Daytime Dynamo Rocket Investigation

Launches of July 10, 2011 and July 4, 2013

Results

from GSFC experiments on Rockets 21.140 and 21.141

Robert Pfaff, Doug Rowland, Jeff Klenzing, Henry Freudenreich, Steve Martin
Goddard Space Flight Center

Daytime Dynamo “Workshop”

St. Michaels, Maryland

March 3-5, 2015

Data from Dynamo Rockets: 21.140 (July 4, 2013) and 21.141 (July 10, 2011)

- **In-situ Magnetometer Data and Current Calculations**

  GSFC Fluxgate Magnetometer
  JPL/UCLA Magnetometer

- **Electric Field Observations**

- **Plasma Density (and Electron Temperature) Observations**

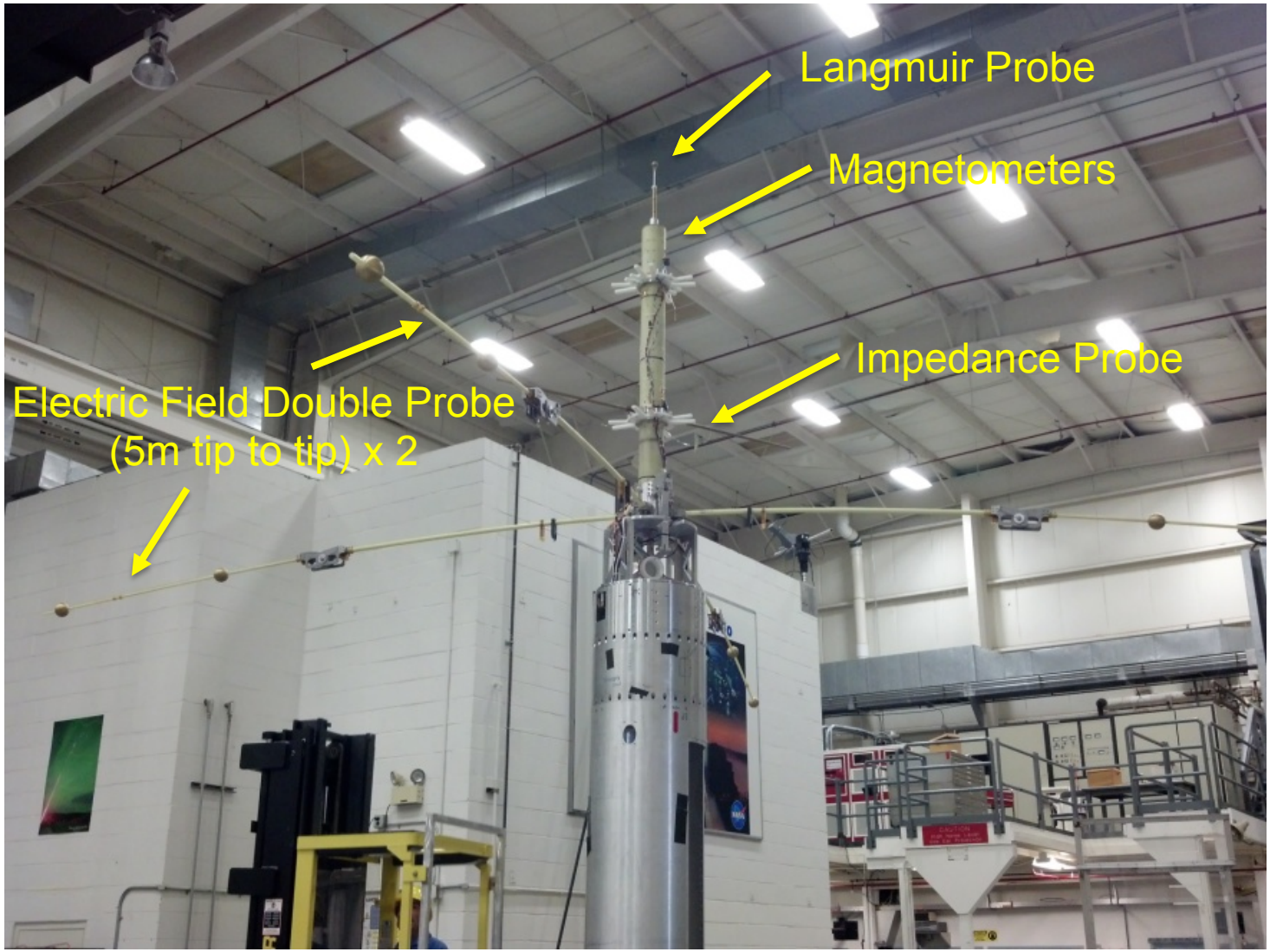
  Langmuir Probe (Jeff Klenzing)
  Impedance Probe (Doug Rowland)

- **Neutral Density, Temperature, Winds, Ion Composition** (Jim Clemmons, Aerospace)

- **Lithium wind observations** (Miguel Larsen, Clemson; JAXA, Japan)

- **Atmosphere Data from Falling Sphere Experiment** (Chad Fish, USU)

Electric Field, Magnetic Field, Plasma Density Experiments -- Dynamo Rockets



Dynamo II Mission

Rockets 21.140 and 41.090

Launch: July 4, 2013

Launch Operations

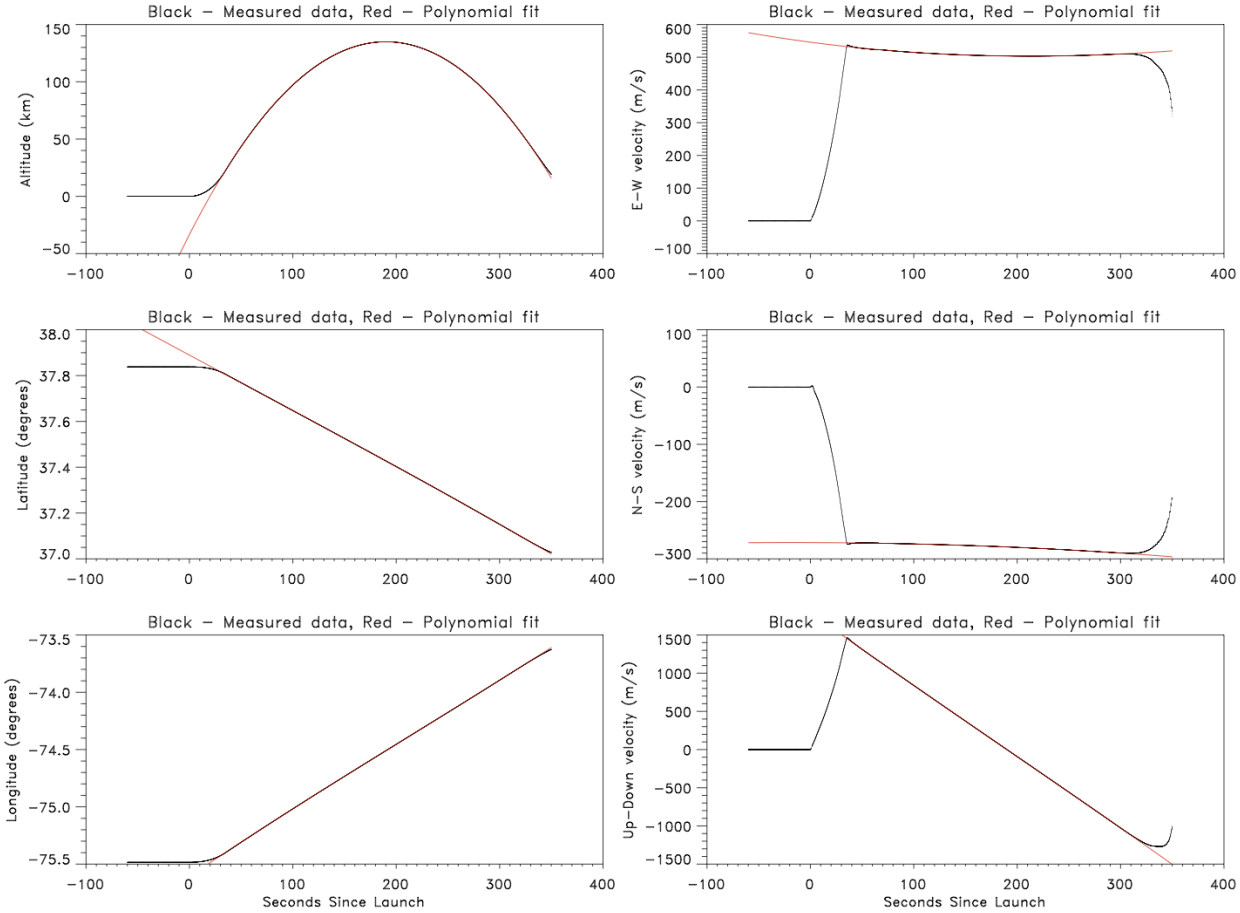
Vehicle and Payload Performance

Rockets 21.140 and 41.090

Launches of July 4, 2013

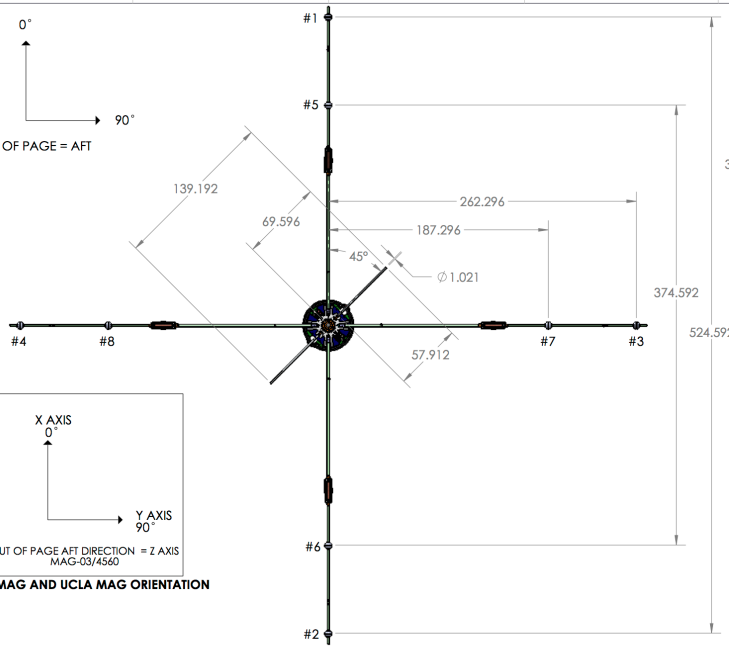
Wallops Island, Virginia -- 21.140

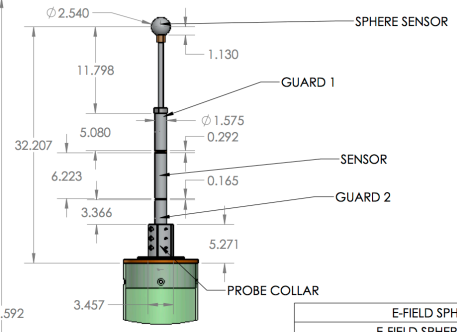
4 July 2013, 14:31:25.0 U.T.



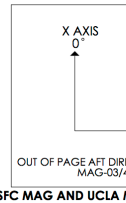
/Volumes/scmraid/Rocket Campaigns/Rocket Flight Data/Flights/Dynamo/ParIII-Jun-2013/Flights/21140/Trajectory
trajectory_plot_21140.ps

SCM Fri Jul 12 15:23:28 2013





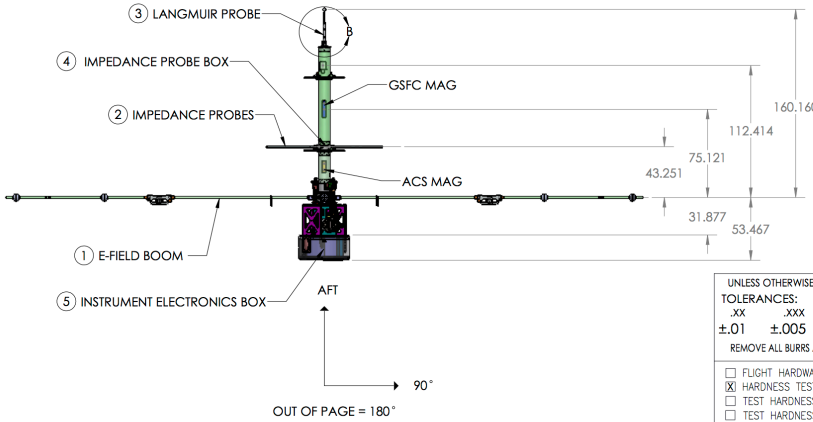
DETAIL B
SCALE 1 : 4

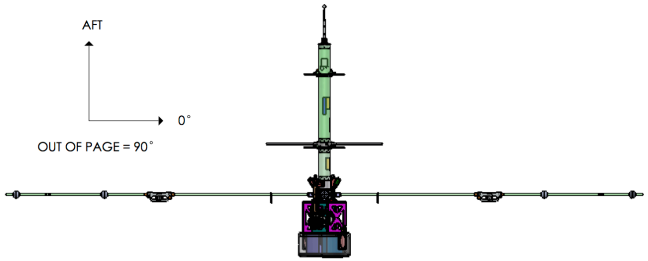


GSFC MAG AND UCLA MAG ORIENTATION

E-FIELD SPHERE DIAMETER	6cm
E-FIELD SPHERE SURFACE AREA	108.182cm^2
E-FIELD SPHERE COATING	TITANIUM NITRIDE
LANGMUIR PROBE SPHERE DIAMETER	2.54cm
LANGMUIR PROBE SPHERE SURFACE AREA	19.153cm^2
LANGMUIR PROBE SENSOR AND GUARD COATING	TITANIUM NITRIDE
LANGMUIR PROBE CYLINDRICAL SENSOR SURFACE AREA	30.788cm^2
LANGMUIR PROBE GUARD 1 SURFACE AREA	25.108cm^2
LANGMUIR PROBE GUARD 2 SURFACE AREA	6.558cm^2
LANGMUIR PROBE COLLAR SURFACE AREA	45.282 cm^2
IMPEDANCE PROBE EXPOSED SURFACE AREA	47.414cm^2

ITEM NO.	QTY.	PART NUMBER	DESCRIPTION
5	1	MJF0000055	8 TRAY ELECTRONICS BOX
4	1	GC131032	IMPEDIANCE PROBE E-BOX
3	1	AHEL0000032	LANGMUIR PROBE
2	2	AHEL0000017	IMPEDIANCE PROBE
1	4	MJF0000014	E-FIELD BOOM





UNLESS OTHERWISE SPECIFIED-DIMENSIONS ARE IN INCHES
TOLERANCES:
.XX ±.01 .XXX ±.005 ∠ ±.2° FRACTIONS ±1/64 125
REMOVE ALL BURRS AND SHARP EDGES R .010 OR CHAMFER MAX.

☐ FLIGHT HARDWARE/POST FAB HARDNESS TEST REQ'D
☒ HARDNESS TEST NOT REQUIRED ☒ NON FLIGHT
☐ TEST HARDNESS PER ASTM E-18, LOCATION OPTIONAL
☐ TEST HARDNESS PER ASTM E-18 WHERE INDICATED ON FIELD OF DRAWING THUS ⊙

☒ NO NON-DESTRUCTIVE EXAMINATION (NDE) REQ'D
☐ NDE REQUIRED PER S-313-009 CODE_____

THIS DRAWING WAS PRODUCED USING
SOFTWARE: SOLIDWORKS VERSION: 2013
FILE NAME: ME82974

NEXT ASSY	USED ON

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION — Goddard Space Flight Center — GREENBELT, MARYLAND

	NAME	INIT	DATE
DESIGNER	M. FOWLE		6/10/2013
DRAWN	M. FOWLE		7/10/2013
CHECKED			
APPROVED			

DRAWING INTERPRETED PER ASME Y14.5-2009

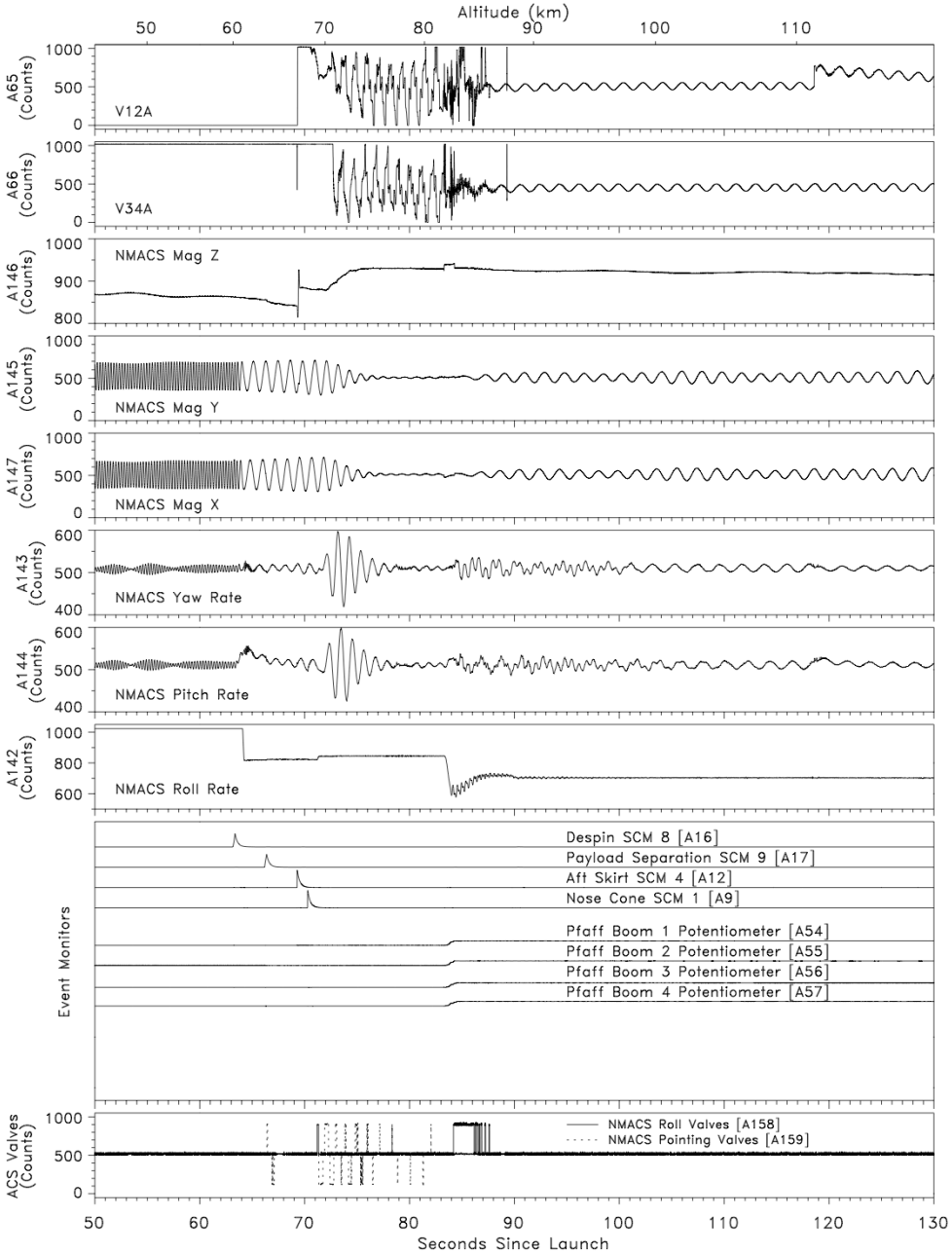
TITLE
AFT EXPERIMENT ASSEMBLY DYNAMO SOUNDING ROCKETS 21.140 & 21.141

SIZE C — MJF0000058 — REV -
CODE 674 — SCALE 1:25 — WT — SH 1 OF 1

REV 1
MJF0000058

Wallops Island, Virginia -- 21.140 (Dynamo II)

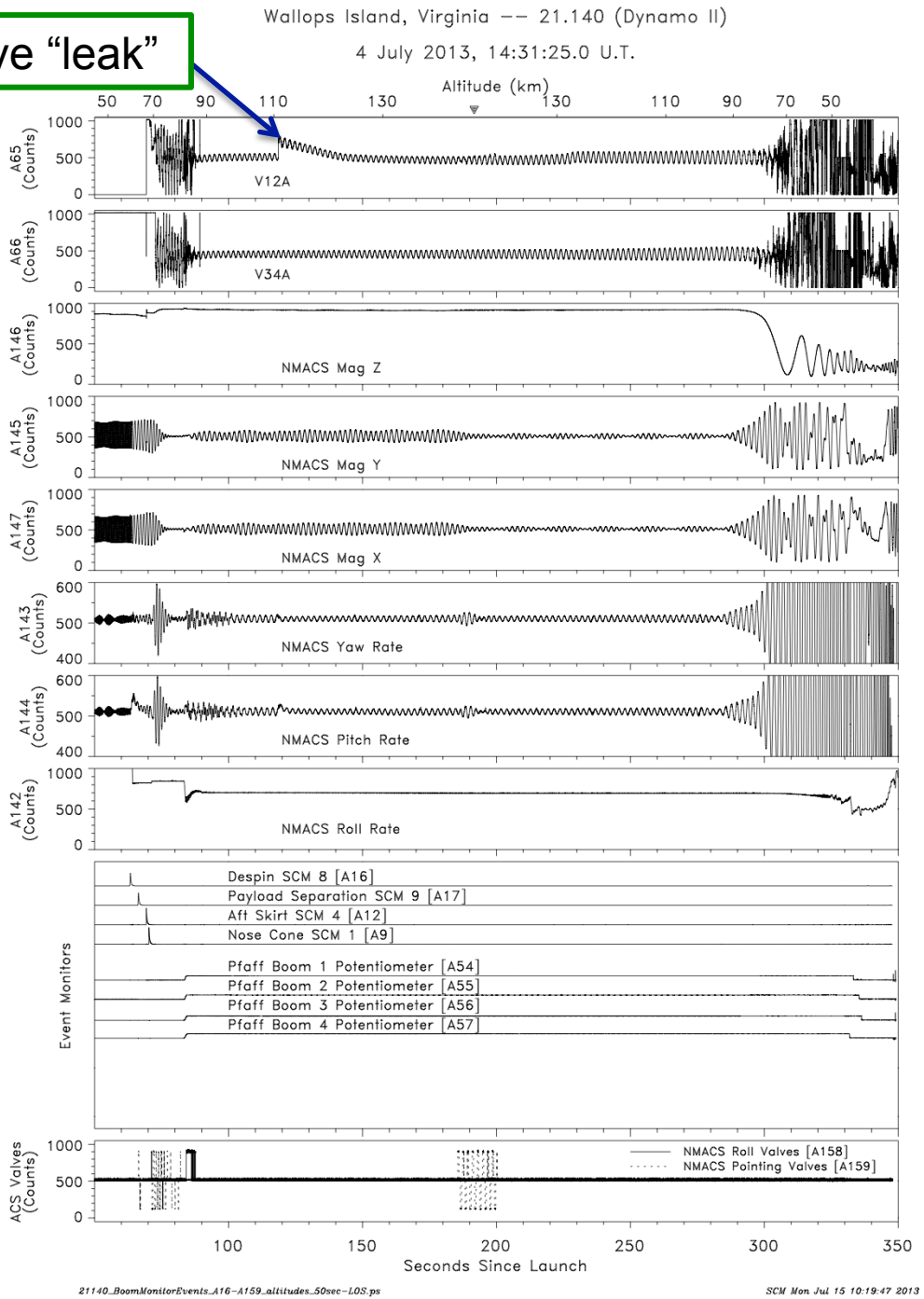
4 July 2013, 14:31:25.0 U.T.



