



Air Force Research Laboratory MOSC Experiment



Incoherent Scatter Observations of Artificially Enhanced Ionosphere during the AFRL Metal Oxide Space Cloud Experiment (MOSC)



Integrity ★ Service ★ Excellence

14th Ionospheric Effects Symposium
12-15 May 2015
Alexandria, VA

**Ronald Caton¹, Keith Groves²,
Todd Pedersen¹, Richard Parris¹,
Jeffrey Holmes¹ and John Retterer²**

¹AFRL, Space Vehicles Directorate, Kirtland AFB, NM

²Institute for Scientific Research, Boston College

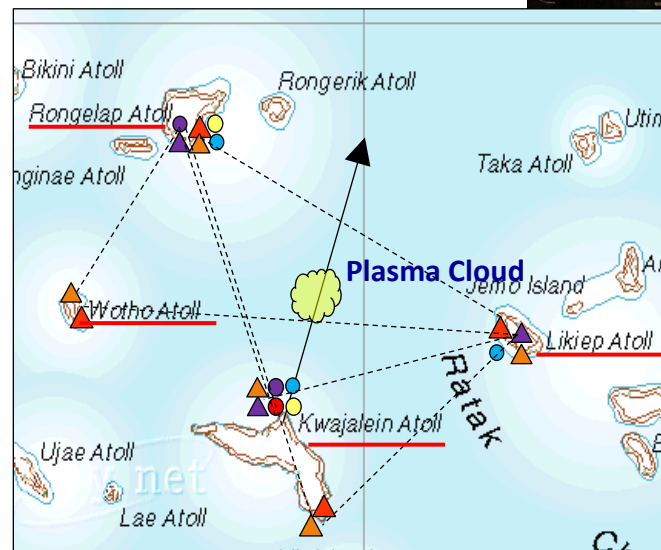
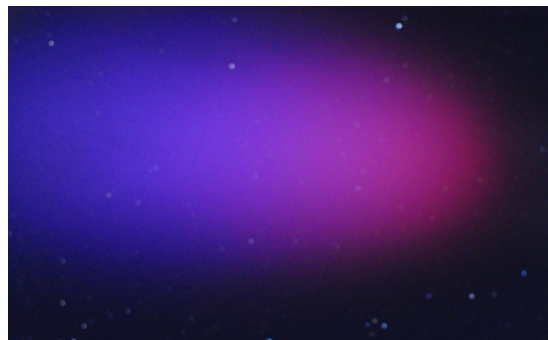


AFRL MOSC Experiment



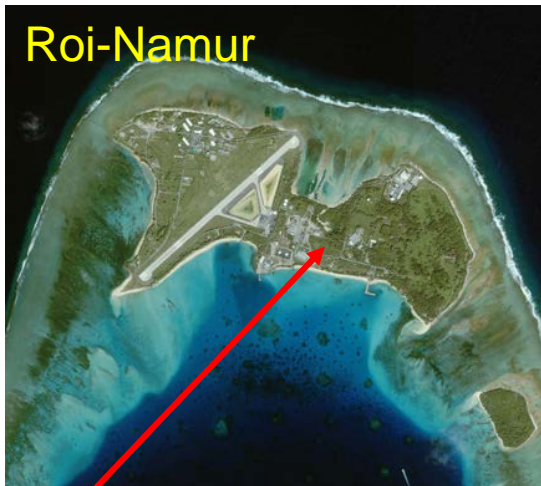
Two Successful Launches from Kwajalein Atoll in May 2013

- First experiment to comprehensively diagnose plasma cloud generated by release of atomized samarium in the upper atmosphere
- Investigate potential for tailored RF propagation environment through **active ionospheric modification**
- Mission team included AFRL, BC, UK Dstl, QinetiQ, NRL, STP, NASA
- Payload for each rocket included
 - Two canisters of samarium (~6 kg)
 - Dual Frequency RF Beacon (NRL CERTO)
- Ground diagnostics from 5 sites included:
 - **Incoherent Scatter Radar**
 - GPS/VHF Scintillation Rxs
 - All-Sky Cameras / Optical Spectrograph
 - Ionosondes
 - Beacon Rx
 - HF Tx/Rx





Kwajalein Atoll & ALTAIR



Advanced Research Project Agency (ARPA) Long-range Tracking and Identification Radar (ALTAIR)

- Dual Frequency
VHF/UHF
- Deep Space Tracking
- 46 m dish
- Peak Power
VHF: 6.0 MW
UHF: 6.4 MW
- Incoherent Scatter

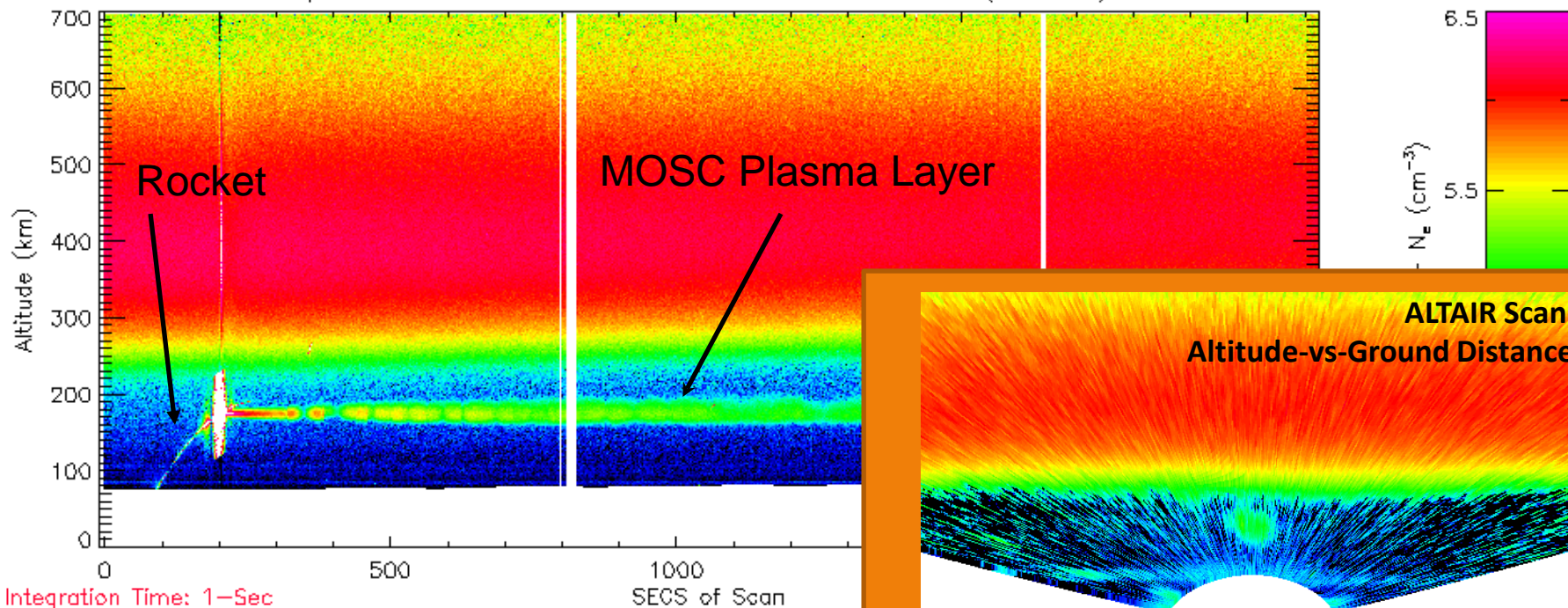




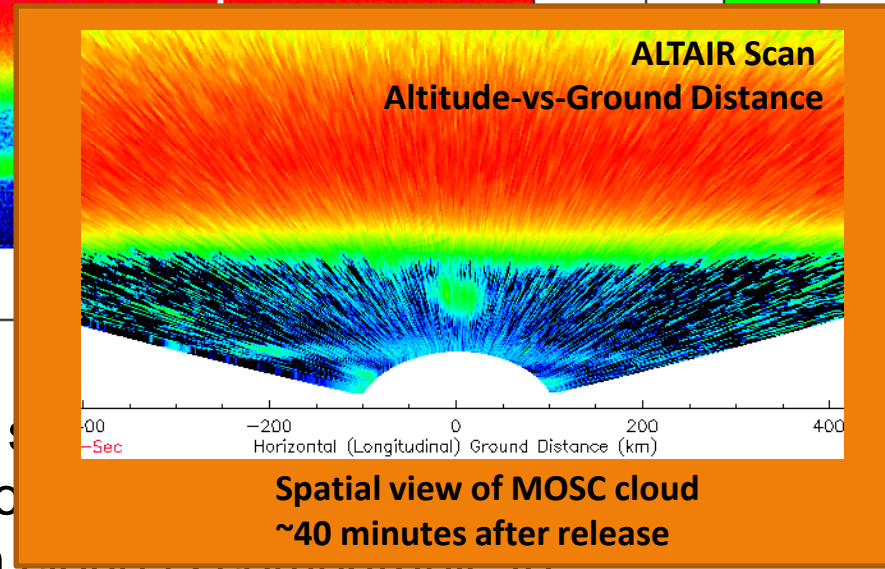
MOSC Launch 2: May 9, 2013 Samarium Release



ALTAIR LW Scan - 09 May 2013 (Day 129) 07:22:35Z - 07:58:00Z
profile_lw_13129_0720_b2_1sec_120.dat: UHF (WF 556)



Integration Time: 1-Sec

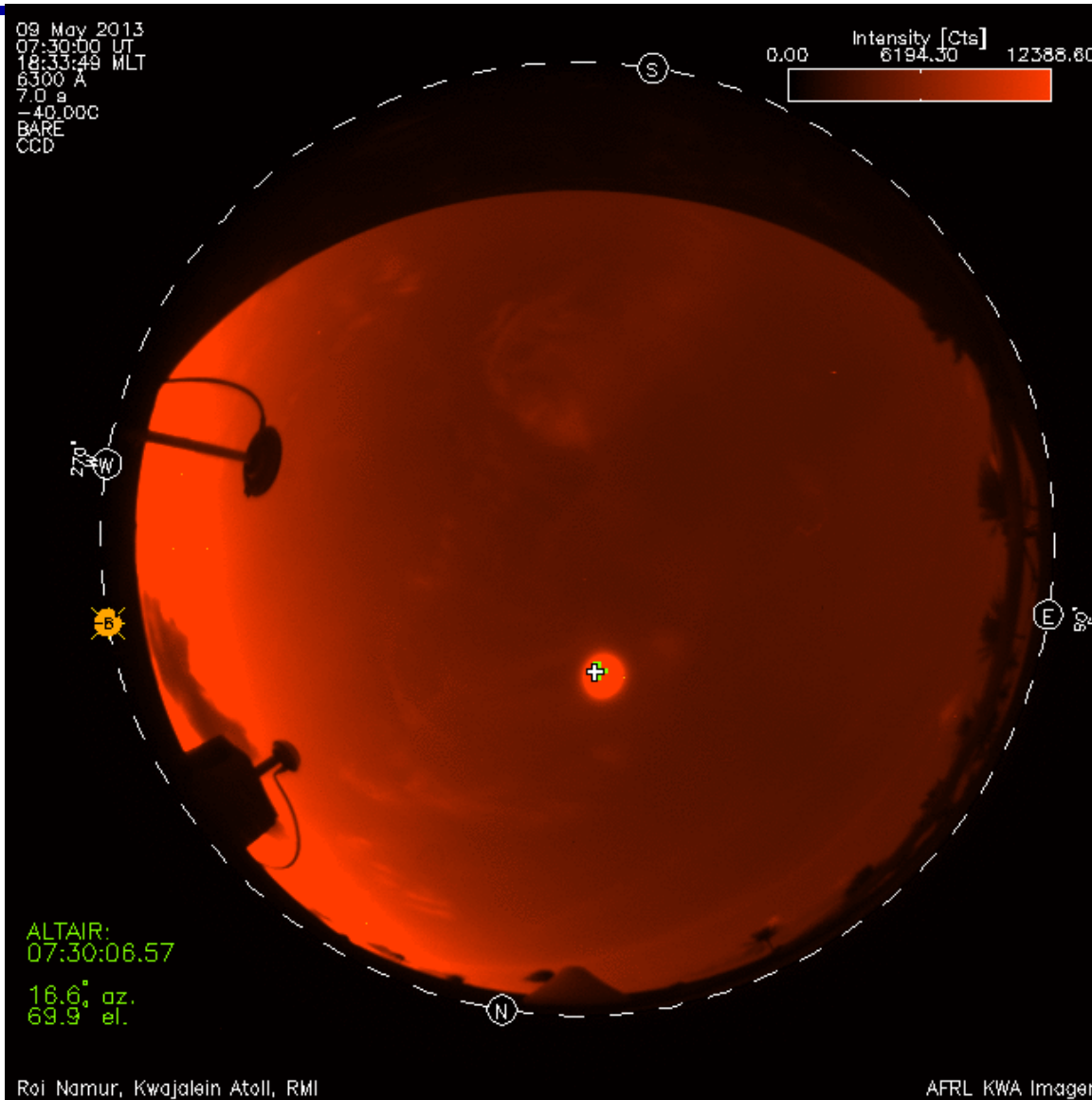


- Initial tracking of cloud with raster scans
- U.25-400, 400 μ s chirp pulse, resolution 100 m
- Peak density of samarium plasma cloud is comparable to natural ionosphere
- **Spatial Scans**





