The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2025-40

Satellite Navigation Science and Technology for Africa

23 March - 9 April, 2009

SCINDA Status and Plans

GROVES Keith
Air Force Research Lab.
Hanscom MA 01731
U.S.A.

AFRL

THE AIR FORCE RESEARCH LABORATORY

LEAD | DISCOVER | DEVELOP | DELIVER

SCINDA Status & Plans

07 April 09

Dr. Keith Groves

Principal Investigator

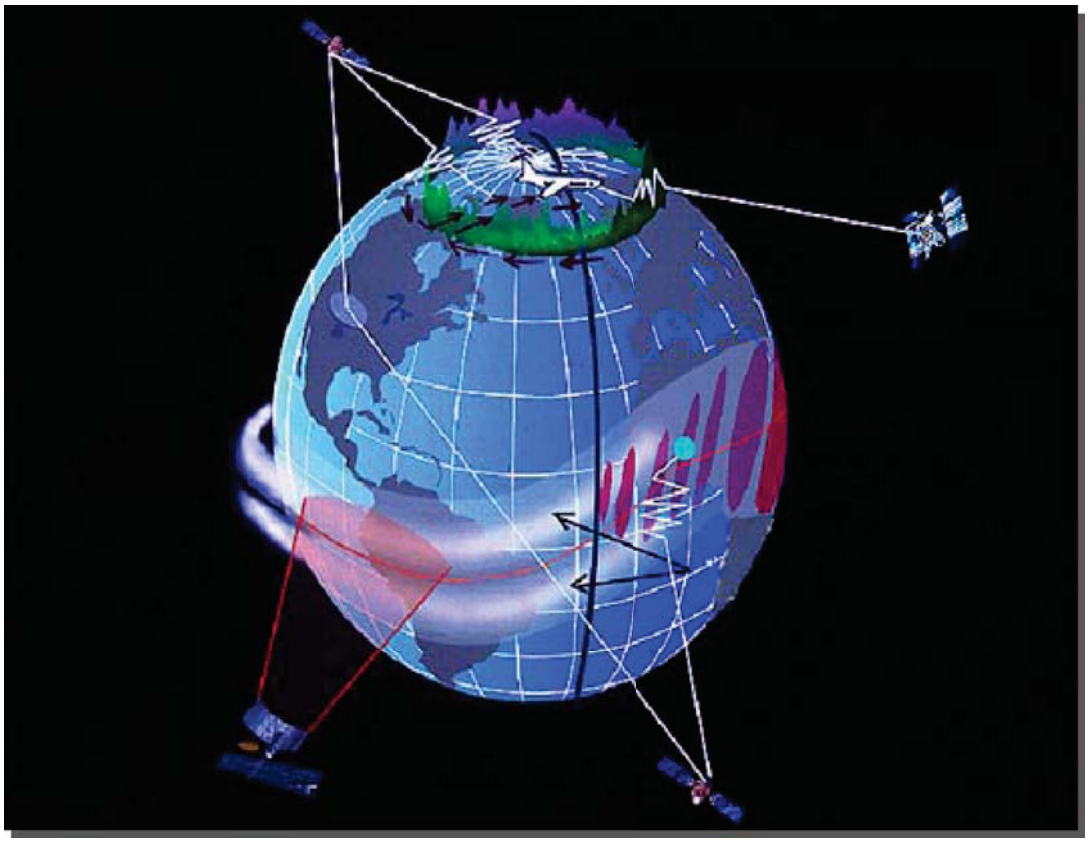
Ionospheric Impacts on RF Systems

Space Vehicles Directorate

Air Force Research Laboratory

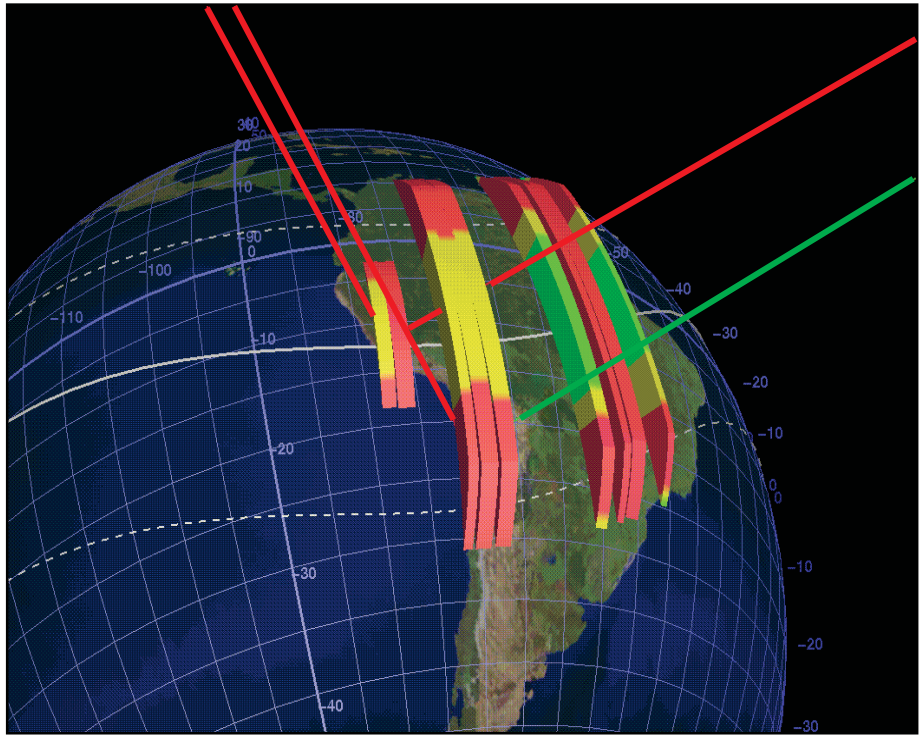
Overview

- SCINDA concept & examples of recent scintillation activity
- Update on sites and planned deployments in Africa
- New developments in SCINDA
- Opportunities for collaboration with C/NOFS and other satellites
- Summary



SCINTILLATION NETWORK DECISION AID (SCINDA)

A *regional nowcasting system* to support research and users of space-based communication and navigation systems

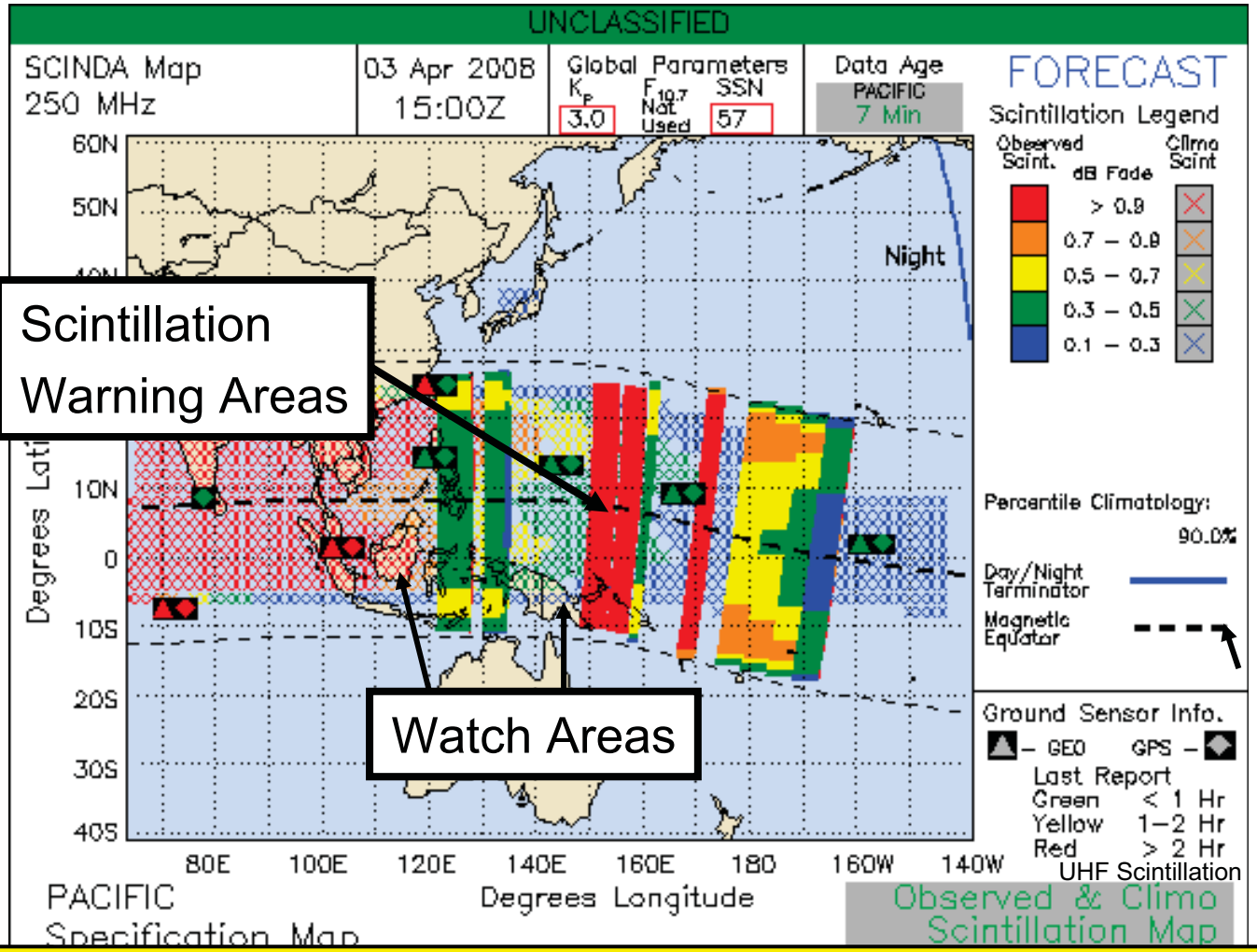


Real-time to 2-Hr Forecasts

- Ground-based sensor network
  - Passive UHF / L-band /GPS scintillation receivers
  - Measures scintillation intensity, eastward drift velocity, and TEC
  - Automated real-time data retrieval via internet
- Data supports research and space weather users
  - Understand on-set, evolution and dynamics of large-scale ionospheric disturbances
  - Empirical model provides simplified visualizations of scintillation regions in real-time

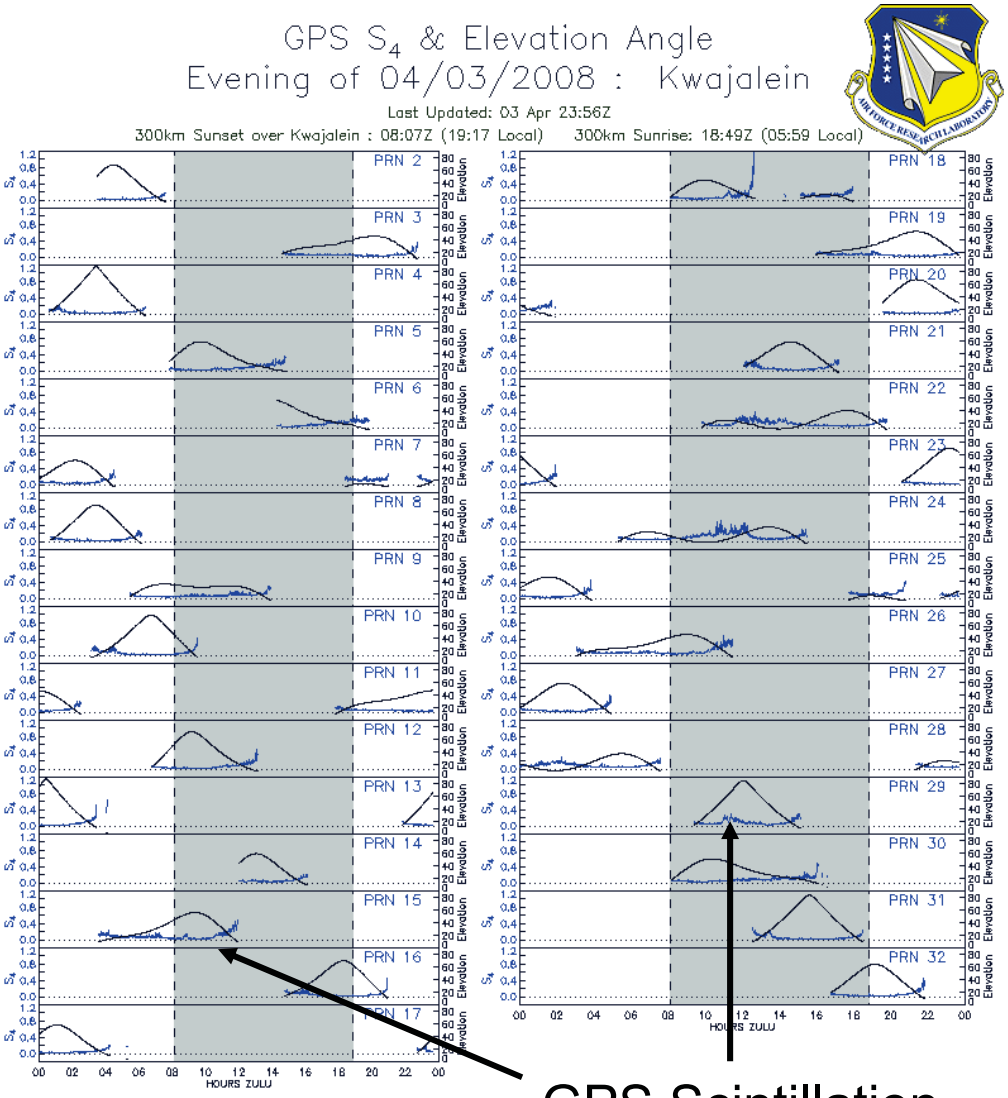
Data-Driven Scintillation Map
April 2008