21140_BoomMonitorEvents_A16-A159_altitudes_50sec-130sec.ps

SCM Mon Jul 15 10:18:52 2013

ACS Valve “leak”



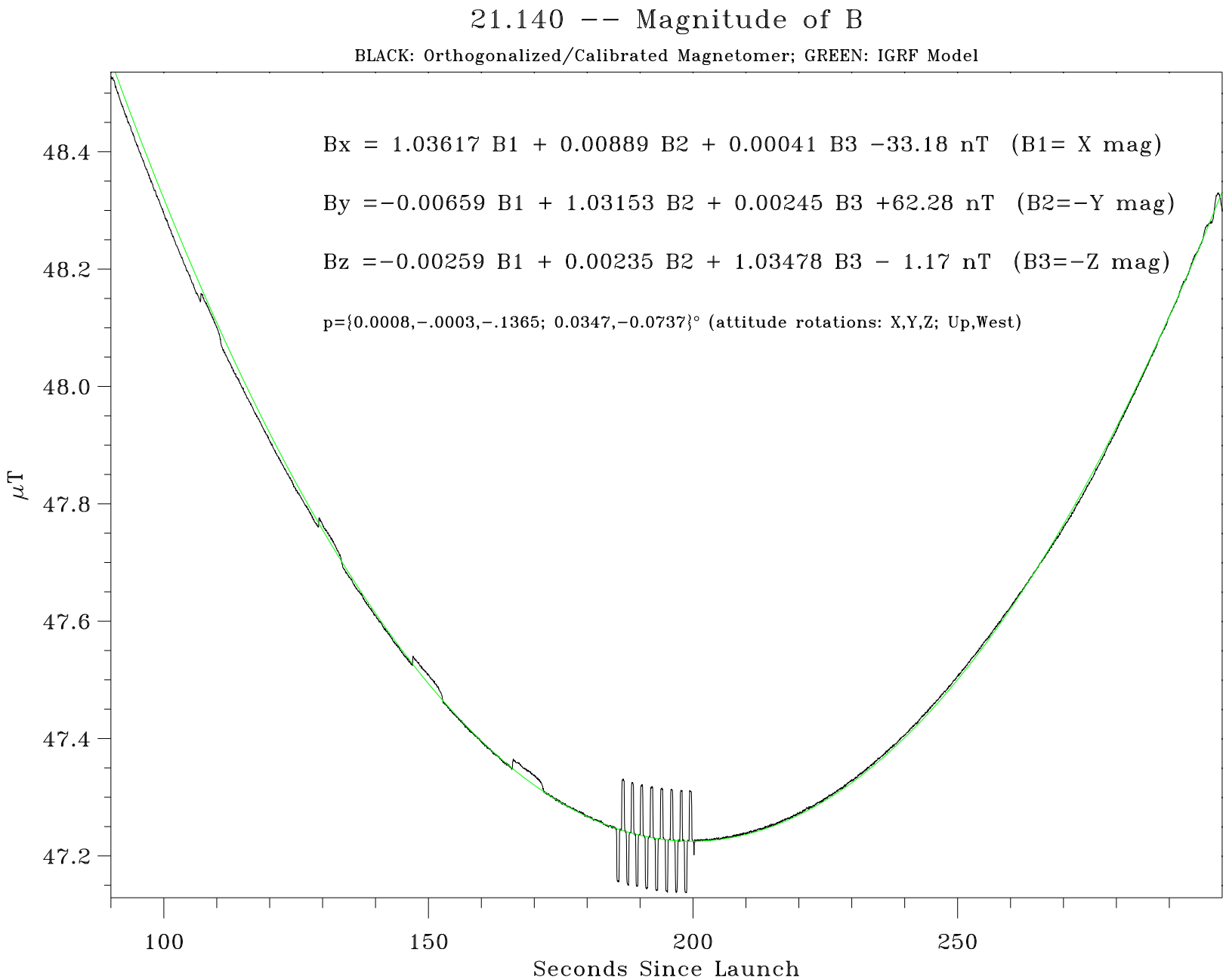
Magnetic Field Observations

GSFC Fluxgate Magnetometer

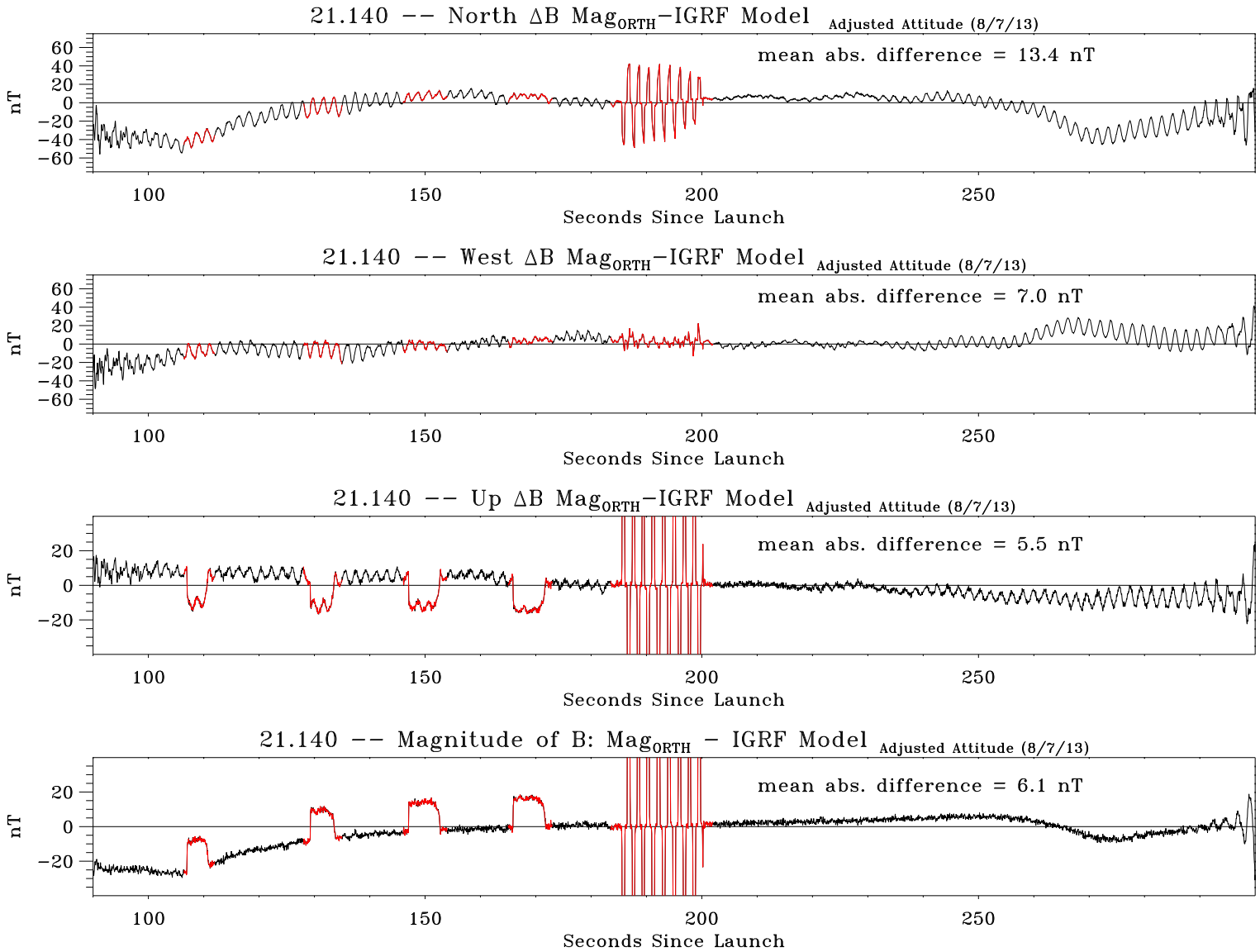
Rocket 21.140

Launch: July 4, 2013

Rocket 21.140 -- Attitude, Non-orthogonality "optimized"

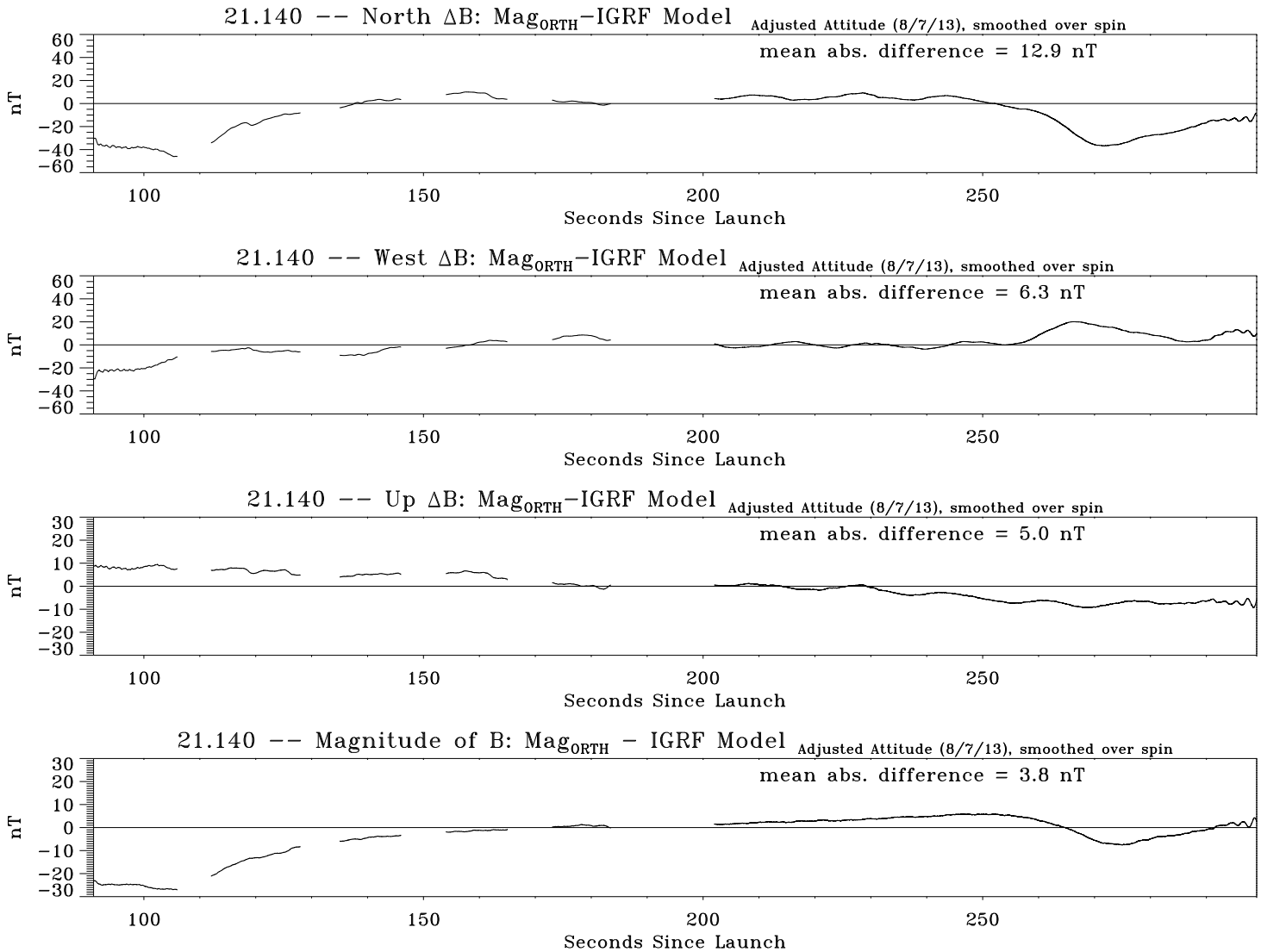


Rocket 21.140 -- Magnetic Components – IGRF



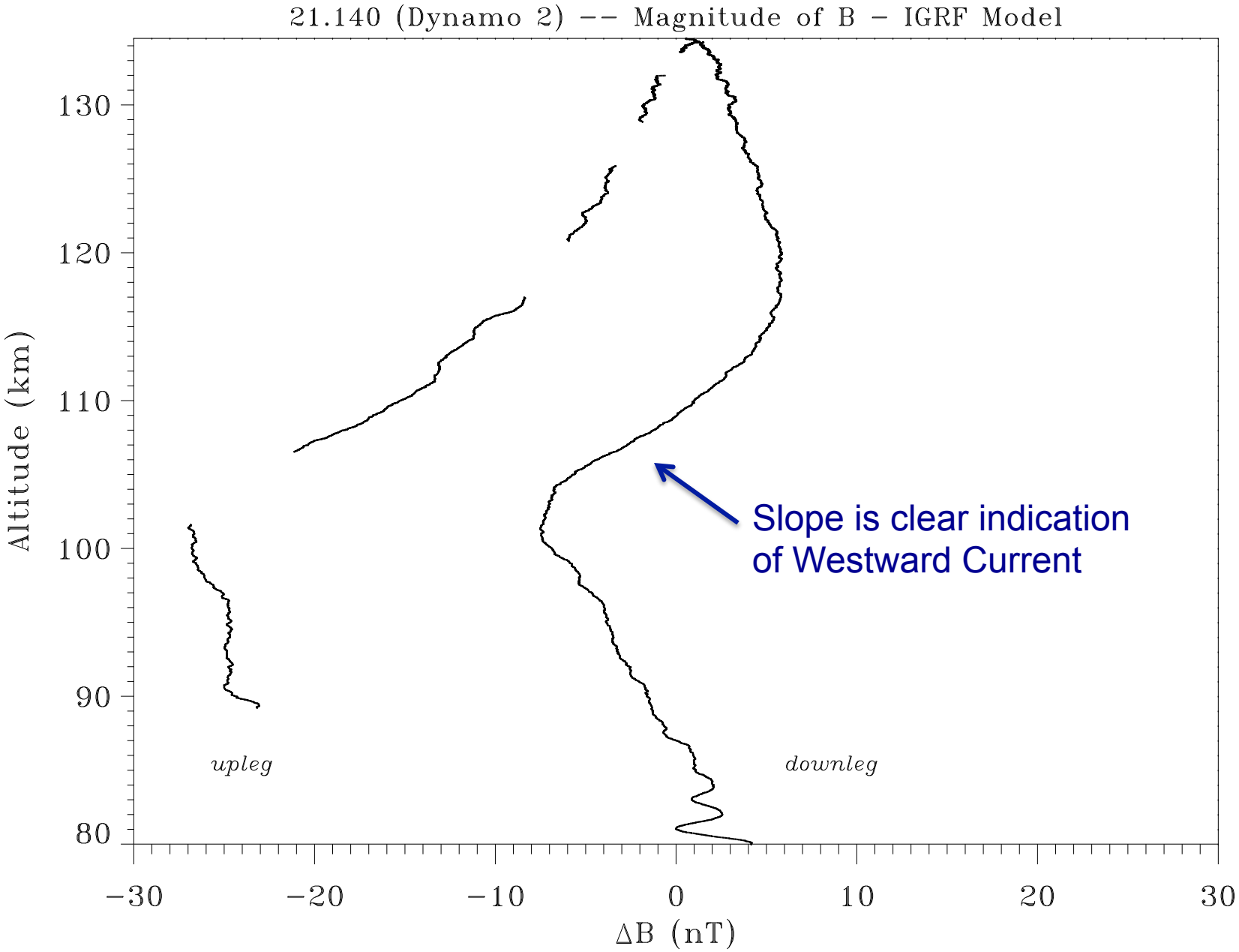
HF 8/08/13 11:14

Rocket 21.140 -- Measured Mag – IGRF (smoothed over spin)



HF 8/08/13 11:12

Rocket 21.140 -- Magnitude of B – IGRF Model



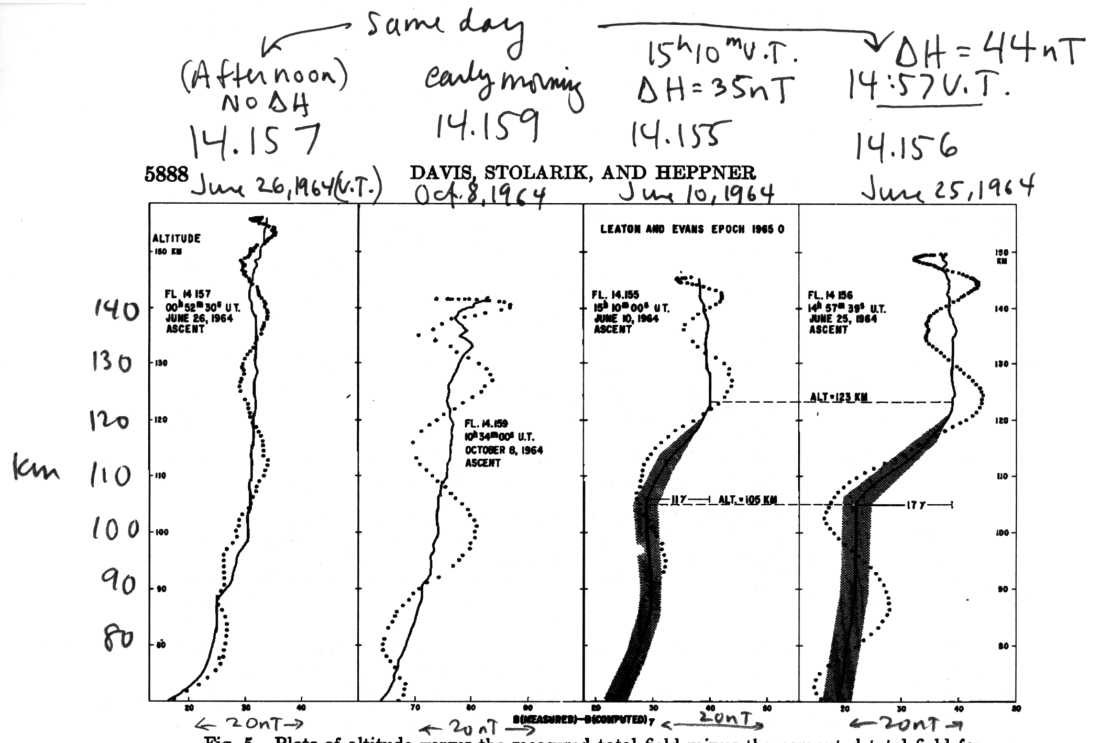


Fig. 5. Plots of altitude versus the measured total field minus the computed total field for the ascent portions of all flights; data points taken at intervals of approximately 1 second. Solid lines represent the data corrected for effects due to vehicle precession.