ALTAIR Pointing Angles 6300 All-Sky Camera vs ALTAIR



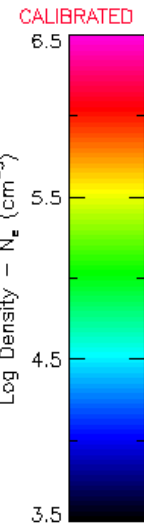
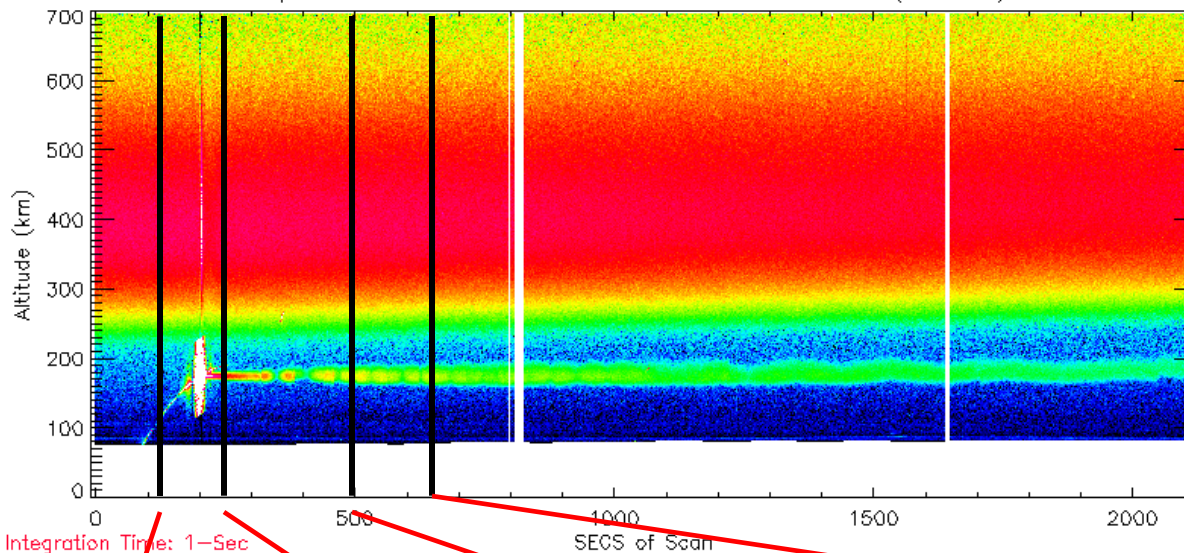
- MOSC 2 cloud in All-Sky Imager from Roi-Namur
- Optical data used to steer ALTAIR raster scans
- Cross-hairs indicate ALTAIR pointing



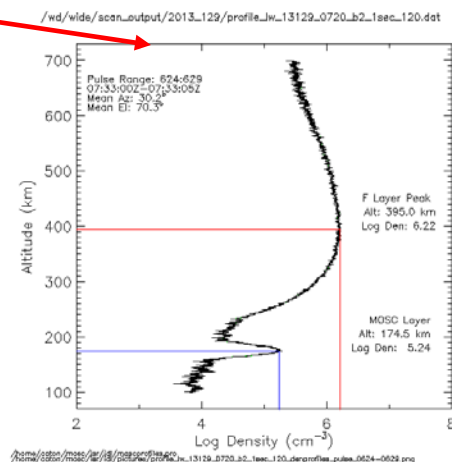
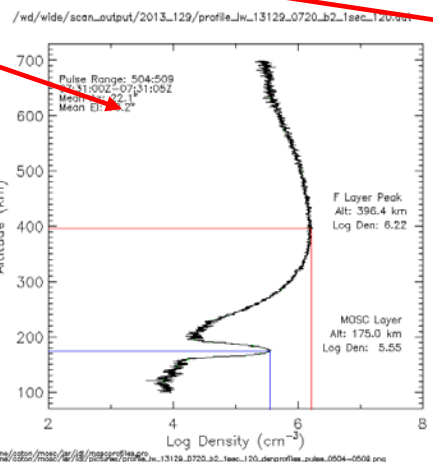
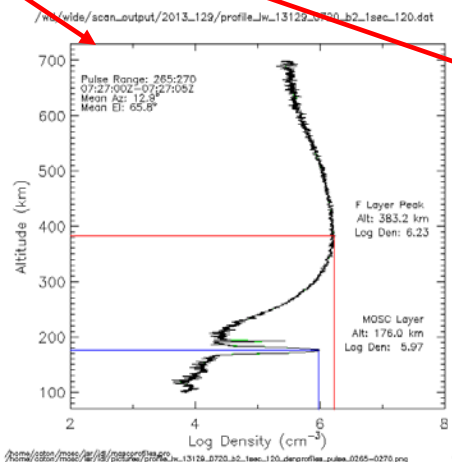
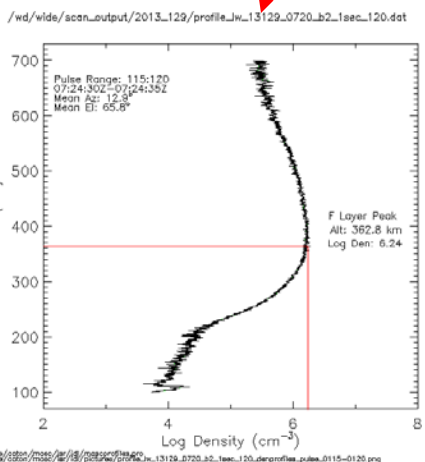
AFRL MOSC Experiment ALTAIR – Launch 2



ALTAIR LW Scan – 09 May 2013 (Day 129) 07:22:35Z – 07:58:00Z
profile_lw_13129_0720_b2_1sec_120.dat: UHF (WF 556)

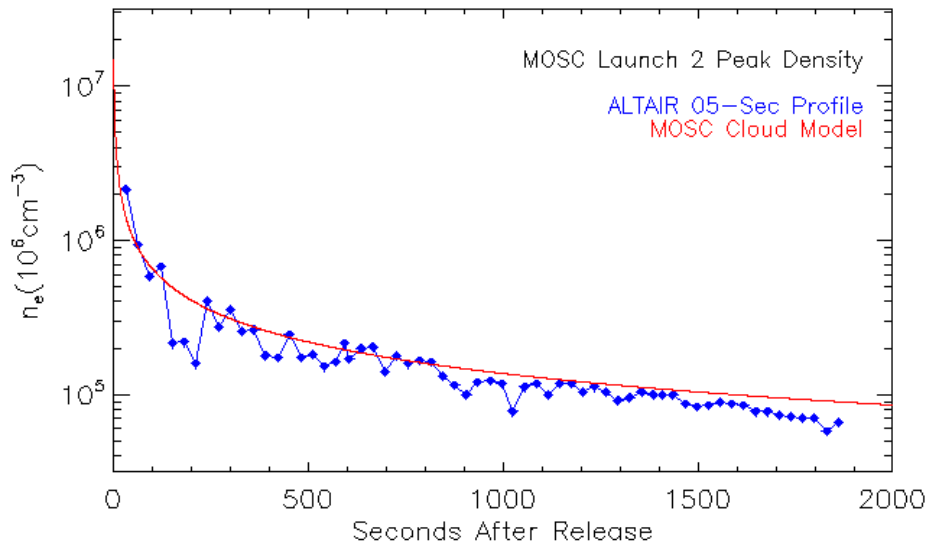


Integration Time: 1-Sec



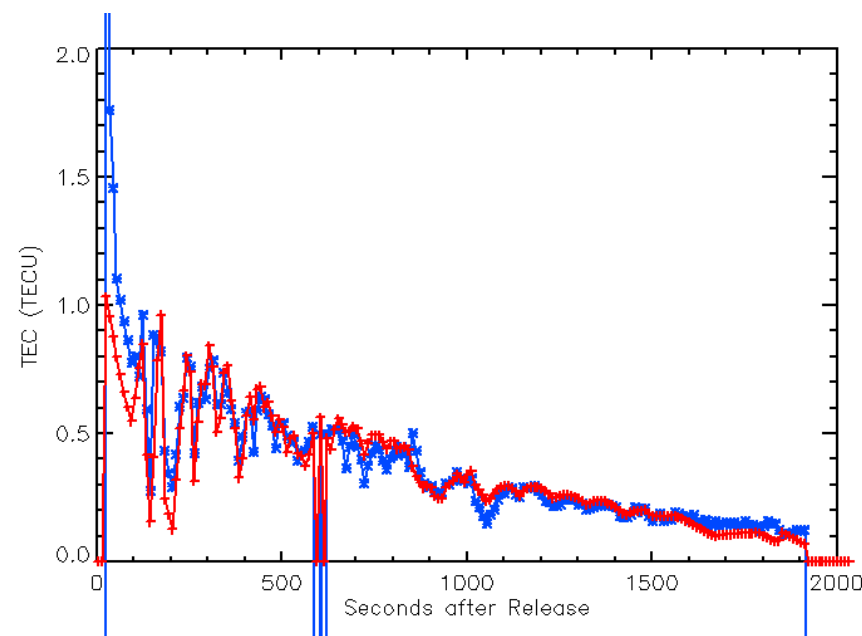


MOSC Cloud Density & TEC with ALTAIR



- MOSC layer density as a function of time – remember, this is NOT the peak density within the cloud
- Compared with MOSC Cloud Model
 - Completely independent of ALTAIR measurements

- Integrating the ALTAIR profiles over the altitude range of the cloud provides line-of-sight measurements of the **Total Electron Content**
- Compared with Cloud Model derived TEC



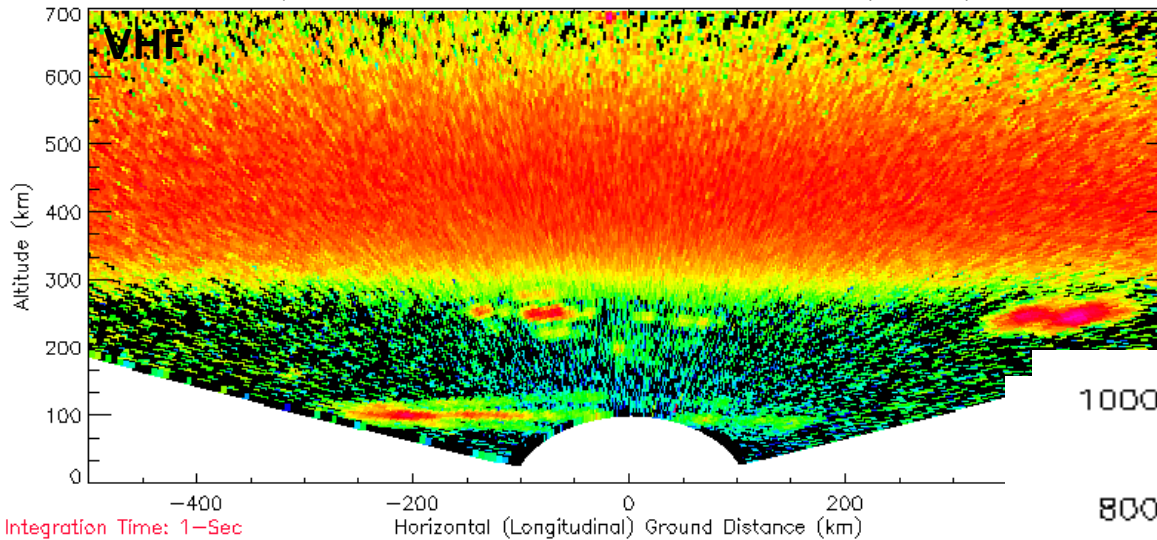


MOSC Launch 2: May 9, 2013

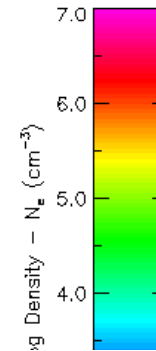
Evolution of Cloud & Ionosphere



ALTAIR FA Scan - 09 May 2013 (Day 129) 08:09:58Z - 08:18:01Z
 profile_fa_13129_0810_b1_1sec_43.dat: VHF (WF 521)