SCINDA User Product Example for 250MHz

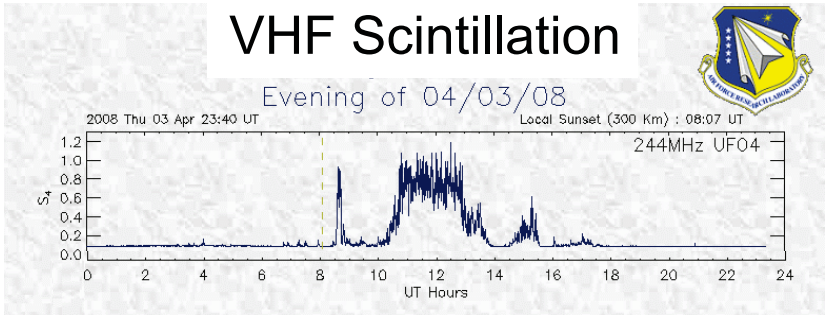


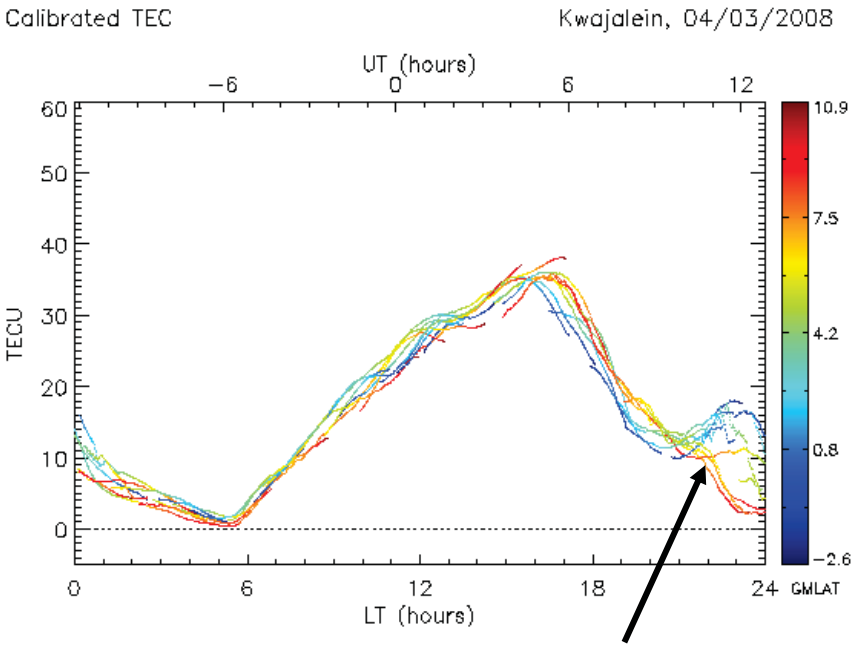
UHF SATCOM band impacted even during solar maximum