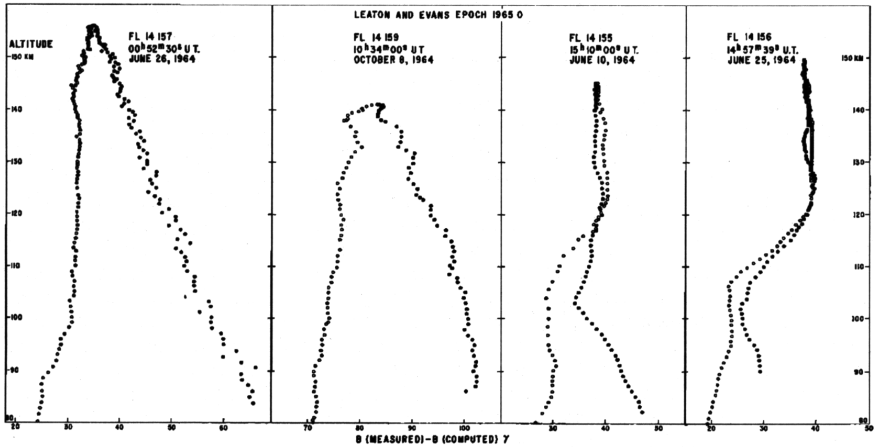
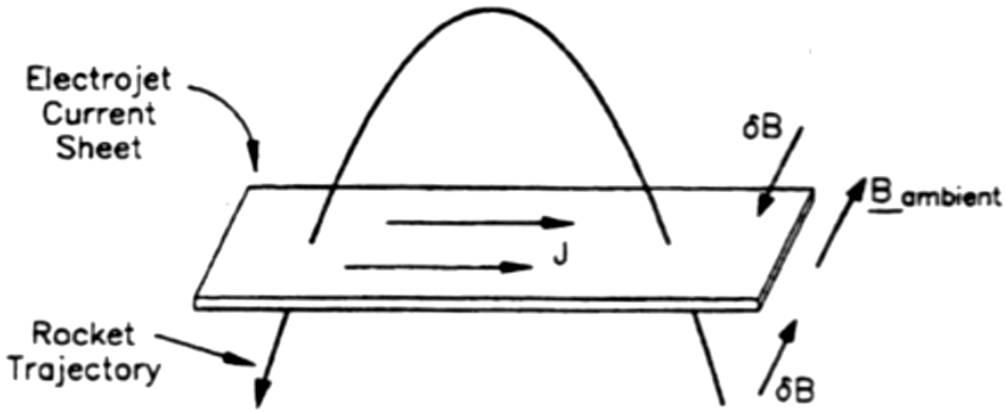
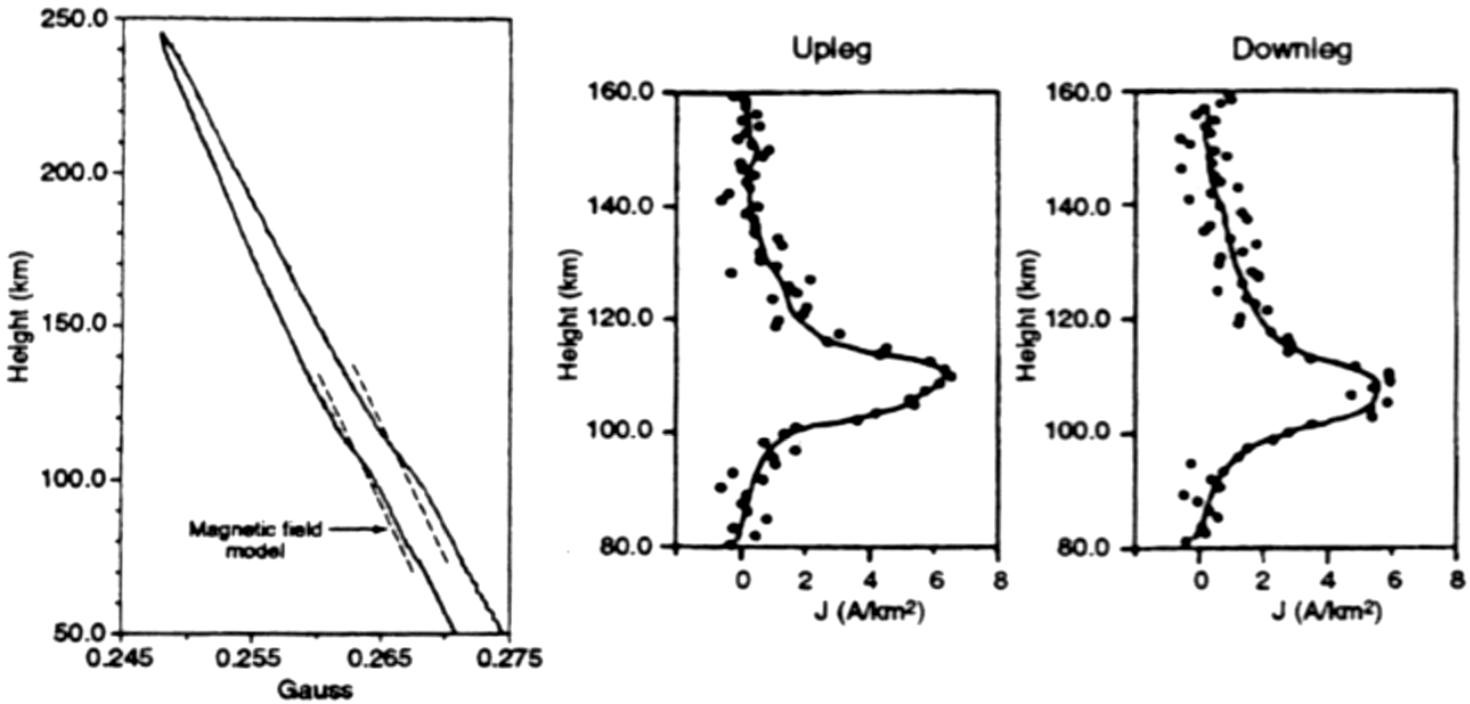


Fig. 6. Precession-corrected ascent (open circles) and descent (dots) data taken at intervals of approximately 1 second above altitude 80 km for all flights.

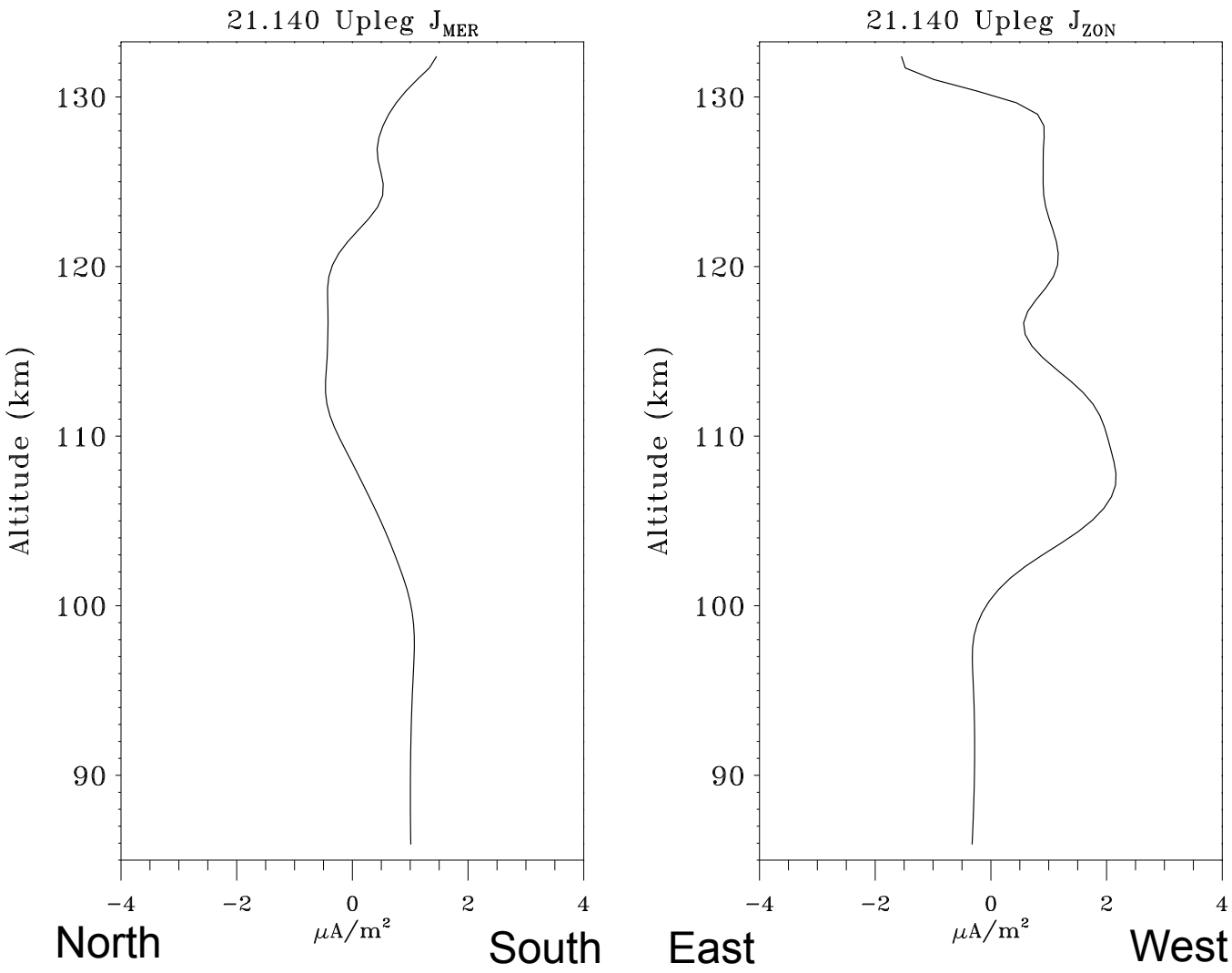
Compare Equatorial Electrojet Current Measurements



NASA 18.150–Punta Lobos, Peru
7 June 1975



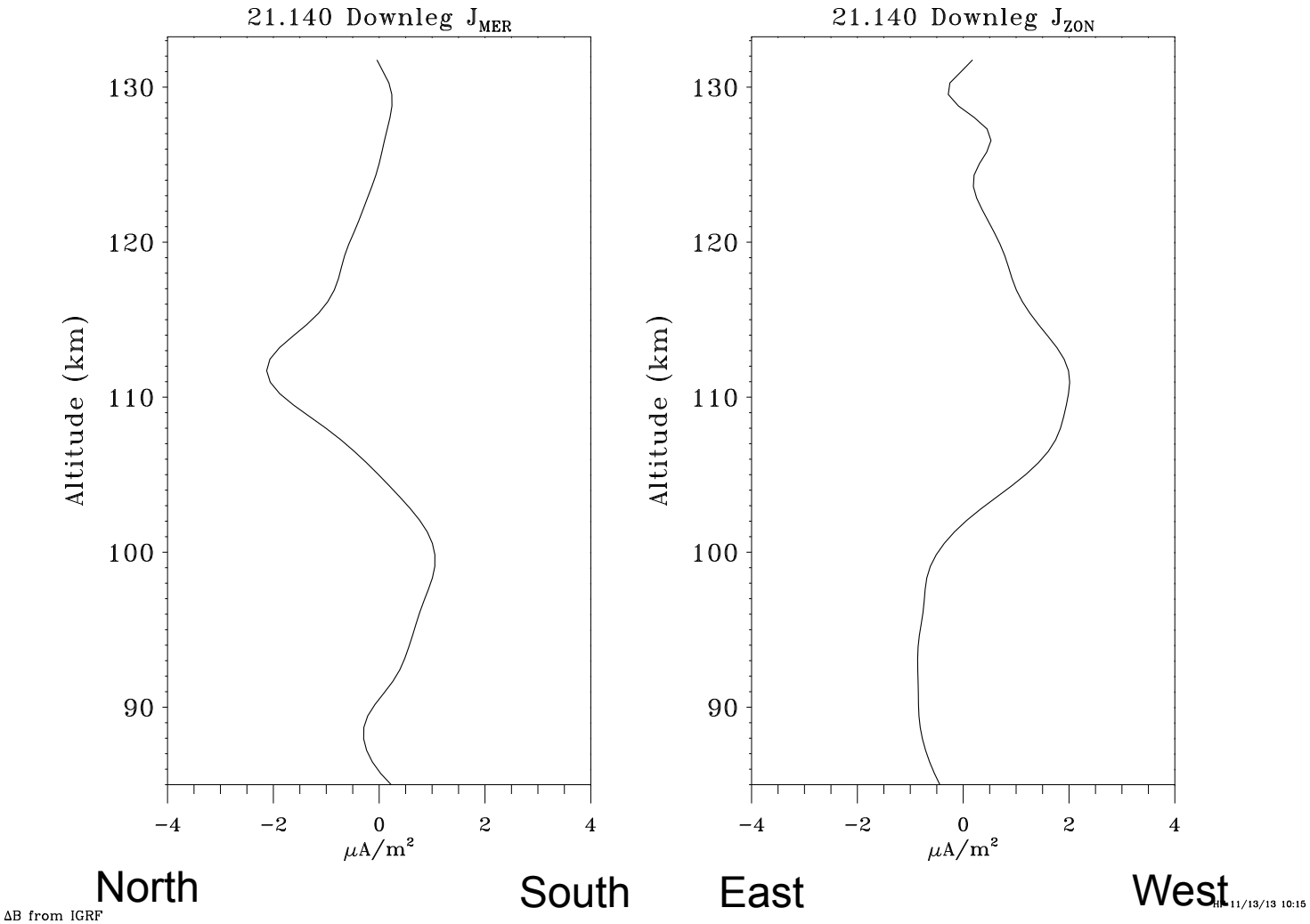
Rocket 21.140 -- Upleg Currents smoothed to remove coning