CALIBRATED DENSITY

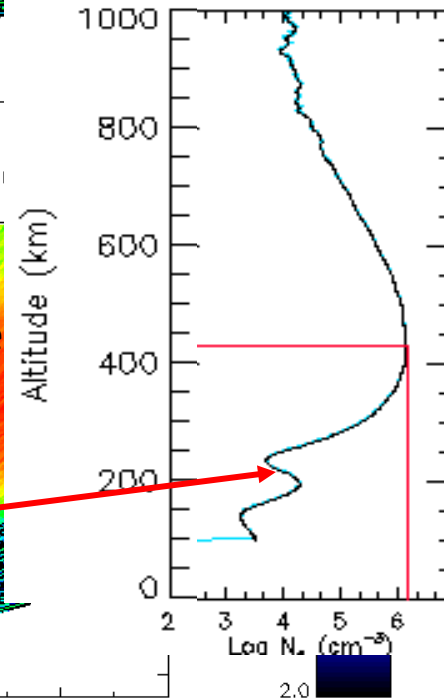
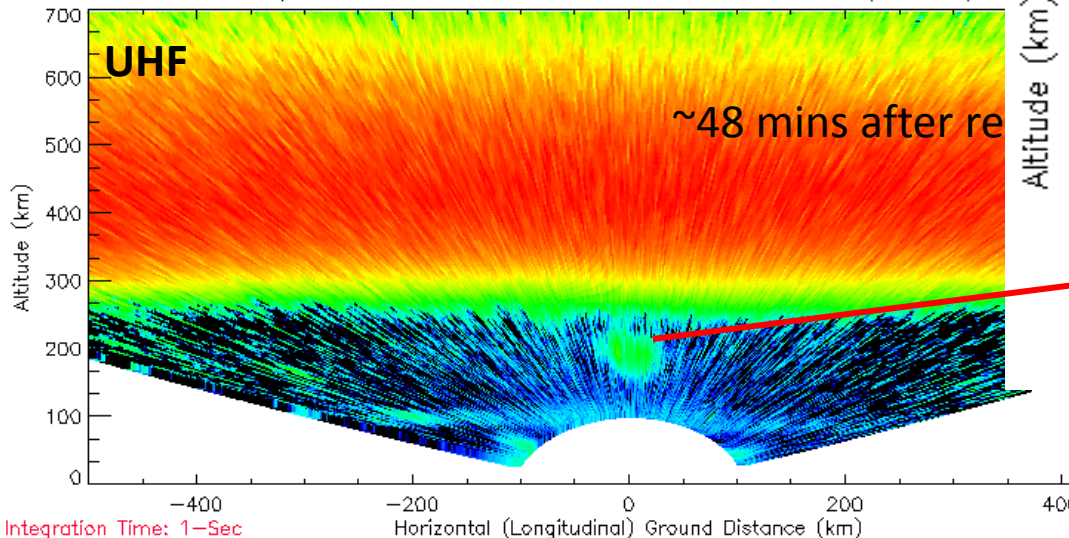


08:10 UT to 08:18 UT
 Perp-B Scans
 Coherent Scatter

~1 m turbulence
 (VEP3-300, 3bit, 300 μ s,
 6km range resolution)

Integration Time: 1-Sec

ALTAIR FA Scan - 09 May 2013 (Day 129) 08:09:57Z - 08:18:01Z
 profile_fa_13129_0810_b2_1sec_43.dat: UHF (WF 568)



0.35 m turbulence
 (UEP1-300, 1bit, 960m
 range resolution)

Integration Time: 1-Sec

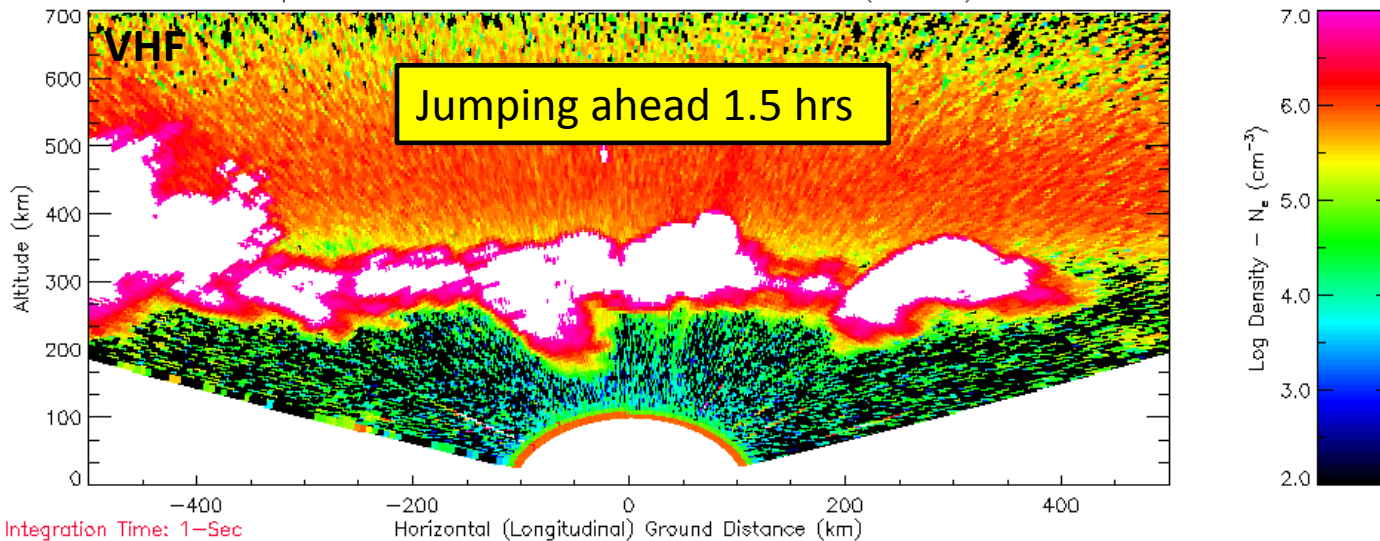




MOSC Launch 2: May 9, 2013 Evolution of Cloud & Ionosphere

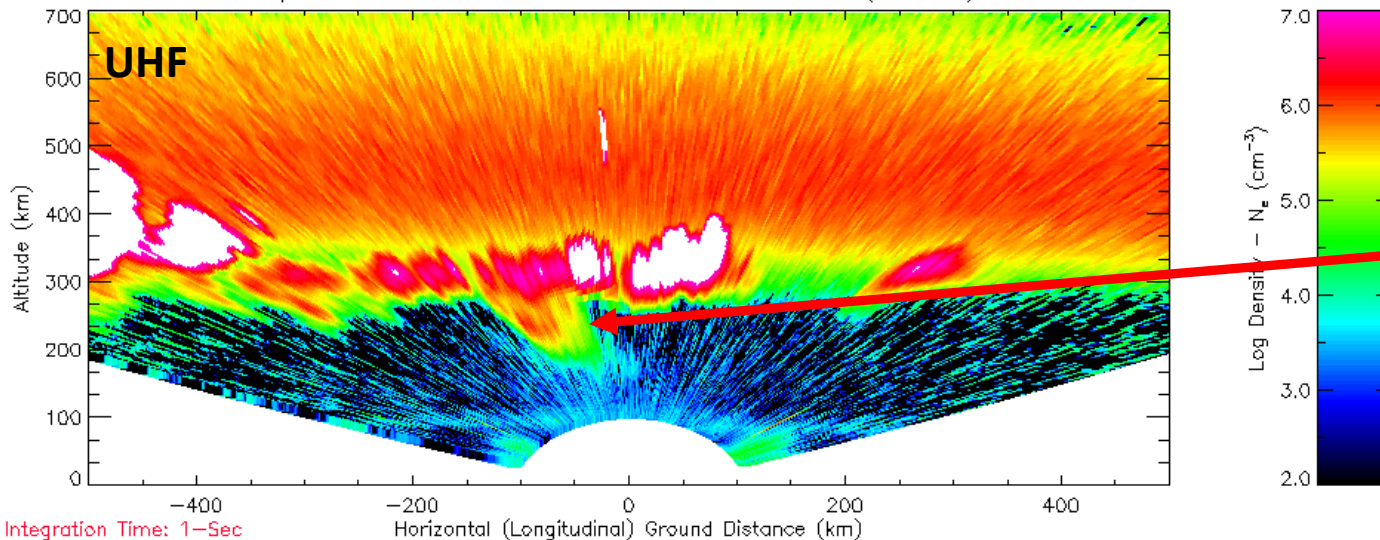


ALTAIR FA Scan - 09 May 2013 (Day 129) 09:39:57Z - 09:48:00Z
profile_fa_13129_0940_b1_1sec_43.dat: VHF (WF 521)



09:40 UT to 09:53 UT
Perp-B Scans
Coherent Scatter
~1 m turbulence

ALTAIR FA Scan - 09 May 2013 (Day 129) 09:39:57Z - 09:48:00Z
profile_fa_13129_0940_b2_1sec_43.dat: UHF (WF 568)



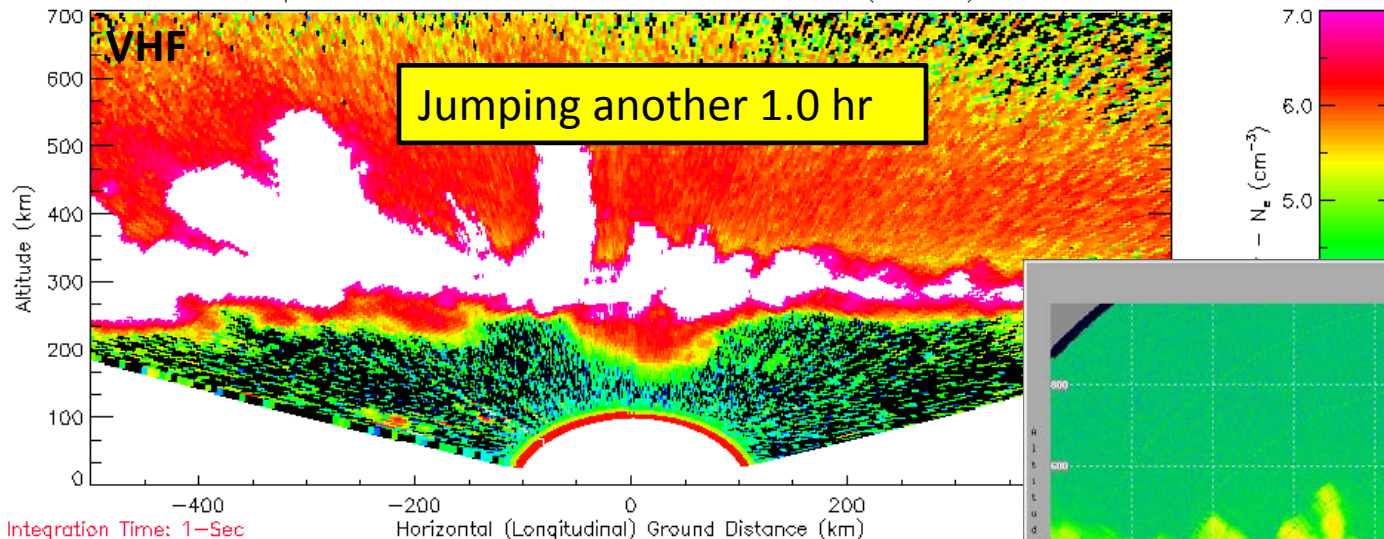
0.35 m turbulence
Beginning to see
interaction with
background
ionosphere