GPS Scintillation in Same Environment Much Weaker than VHF



GPS Scintillation

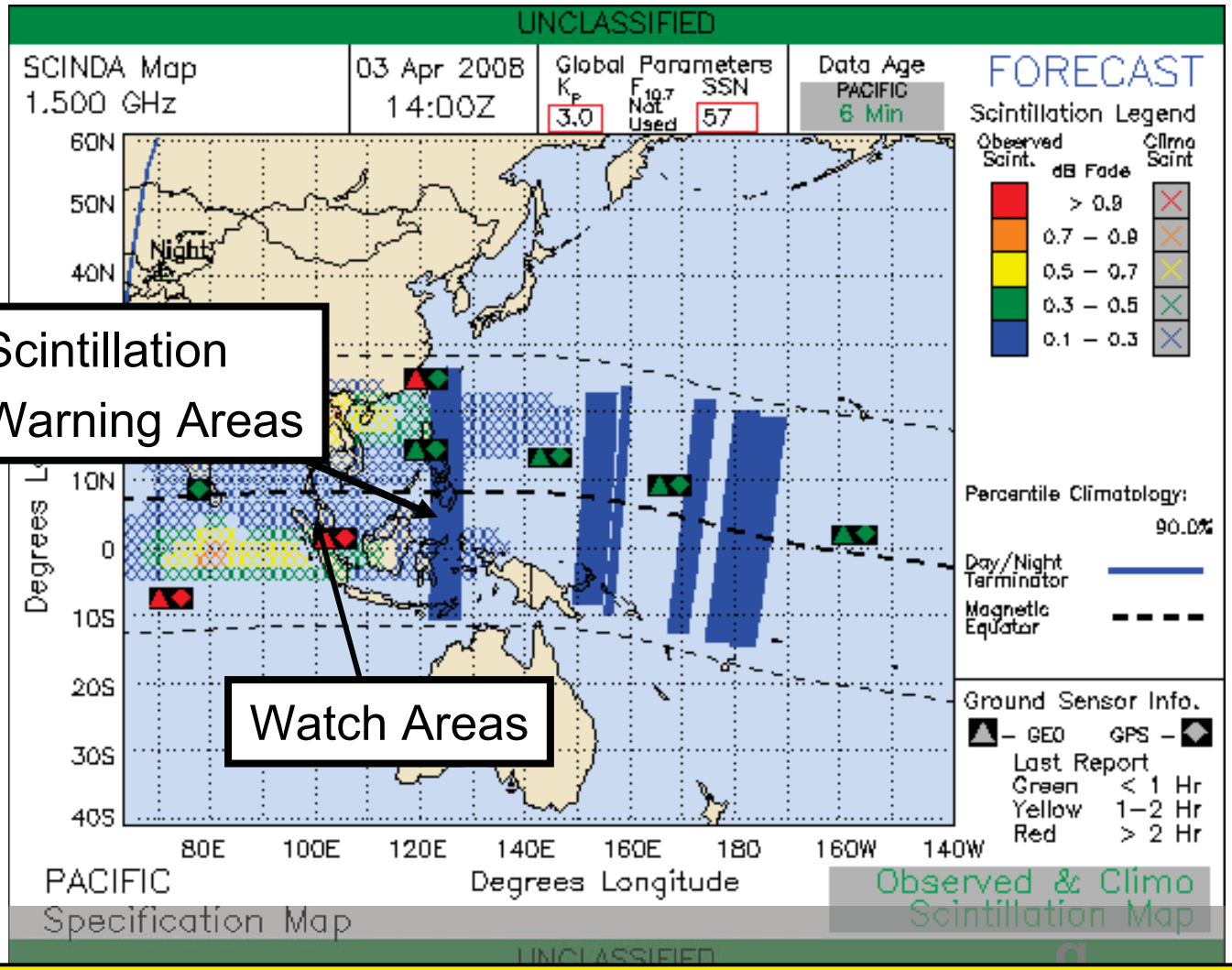




Latitude variation

Data-Driven Scintillation Map
April 2008

SCINDA User Product Example for GPS

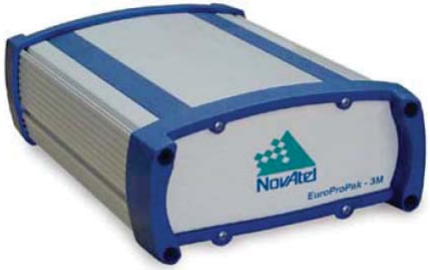


Modest Effects on GPS Frequencies During Solar Min

SCINDA Sensor Suite

Tri-band Beacon System

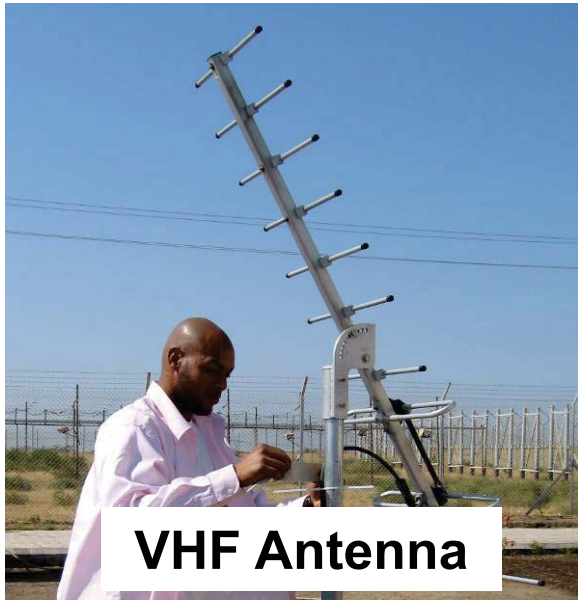
Narrowband VHF Receiver



GSV4004B

GPS Receiver

GPS Antenna



VHF Antenna

Typical Hardware Configuration

Antenna Layout

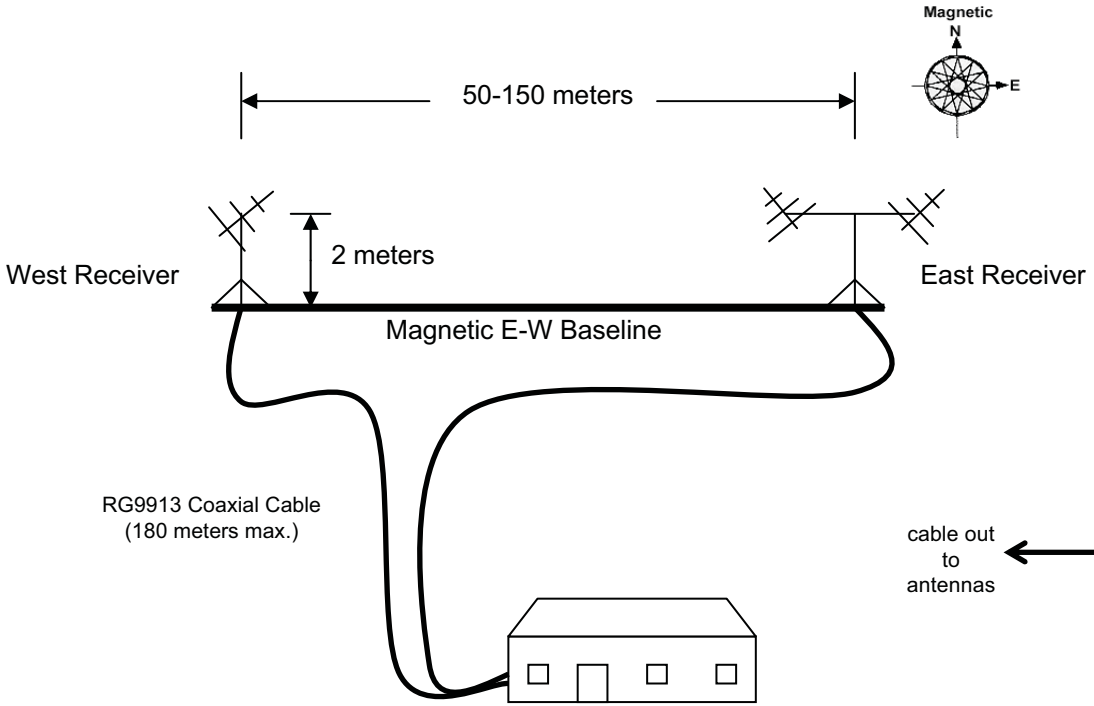
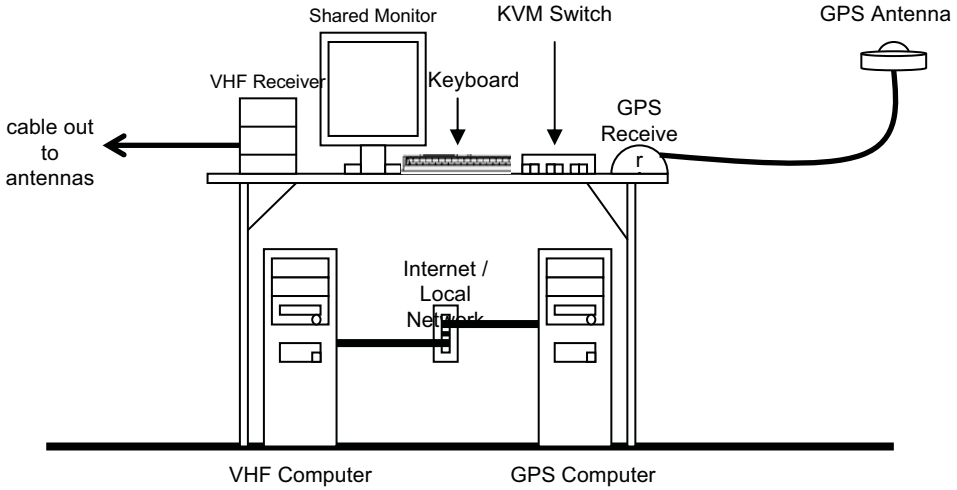
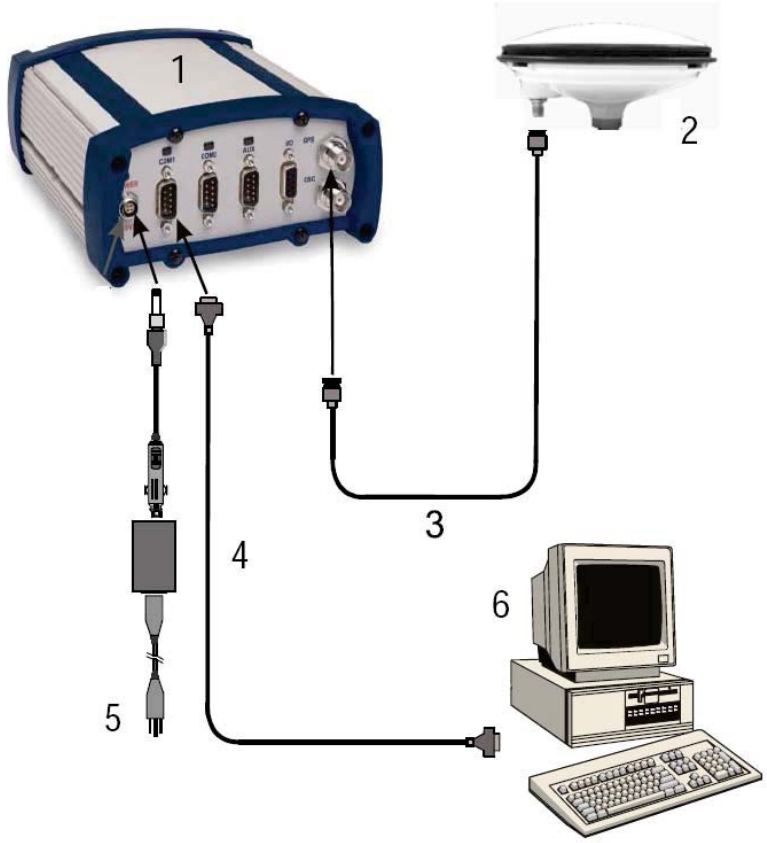


Figure 5. VHF (250 MHz) Receiver Chain and Data Acquisition System



Receivers Set-Up

GPS System Installation



Equipment List

1: NovAtel GSV 4004B GPS receiver

2: NovAtel dual frequency antenna

3: Antenna cable (30 meter maximum)

4: Serial cable

5: Power cable

6: Personal computer running Linux

GPS-SCINDA System Software

GPS-SCINDA Scintillation Monitoring System

- Operating System: Debian Linux
- Software runs in text mode in a Linux console
- Configurable via command line interface
- Sends data via Internet connection and SFTP

GPS Data Logging

What we measure: GPS System Outputs

- GPS L1 signal (1575 MHz)
  - S4 scintillation index
- GPS L2 signal (1228 MHz)
  - S4 scintillation index (not useful at this time)
- Both the L1 and L2 signals
  - Total Electron Content (TEC)
  - Rate of TEC Change (ROTI)
- Raw amplitude and phase data (50 Hz) can be recorded as desired
- New data plotting and analysis tools available
  - C. Carrano presentation/software Wednesday

Mounting the GPS Antenna

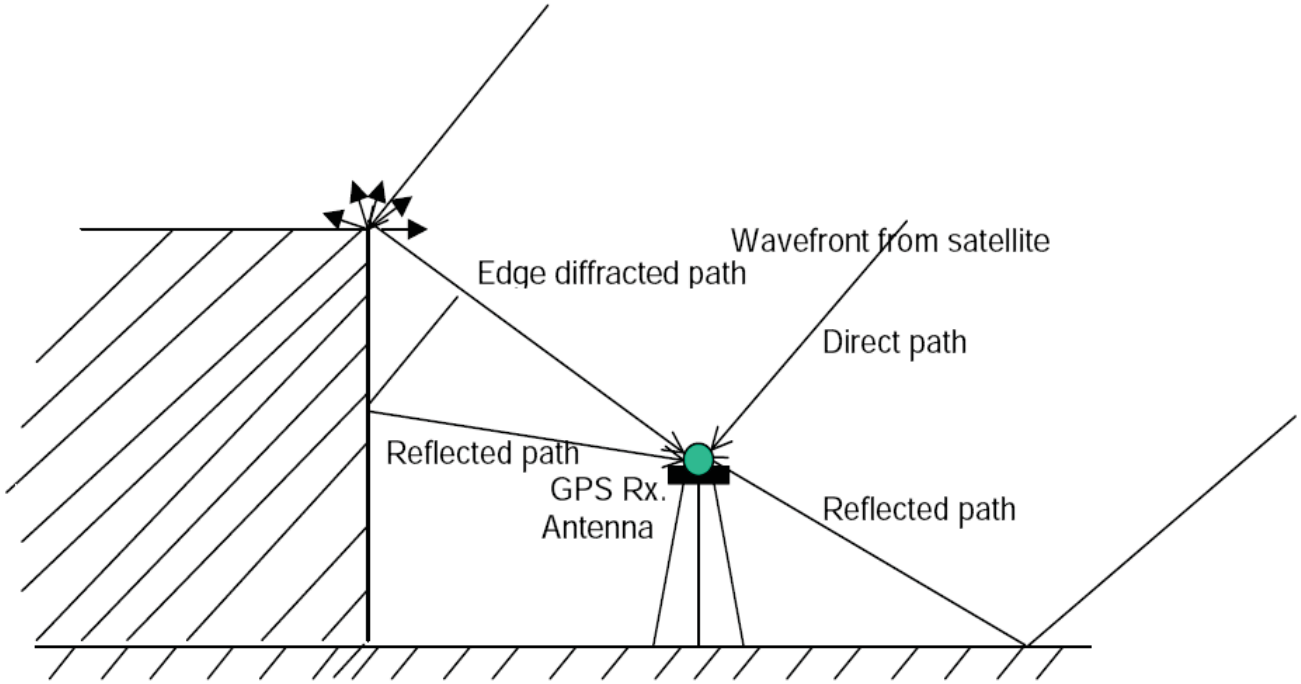
GPS Antenna should be installed high, with minimal obstructions from buildings, other antennas and equipment, power lines, and trees. Antenna cable length should not exceed 30 m to limit signal losses.

GPS antenna

Important: Moving the antenna or changing cables can change the receiver bias.

GPS Multipath

Only the portion of the signal that travels along the direct path from the satellite is useful. All other contributions are called multipath.



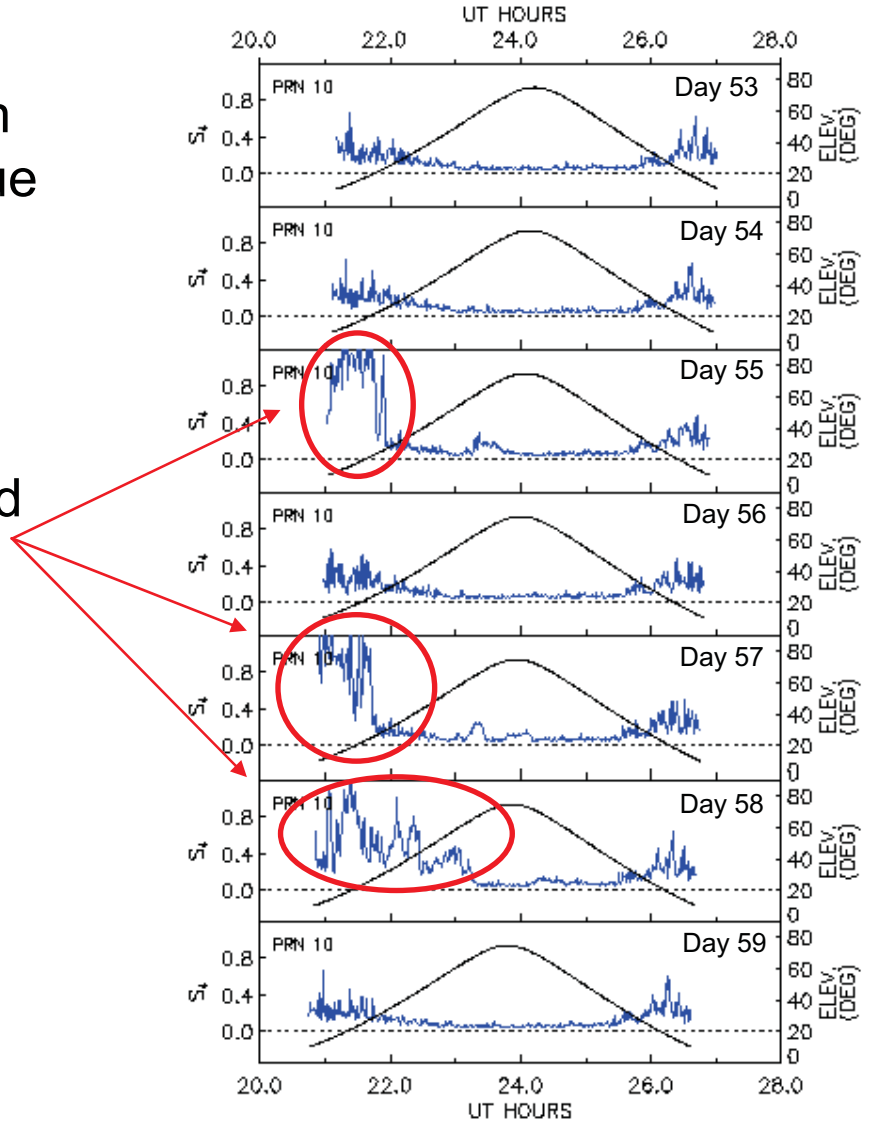
Signal interference at the antenna due to multipath causes fluctuations that can resemble scintillation, but these fluctuations are not caused by the ionosphere.