ΔB from IGRF

HF 11/13/13 10:13

Rocket 21.140 -- Downleg Currents smoothed to remove coning

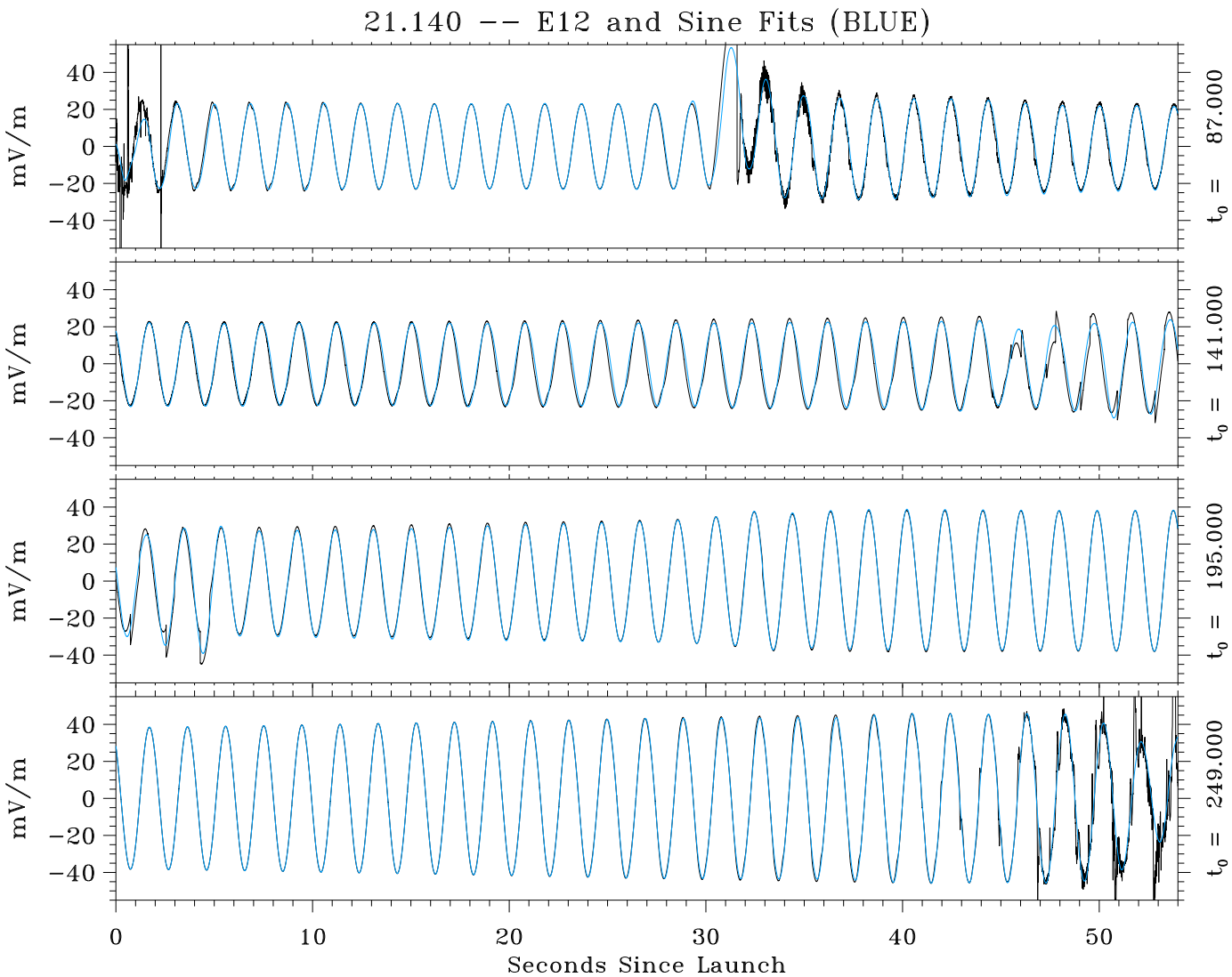


Electric Field Observations

Rocket 21.140

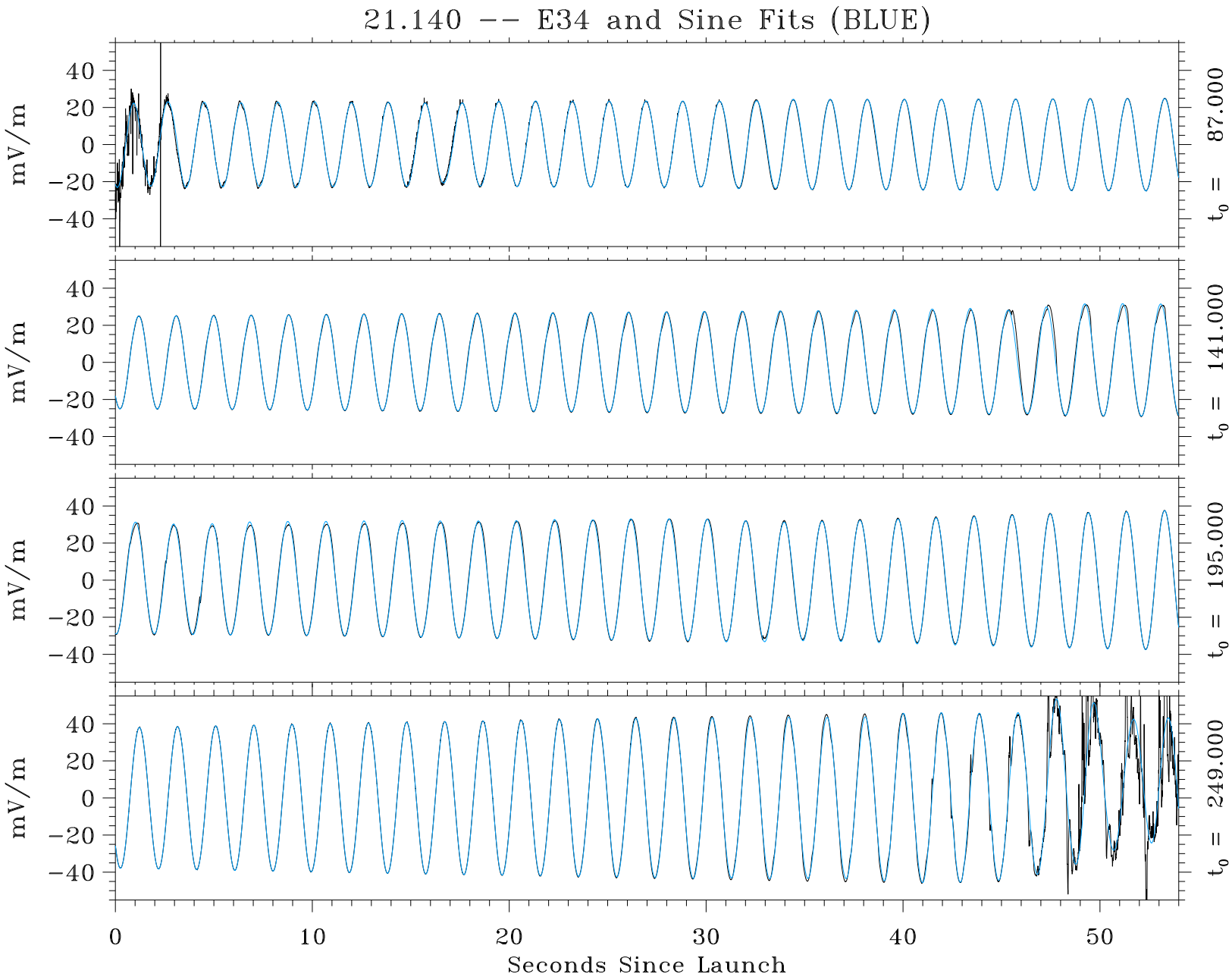
Launch: July 4, 2013

Rocket 21.140 -- E12 Data and Sine Fits

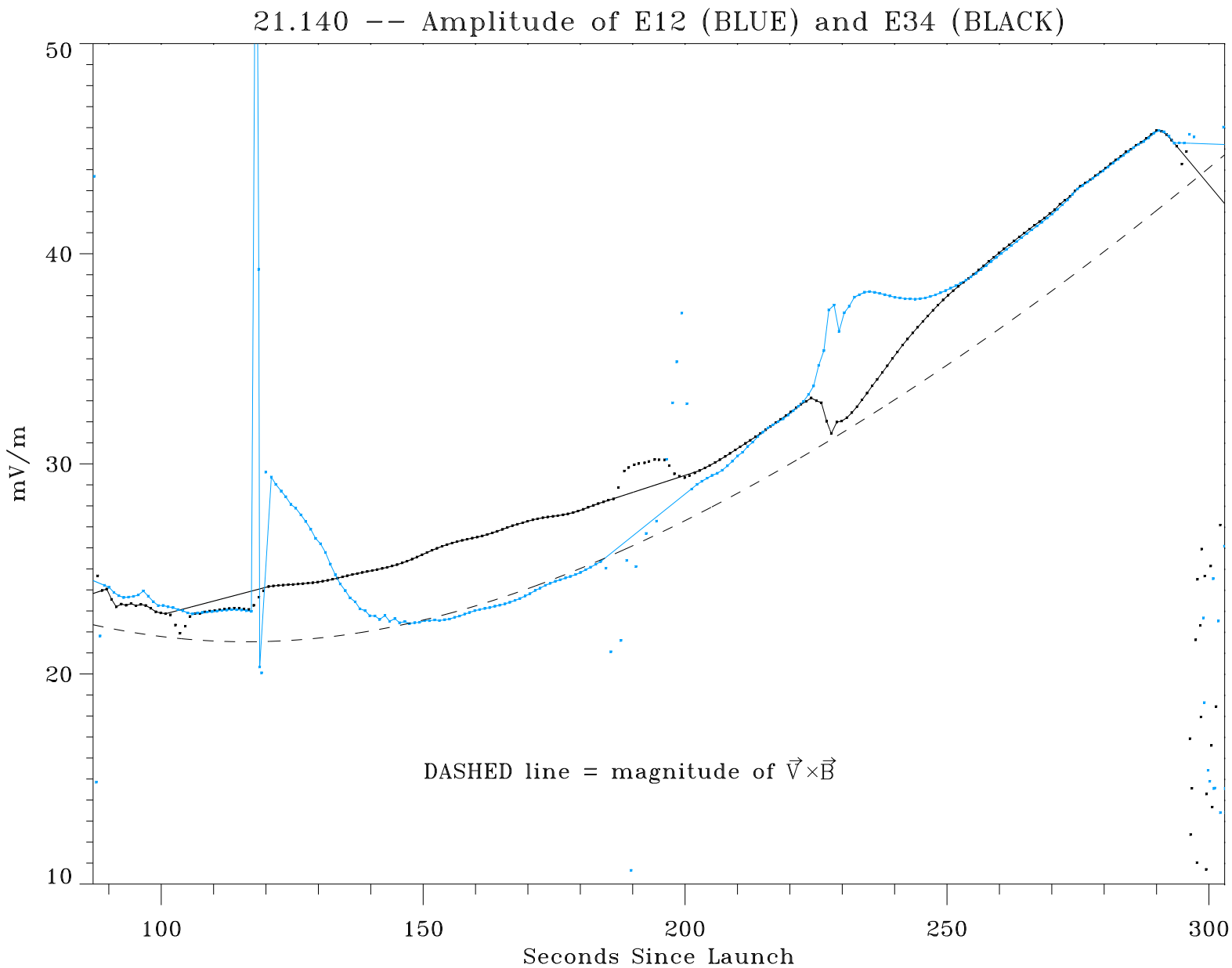


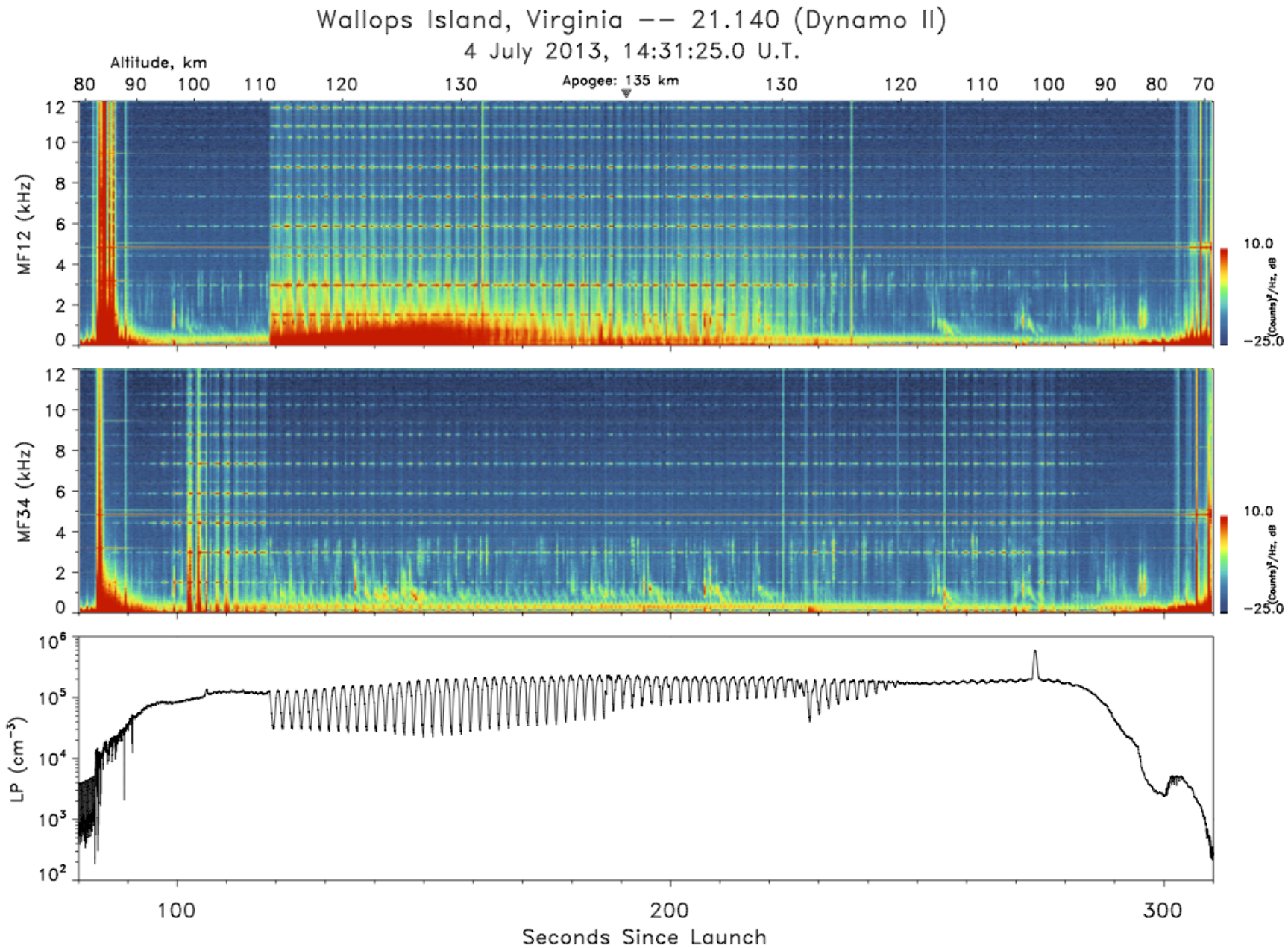
HF 7/16/13 11:34

Rocket 21.140 E34 Data and Sine Fits



Rocket 21.140 -- Amplitudes of E12, E34, V x B





Plot Created: Feb 24 2014

SCM Mon Feb 24 11:53:26 2014
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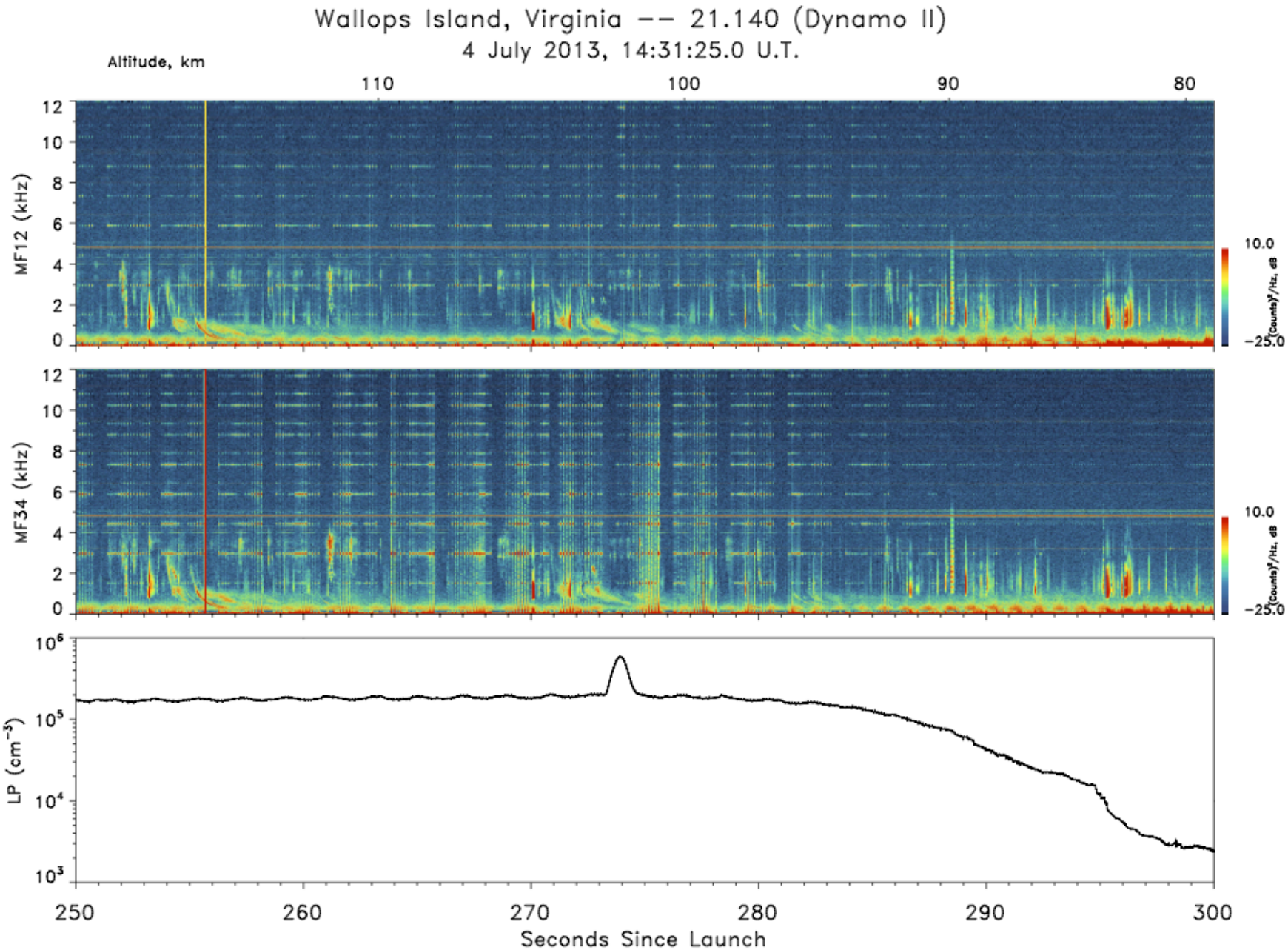
Panel 1: fftsize 16384, overlap 8192, SR 120000, Win HN, lps 2.43913
Panel 2: fftsize 16384, overlap 8192, SR 120000, Win HN, lps 2.43913


Wallops Island, Virginia -- 21.140 (Dynamo II)
4 July 2013, 14:31:25.0 U.T.
Altitude, km
110
100
90
80
MF12 (kHz)
MF34 (kHz)
10.0
-25.0
(Counts)²/Hz, dB
LP (cm⁻³)
Seconds Since Launch
Plot Created: Feb 24 2014
Panel 1: fftsize 16384, overlap 8192, SR 120000, Win HN, lps 14.6
Panel 2: fftsize 16384, overlap 8192, SR 120000, Win HN, lps 14.6
SCM Mon Feb 24 15:05:53 2014
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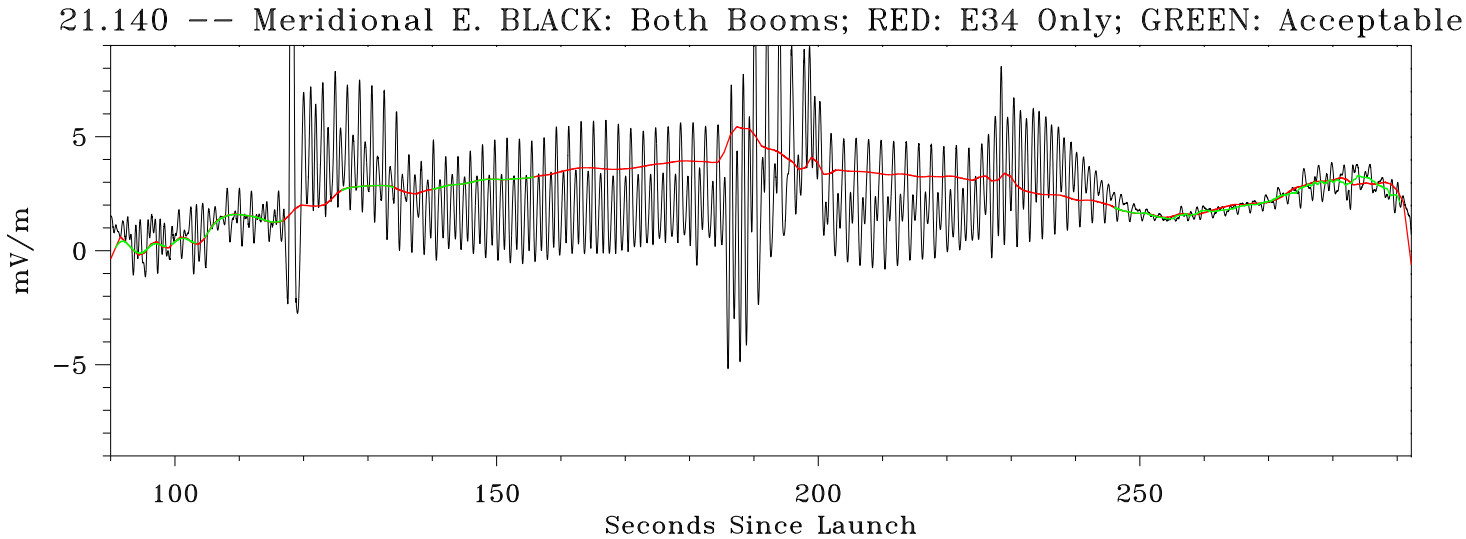
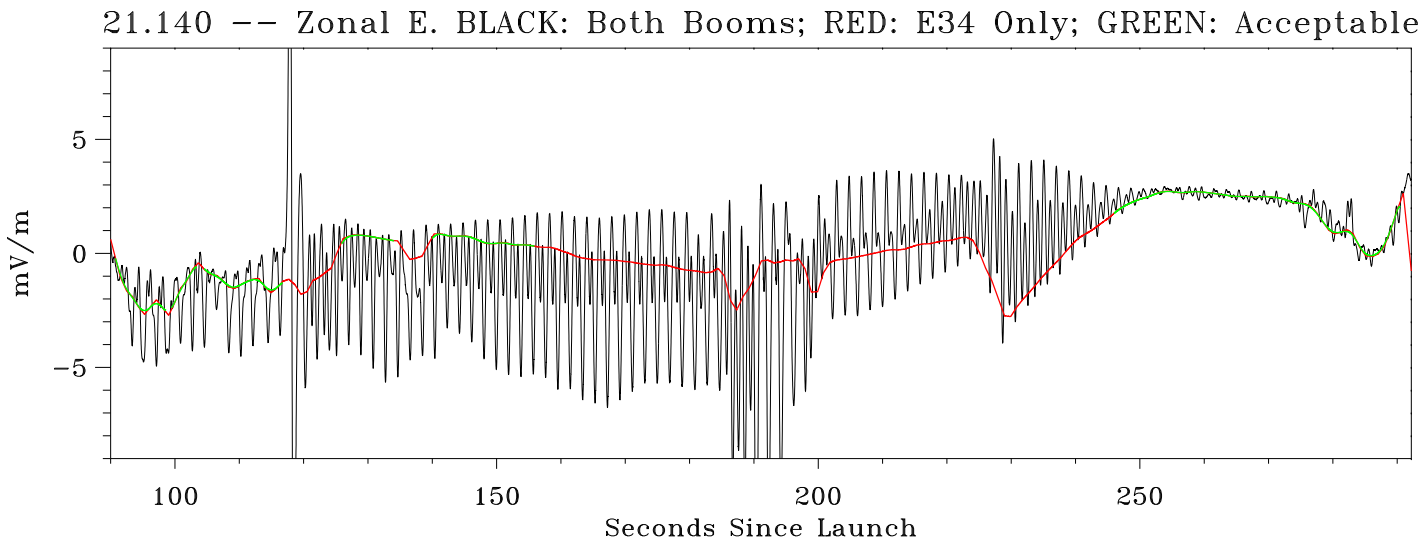
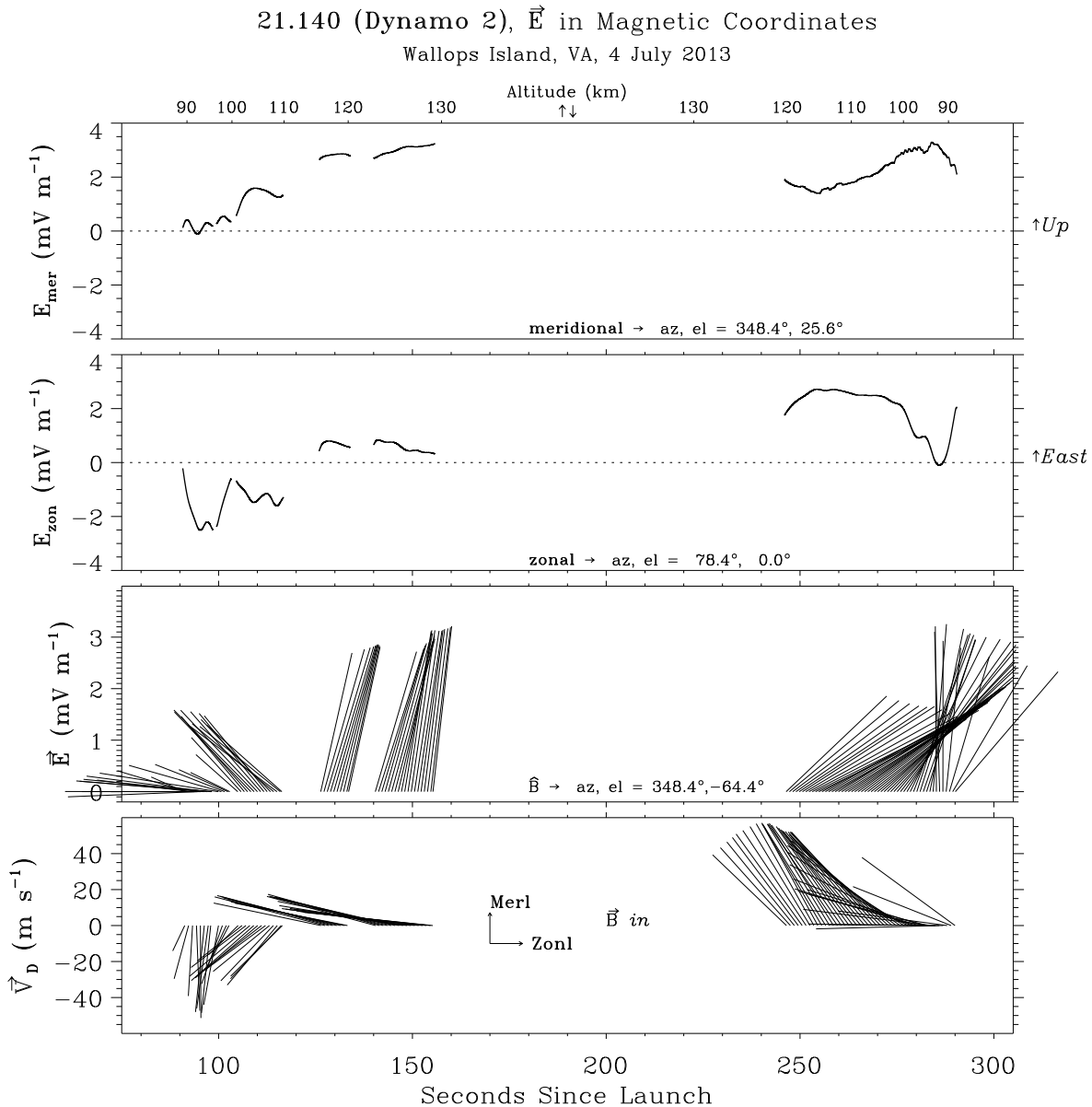
Rocket 21.140





