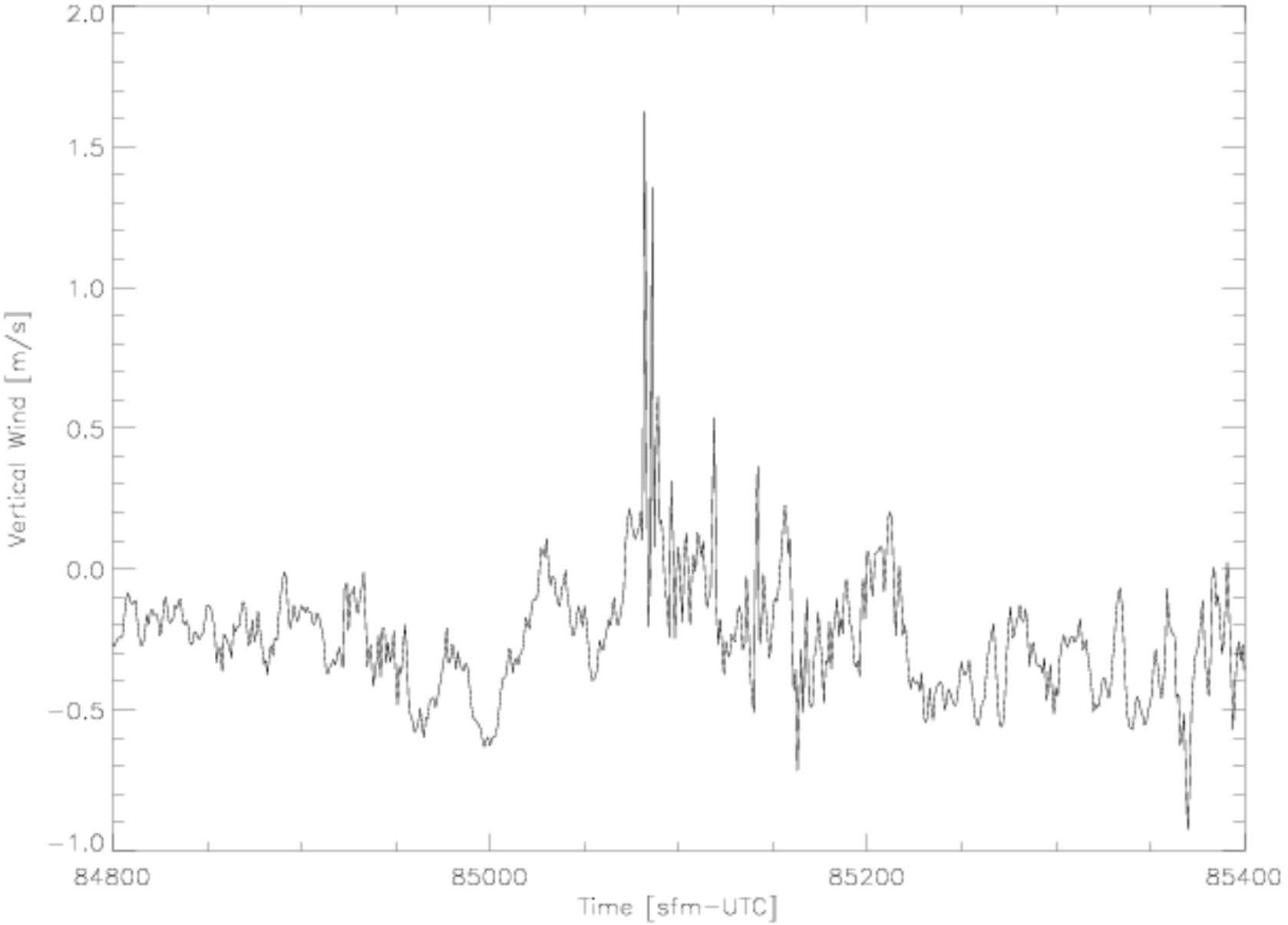
The vertical wind versus time for the time period of the alpha angle calibration on July 11, 2003.

Alpha Angle Check



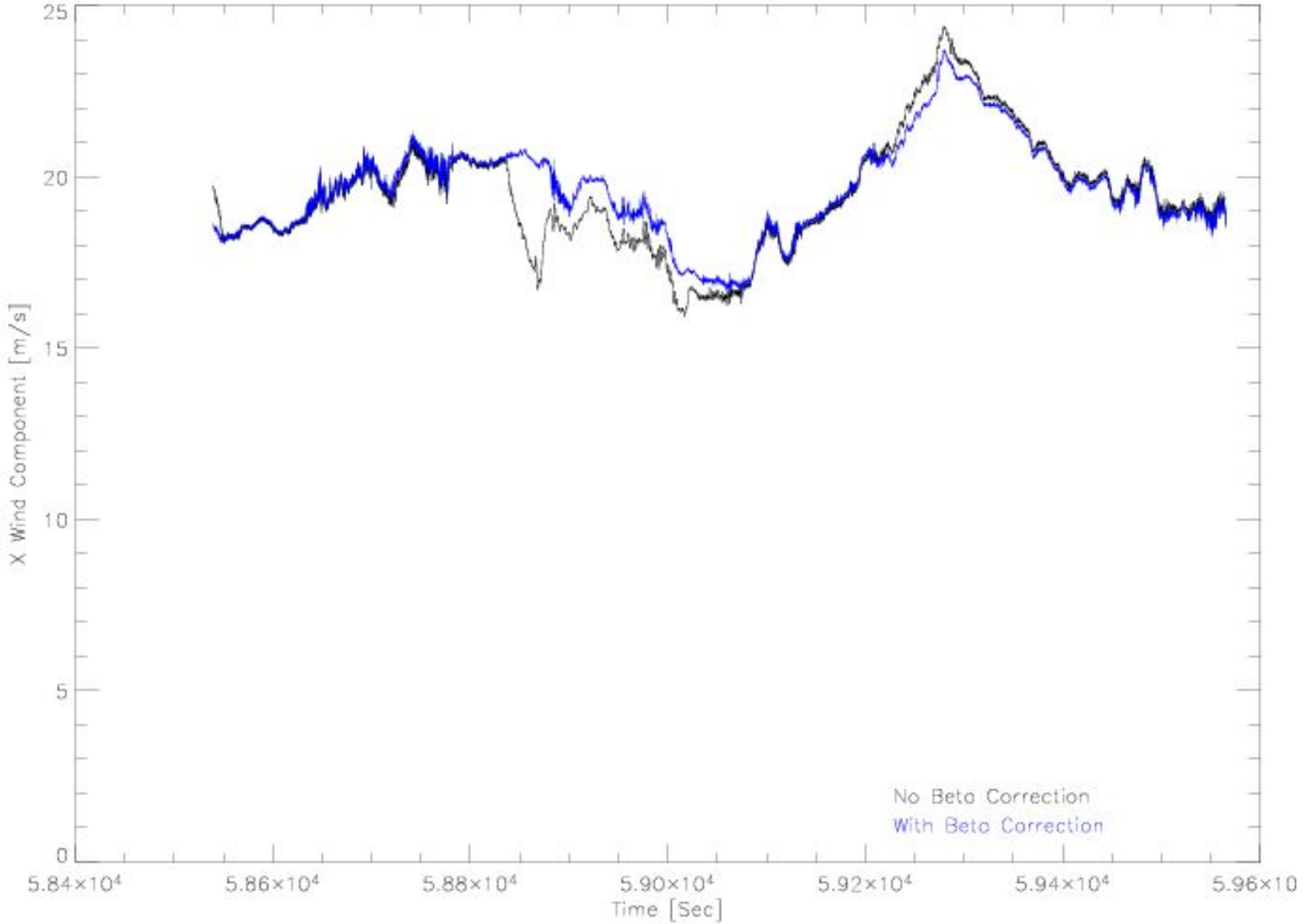
The aircraft's vertical velocity during the October 8, 2003 flight.