Multipath and Scintillation

The pattern of multipath scintillation changes slowly from day to day (due to the 4 minute daily rotation of the GPS constellation)

Ionospheric scintillation changes quasi-randomly from day to day and is superimposed on the multipath background

Multipath due to ground-based obstructions of the sky is usually encountered at low elevations



Data from Ascension Island in 2006

New VHF Scintillation Sensor
Software Digital Radio (SDR)

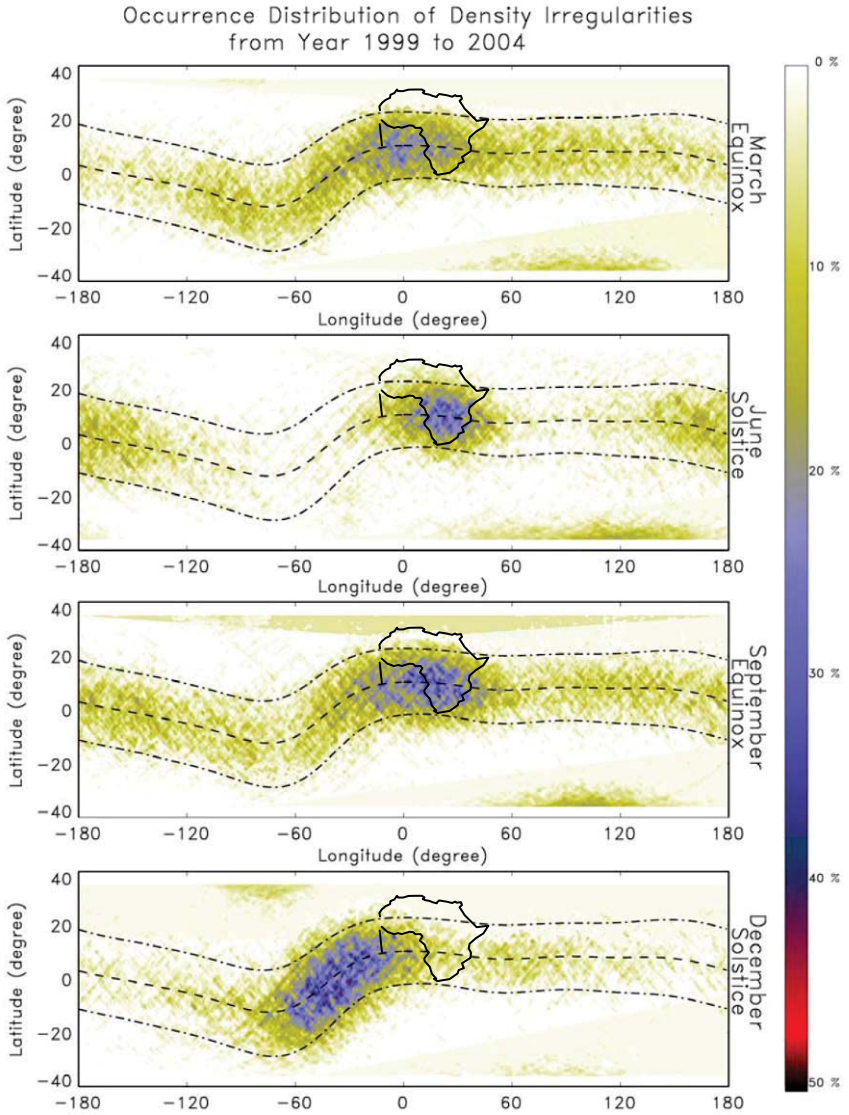
SDR monitors multiple VHF GEO channels

- AFRL/RVBXI is pursuing a new VHF geostationary beacon sensor exploiting software digital radio technology
  - Much greater capability (10x), much less costly (1/10) than existing hardware receiver
  - Enables sensor proliferation→ sustenance for data-starved models!
  - Plan is to adopt technology for other RF monitoring systems (e.g., C/NOFS beacon receiver)

Space Science across Africa

AFRL hopes to develop 10-12 new sites in Africa & Asia over the next 2 years

- Scintillation activity across Africa assumed high based on satellite observations, but ground-based measurements are needed
- UN Basic Space Science Initiative (BSSI) focused on IHY 2007-2011
- AFRL participation in UN-sponsored workshop to identify host nation partners & collaborators
- Goal is to establish robust monitoring network with scientific collaboration across Africa and Asia



Adapted from S.Y. Su, 2005

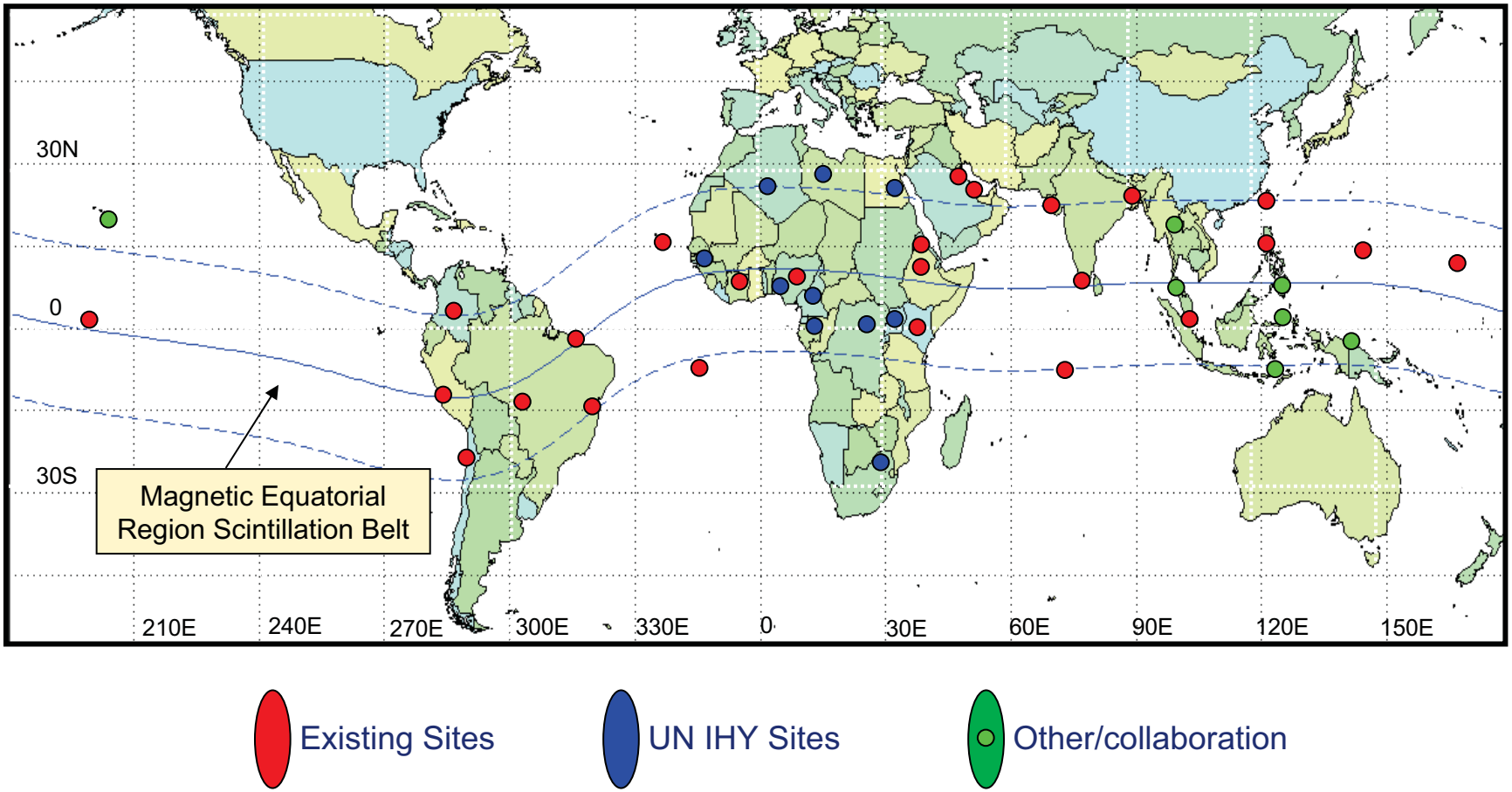
2nd SCINDA IHY Workshop in Ethiopia

Purpose: Train participants in equatorial ionospheric physics and SCINDA sensor installation, operation and maintenance

- Held 11 Nov 07 - more than 50 participants; 12 nations represented
- Visited Ethiopia installations to verify site quality
- More than 10 new sites planned across Africa
- Plan to conduct 3nd workshop in Zambia in June 2009