HF 8/12/13 11:16

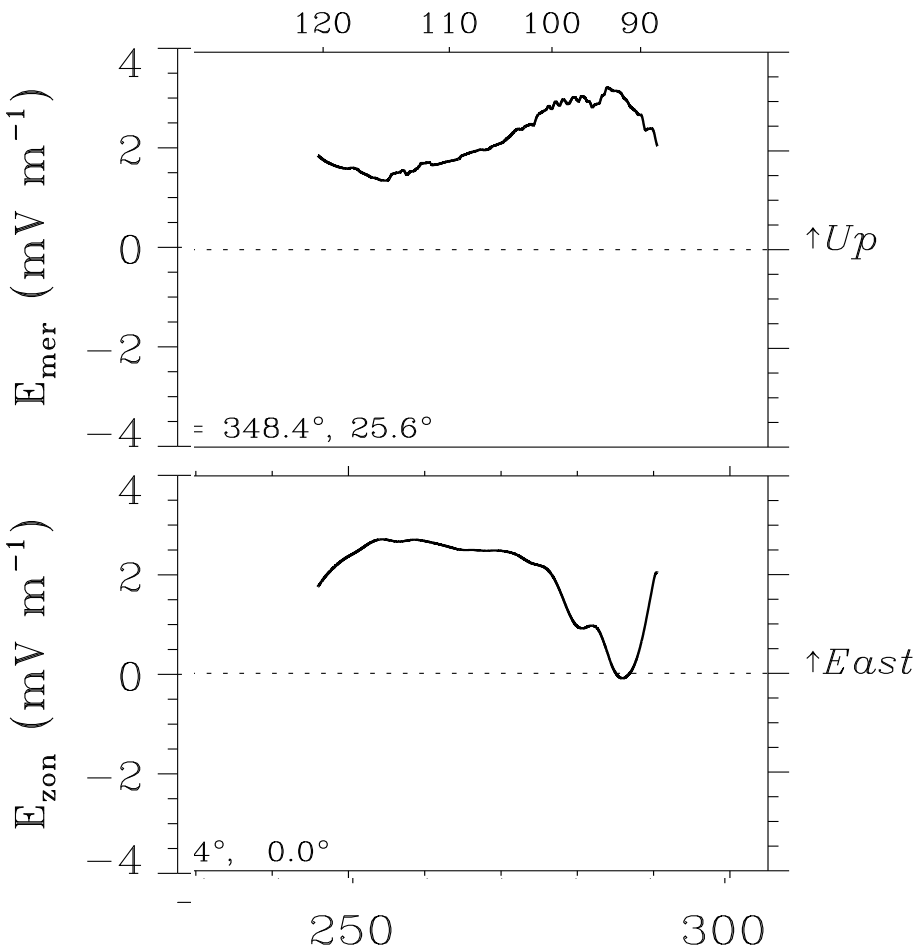
Rocket 21.140



HF 8/15/13 11:35

Rocket 21.140

DC Electric Fields (– V x B)



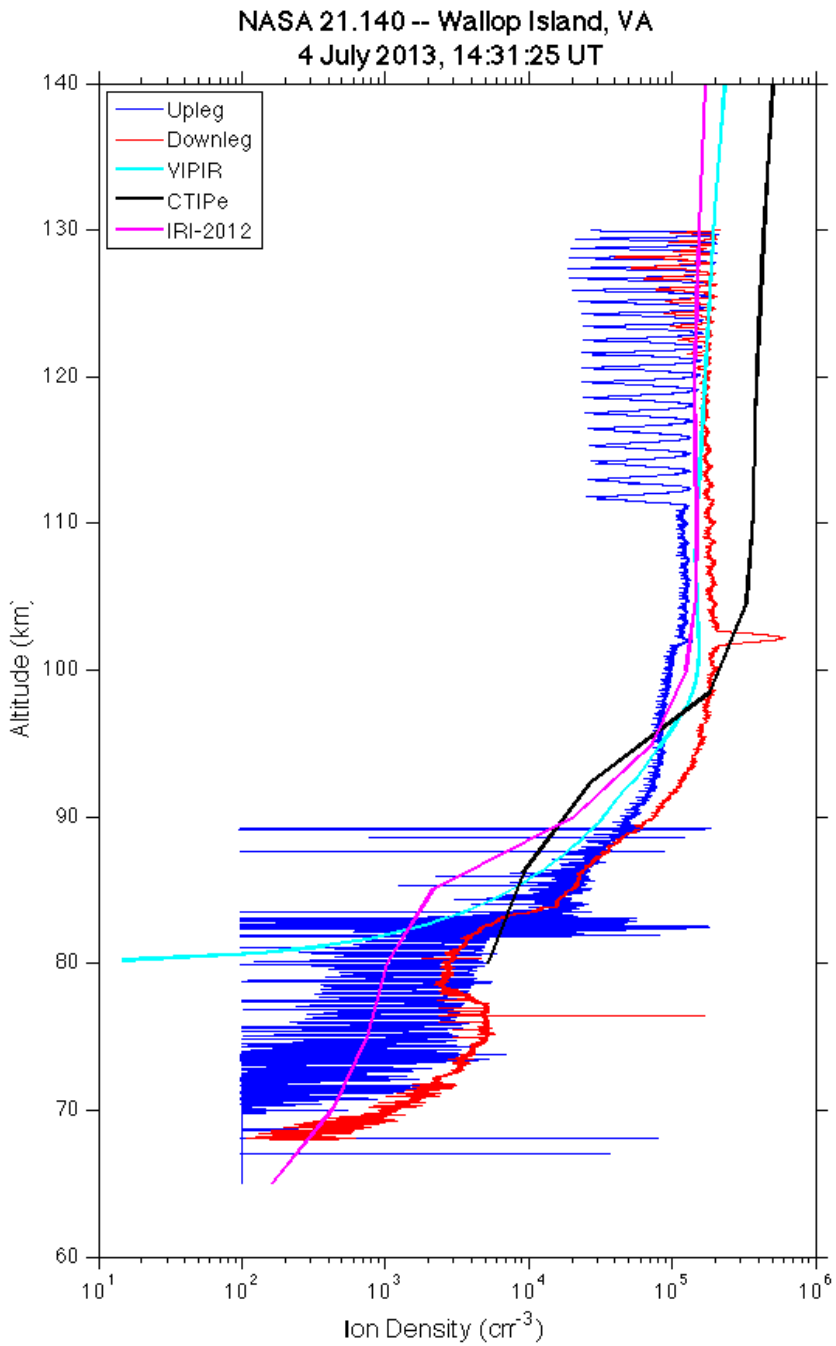
Plasma Density Observations

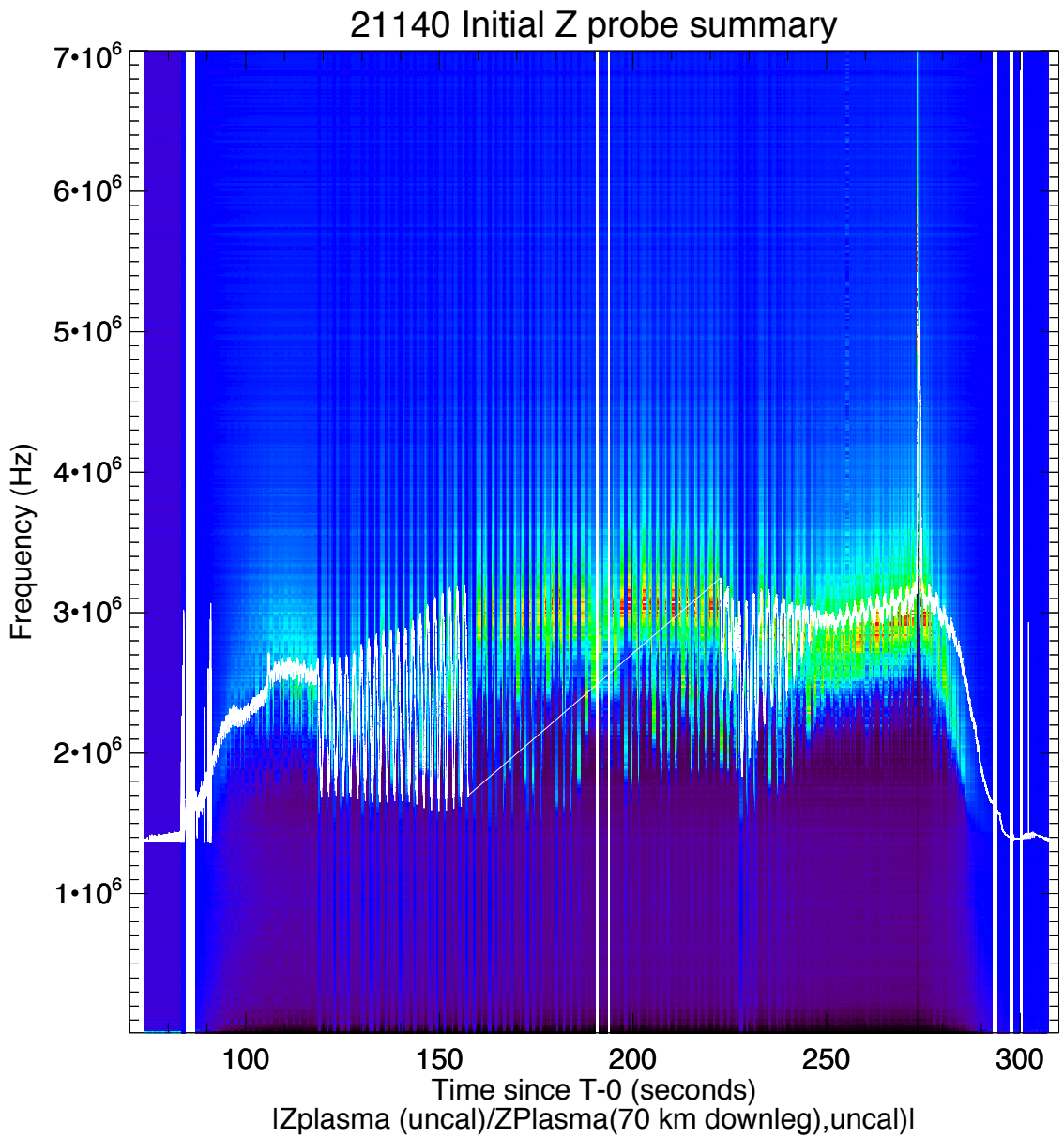
GSFC Langmuir Probe (Klenzing)

GSFC Impedance Probe (Rowland)

Rocket 21.140

Launch: July 4, 2013


NASA 21.140 -- Wallop Island, VA
4 July 2013, 14:31:25 UT
Upleg
Downleg
VIPIR
CTIPe
IRI-2012
Altitude (km)
Ion Density (cm^{-3})
140
130
120
110
100
90
80
70
60
10^1
10^2
10^3
10^4
10^5
10^6


21140 Initial Z probe summary
7•10^6
6•10^6
5•10^6
4•10^6
3•10^6
2•10^6
1•10^6
Frequency (Hz)
100
150
200
250
300
Time since T-0 (seconds)
|Zplasma (uncal)/ZPlasma(70 km downleg),uncal)|

Composite Plots

Measurements (ideal): **E**, **E** x **B**, $\mathbf{J}_{meas}$, Ne, Un, Nn, Mi,

Derived Quantities: Mobility (collision frequencies)

Use measured **E**, **J**, Ne to find Un that satisfies

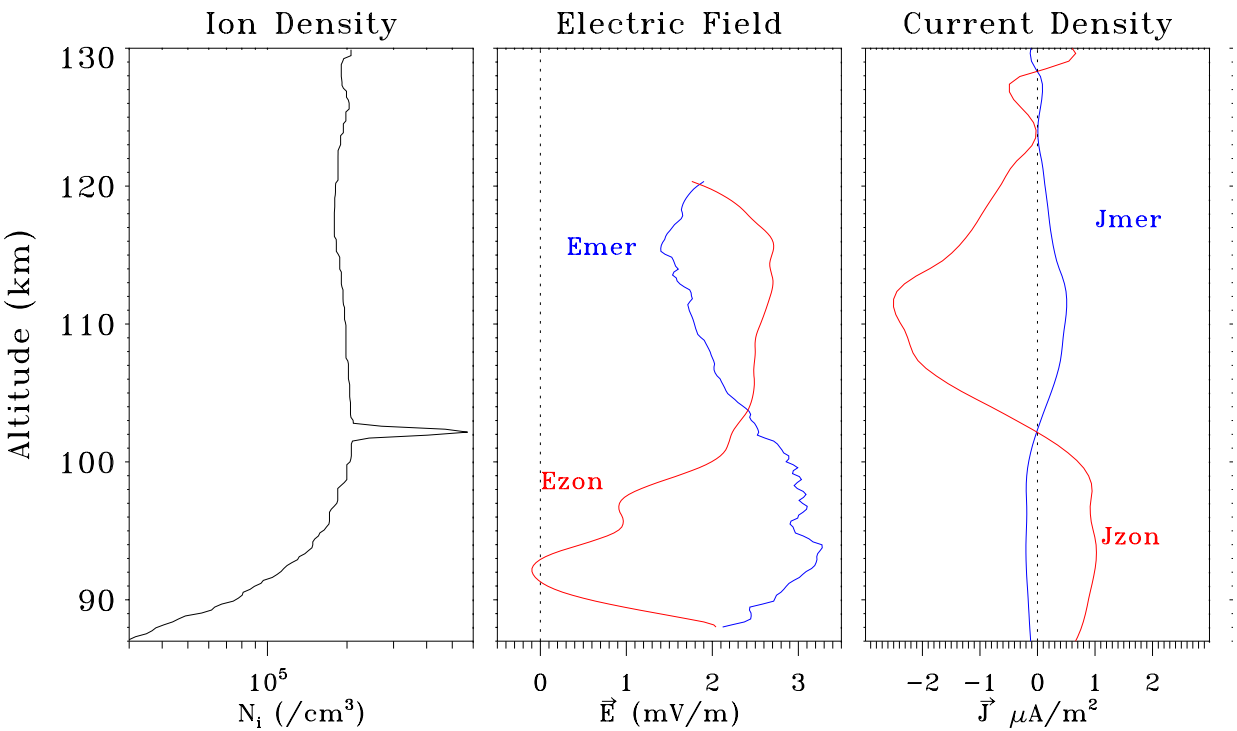
Dynamo Equation:

$$\mathbf{J} = \underline{\sigma} \bullet (\mathbf{E} + \mathbf{U} \times \mathbf{B})$$

$$\mathbf{J} = \underline{\sigma} \bullet (\mathbf{E} + \mathbf{U} \times \mathbf{B})$$

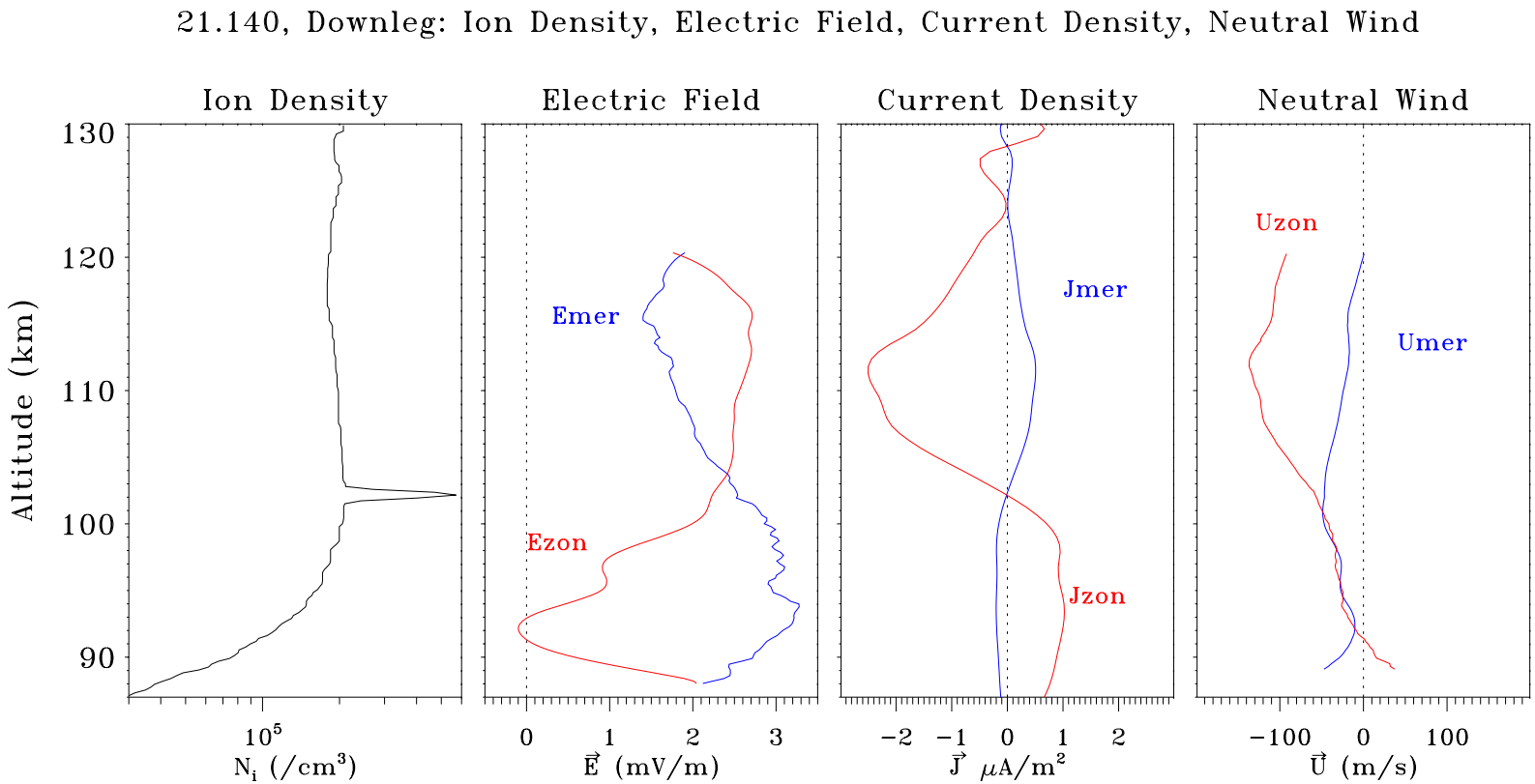
$$\begin{aligned}
\mathbf{J} &= \sigma_P (\mathbf{E}_\perp + \mathbf{u} \times \mathbf{B}) \\
&\quad + \sigma_H \hat{b} \times (\mathbf{E}_\perp + \mathbf{u} \times \mathbf{B}) + \sigma_\circ \mathbf{E}_{||} \\
\sigma_P &= e^2 \sum_j \frac{n_j \nu_j}{m_j (\nu_j^2 + \Omega_j^2)} \\
\sigma_H &= e^2 \sum_j \frac{-n_j \Omega_j}{m_j (\nu_j^2 + \Omega_j^2)} \\
\sigma_\circ &= e^2 \sum_j \frac{n_j}{m_j \nu_j}
\end{aligned}$$