MOSC Launch 2: May 9, 2013 Evolution of Cloud & Ionosphere

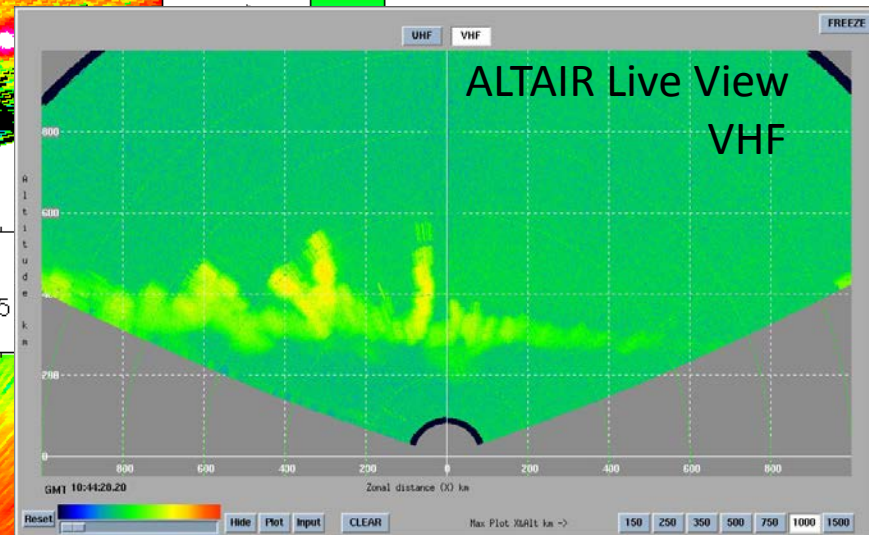
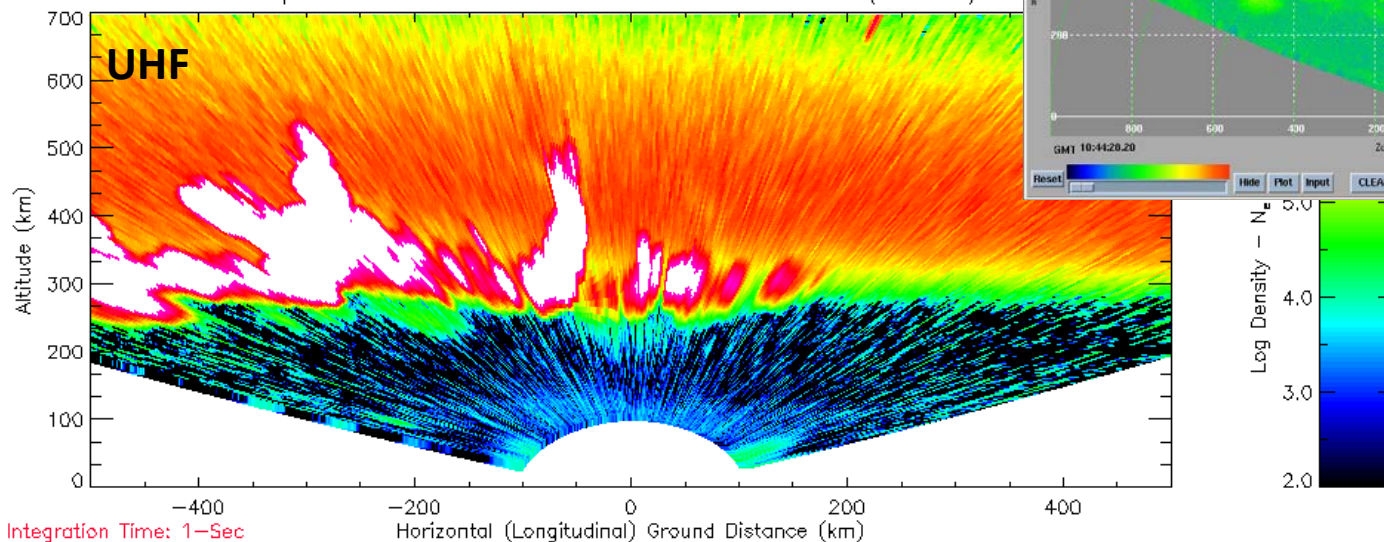


ALTAIR FA Scan - 09 May 2013 (Day 129) 10:35:49Z - 10:43:52Z
profile_fa_13129_1035_b1_1sec_43.dat: VHF (WF 521)



10:36 UT to 10:44 UT
Perp-B Scans
Coherent Scatter
~1 m turbulence

ALTAIR FA Scan - 09 May 2013 (Day 129) 10:35:48Z - 10:43:52Z
profile_fa_13129_1035_b2_1sec_43.dat: UHF (WF 568)



fully developed
plumes drifting in
from the west



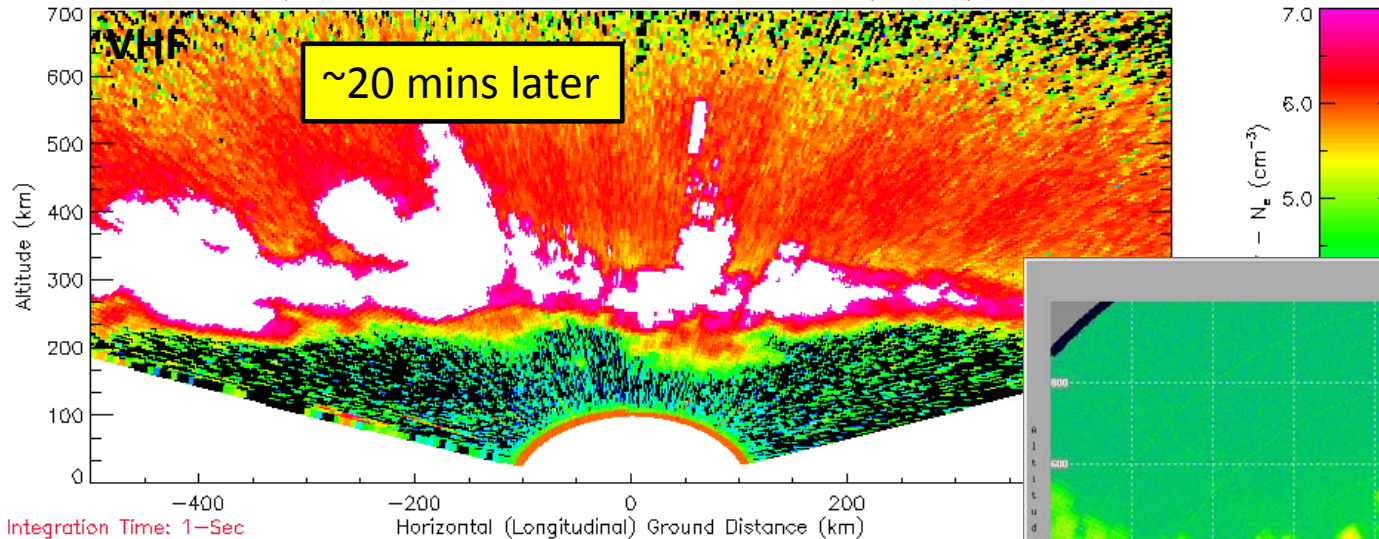


MOSC Launch 2: May 9, 2013

Evolution of Cloud & Ionosphere

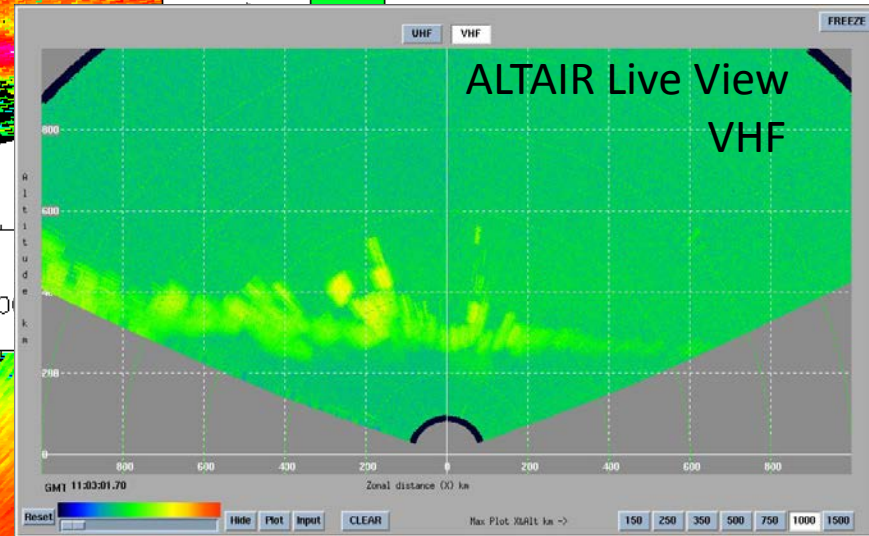
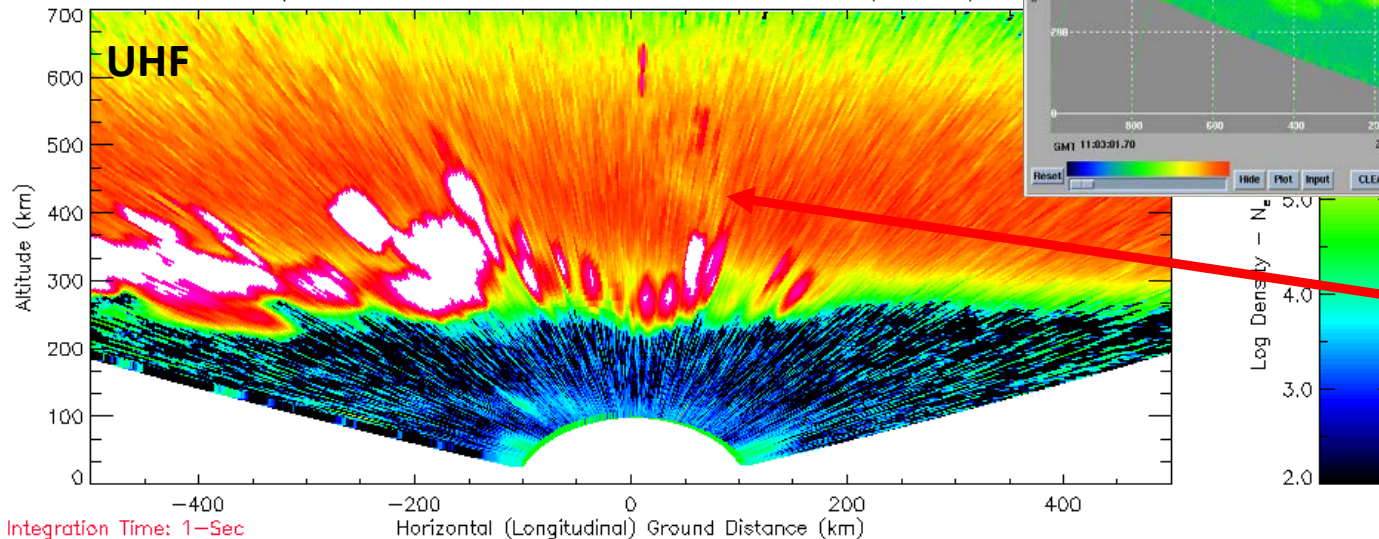


ALTAIR FA Scan - 09 May 2013 (Day 129) 10:54:57Z - 11:03:00Z
 profile_fa_13129_1055_b1_1sec_43.dat: VHF (WF 521)



10:55 UT to 11:03 UT
 Perp-B Scans
 Coherent Scatter
 ~1 m turbulence

ALTAIR FA Scan - 09 May 2013 (Day 129) 10:54:57Z - 11:03:00Z
 profile_fa_13129_1055_b2_1sec_43.dat: UHF (WF 568)



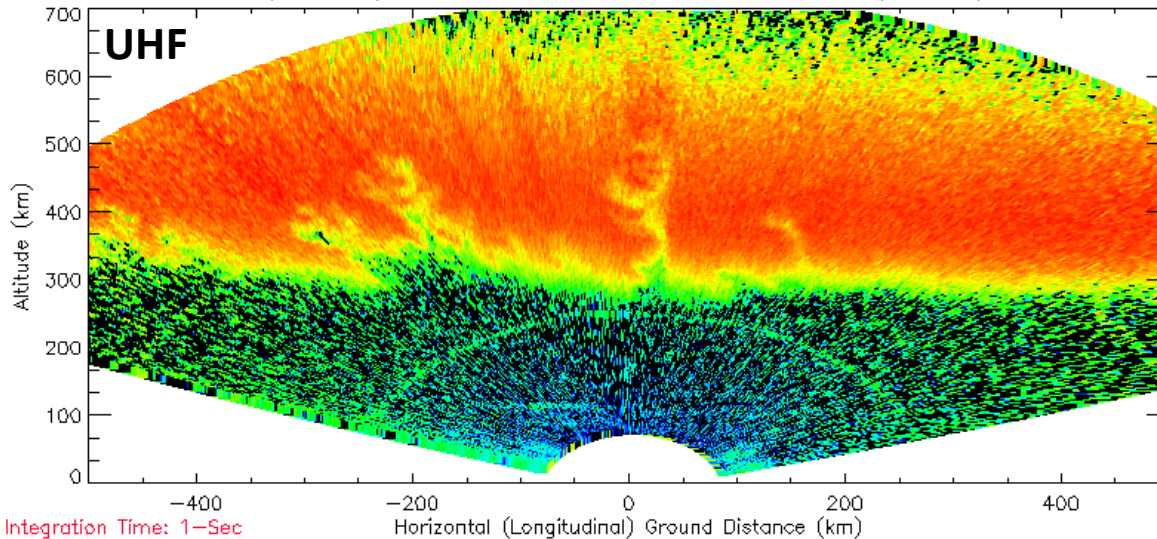
Note the lack of coherent scatter at ~0.35 m



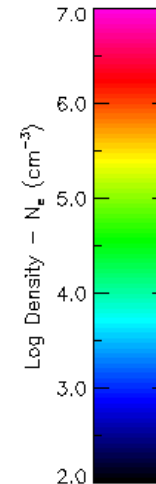
MOSC Launch 2: May 9, 2013 Evolution of Cloud & Ionosphere



ALTAIR OP Scan - 09 May 2013 (Day 129) 10:45:28Z - 10:53:31Z
profile_op_13129_1045_b2_1sec_120.dat: UHF (WF 556)