Alpha Angle Check



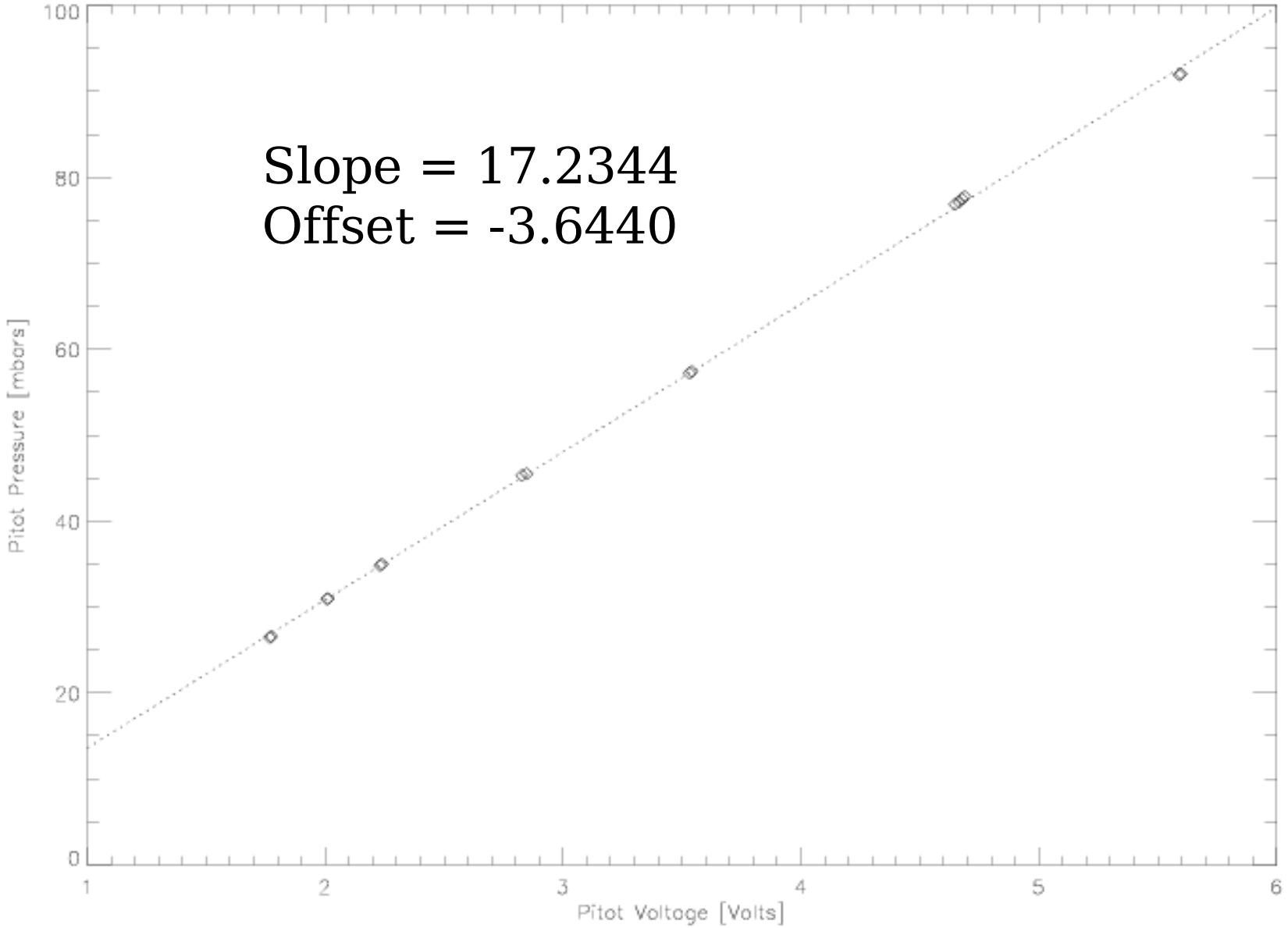
The vertical wind versus time during the October 8, 2003 flight.