21.140, Downleg: Ion Density, Electric Field, Current Density, Neutral Wind



Zonal is Positive East, Meridional is Positive Up/North

HF 2/24/14 15:15



Neutral Winds are Derived from E, J, and Ne

Zonal is Positive East, Meridional is Positive Up/North

HF 2/24/14 15:15

Launch Operations

Vehicle and Payload Performance

Rockets 21.141 and 41.091

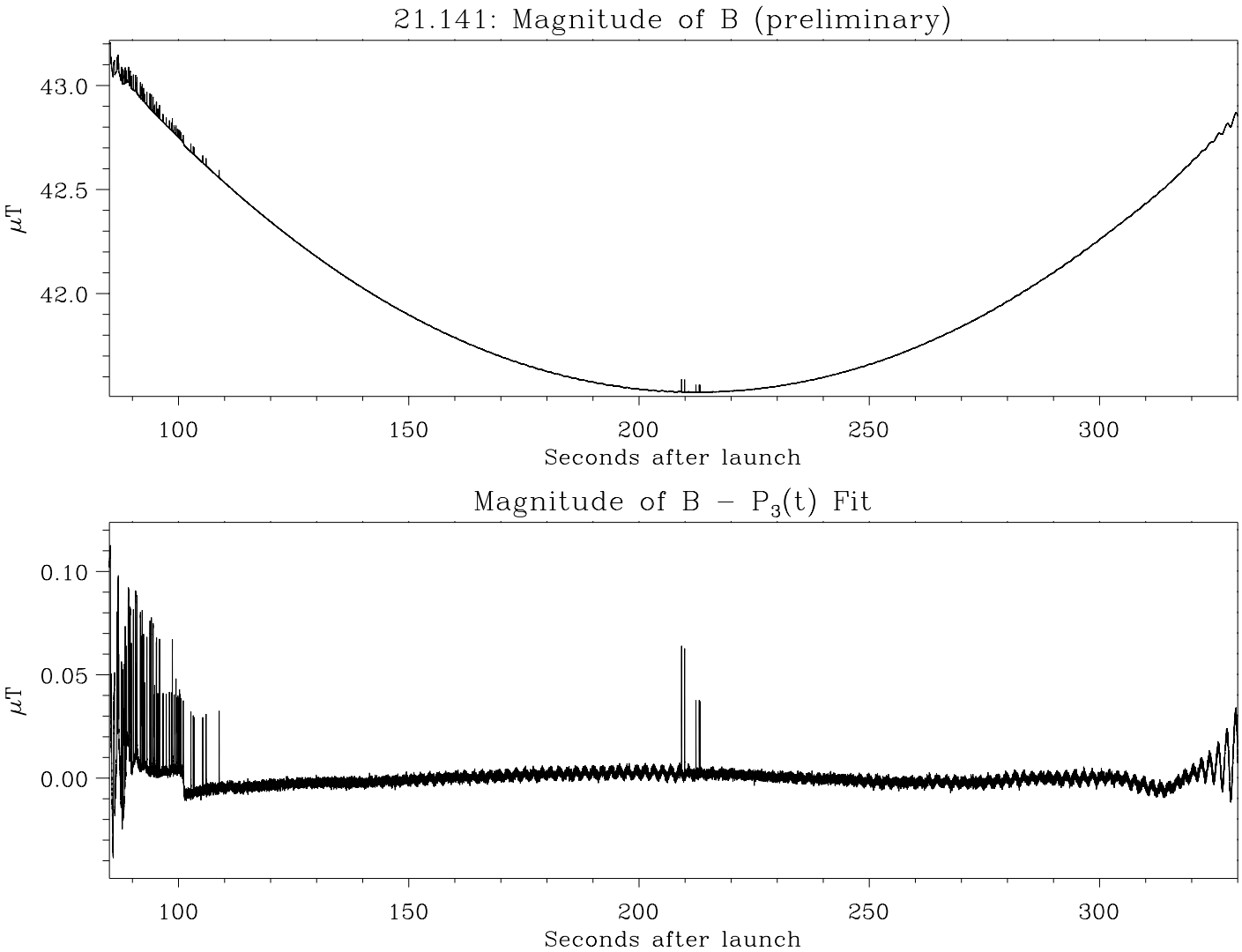
Launches of July 10, 2011

Magnetic Field Observations

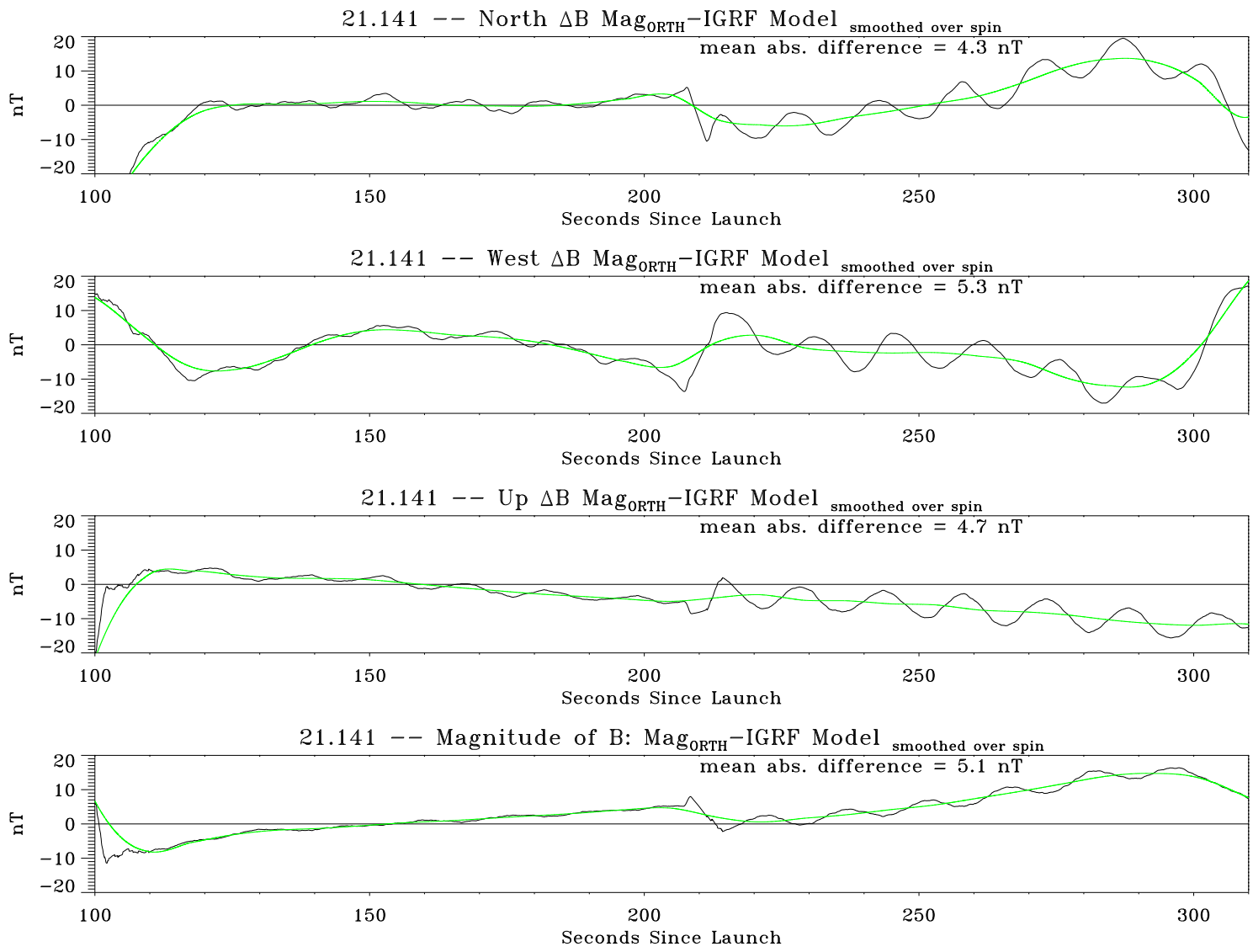
GSFC Fluxgate Magnetometer

Rocket 21.141

Launch: July 10, 2011

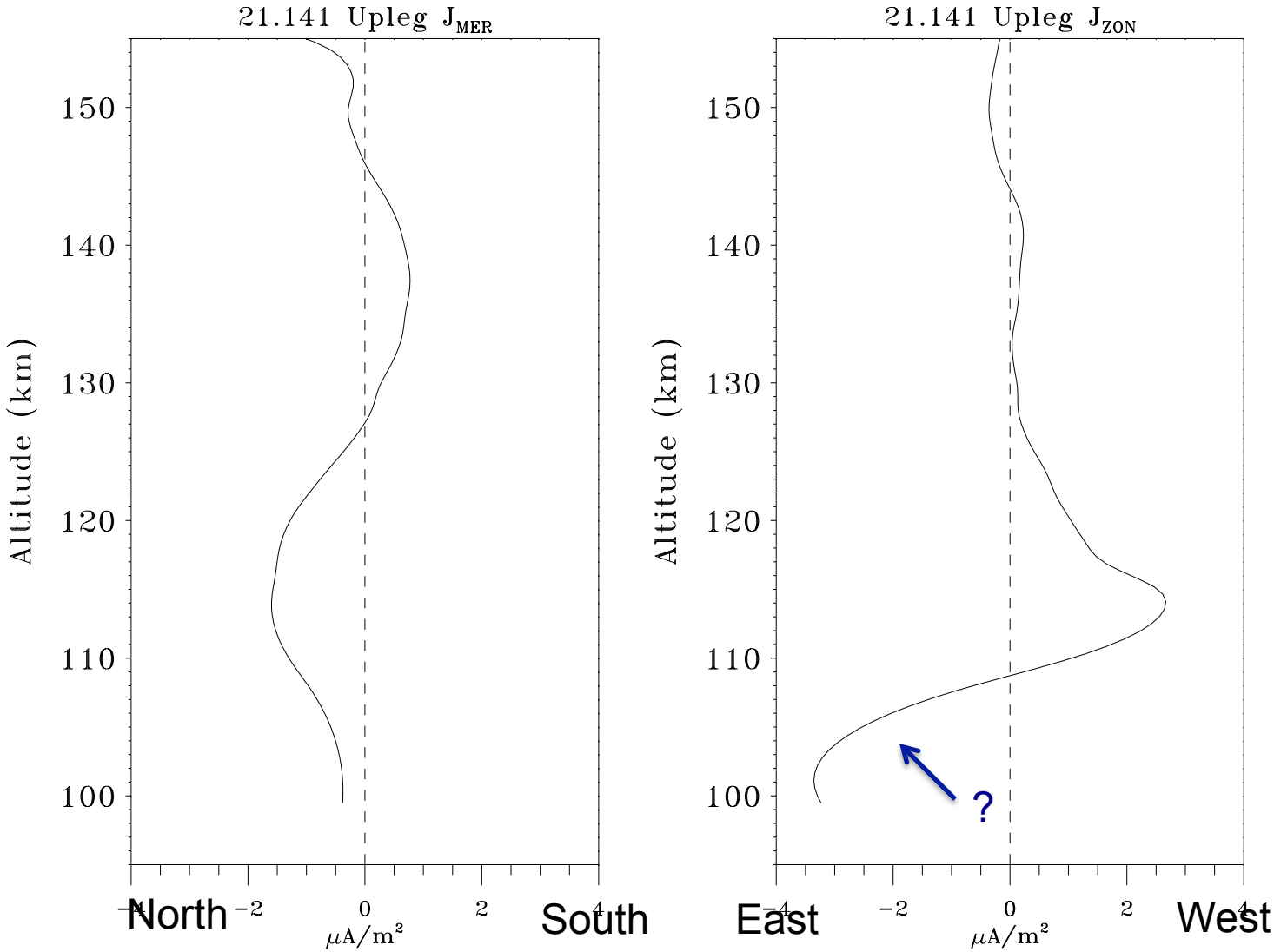


HF 7/13/11 09:44

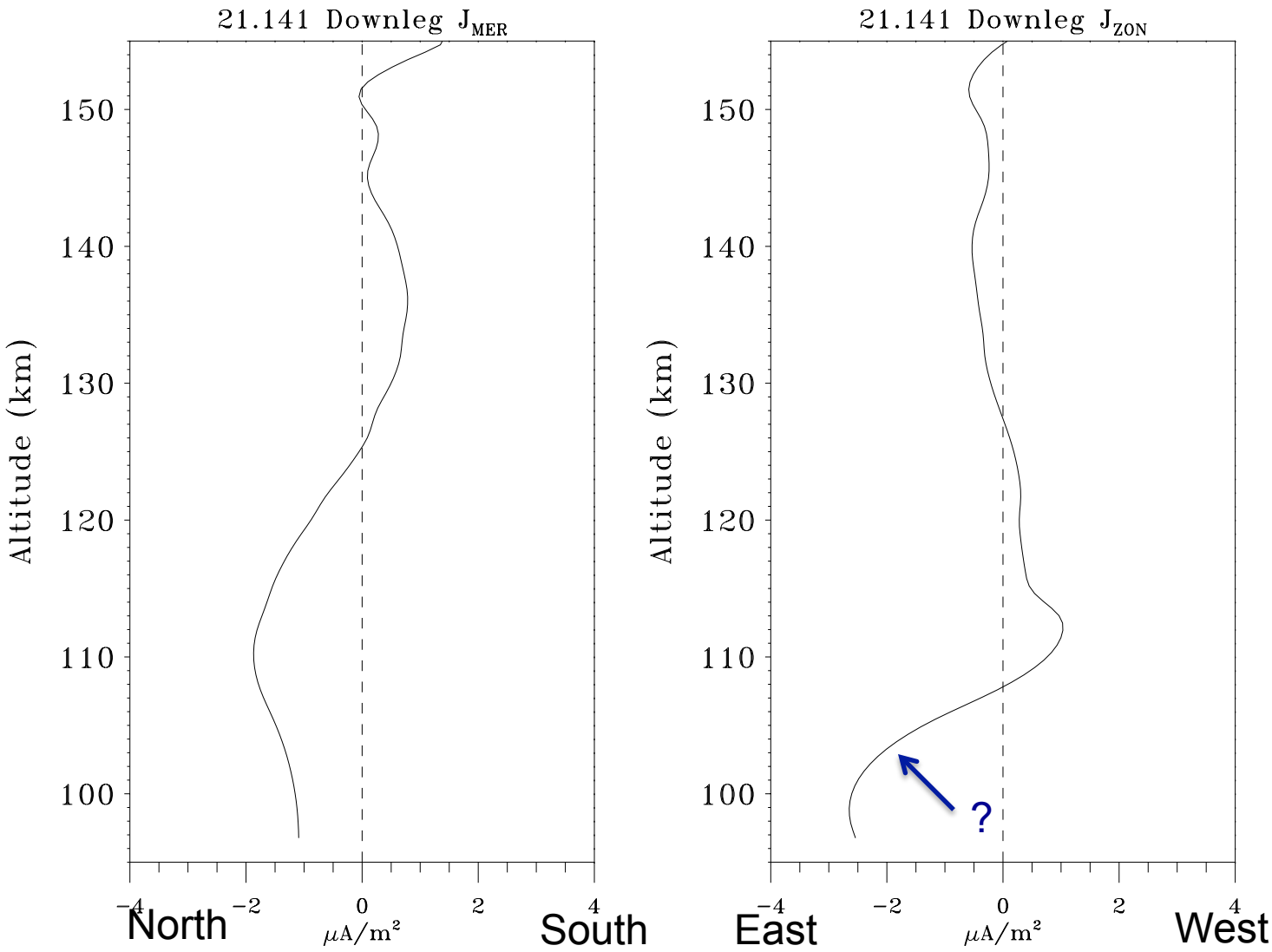


9/18/13 Mag and attitude corrections

HF 9/24/13 12:19



HF 9/24/13 17:02

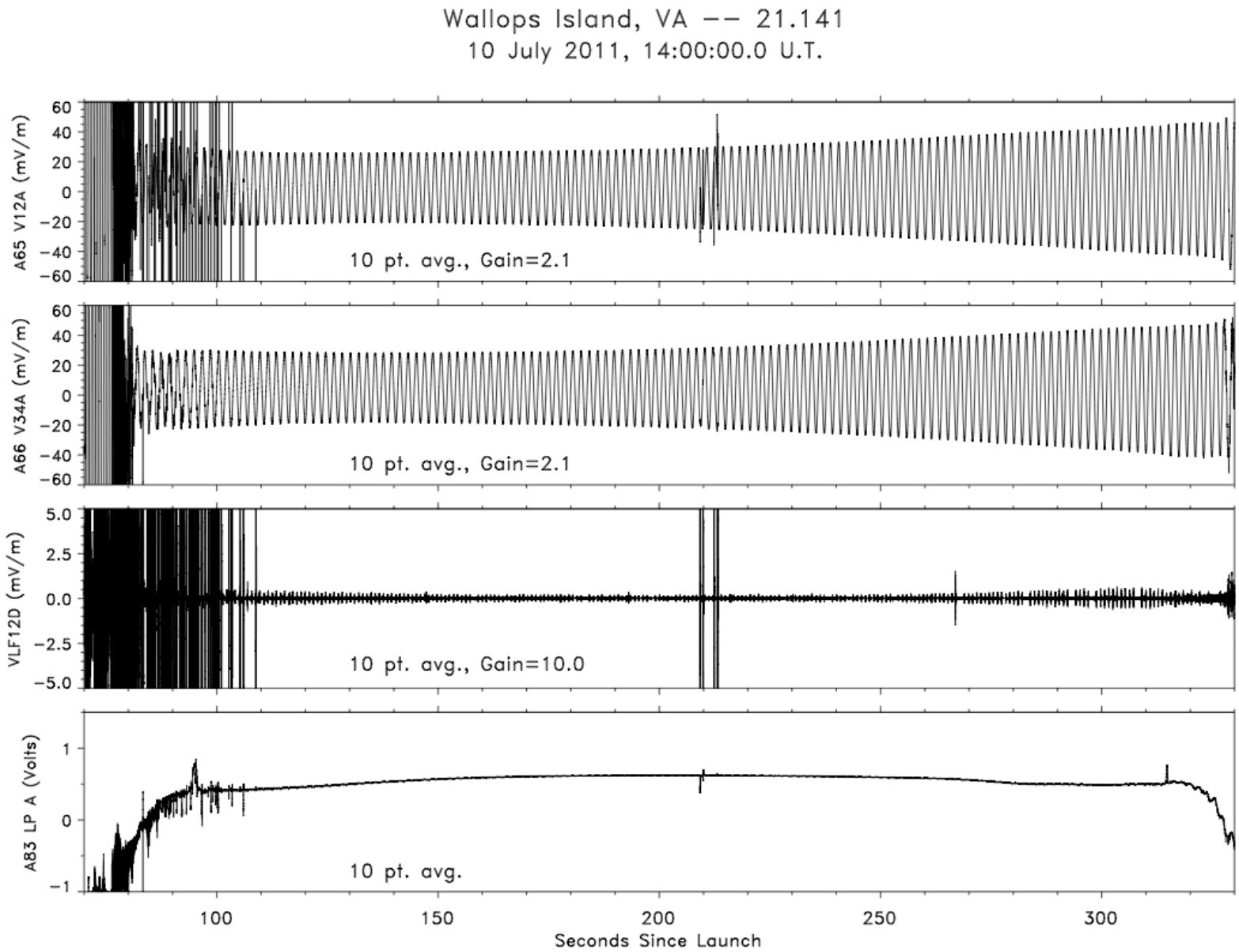


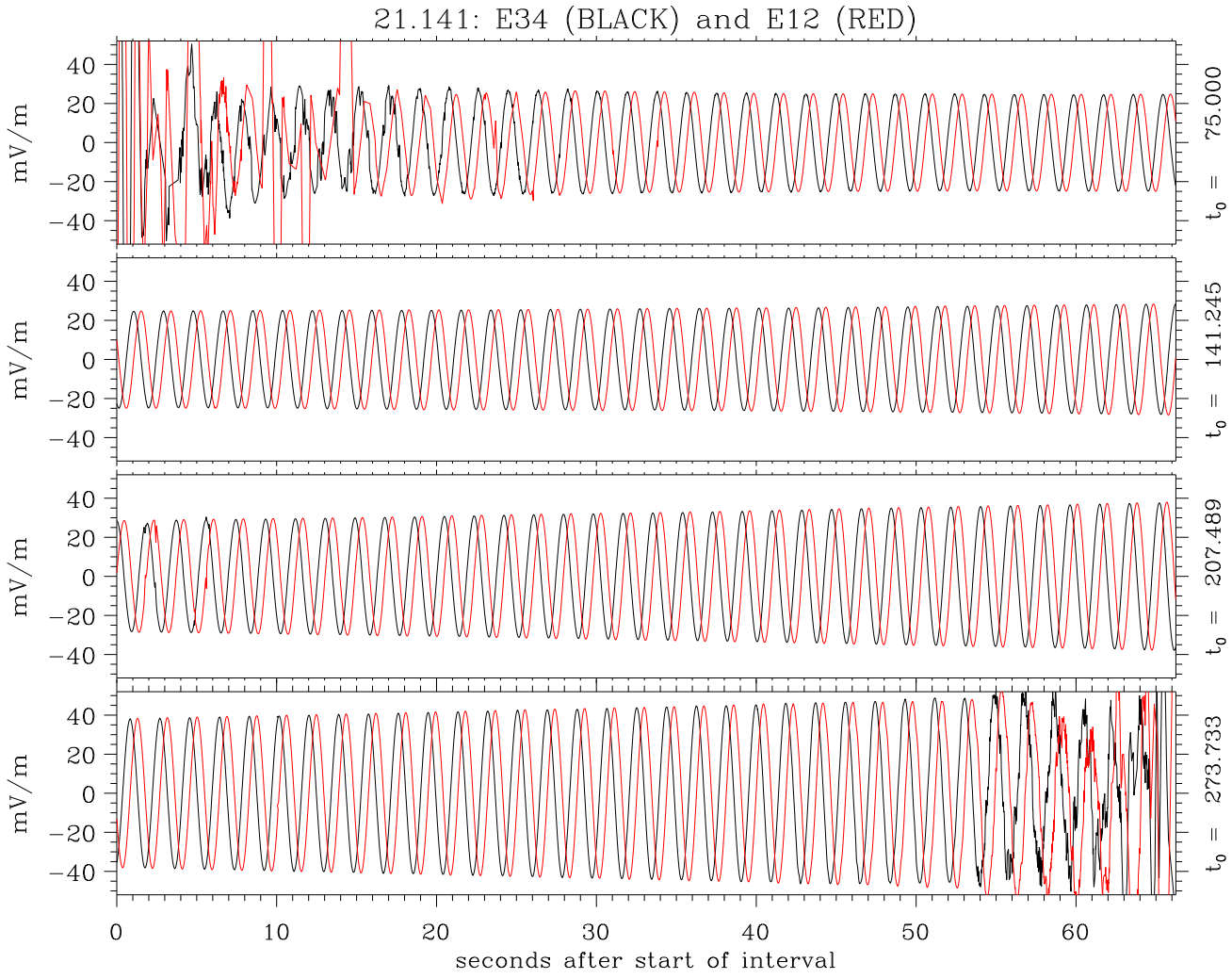
HF 9/24/13 17:01

Electric Field Observations

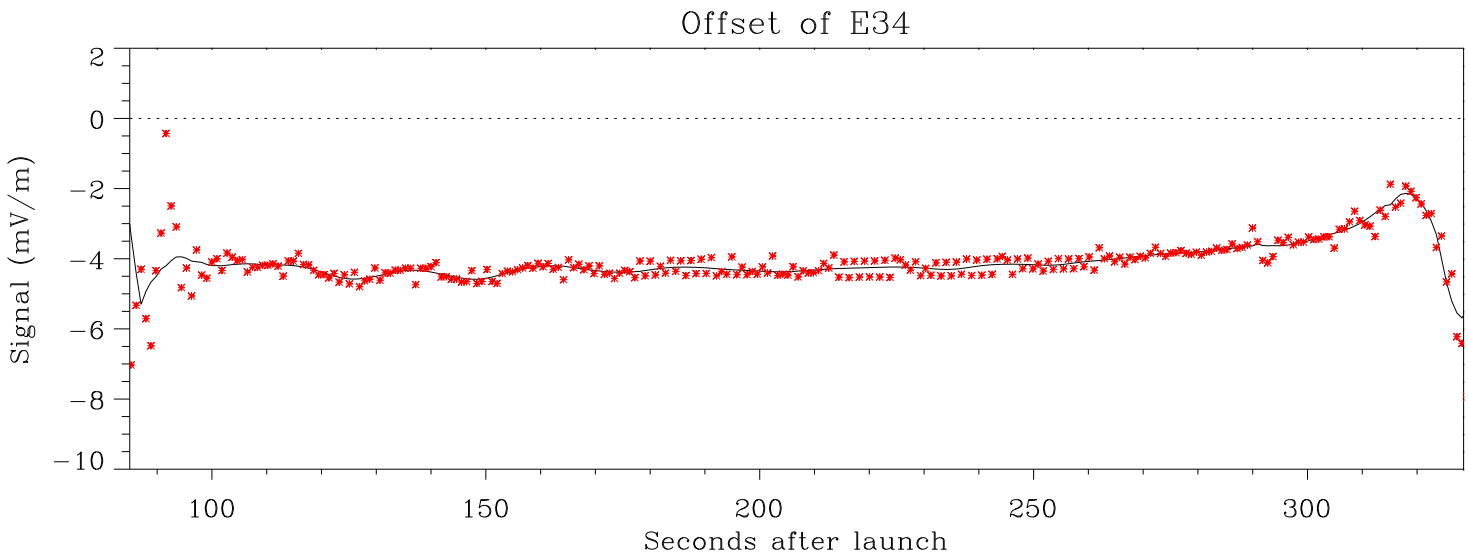