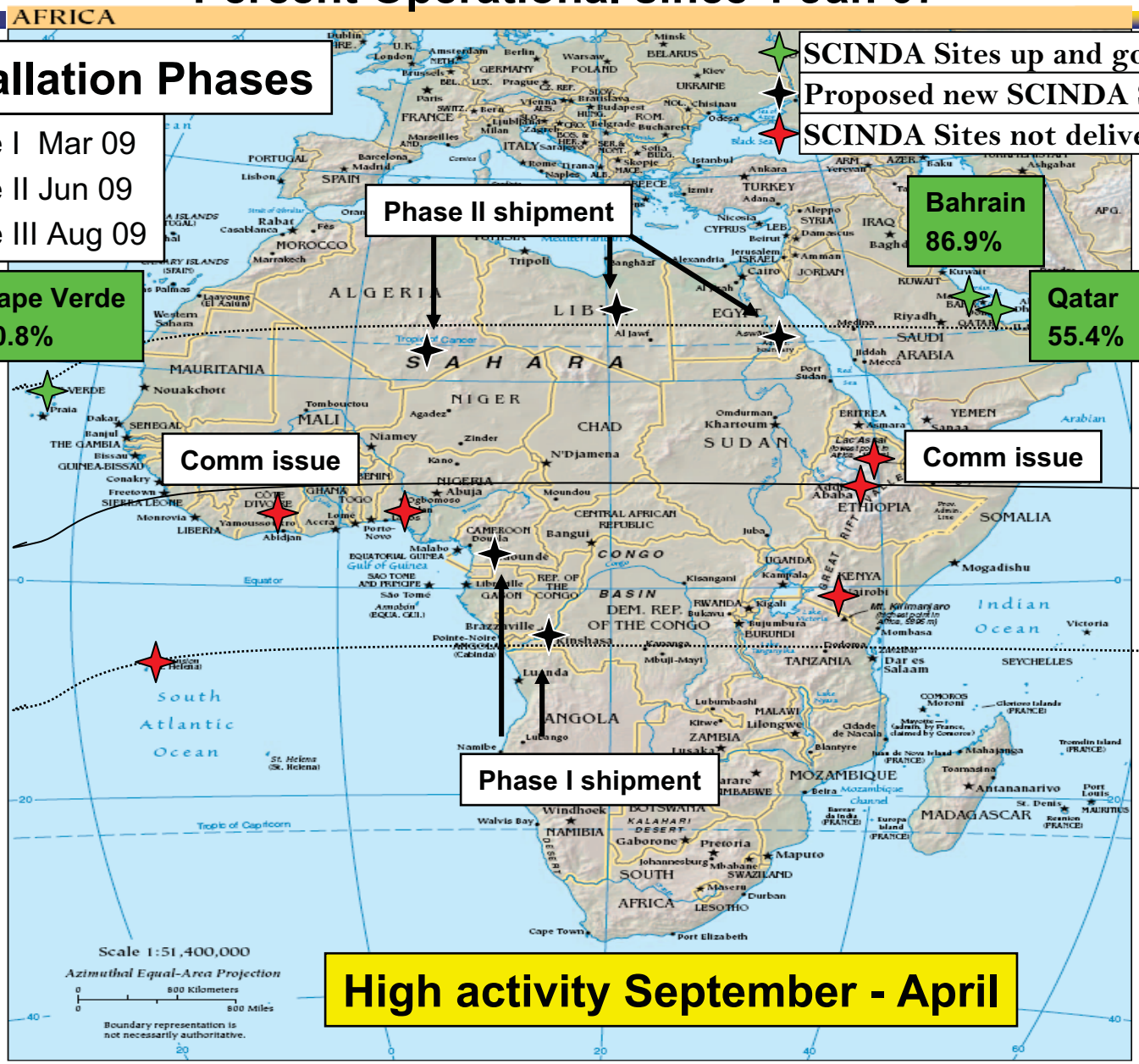
SCINDA Ground Stations

Present and anticipated thru 2009



Sites in Africa

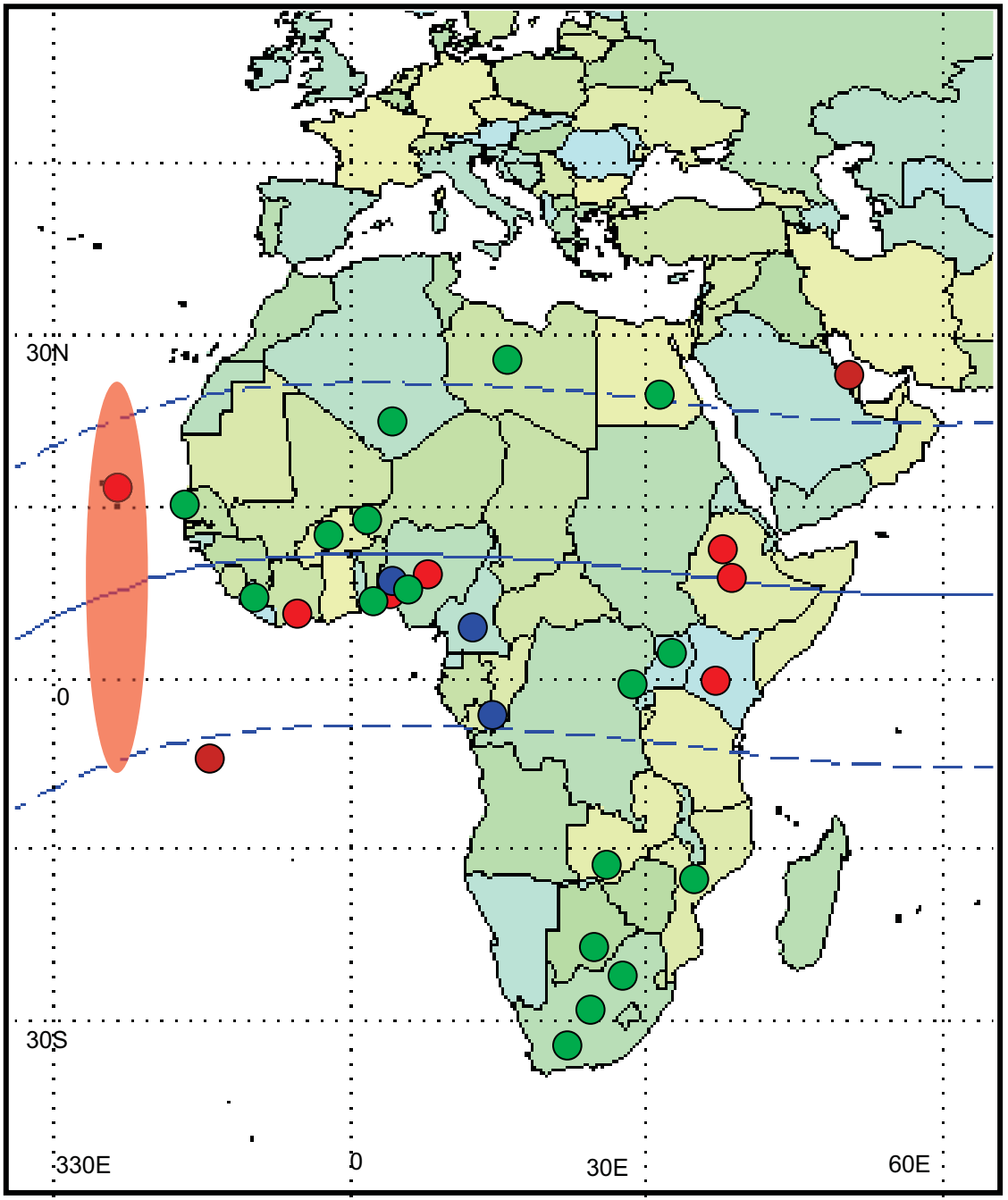
Percent Operational since 1 Jan 07



SCINDA Africa Network
Existing Sites

1. Sal, Cape Verde,
   Mr. Jose Pimenta Lima
2. Abidjan, Ivory Coast,
   Dr. Olivier Obrou
3. Akure, Nigeria,
   Dr. Babatunde Rabiu
4. Lagos, Nigeria,
   Dr. Larry Amaeshi
5. Addis Ababa, Ethiopia,
   Dr. Gizaw Mengistu
6. Bahir Dar, Ethiopia,
   Dr. Baylie Damtie
7. Nairobi, Kenya,
   Dr. Paul Baki

- Pre-2006 SCINDA sites
- Existing IHY Sites
- Planned IHY Sites 2008
- Potential IHY Sites 2009



New Sites Expected by June 09

Yaounde, Cameroon
Dr. Guemene Dountio
Dr. Cesar Mbane

Congo Brazzaville
Dr. Dinga Bienvenue

- Provides coverage in important Central African area

Geographic coordinates of the Abidjan GPS receiver

Source: O. Obrou

Dr. Olivier Obrou, P.I.