Beta Angle Calibration



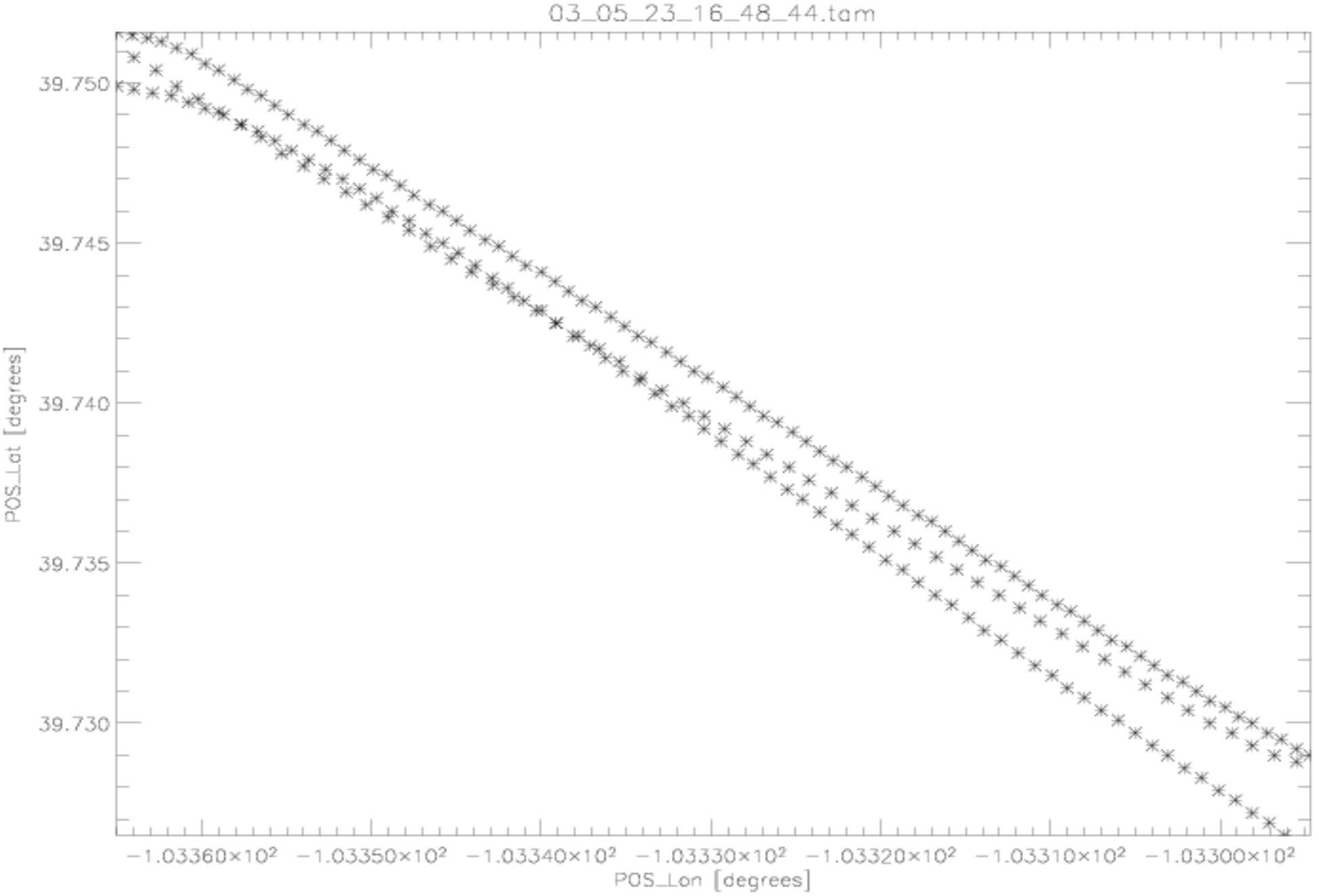
The X (East) component of the wind versus time for the time period of the beta angle calibration on July 11, 2003.

Pitot Pressure Calibration

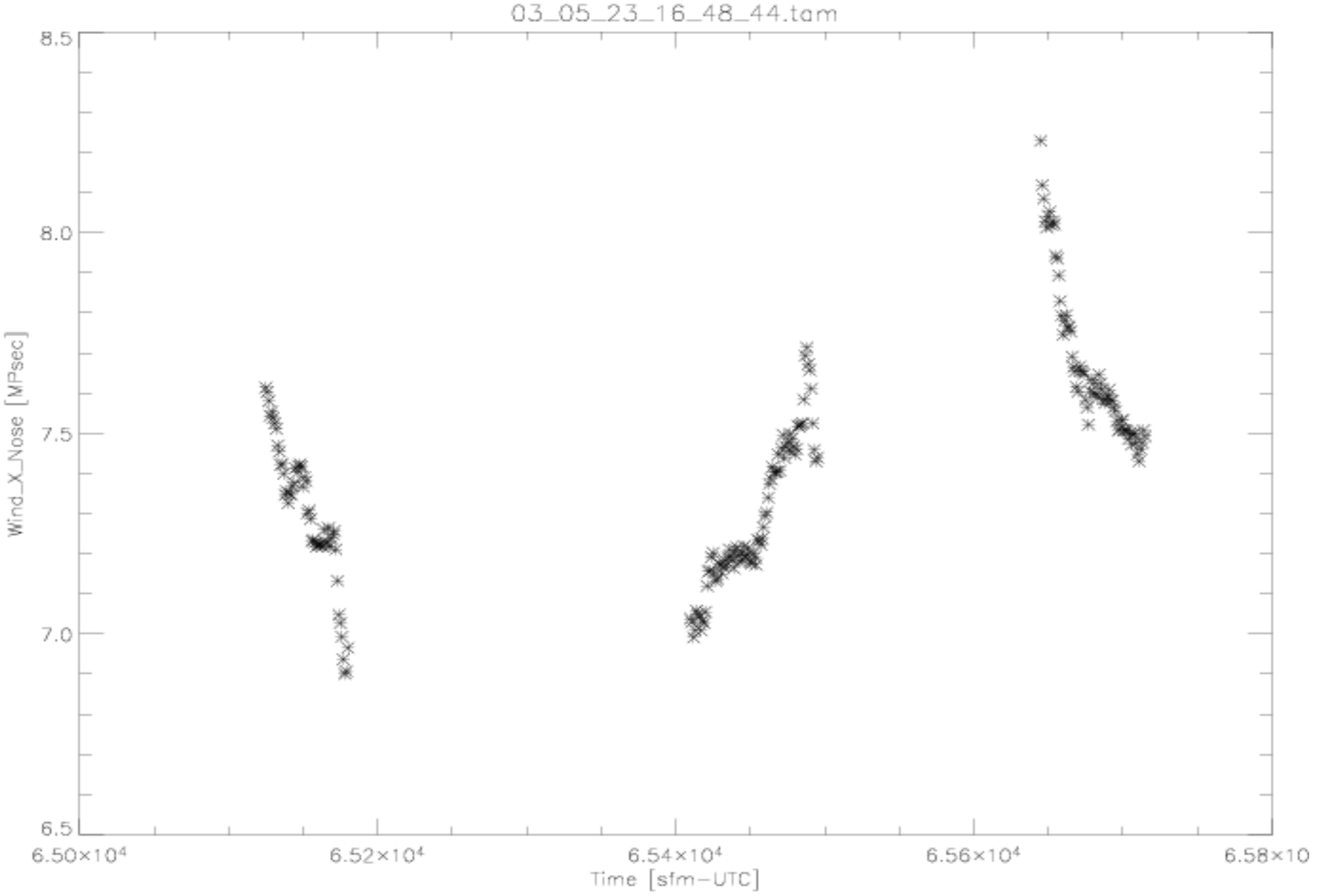


The nose pitot pressure versus the measured pressure transducer voltage for the July 11, 2003 reverse track flight.