Rocket 21.141

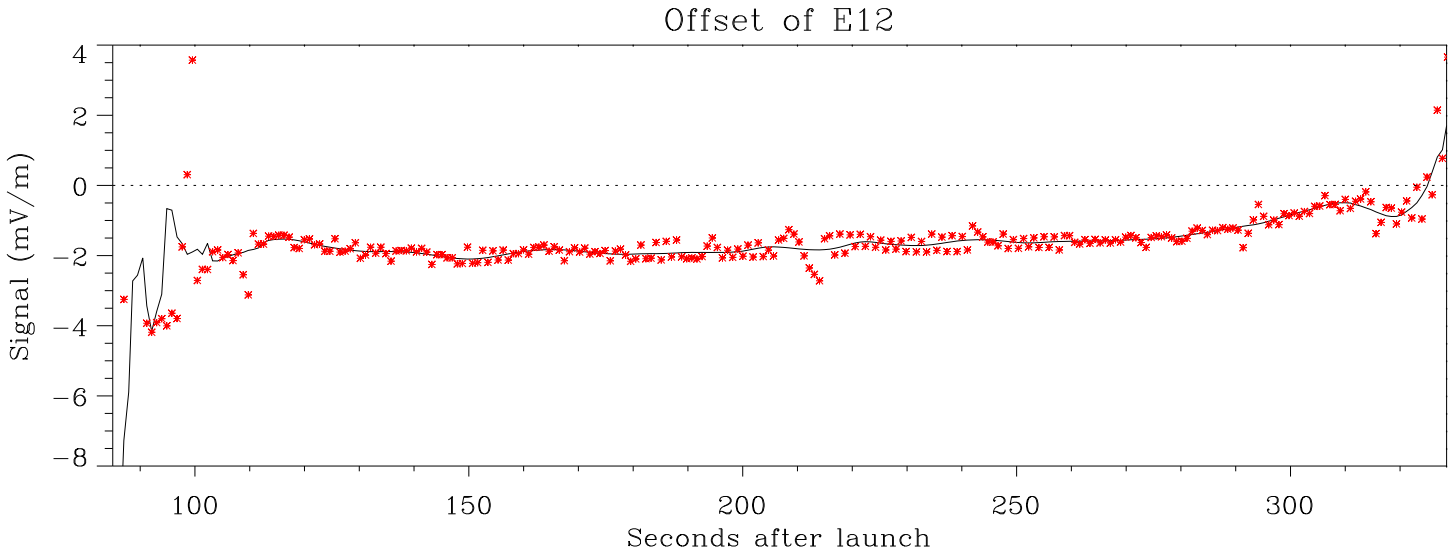
Launch: July 10, 2011


Wallops Island, VA -- 21.141
10 July 2011, 14:00:00.0 U.T.
A65 V12A (mV/m)
10 pt. avg., Gain=2.1
A66 V34A (mV/m)
10 pt. avg., Gain=2.1
VLF12D (mV/m)
10 pt. avg., Gain=10.0
A83 LP A (Volts)
10 pt. avg.
Seconds Since Launch

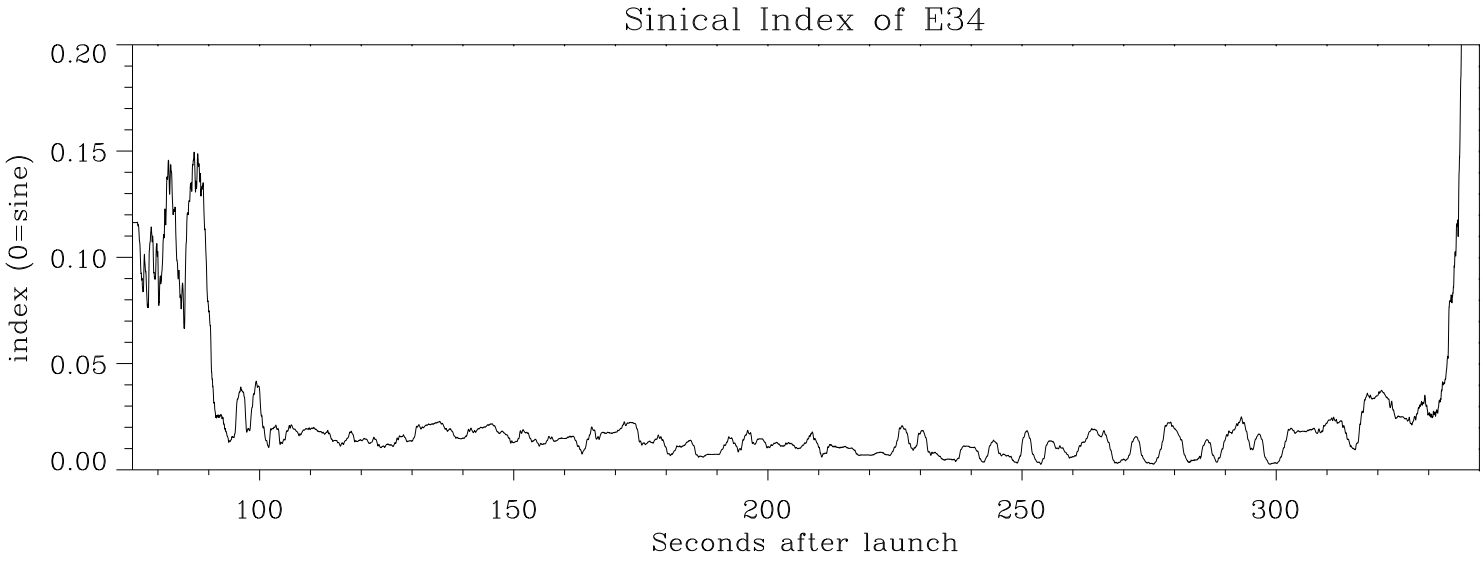


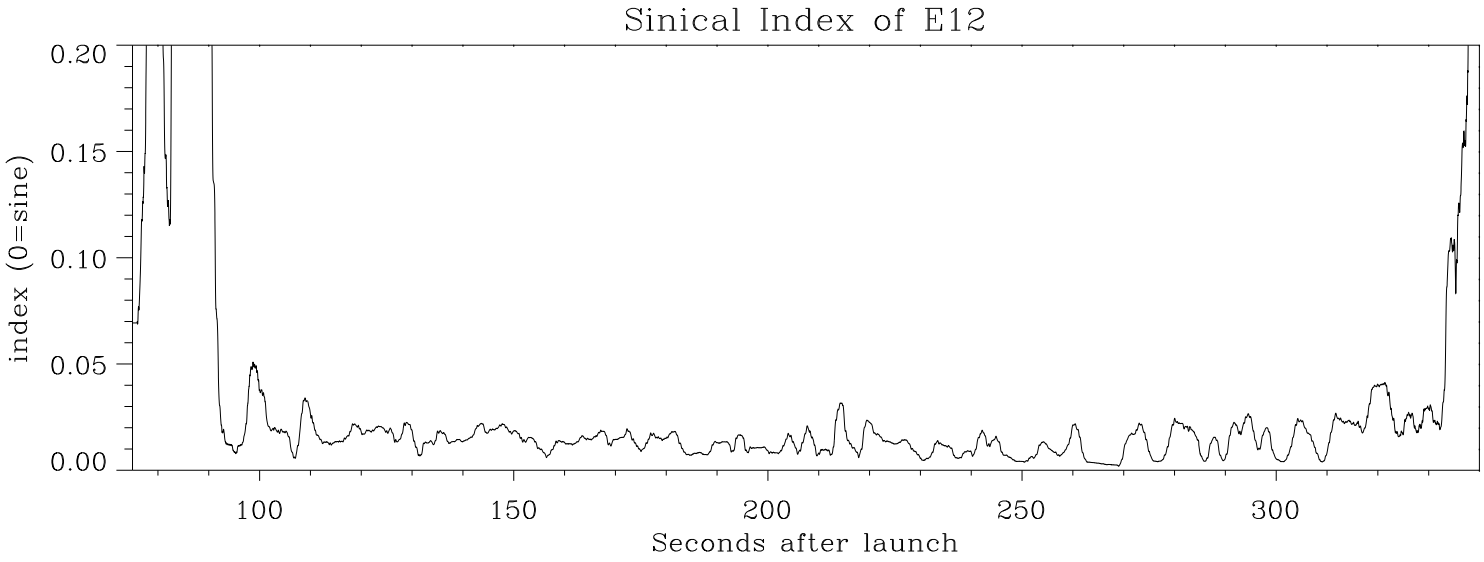
HF 8/15/11 15:53



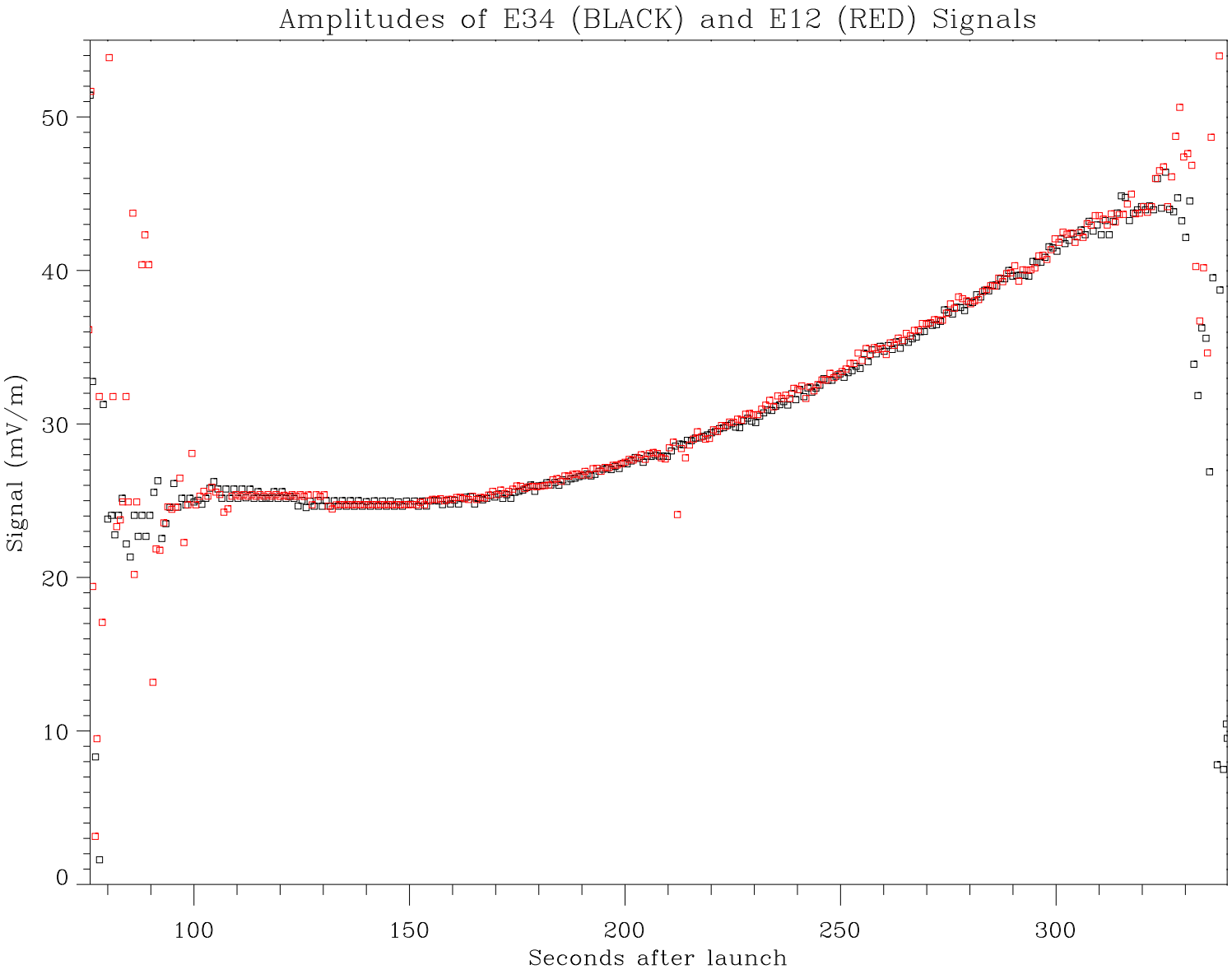


HF 8/15/11 14:06

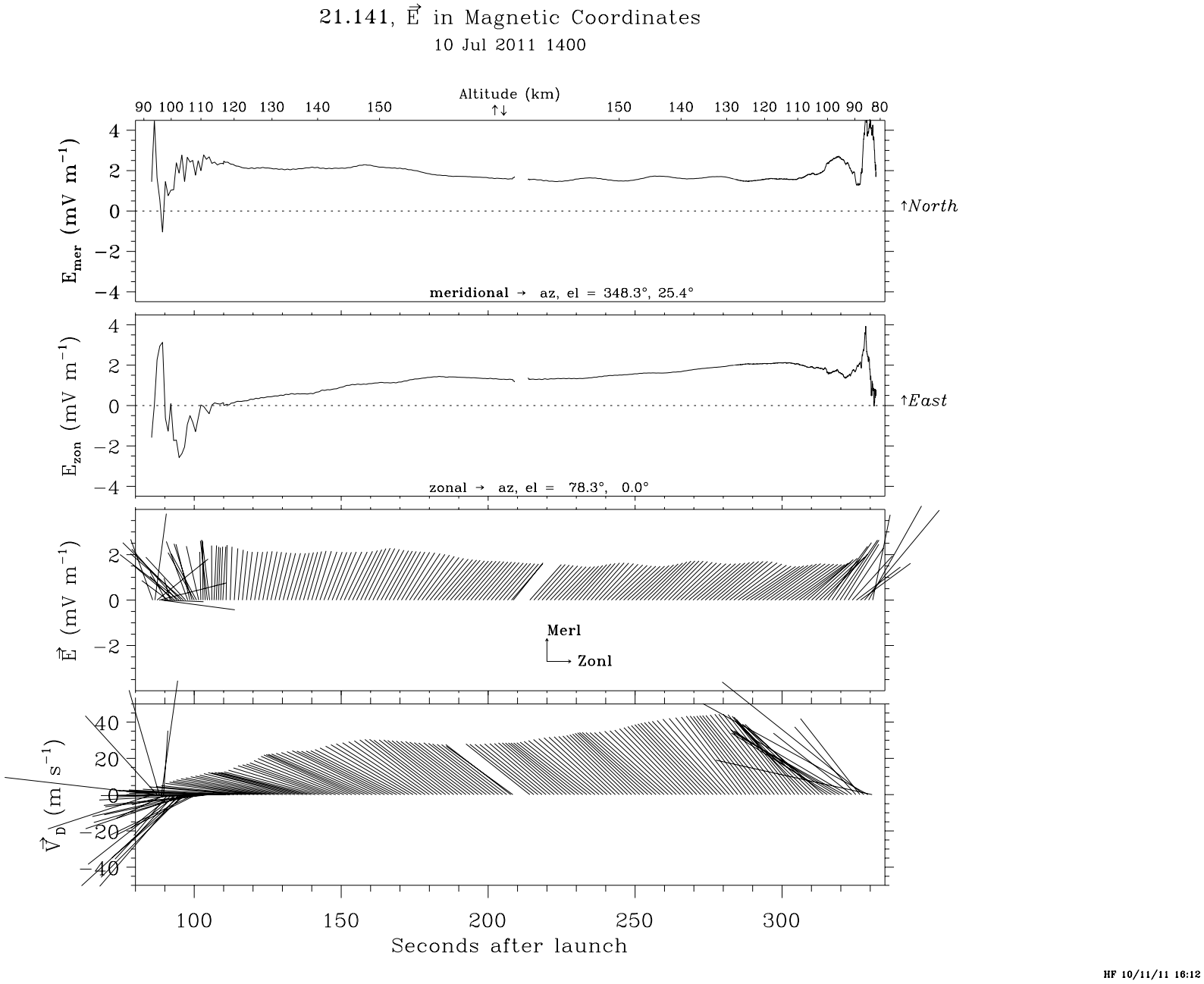




HF 8/15/11 14:56



HF 8/15/11 14:13


21.141, $\vec{E}$ in Magnetic Coordinates
10 Jul 2011 1400
Altitude (km)
90 100 110 120 130 140 150 150 140 130 120 110 100 90 80
E_{mer} (mV m^{-1})
↑North
meridional → az, el = 348.3°, 25.4°
E_{zon} (mV m^{-1})
↑East
zonal → az, el = 78.3°, 0.0°
$\vec{E}$ (mV m^{-1})
Merl
Zonl
$\vec{V}_D$ (m s^{-1})
Seconds after launch
HF 10/11/11 16:12