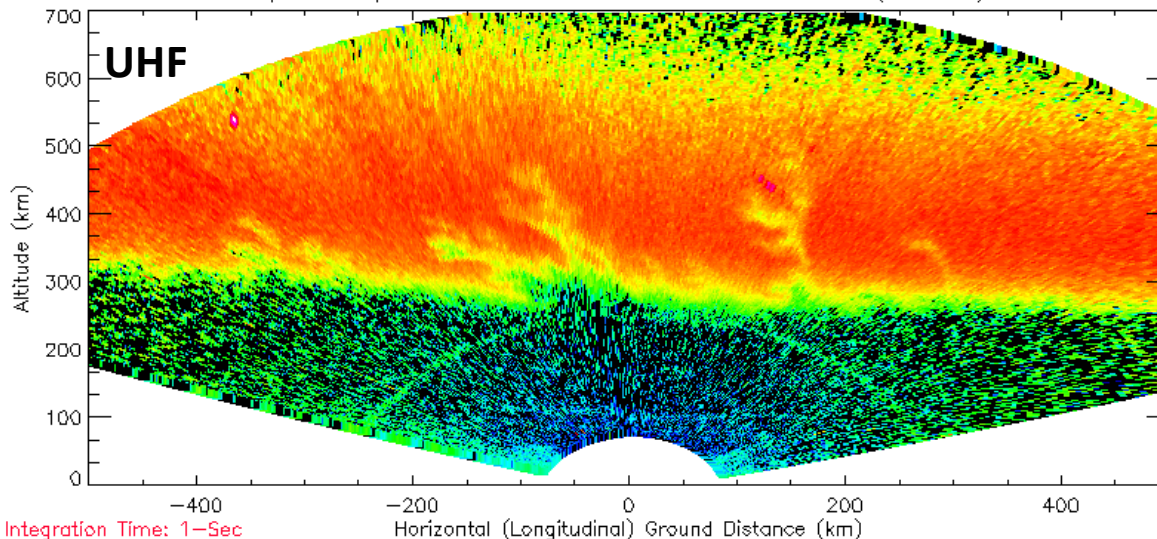
CALIBRATED DENSITY



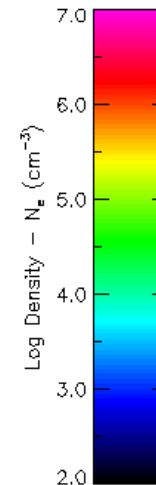
10:45 UT to 10:53 UT
Off-Perp Scans
(240m range resolution)

Here, we see true density measurements

ALTAIR OP Scan - 09 May 2013 (Day 129) 11:04:57Z - 11:13:01Z
profile_op_13129_1105_b2_1sec_120.dat: UHF (WF 556)



CALIBRATED DENSITY



11:05 UT to 11:13 UT

Strong evidence of the existence of a plume remains after the 10:55 UT to 11:03 UT Perp-B scan.





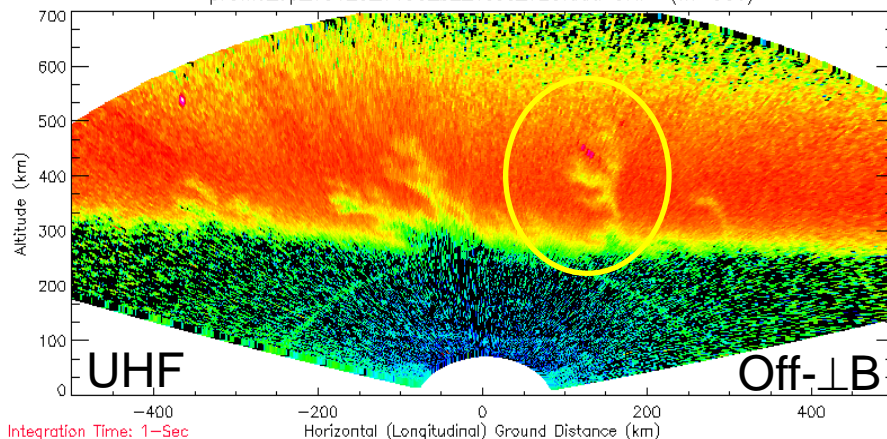
Possible Interaction of MOSC cloud with background ionosphere



- Clearly illustrates existence of large-scale structure with an irregularity (turbulence) spectrum rapidly decaying at short-scales
- Preliminary investigation indicates this anomalous behavior is a result of an interaction with the MOSC cloud

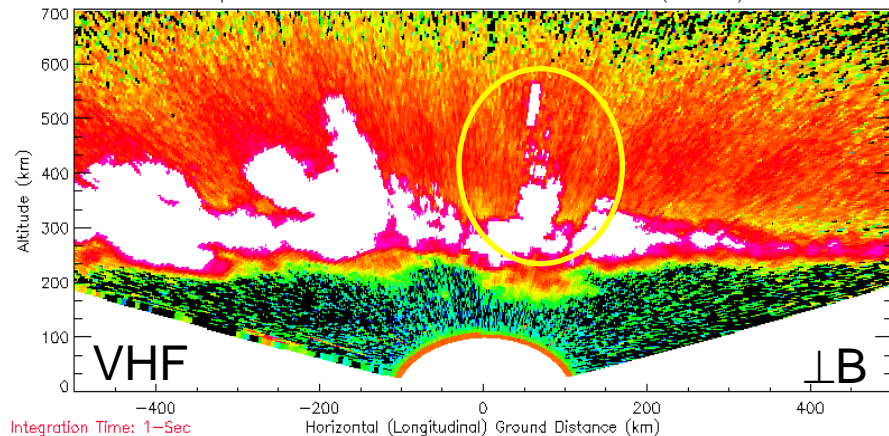
11:05 UT to 11:13 UT

ALTAIR OP Scan - 09 May 2013 (Day 129) 11:04:57Z - 11:13:01Z
profile_op_13129_1105_b2_1sec_120.dat: UHF (WF 556)

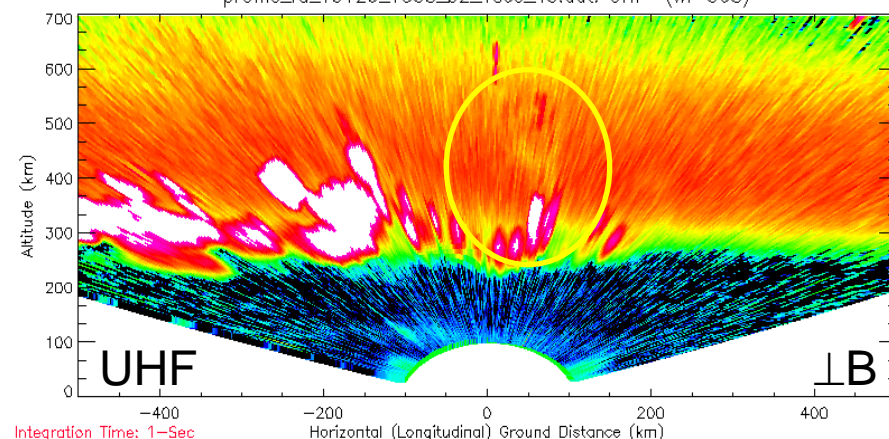


10:55 UT to 11:03 UT

ALTAIR FA Scan - 09 May 2013 (Day 129) 10:54:57Z - 11:03:00Z
profile_fa_13129_1055_b1_1sec_43.dat: VHF (WF 521)



ALTAIR FA Scan - 09 May 2013 (Day 129) 10:54:57Z - 11:03:00Z
profile_fa_13129_1055_b2_1sec_43.dat: UHF (WF 568)

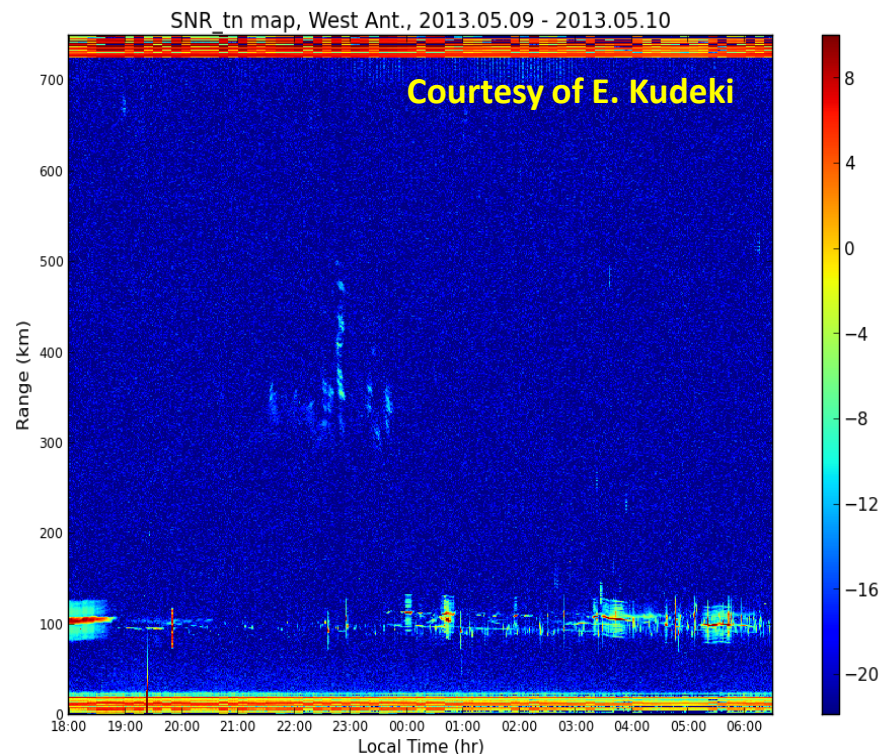




VHF Backscatter observation of MOSC Univ of Illinois Radar Imaging System(IRIS)



- Evidence that the 3m scale structure was suppressed due to interaction with the Sm cloud
- VHF backscatter radar on Roi-Namur for Equatorial Vortex Experiment (EVEX)
- RTI - night of second MOSC launch
- Well developed density perturbations to the west in ALTAIR were suppressed when they passed through the IRIS beam



Unlike any other night during the campaign

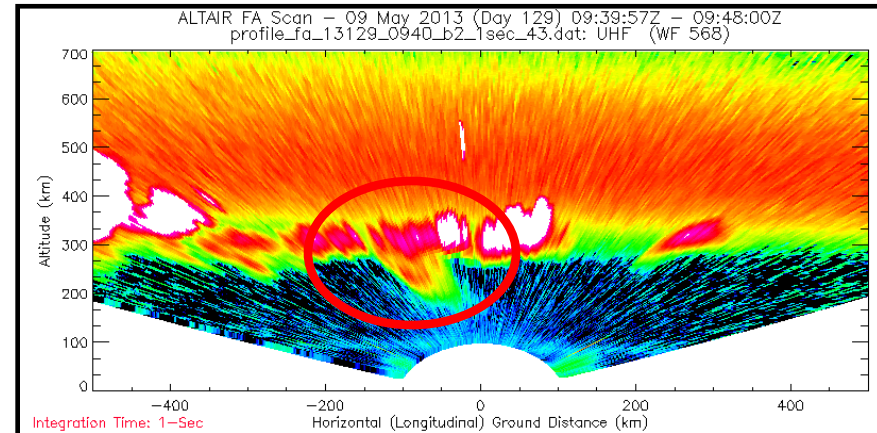
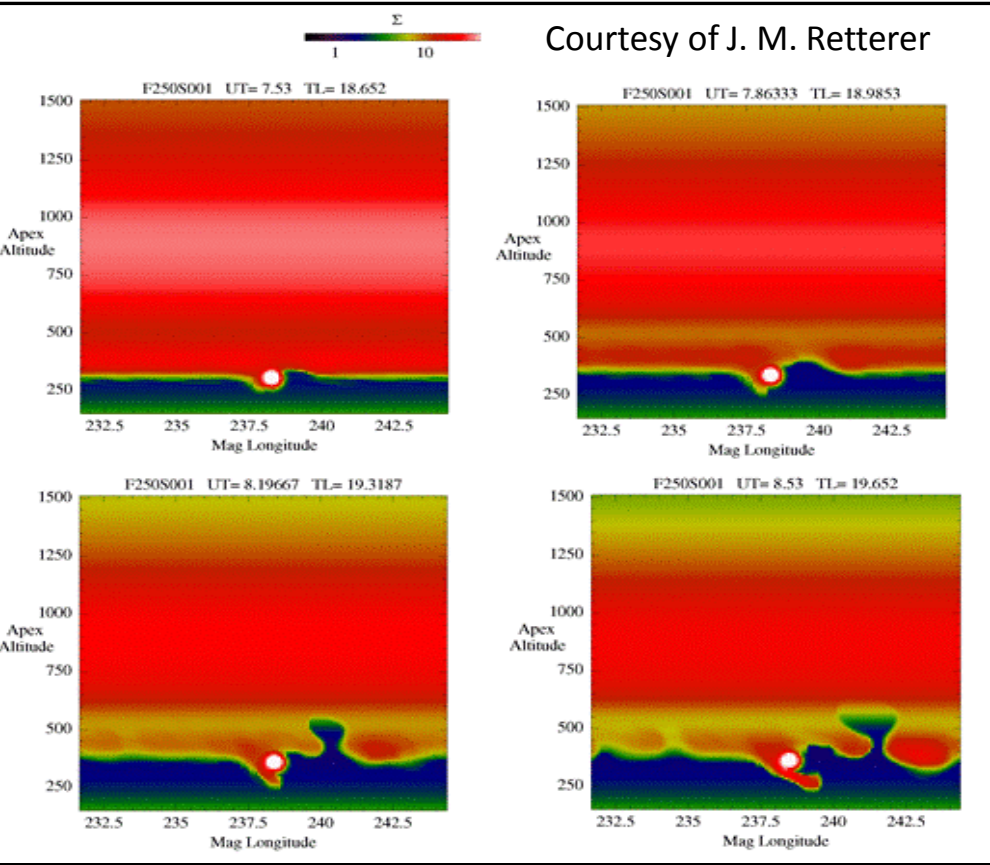