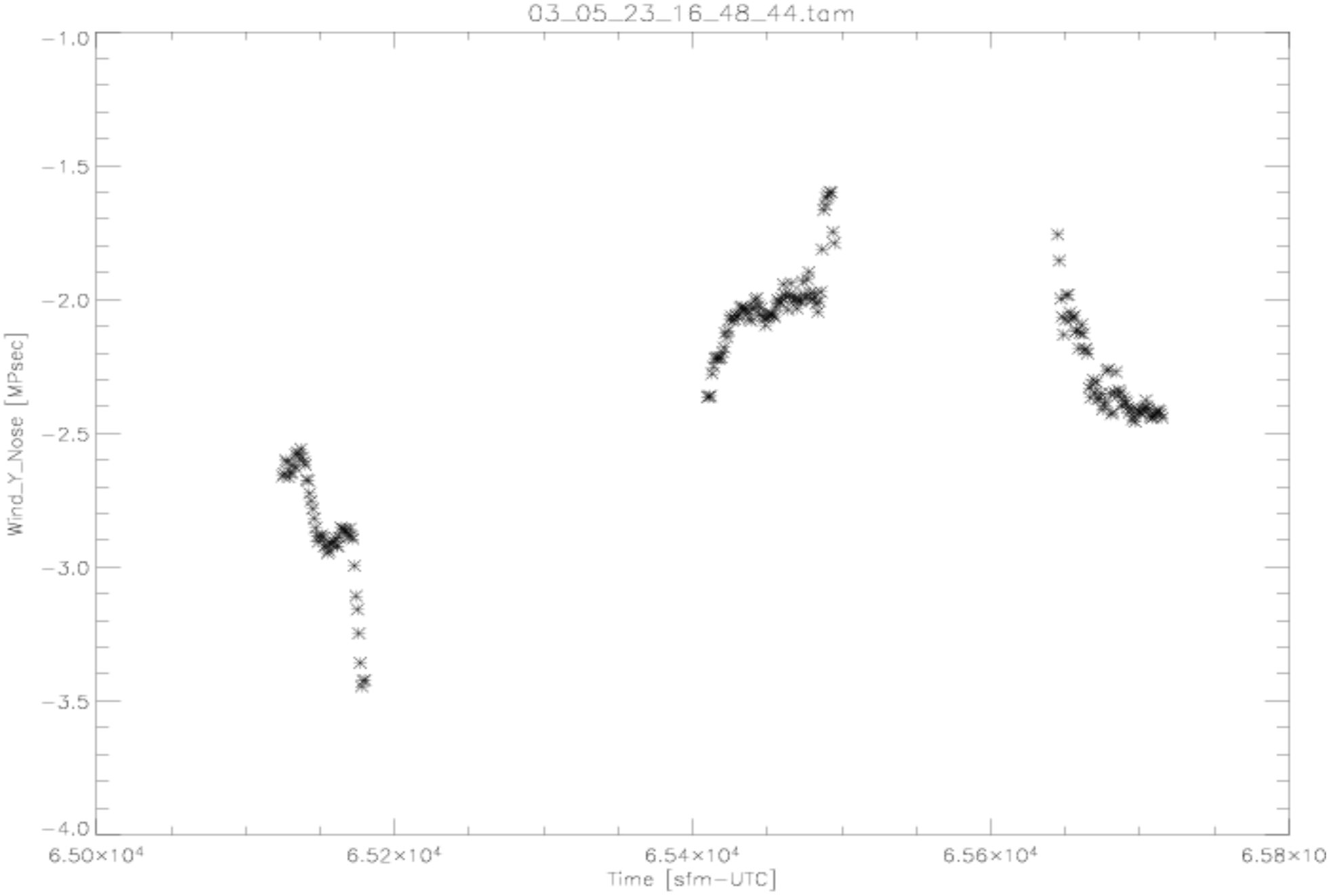
Reverse Track Flight: May 23, 2003



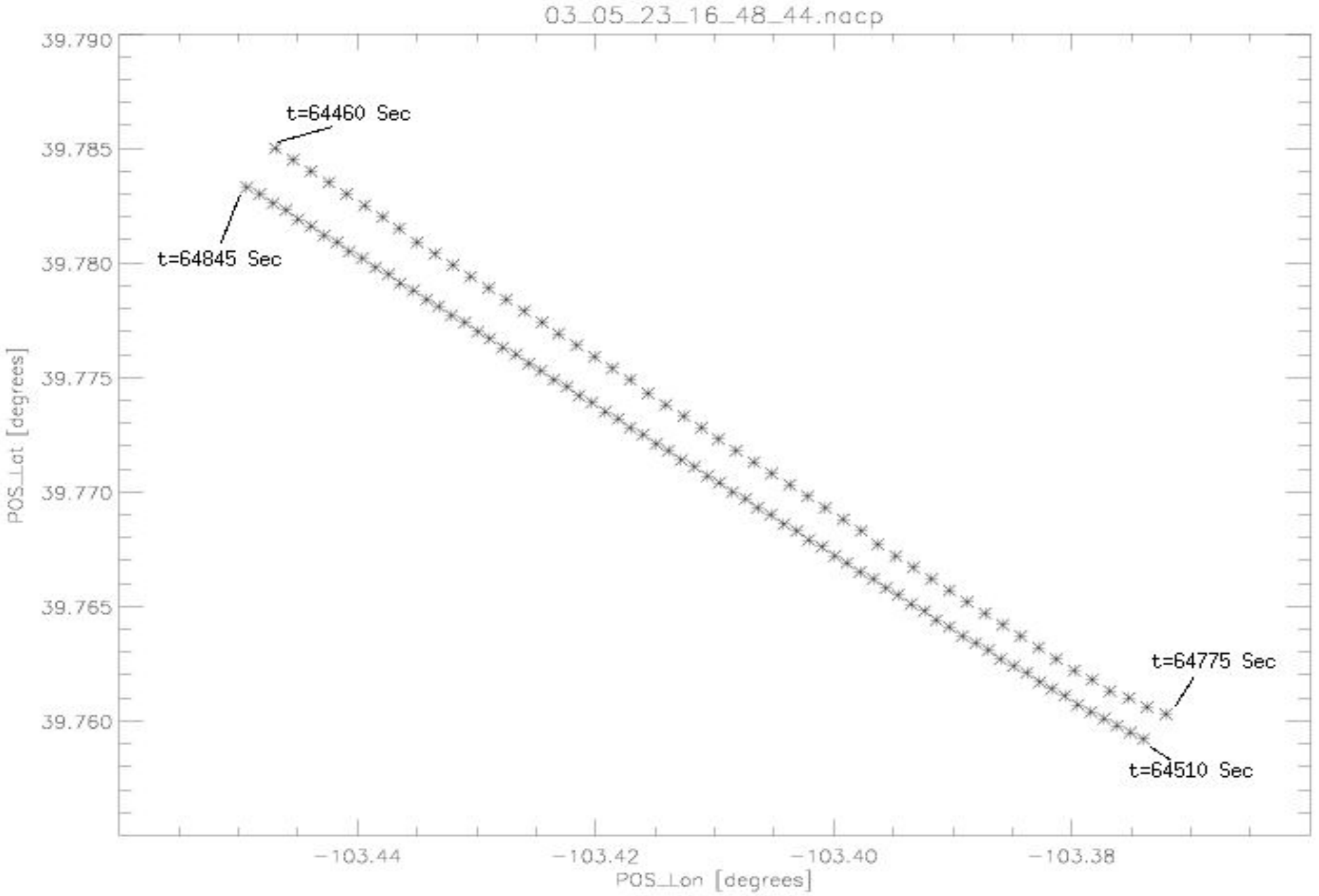
Reverse Track Flight: May 23, 2003