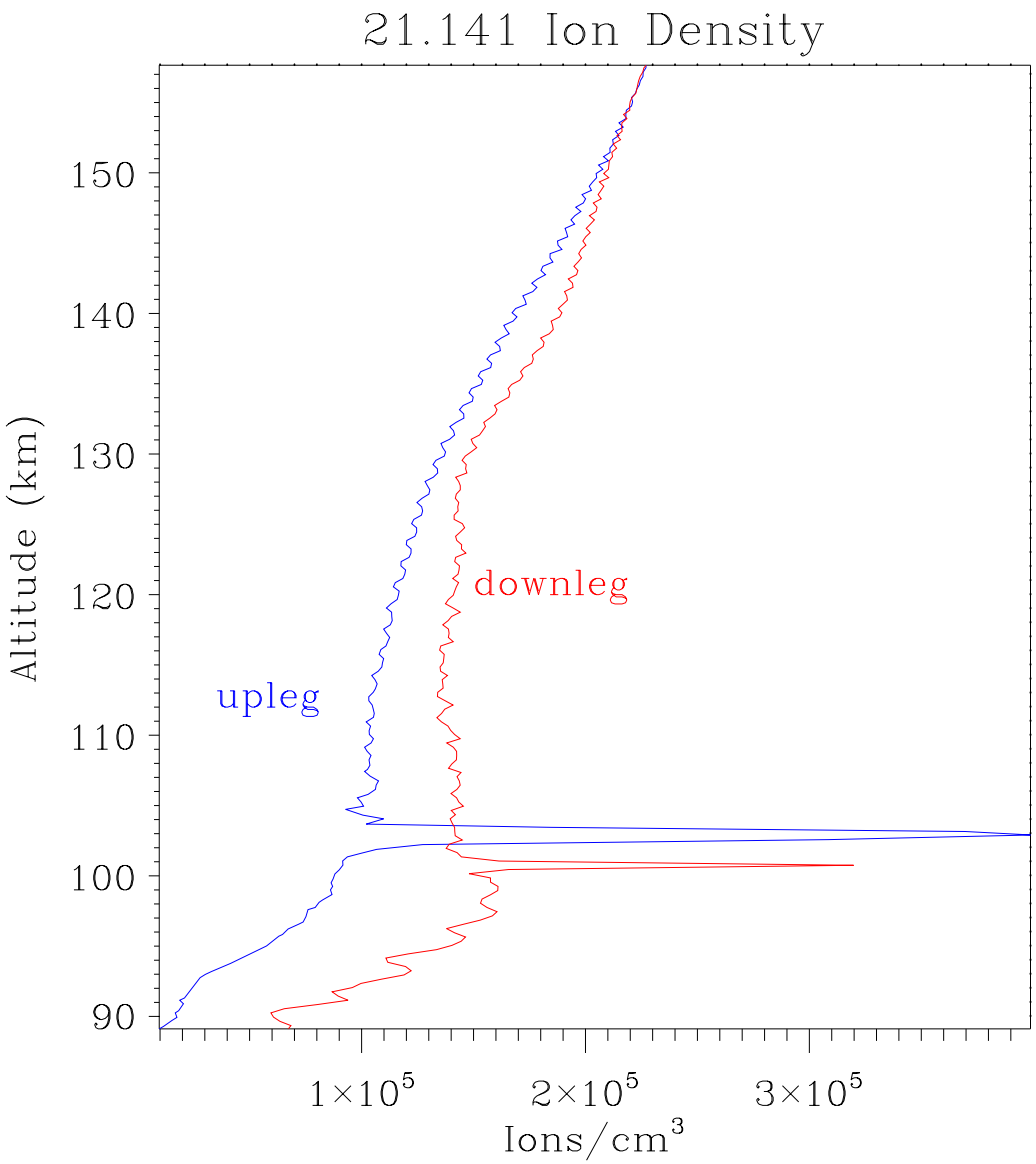
Plasma Density Observations

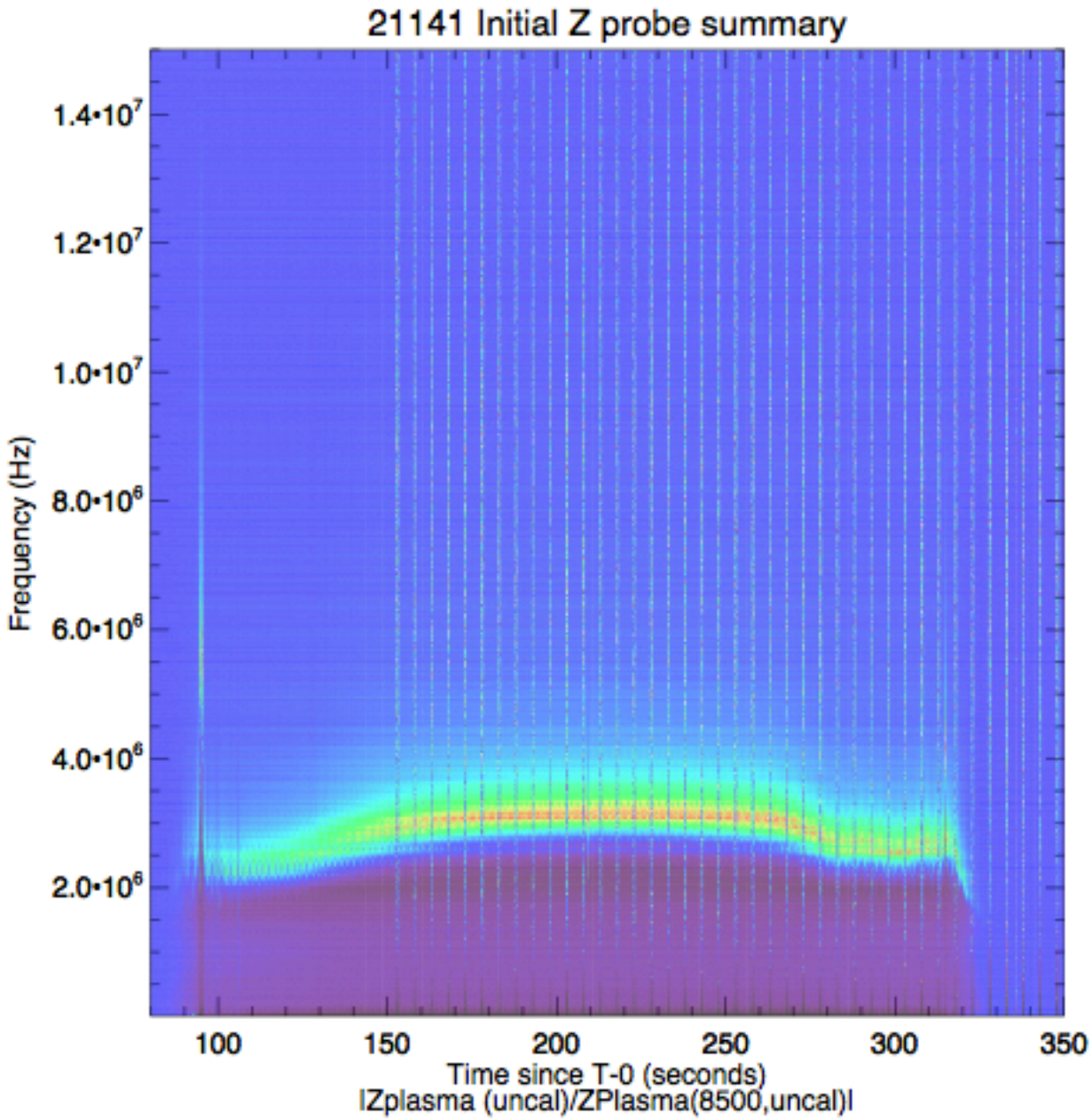
GSFC Langmuir Probe (Klenzing)

GSFC Impedance Probe (Rowland)

Rocket 21.141

Launch: July 10, 2011


21.141 Ion Density
Altitude (km)
150
140
130
120
110
100
90
upleg
downleg
1×10^5
2×10^5
3×10^5
Ions/cm^3


21141 Initial Z probe summary
Frequency (Hz)
1.4•10^7
1.2•10^7
1.0•10^7
8.0•10^6
6.0•10^6
4.0•10^6
2.0•10^6
100
150
200
250
300
350
Time since T-0 (seconds)
|Zplasma (uncal)/ZPlasma(8500,uncal)|

Composite Plots

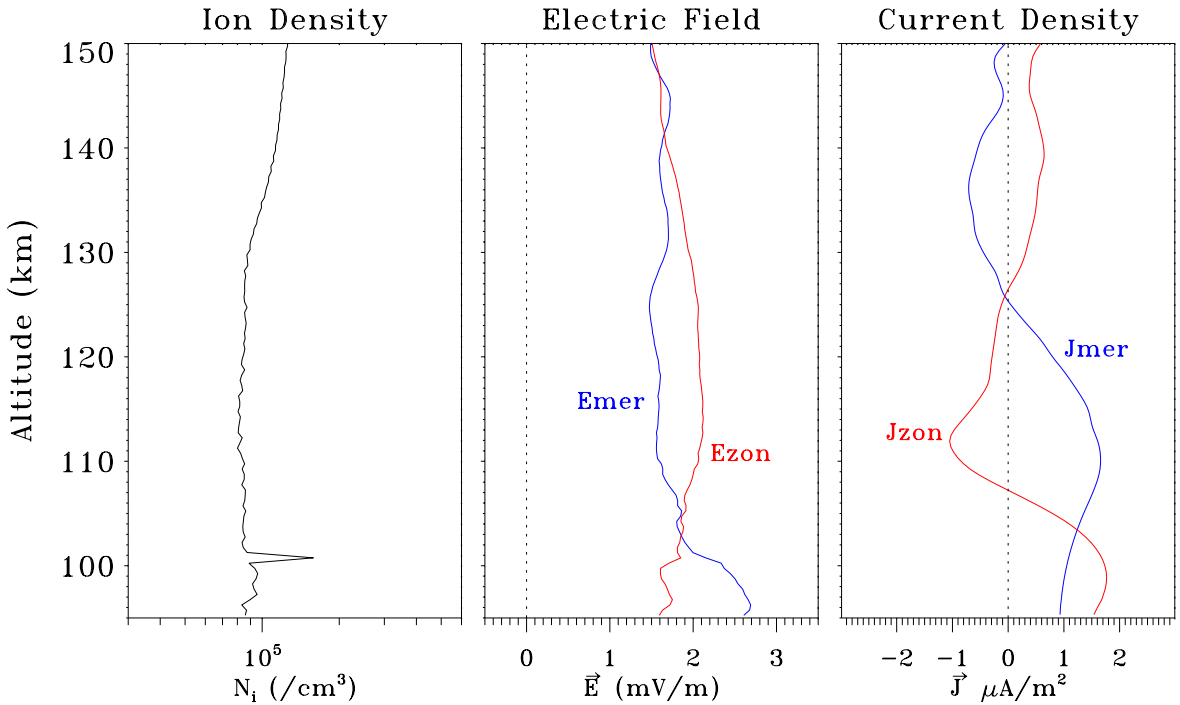
Measurements: E, E x B, J_{meas}, Ne, Un, Nn, Mi,

Derived Quantities: Mobility, Conductivity, $J_{Derived}$

Rocket 21.141

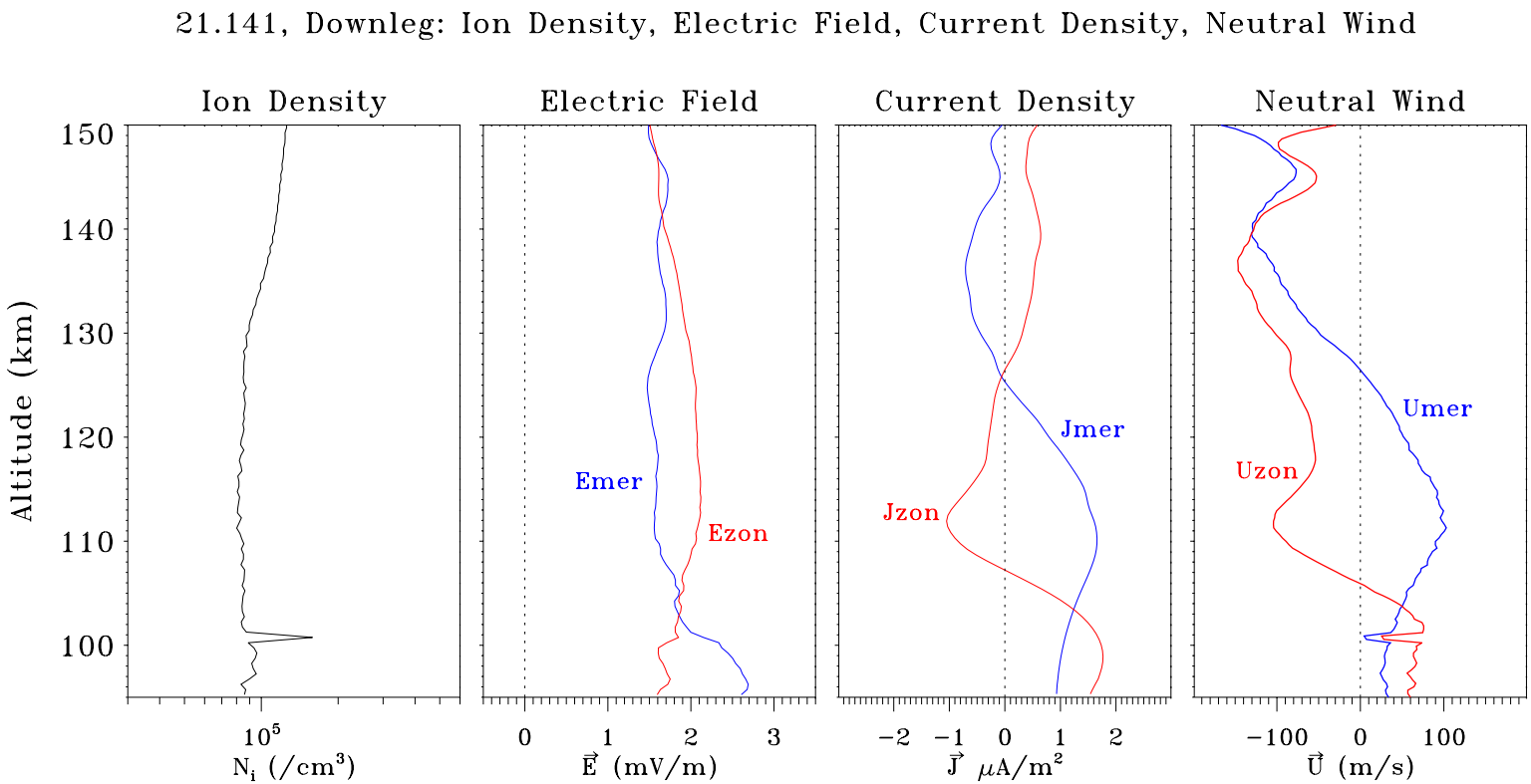
Launch: July 10, 2011

21.141, Downleg: Ion Density, Electric Field, Current Density, Neutral Wind



Zonal is Positive East, Meridional is Positive Up/North

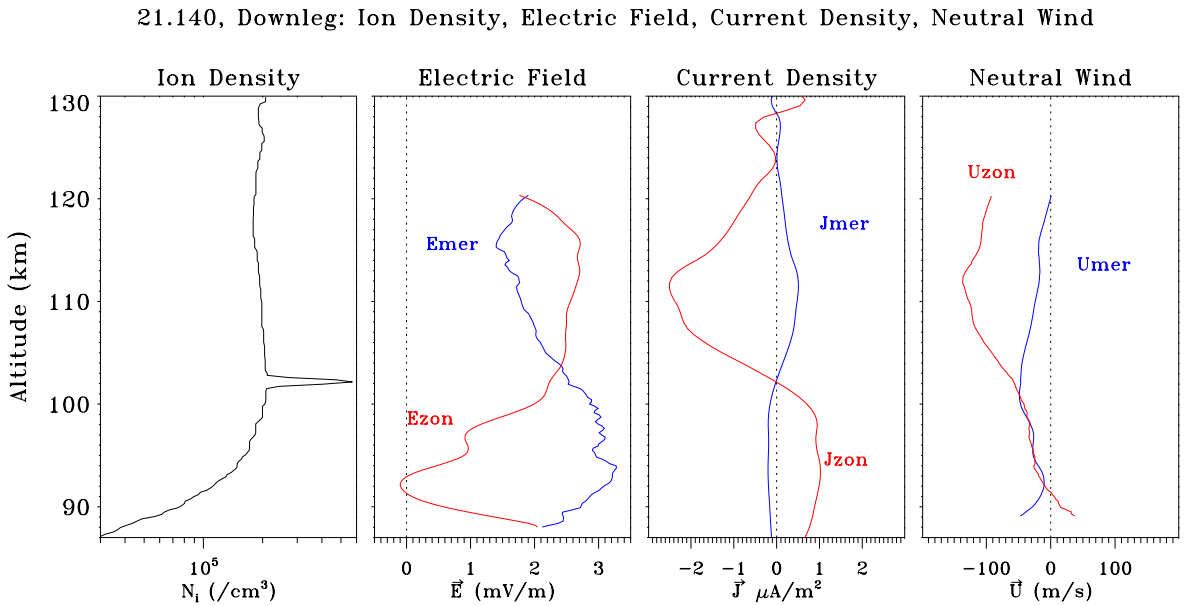
HF 2/25/14 12:56

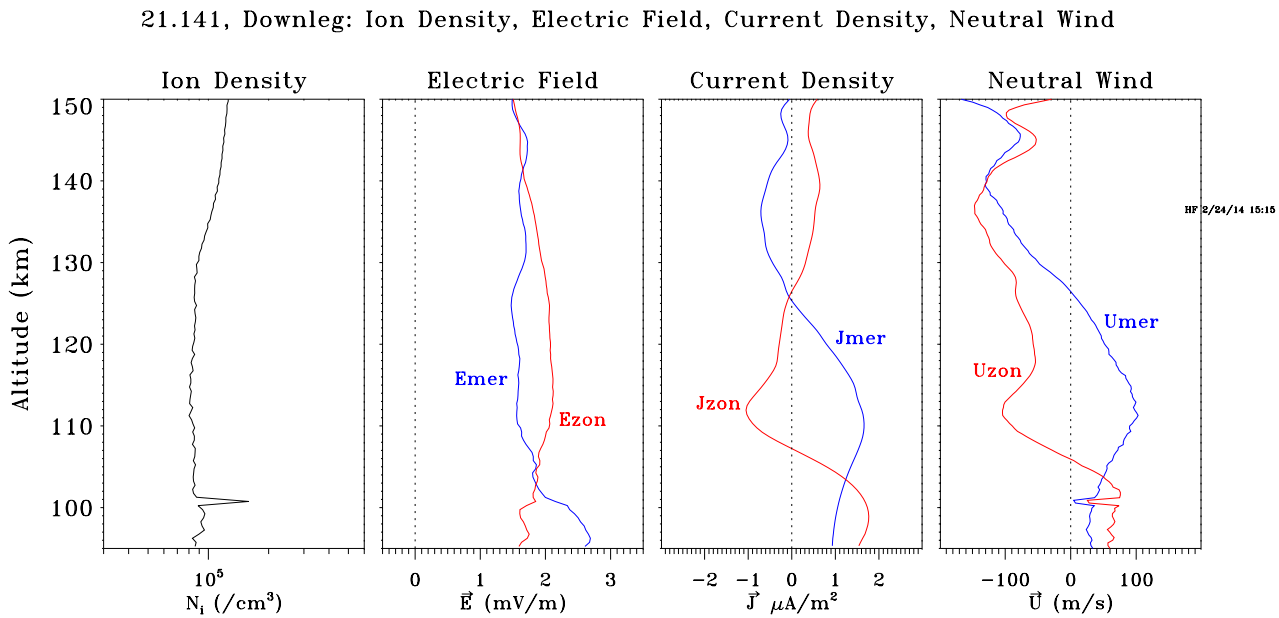


Neutral Winds are Derived from E, J, and Ne

Zonal is Positive East, Meridional is Positive Up/North

HF 2/25/14 12:56

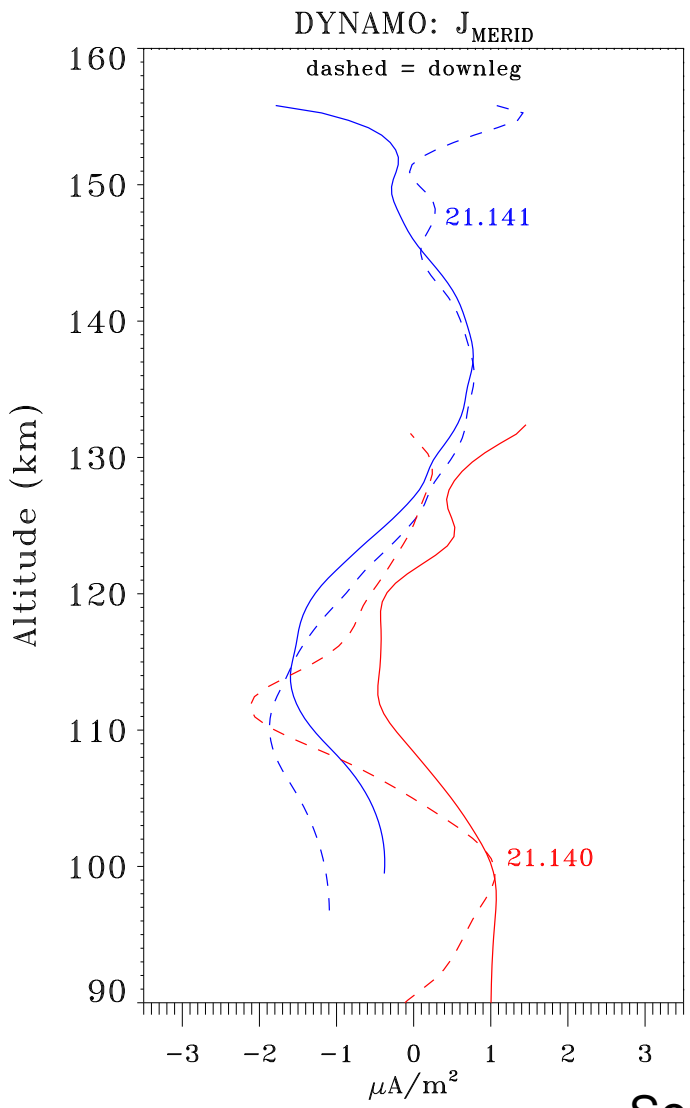




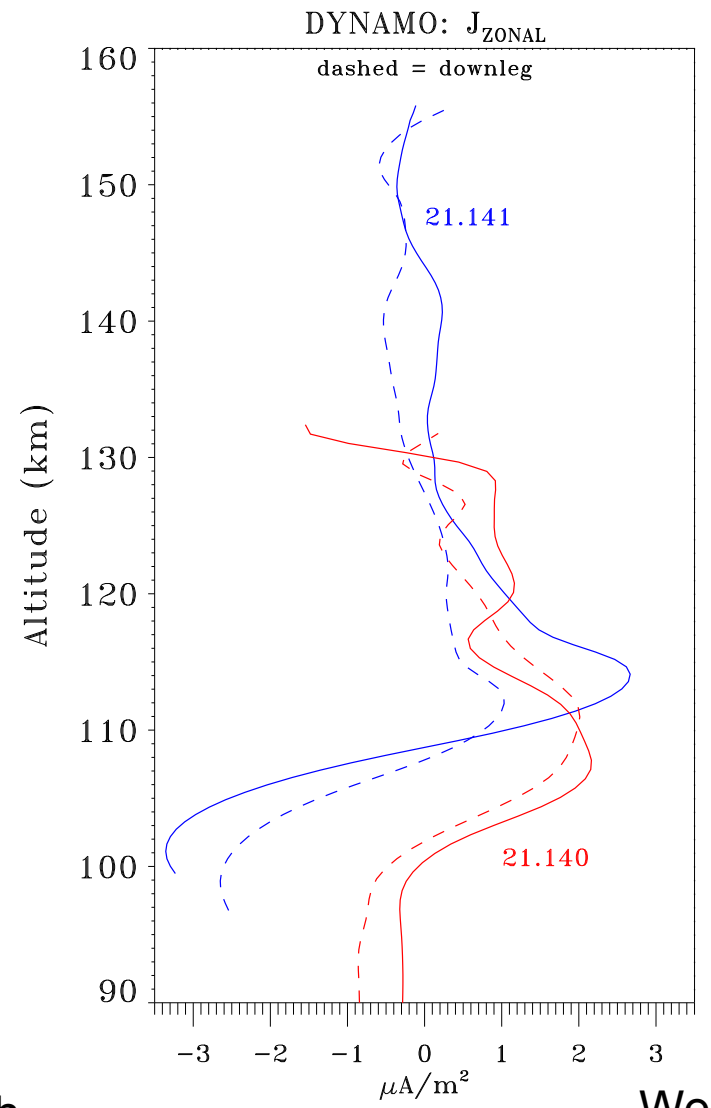
Neutral Winds are Derived from E, J, and Ne

Zonal is Positive East, Meridional is Positive Up/North

Current Densities -- Both Rockets



South



West

HF 11/12/13 17:23

Some Features of Measurements Presented Thus Far….

- Westward zonal currents of 1-2 A/km2 near 110 km, consistent with ground-based measurements…

- DC electric fields poleward and eastward, of ~2 mV/m (~40 m/s)

- Plasma density follows expected daytime profile

- Westward neutral winds of ~ 100 m/s needed to make measured quantities consistent with the dynamo equation

- Sporadic-E enhanced plasma density layer present. No obvious affect on currents.