PBMOD



Modeling of the MOSC Release

- 7 kg of SmO^+ ...fully ionized...
 - MOSC results were ~10% yield
- Release at 250 km apex altitude
- Generates “comma” feature



The “comma” feature was observed in both MOSC releases



Summary



- With the ALTAIR radar, in conjunction measurements from other ground sensors, we successfully characterized plasma characteristics of ionized samarium in space
- Even a **small amount of samarium** plasma appears to have had a **remarkable influence on the ambient ionosphere**
- Evidence of the damping of short-scale irregularities



AFRL would like to acknowledge the **DoD Space Test Program** for their sponsorship of the MOSC Experiment



Backup Charts

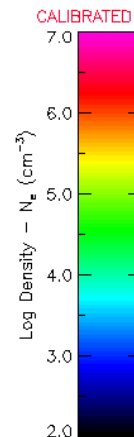
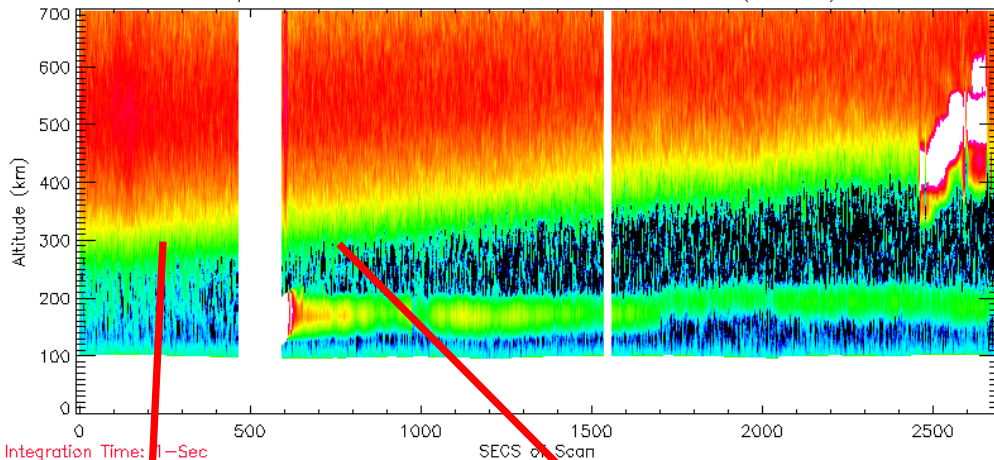




MOSC Launch 1: May 1, 2013 Samarium Release



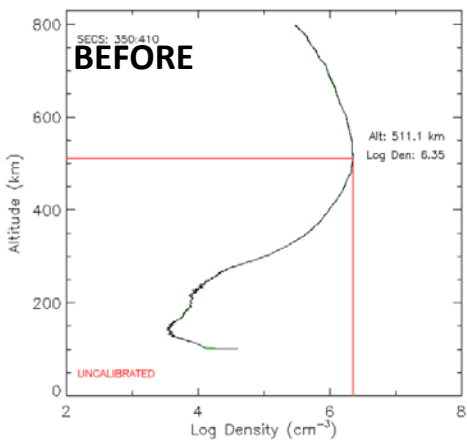
ALTAIR WN Scan - 01 May 2013 (Day 121) 07:30:38Z - 08:15:30Z
profile_wn_13121_0730_b2_1sec_43.dat: UHF (WF 568)



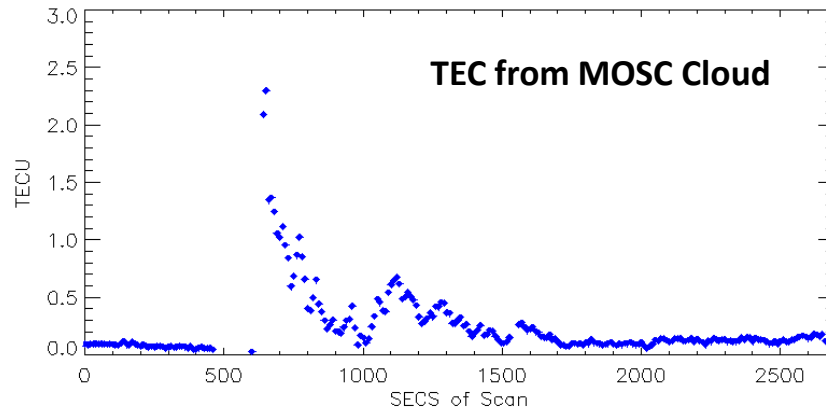
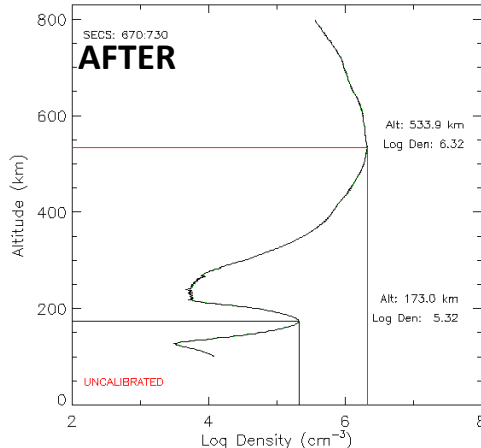
- Very active night - Kp 5+
- Not ideal for comparison but successful launch
- UEP1-300, 300 μ s pulse
- 960 m range resolution

Integration Time: 1-Sec

/wd/wide/scan_output/2013_121/profile_wr_13121_0730_b2_1sec_43.dat



/wd/wide/scan_output/2013_121/profile_wr_13121_0730_b2_1sec_43.dat



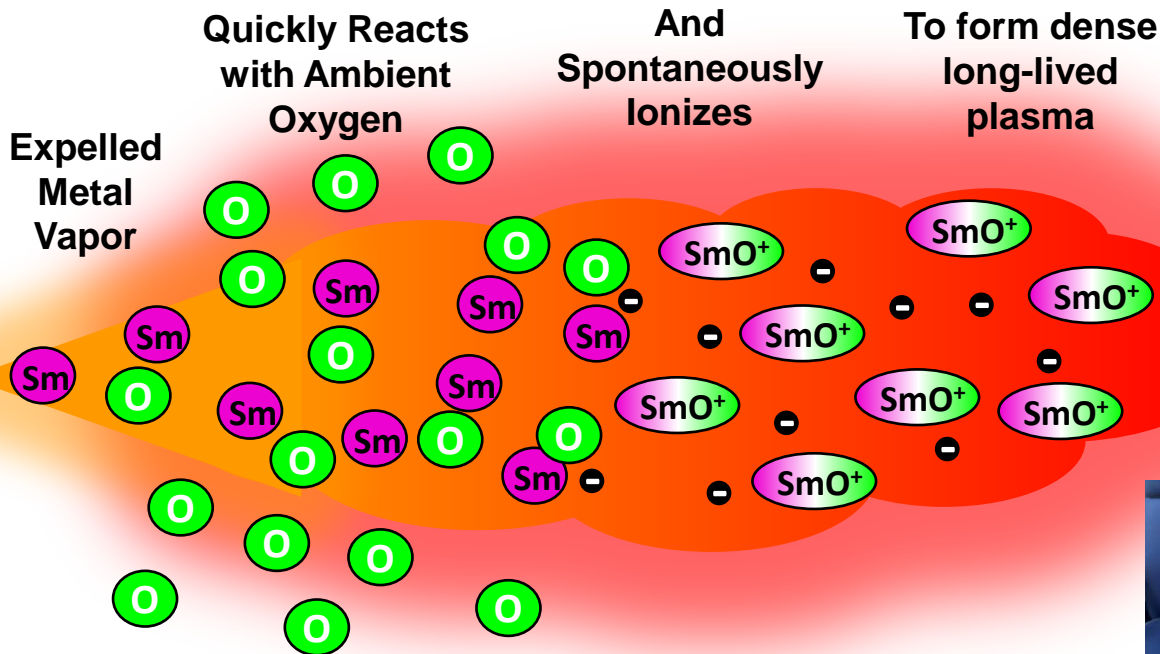
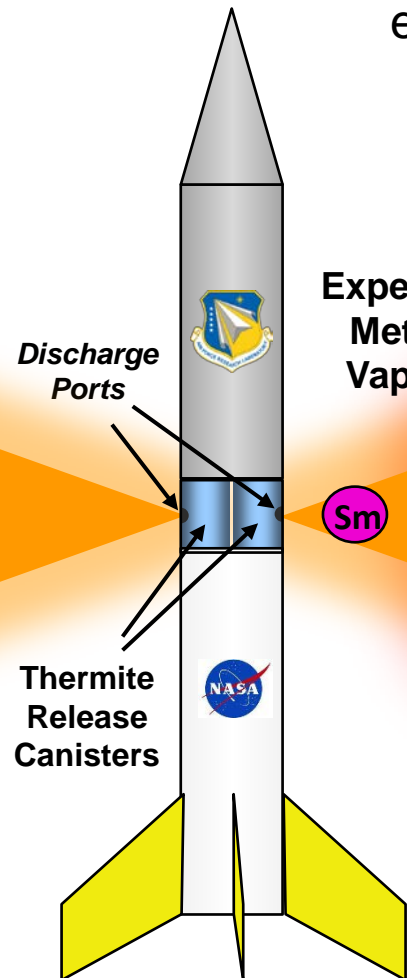


AFRL MOSC Experiment Samarium Release



- Many Lanthanide metals spontaneously ionize upon reaction with atomic oxygen
- Samarium (Sm) has a relatively low boiling point (2021K), allowing efficient vaporization by Titanium-Boron thermite (~3500K)

Terrier MK70-
Improved Orion
Sounding Rocket



Predicted
artificial density
after 1 hour:

$10^8/\text{cc}$

Typical natural
density:

$10^6/\text{cc}$



Actual burst-disc
release canister

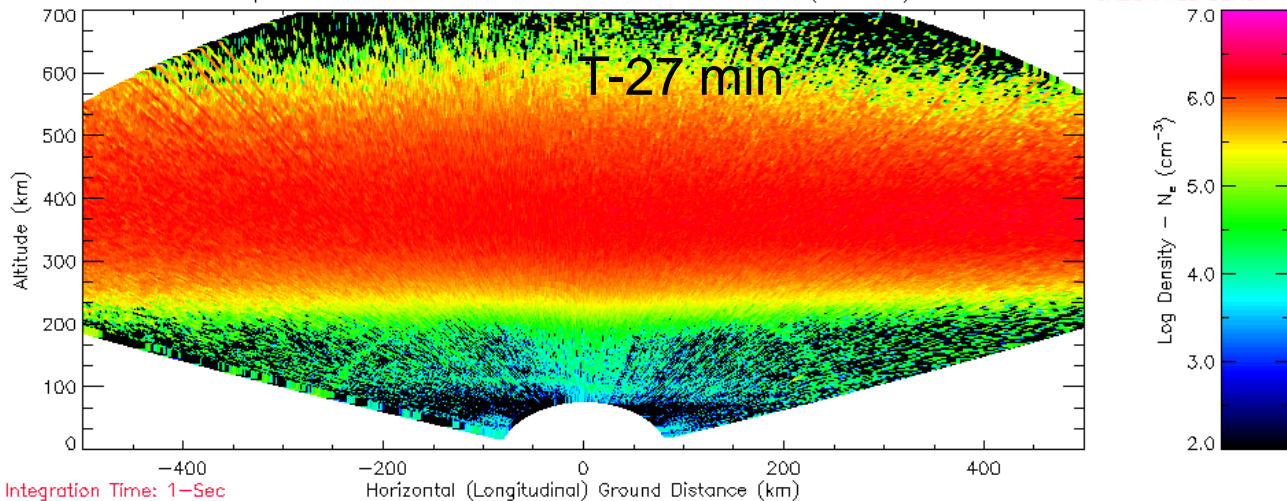


MOSC Launch 2: May 9, 2013

Evolution of Cloud & Ionosphere



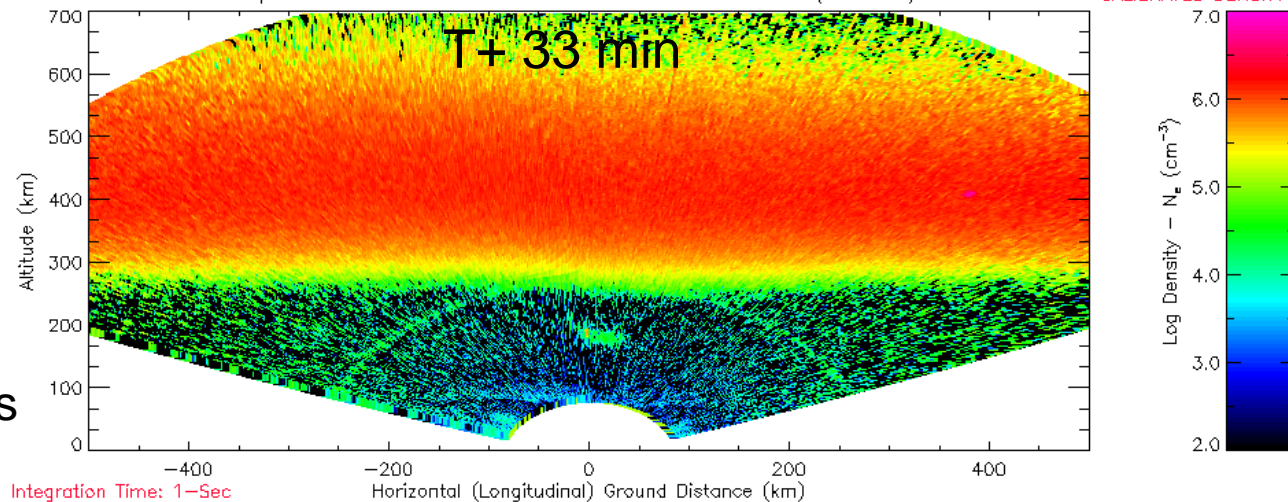
ALTAIR FA Scan - 09 May 2013 (Day 129) 07:00:04Z - 07:08:09Z
 profile_fa_13129_0700_b2_1sec_120.dat: UHF (WF 556)



- Smooth ionosphere as sunset approaches

- Still appears smooth an hour later, but samarium cloud is weakly evident
- Note that base of layer has risen (~50 km); peak density has decreased ~10%

ALTAIR FA Scan - 09 May 2013 (Day 129) 07:59:57Z - 08:08:03Z
 profile_fa_13129_0800_b2_1sec_120.dat: UHF (WF 556)

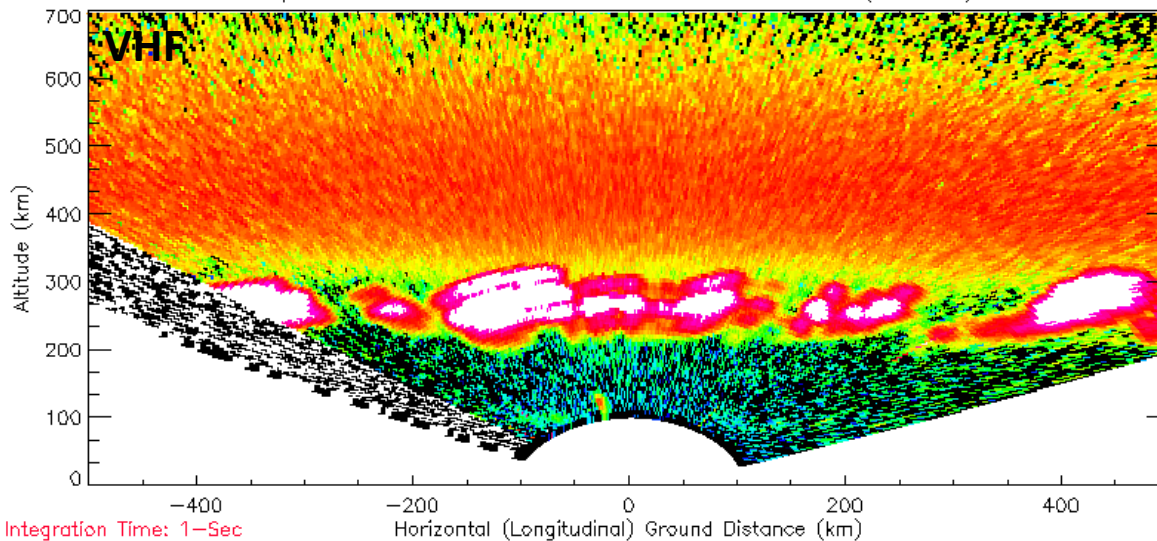




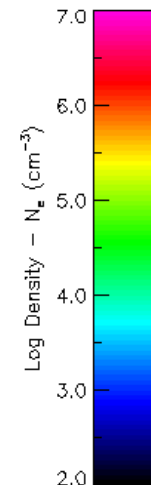
MOSC Launch 2: May 9, 2013 Evolution of Cloud & Ionosphere



ALTAIR FA Scan - 09 May 2013 (Day 129) 08:45:32Z - 08:53:10Z
profile_fa_13129_0845_b1_1sec_43.dat: VHF (WF 521)



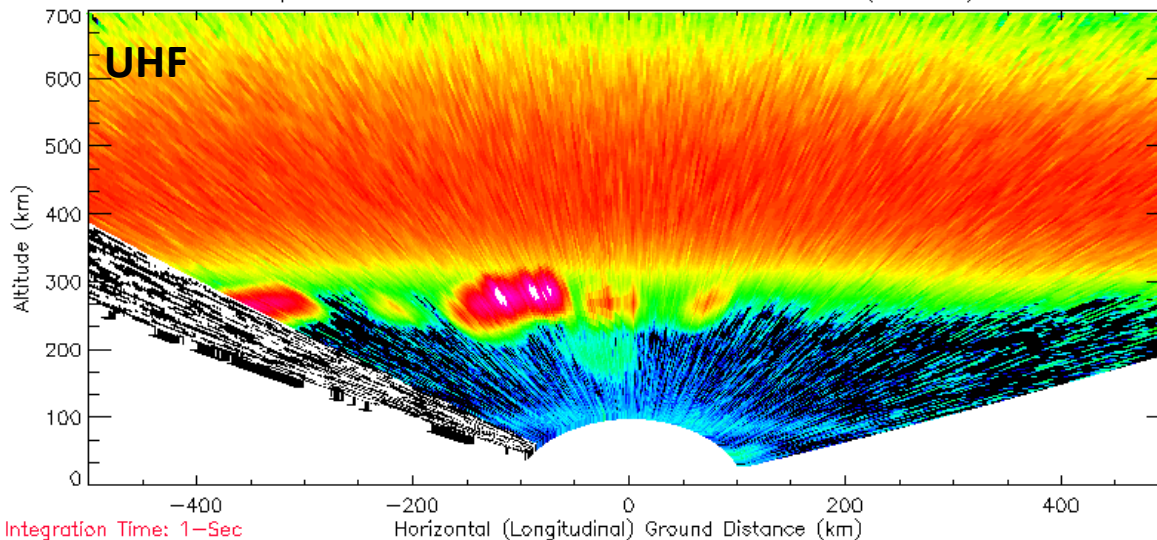
CALIBRATED DENSITY



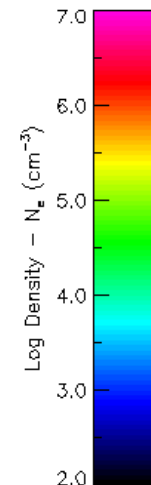
08:45 UT to 08:53 UT
Perp-B Scans
Coherent Scatter

~1 m turbulence

ALTAIR FA Scan - 09 May 2013 (Day 129) 08:45:31Z - 08:53:10Z
profile_fa_13129_0845_b2_1sec_43.dat: UHF (WF 568)



CALIBRATED DENSITY



0.35 m turbulence

Cloud is moving
westward

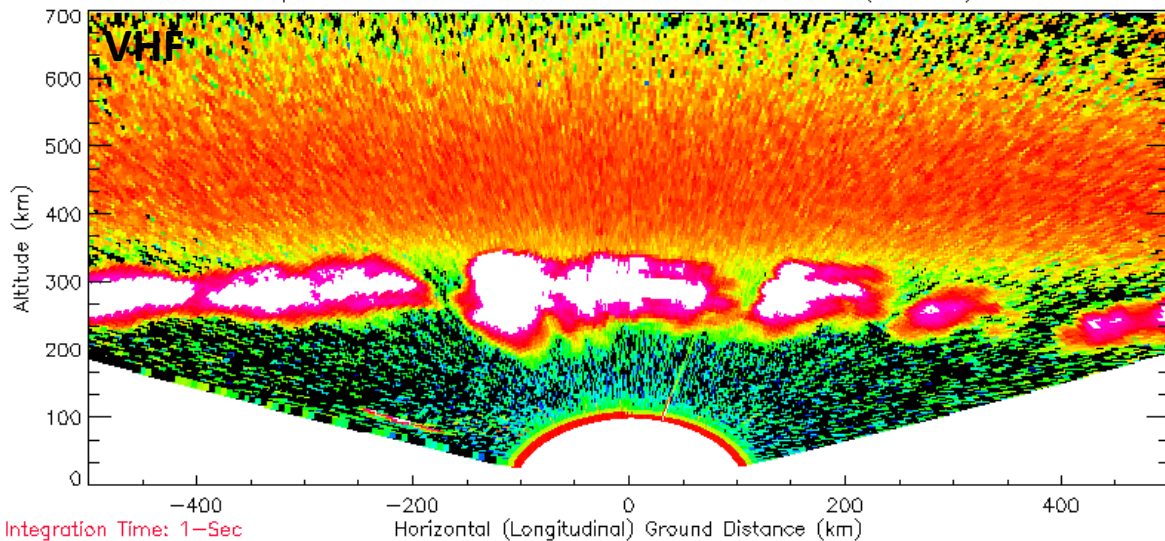




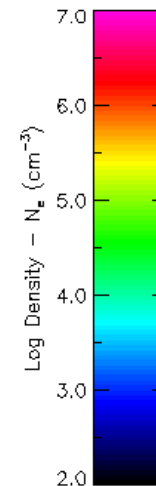
MOSC Launch 2: May 9, 2013 Evolution of Cloud & Ionosphere



ALTAIR FA Scan - 09 May 2013 (Day 129) 09:09:58Z - 09:18:01Z
profile_fa_13129_0910_b1_1sec_43.dat: VHF (WF 521)



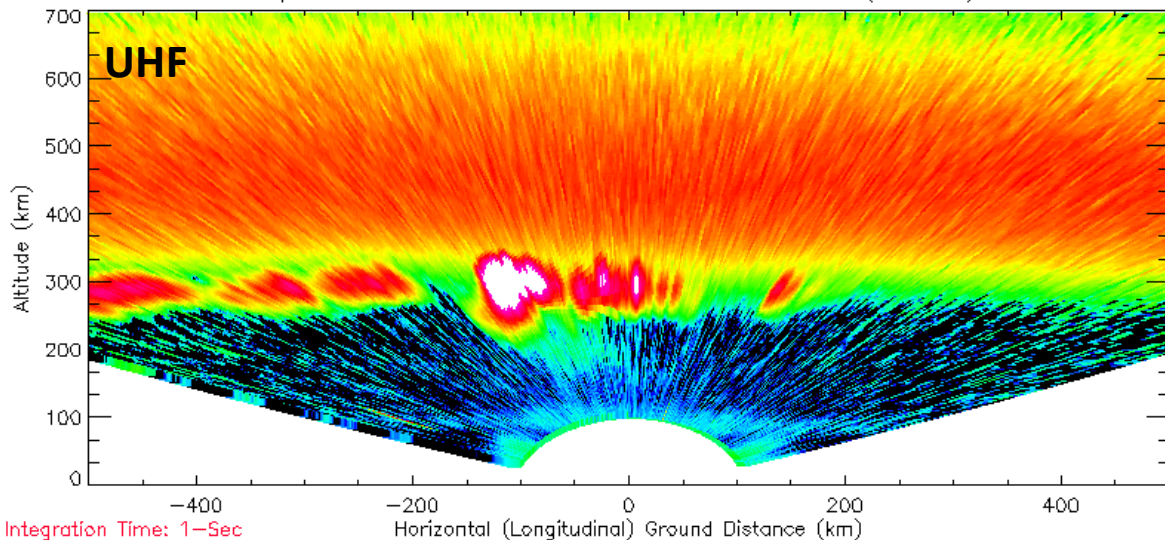
CALIBRATED DENSITY



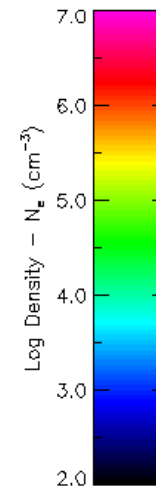
09:10 UT to 09:18 UT
Perp-B Scans
Coherent Scatter