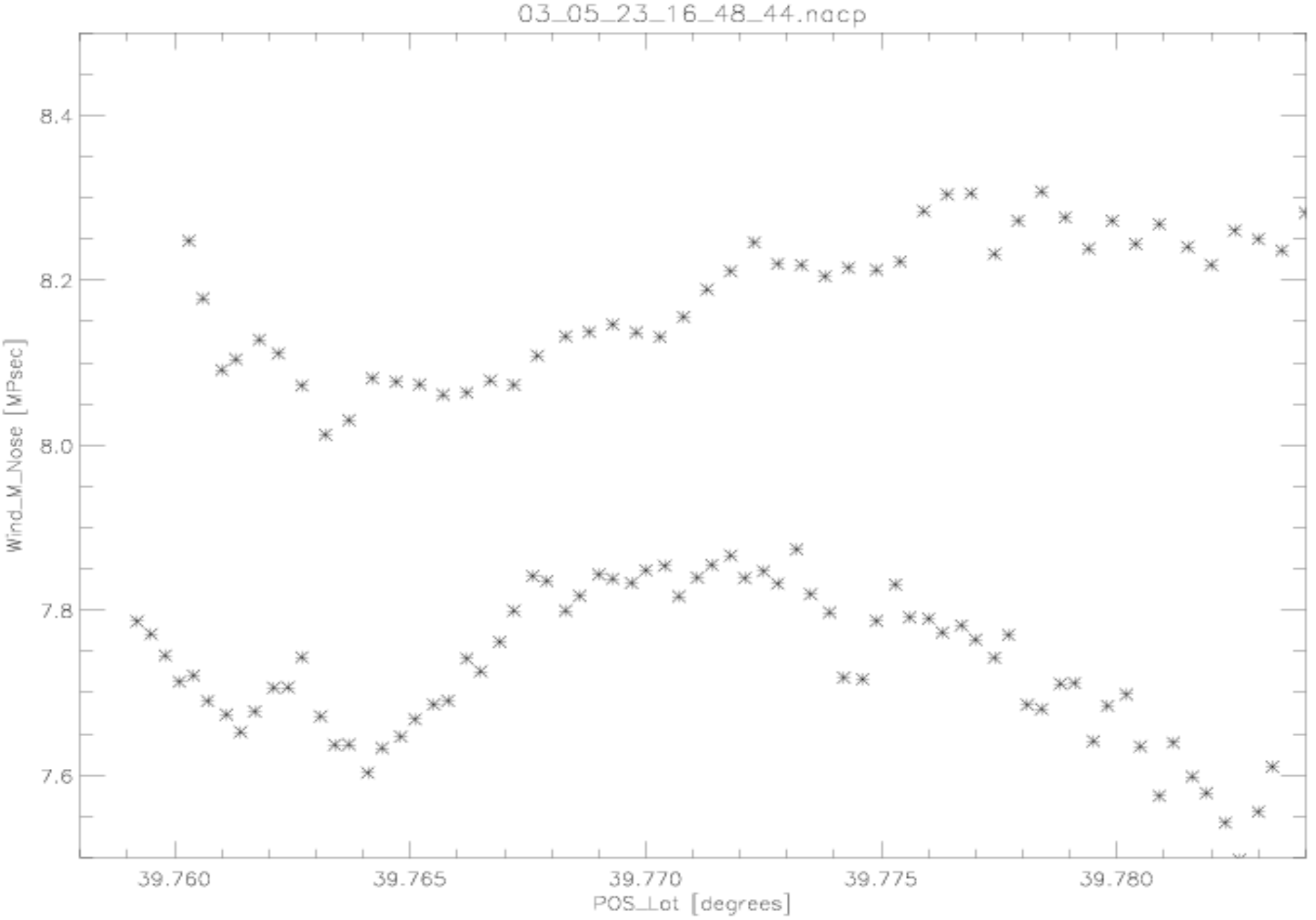
Reverse Track Flight: May 23, 2003



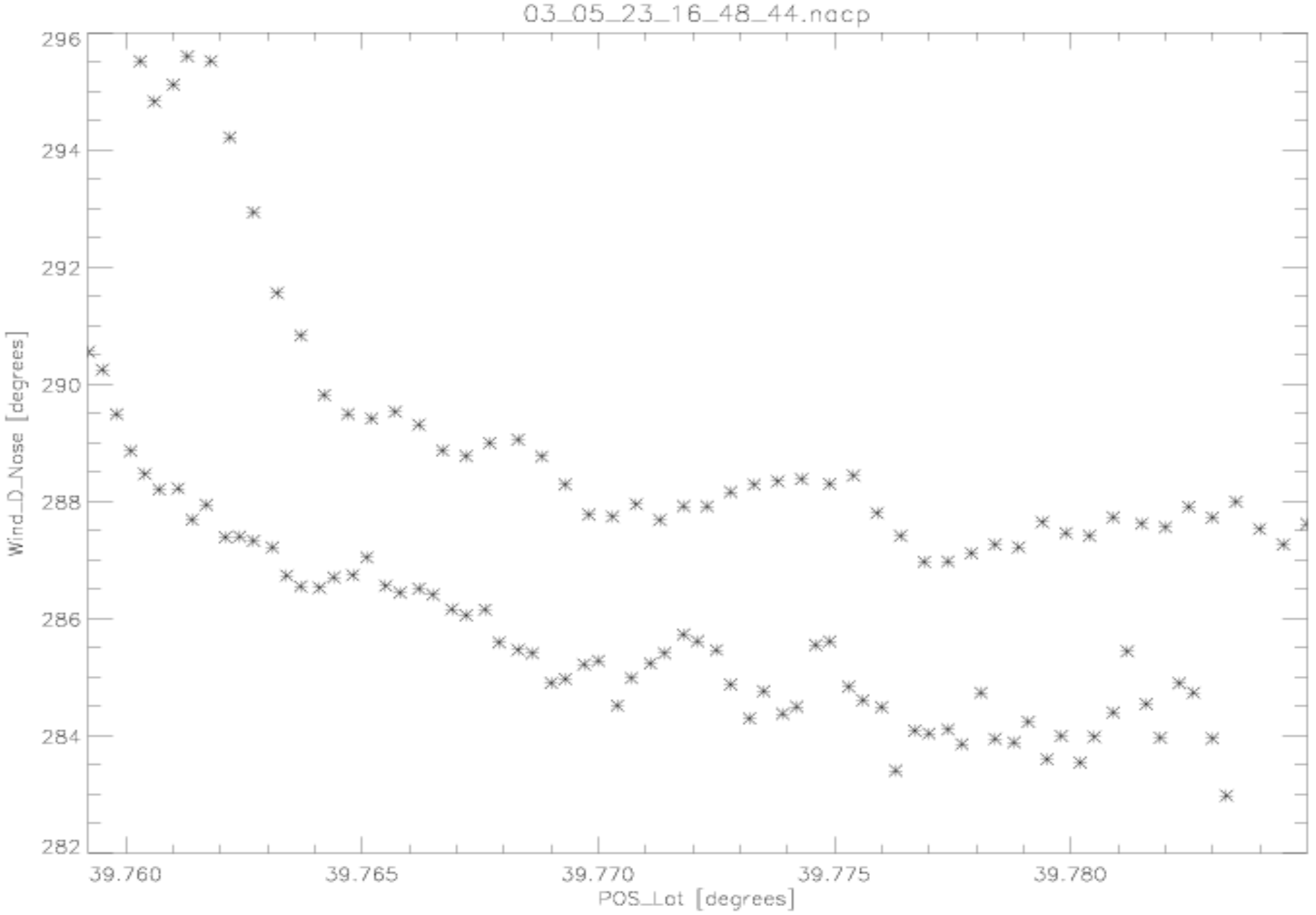