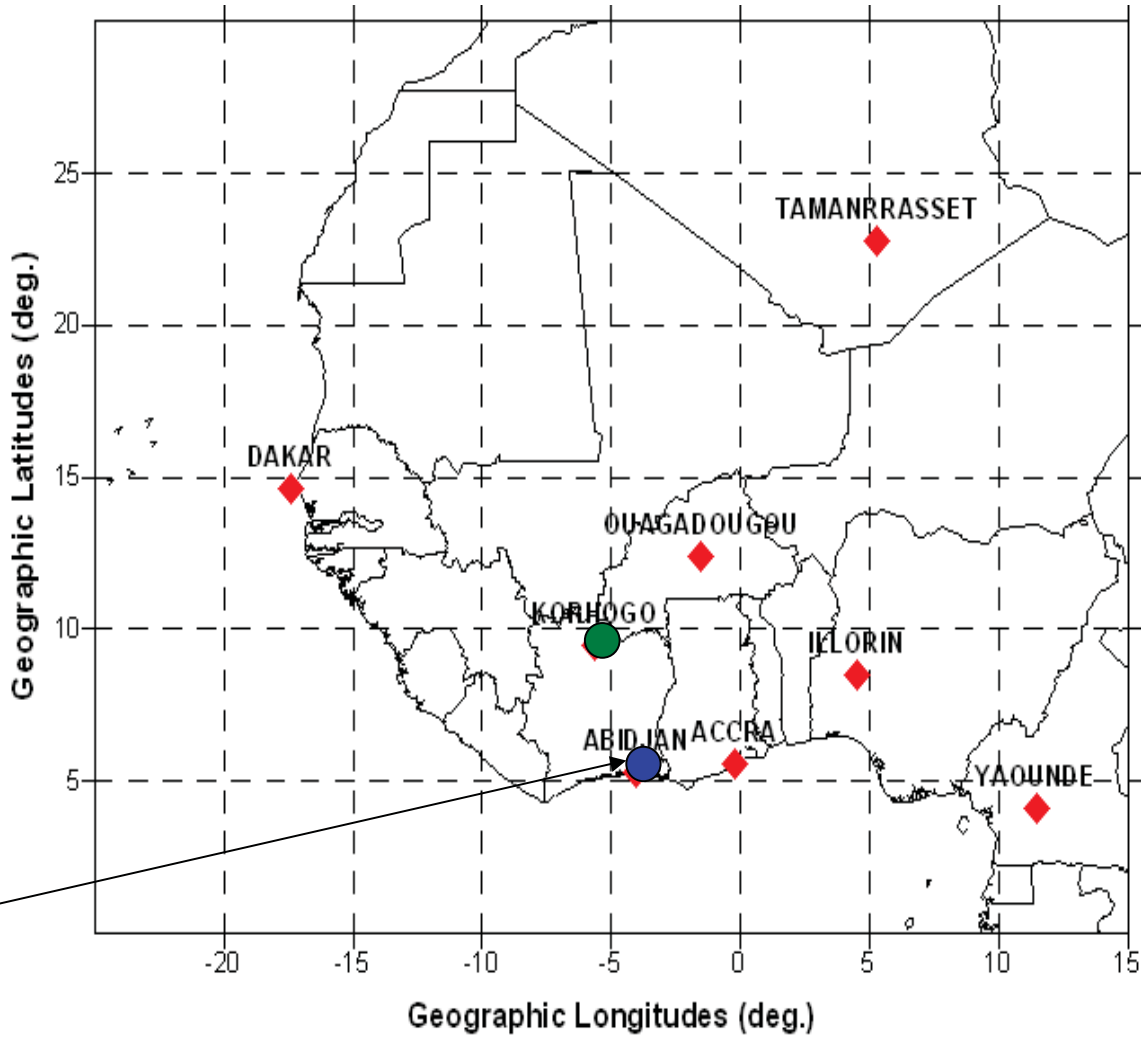
GPS receiver

Lat = 5.35°N

Long =-3.98°W

dip = -10.18°S

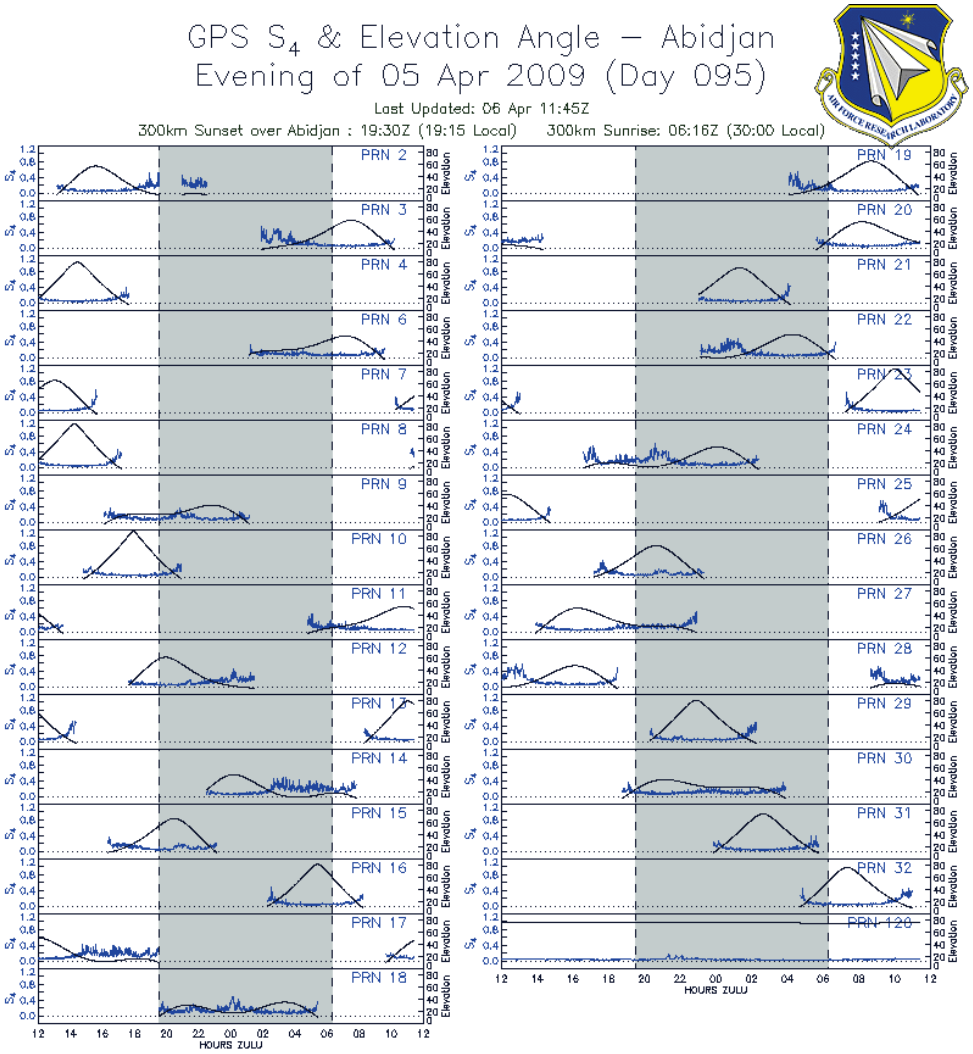
Abidjan, Ivory Coast



GPS RECEIVER AND ACQUISITION SYSTEM
Abidjan

Source: O. Obrou

North side of the Building


GPS S4 & Elevation Angle – Abidjan
Evening of 05 Apr 2009 (Day 095)
Last Updated: 06 Apr 11:45Z
300km Sunset over Abidjan : 19:30Z (19:15 Local)
300km Sunrise: 06:16Z (30:00 Local)
PRN 2
PRN 3
PRN 4
PRN 6
PRN 7
PRN 8
PRN 9
PRN 10
PRN 11
PRN 12
PRN 13
PRN 14
PRN 15
PRN 16
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PRN 23
PRN 24
PRN 25
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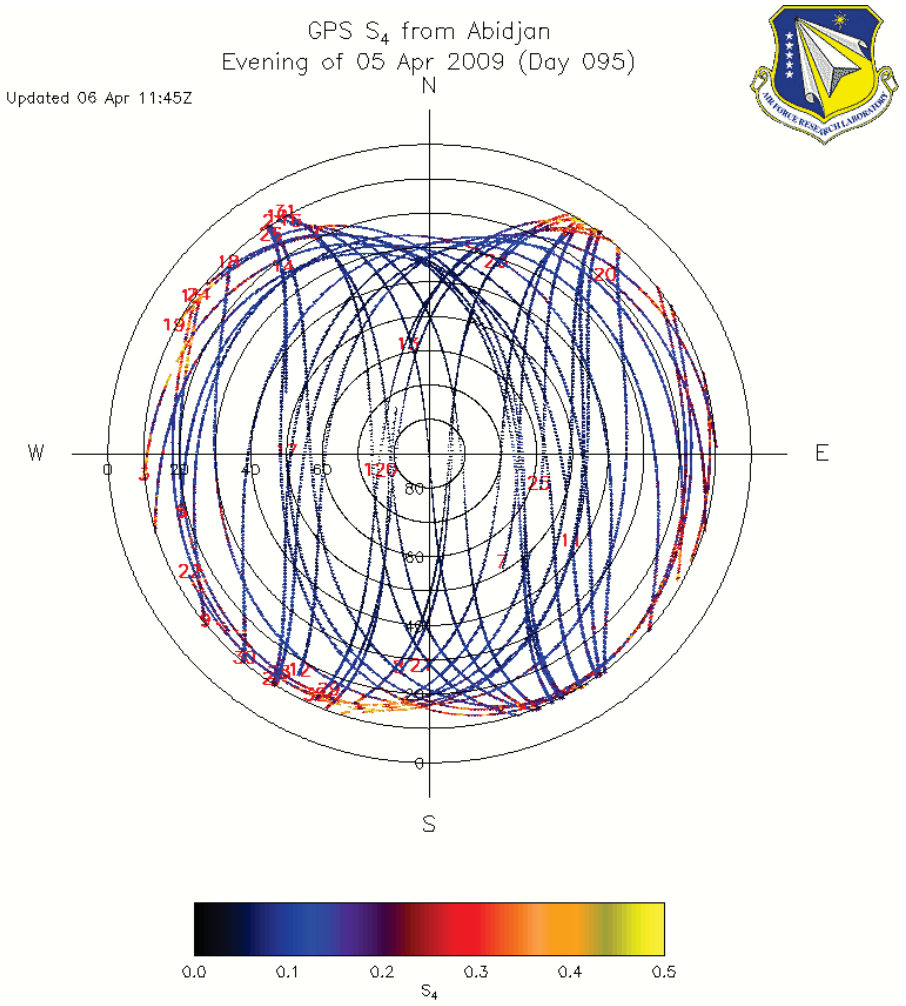
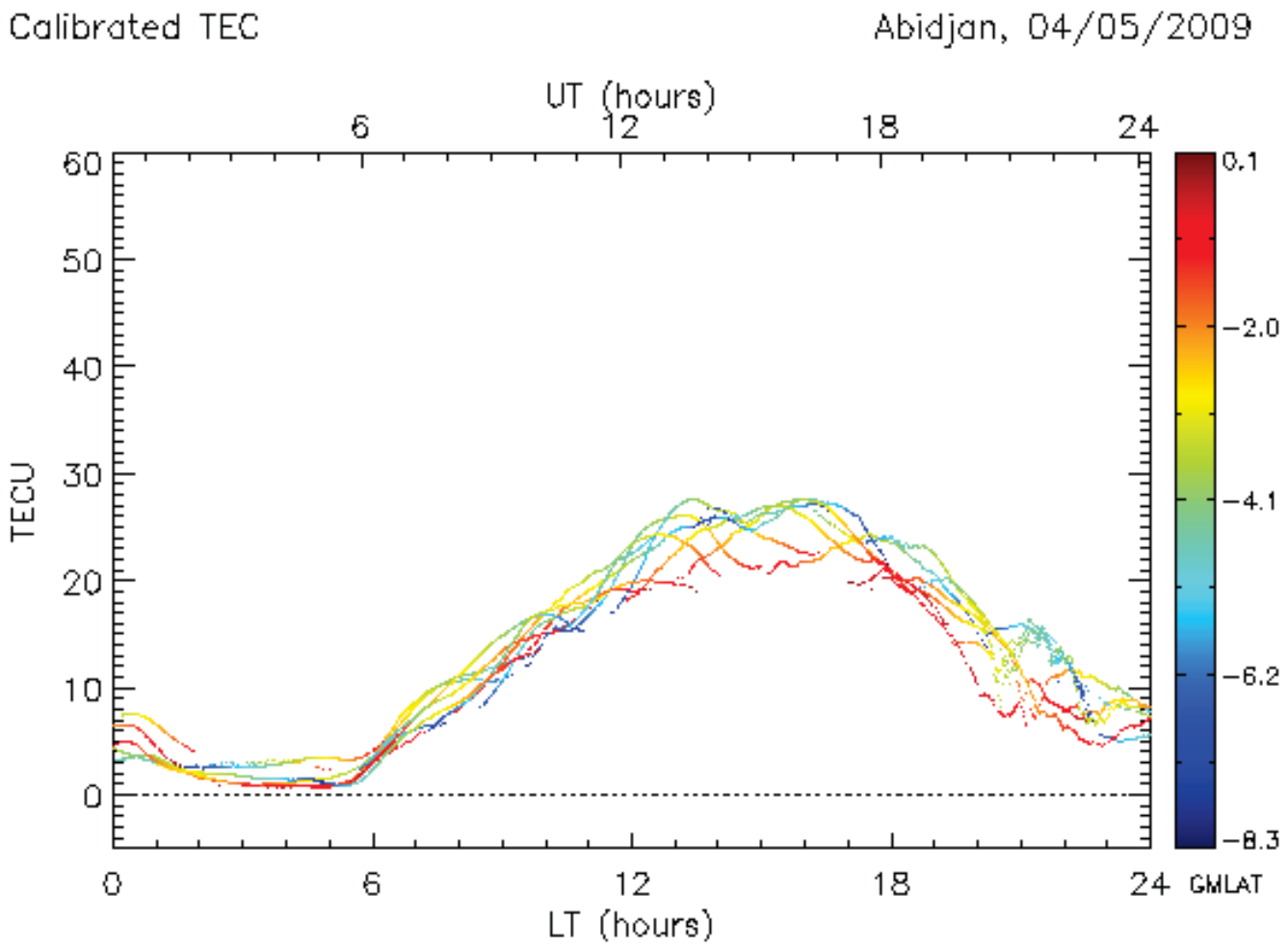
PRN 29
PRN 30
PRN 31
PRN 32
PRN 120
S4
Elevation
HOURS ZULU

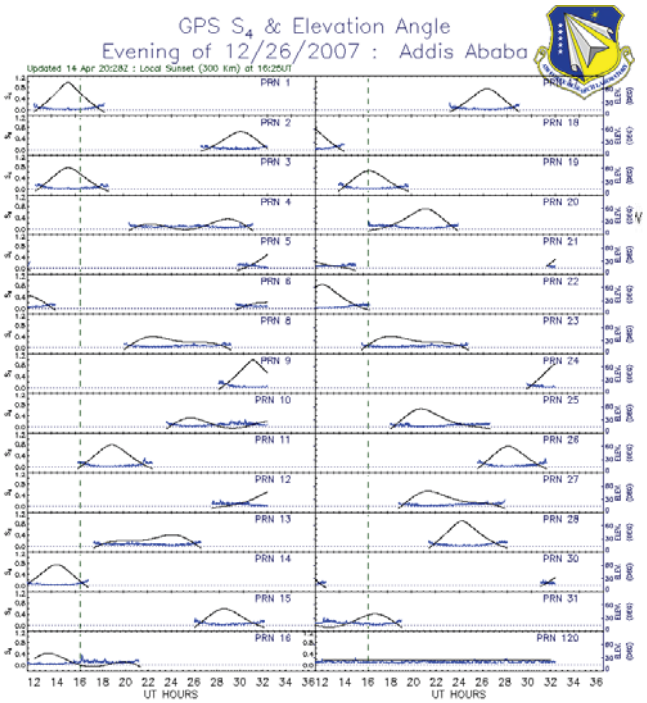

GPS S4 from Abidjan
Evening of 05 Apr 2009 (Day 095)
Updated 06 Apr 11:45Z
N
W
E
S
0
20
40
60
80
0.0
0.1
0.2
0.3
0.4
0.5
S4