~1 m turbulence

ALTAIR FA Scan - 09 May 2013 (Day 129) 09:09:57Z - 09:18:00Z
profile_fa_13129_0910_b2_1sec_43.dat: UHF (WF 568)



CALIBRATED DENSITY



0.35 m turbulence

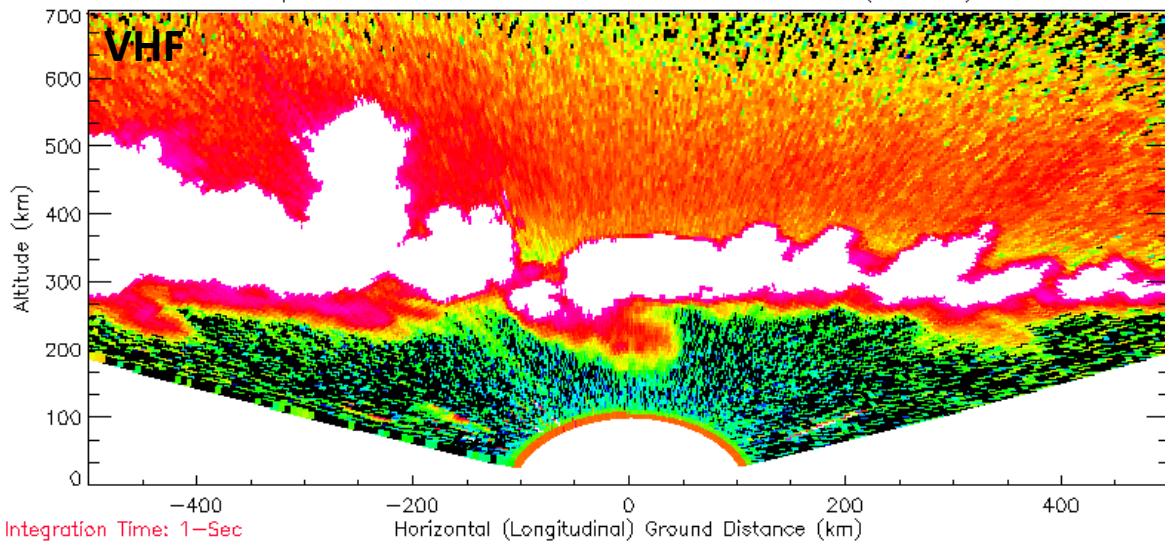
Cloud is moving
slowly westward



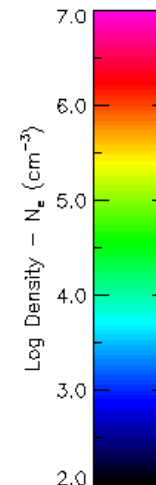
MOSC Launch 2: May 9, 2013 Evolution of Cloud & Ionosphere



ALTAIR FA Scan - 09 May 2013 (Day 129) 10:09:57Z - 10:18:00Z
profile_fa_13129_1010_b1_1sec_43.dat: VHF (WF 521)



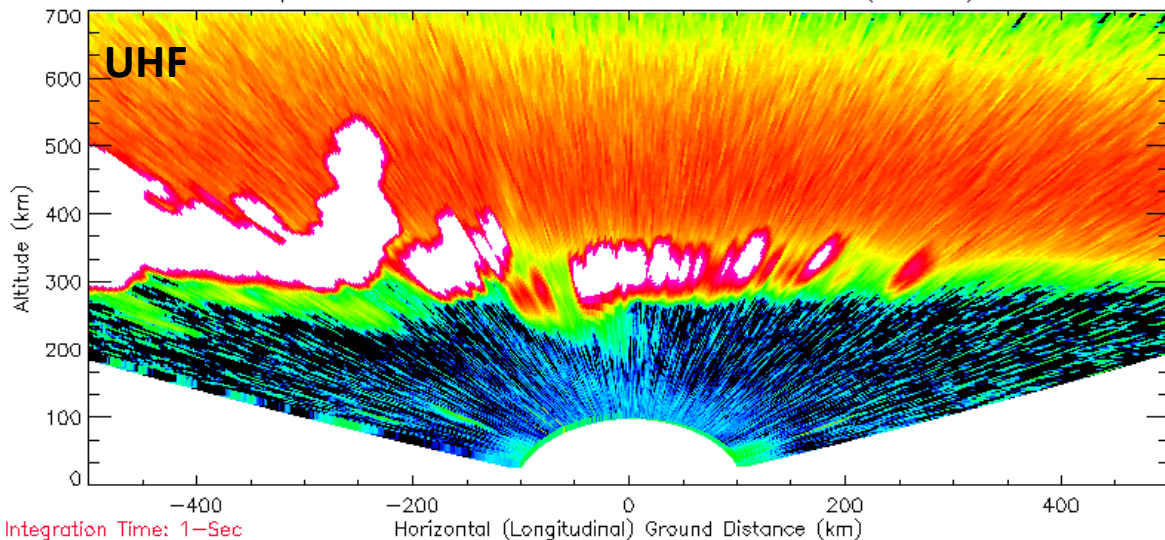
CALIBRATED DENSITY



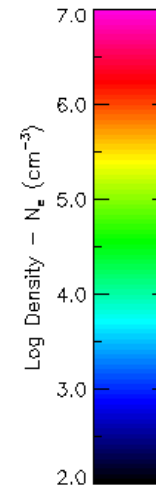
10:10 UT to 10:18 UT
Perp-B Scans
Coherent Scatter

~1 m turbulence

ALTAIR FA Scan - 09 May 2013 (Day 129) 10:09:57Z - 10:18:02Z
profile_fa_13129_1010_b2_1sec_43.dat: UHF (WF 568)



CALIBRATED DENSITY



0.35 m turbulence

First fully
developed plume
drifting in from the
west

Integration Time: 1-Sec



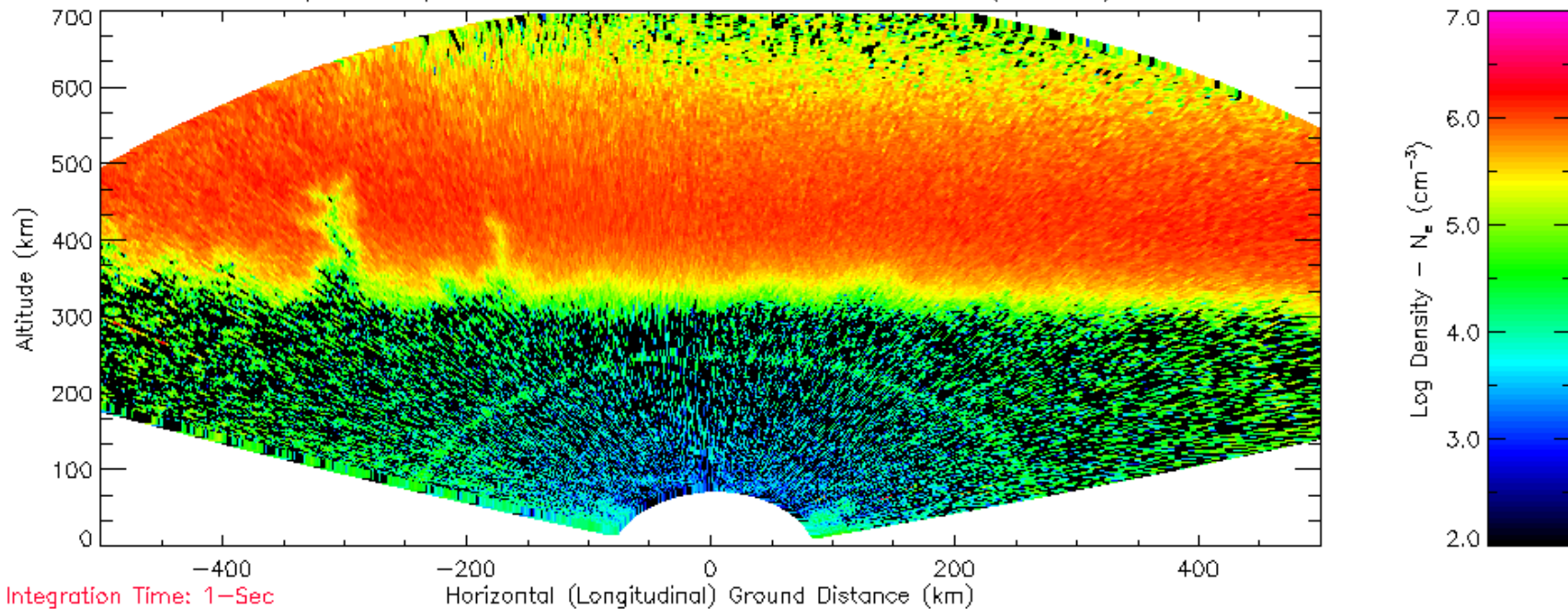


Off-Perp Incoherent Scatter Scans



10:00 UT to 10:08 UT

ALTAIR OP Scan - 09 May 2013 (Day 129) 09:59:57Z - 10:08:01Z
profile_op_13129_1000_b2_1sec_120.dat: UHF (WF 556)



Higher resolution scanning mode (same as used during earlier raster scanning)

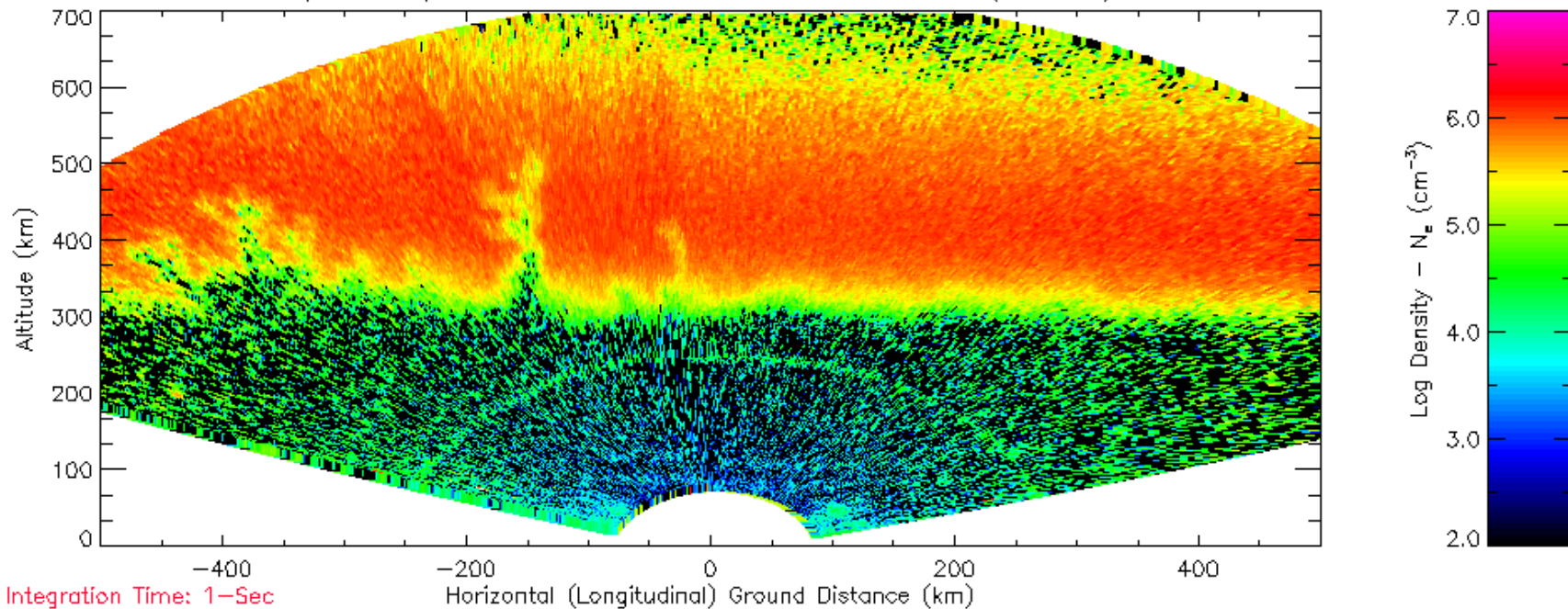


Off-Perp Incoherent Scatter Scans



10:20 UT to 10:28 UT

ALTAIR OP Scan - 09 May 2013 (Day 129) 10:19:57Z - 10:28:01Z
profile_op_13129_1020_b2_1sec_120.dat: UHF (WF 556)



Integration Time: 1-Sec



Off-Perp Incoherent Scatter Scans



11:05 UT to 11:13 UT

ALTAIR OP Scan - 09 May 2013 (Day 129) 11:04:57Z - 11:13:01Z
profile_op_13129_1105_b2_1sec_120.dat: UHF (WF 556)