Reverse Track Flight: May 23, 2003



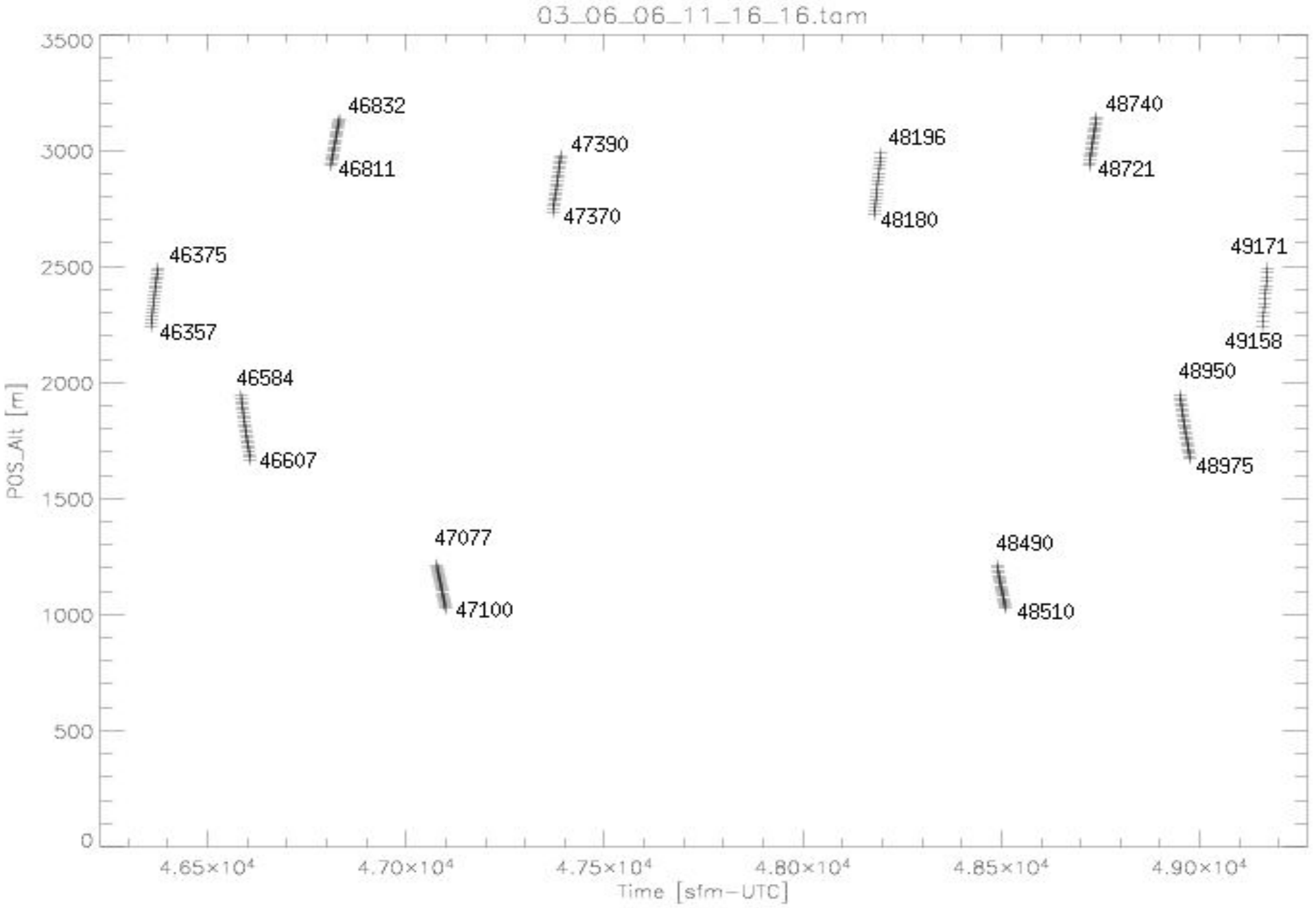
Reverse Track Flight: May 23, 2003



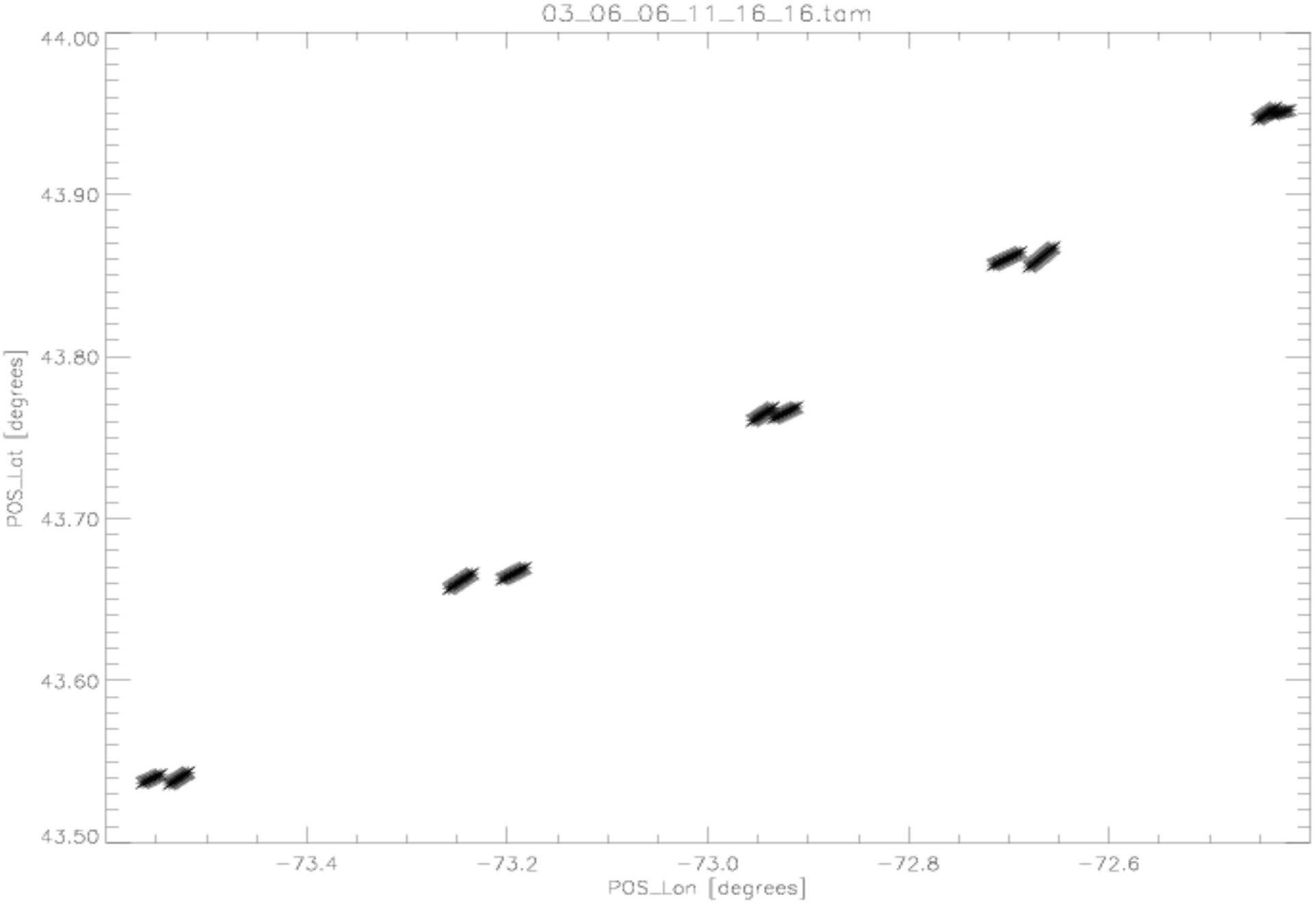