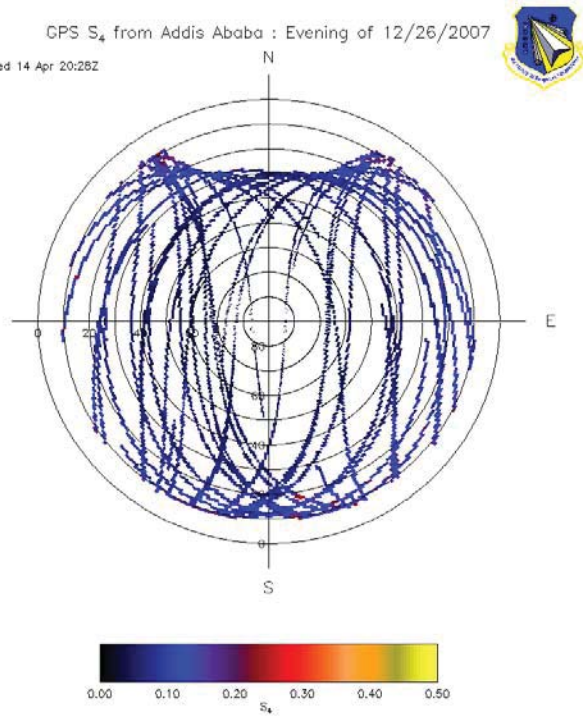
Diurnal variation of TEC over Abidjan

Source: O



Addis Ababa, Ethiopia
Dr. Gizaw Mengistu



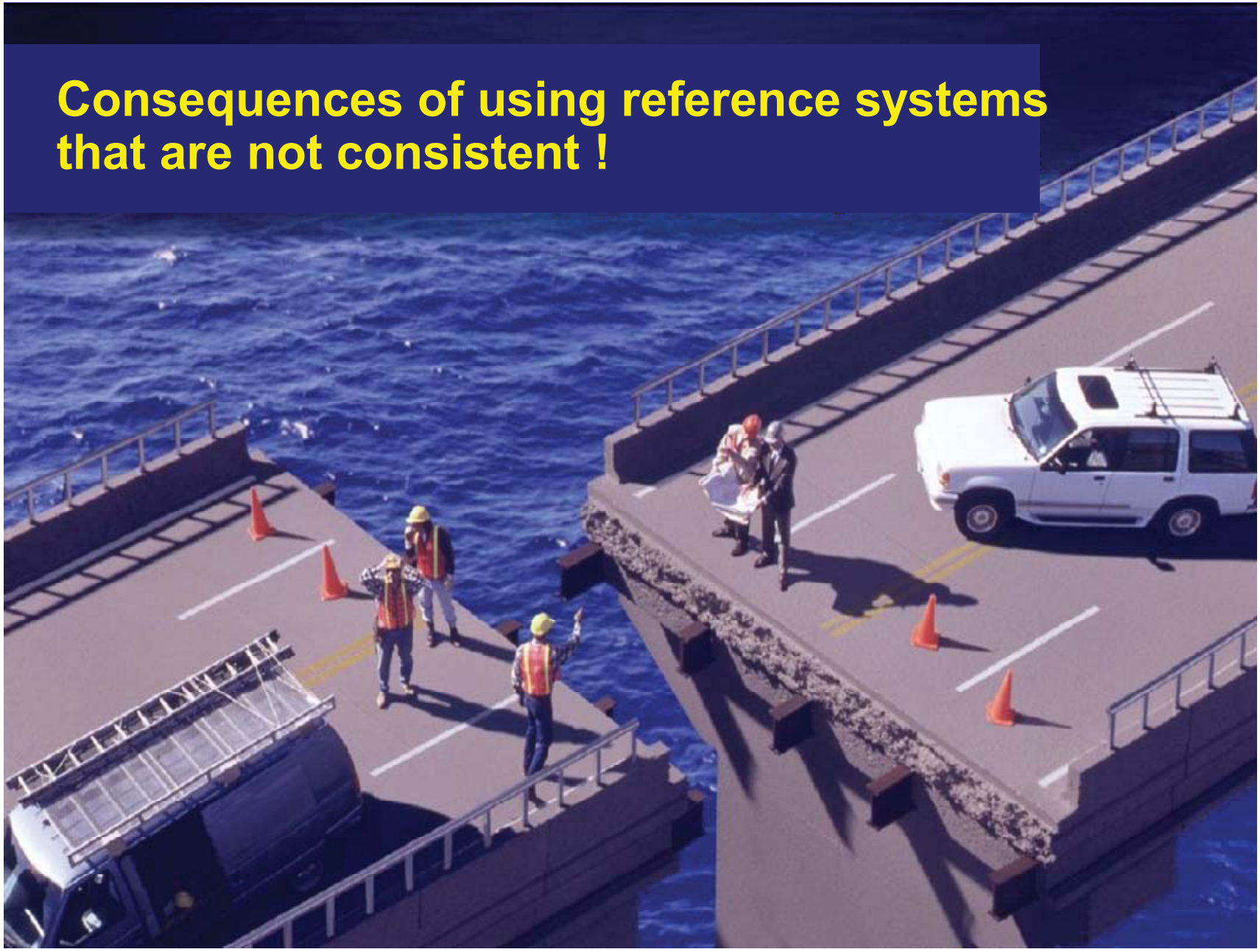


- **Good environment; low multi-path**
- **Real-time comm expected by Jun09**
- **Numerous students involved in various aspects of data analysis & modeling**

Akure, Nigeria
Dr. Babatunde Rabiu

- **Recently initiated real-time observations**
- **Initiated a Center for Space Research**
- **Numerous students involved in various aspects of data**

Consequences of using reference systems that are not consistent !



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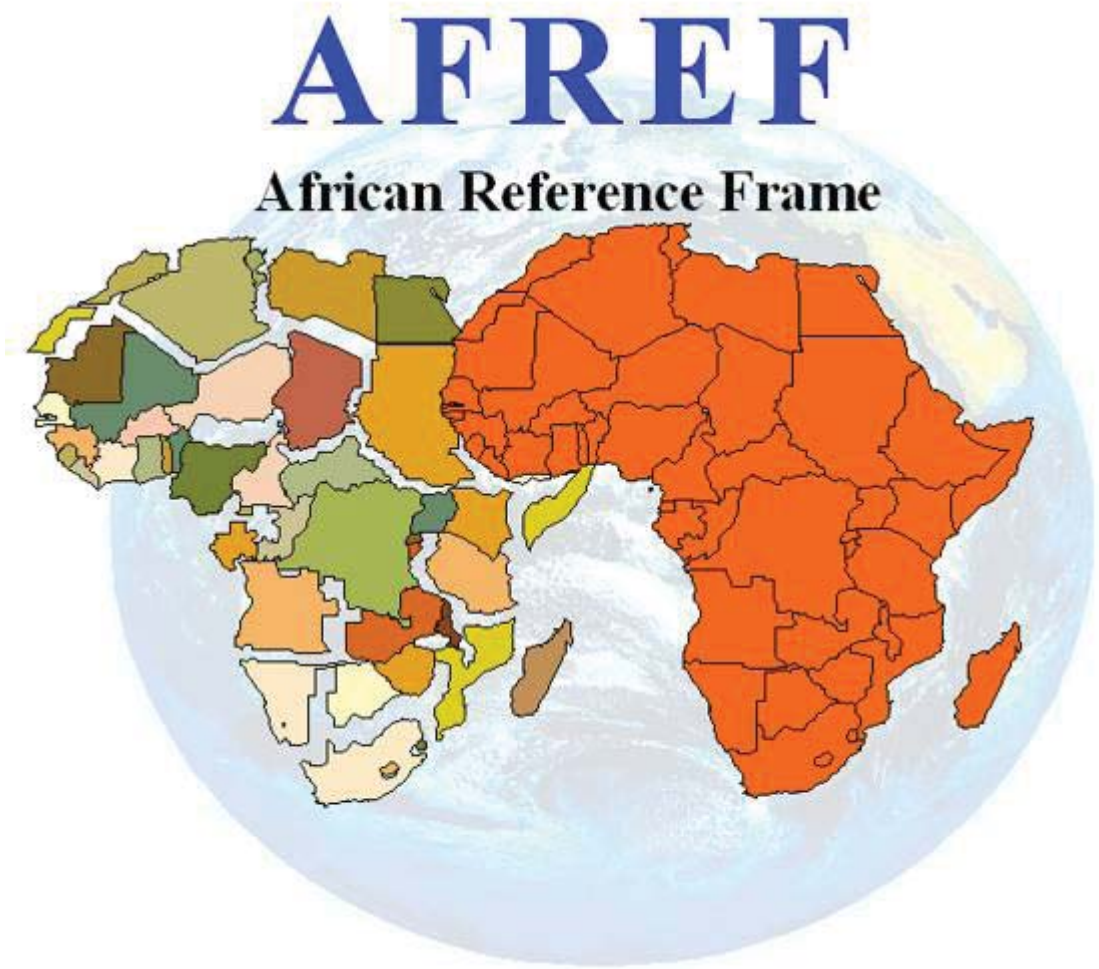
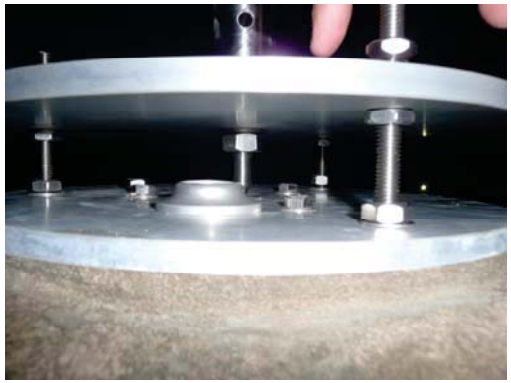


- African initiative to unify the different datums

New Requirements for SCINDA GPS Installations

"Monumented" Installation to support Geodetic & other communities

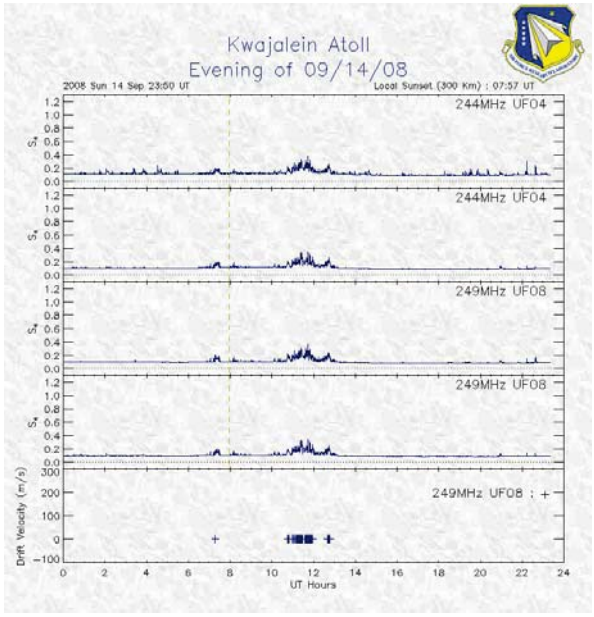


– Sharing sensors to leverage efforts

Not a lot of extra effort for a lot of extra benefit

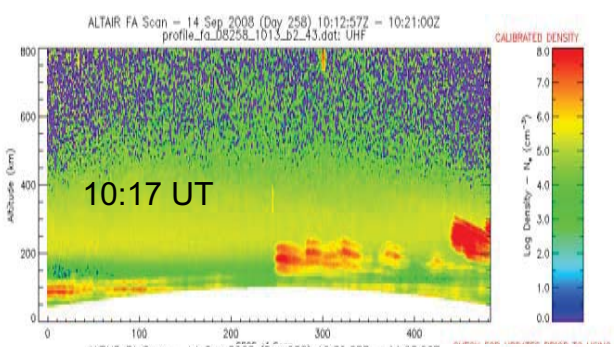
Common Observation Periods
C/NOFS & ALTAIR

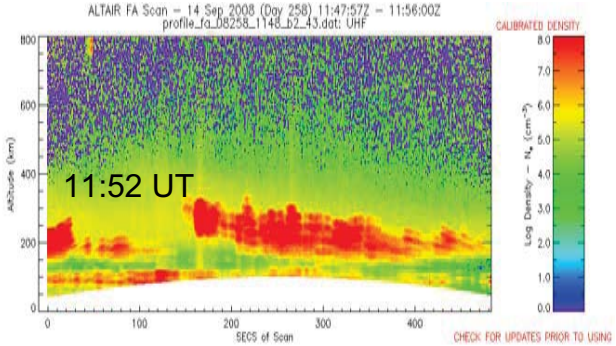
- **Both systems operating Sep 14, 15, 27, 28, & 29**