Reverse Track Flight: May 23, 2003



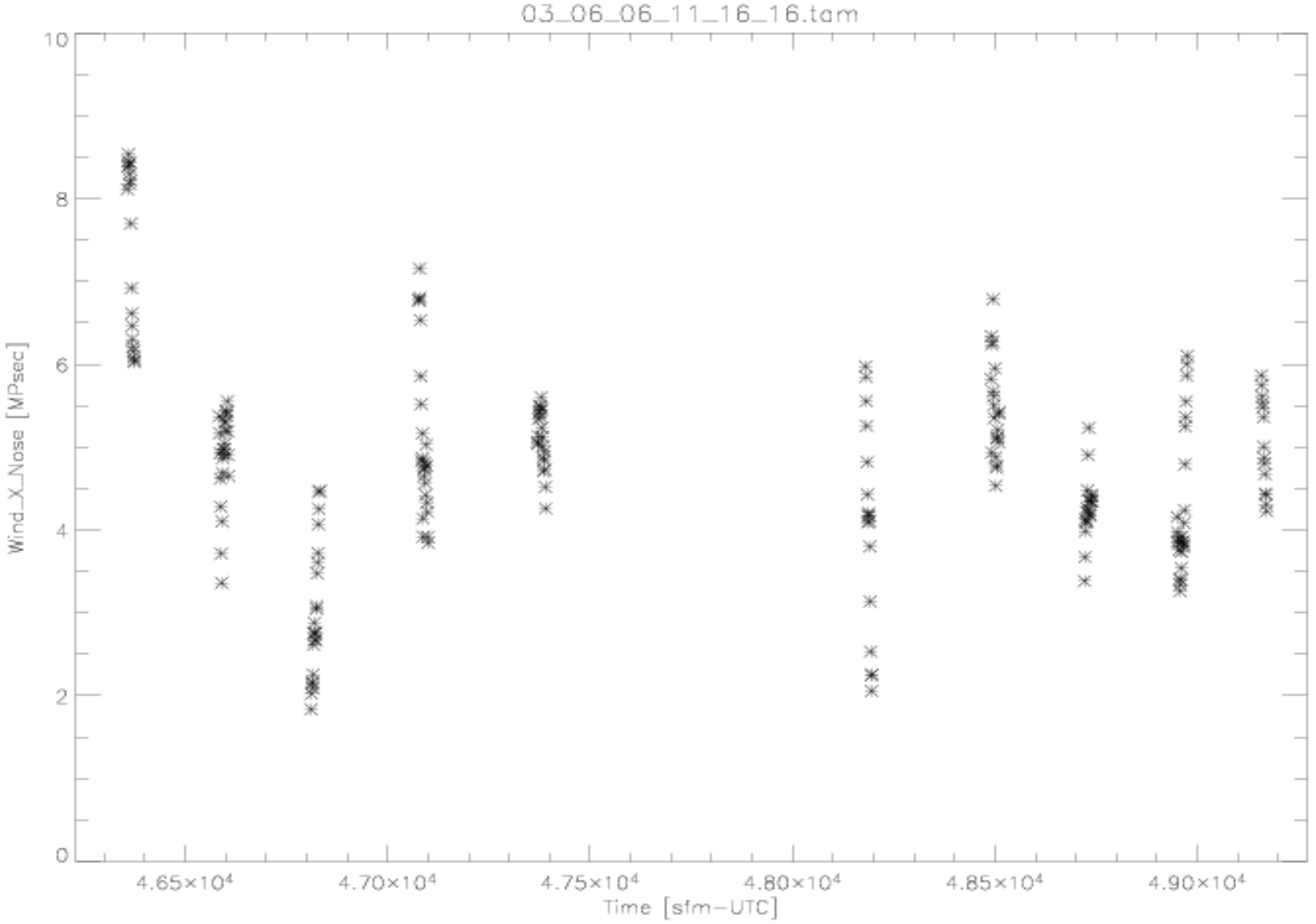
COBRA Flight: June 6, 2003



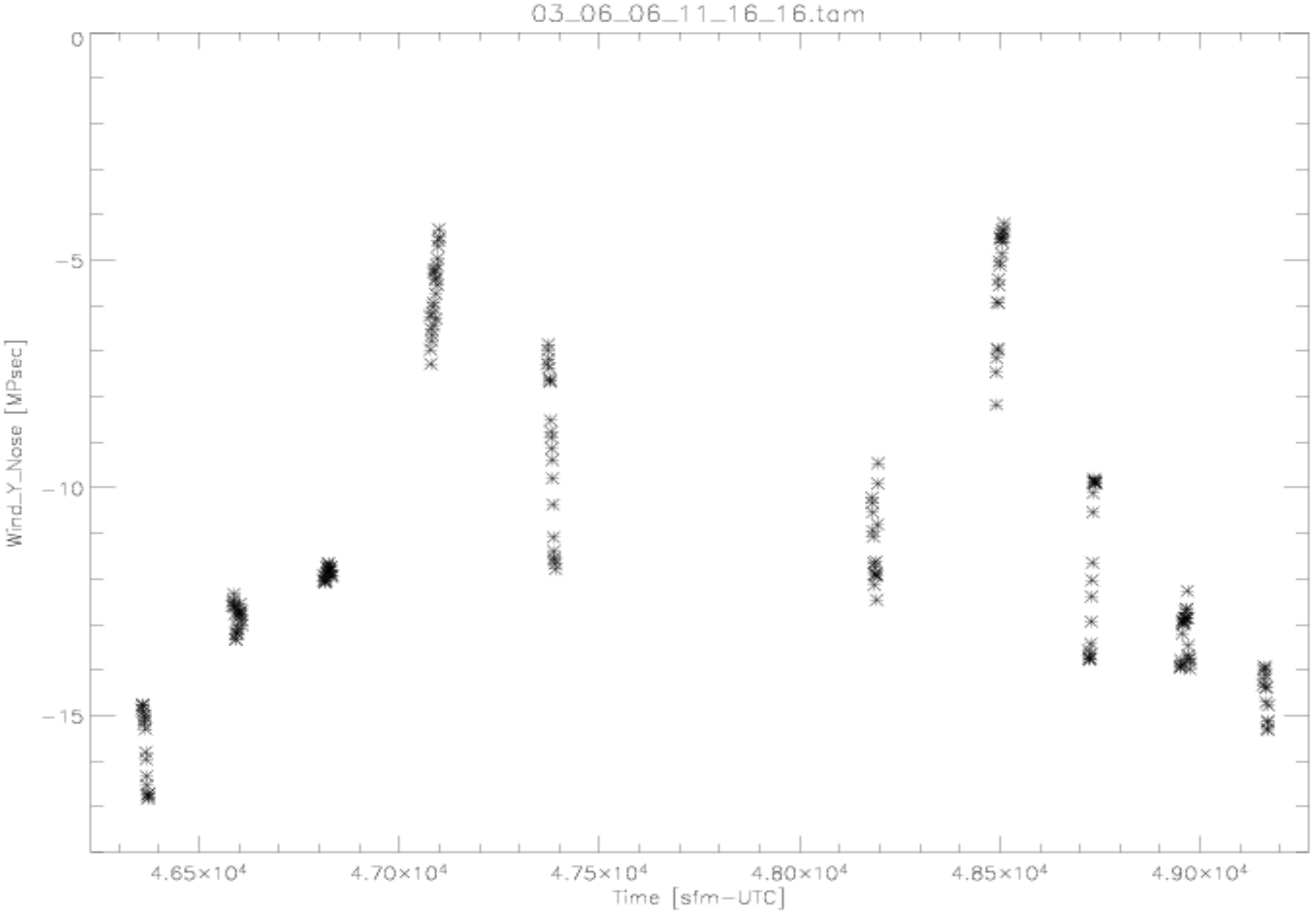
COBRA Flight: June 6, 2003



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

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