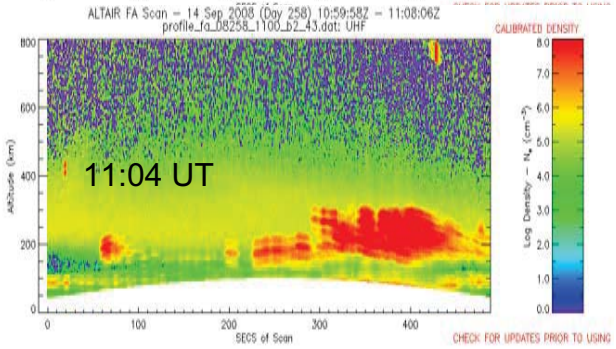


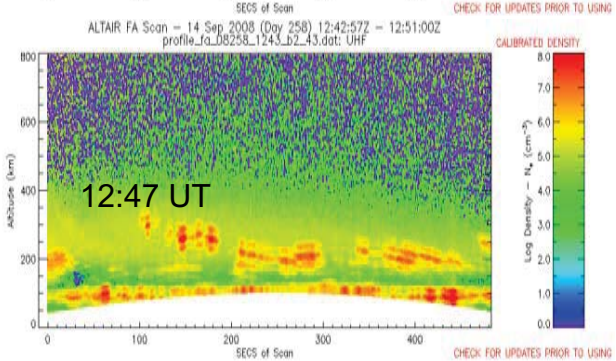
VHF S4

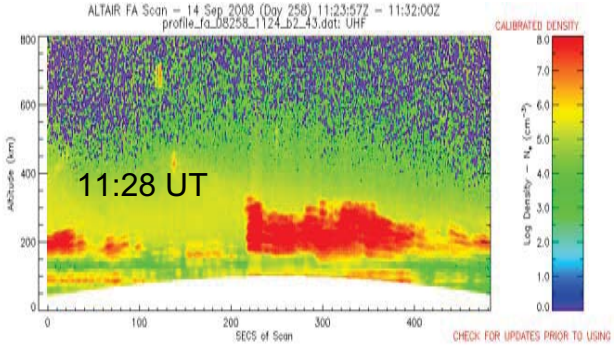
Sep 14 2008 Day 258

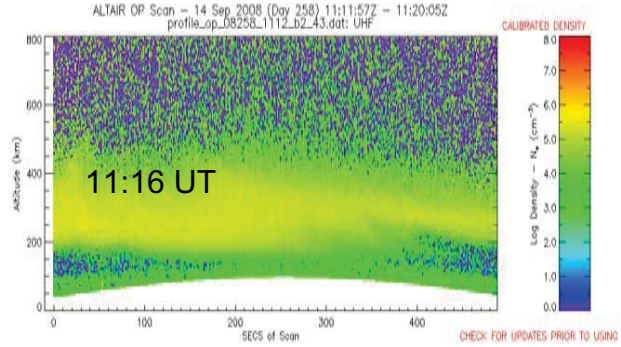




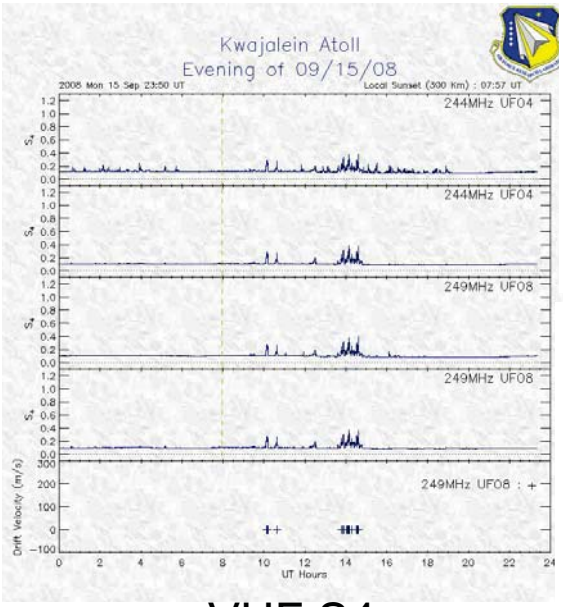




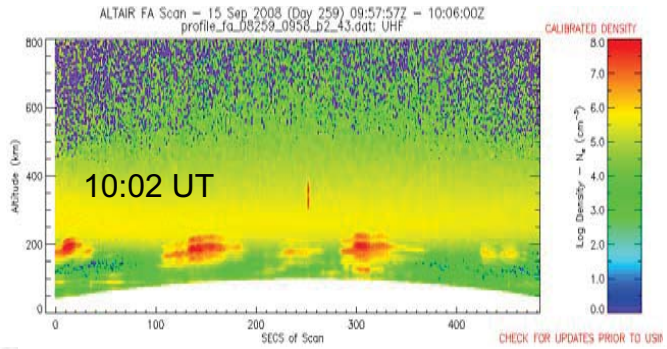


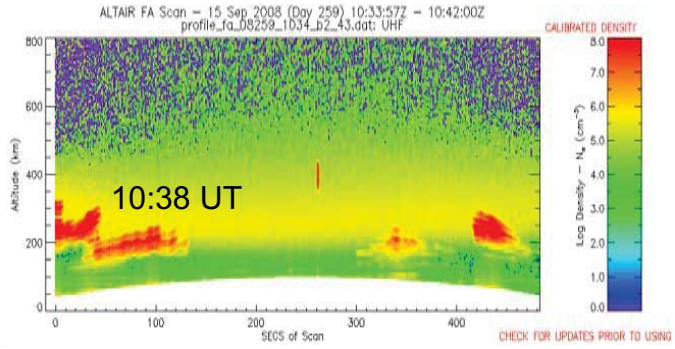


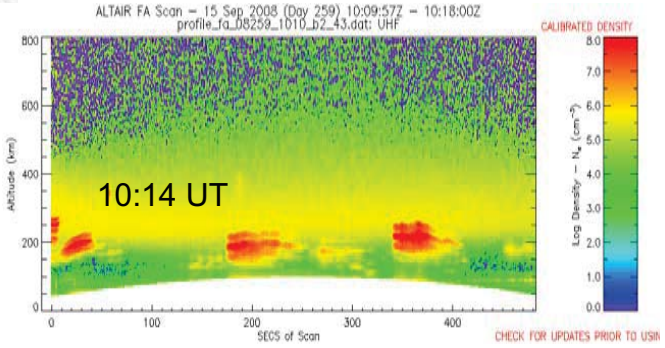
Common Observations
15 Sep 2008

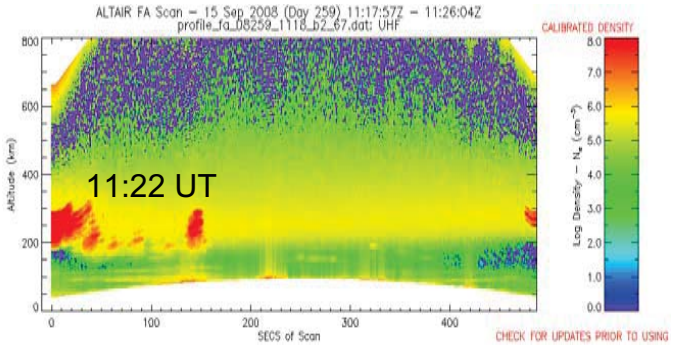


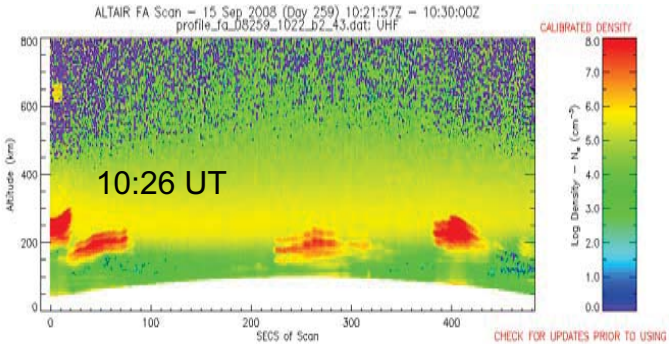
VHF S4

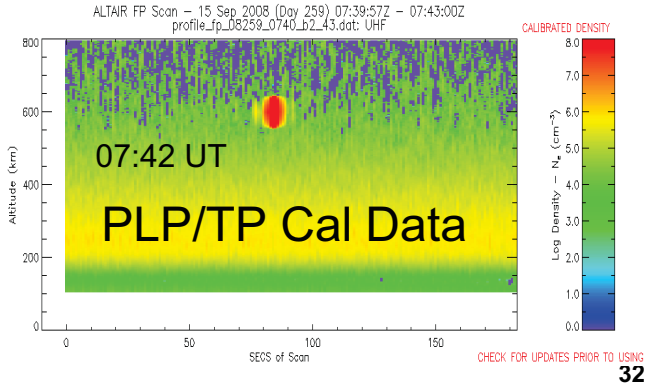




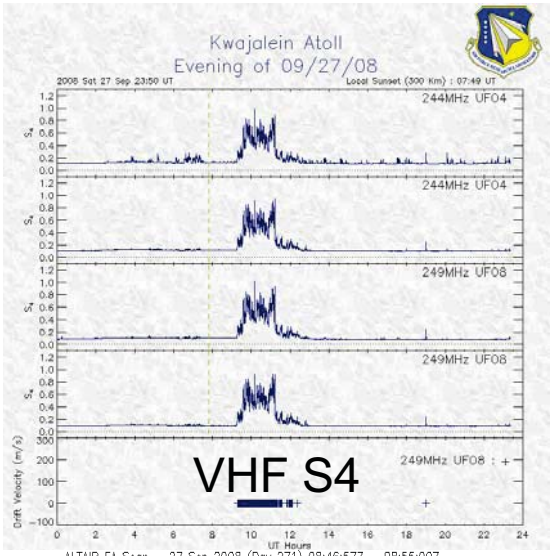


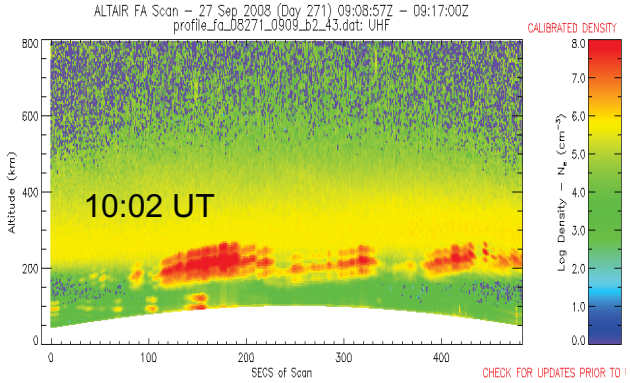


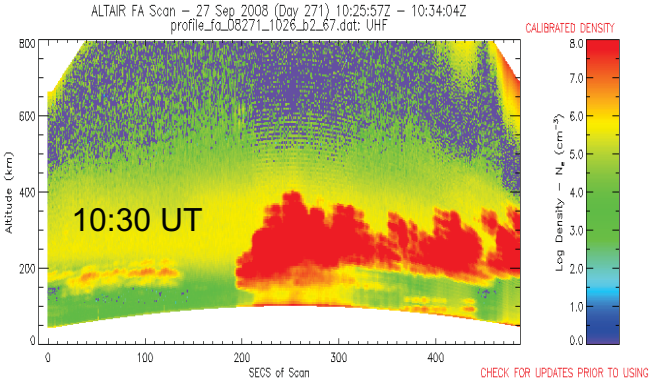


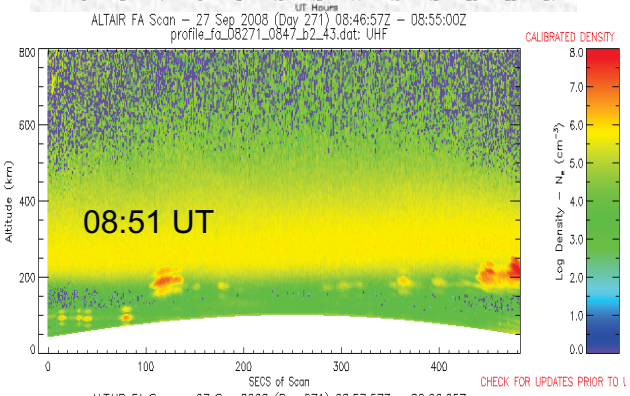


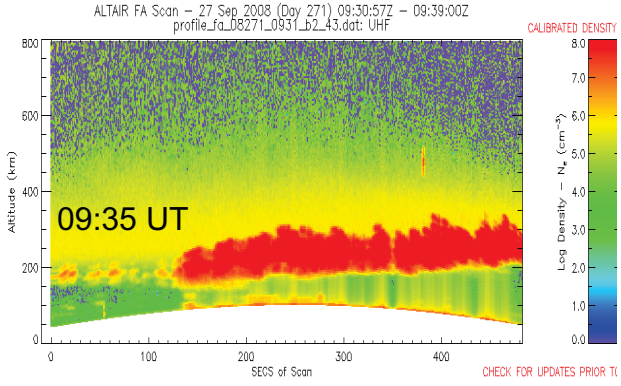
Common Observations
27 Sep 2008

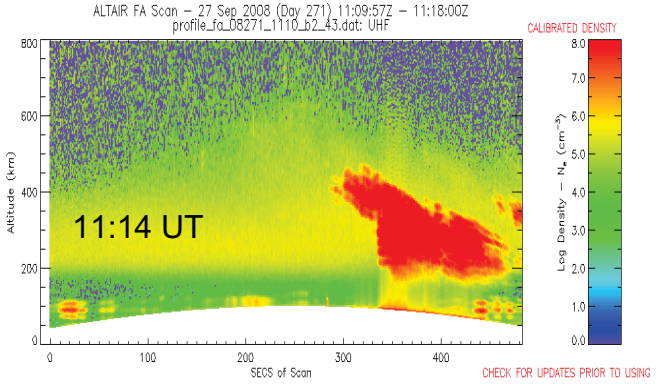


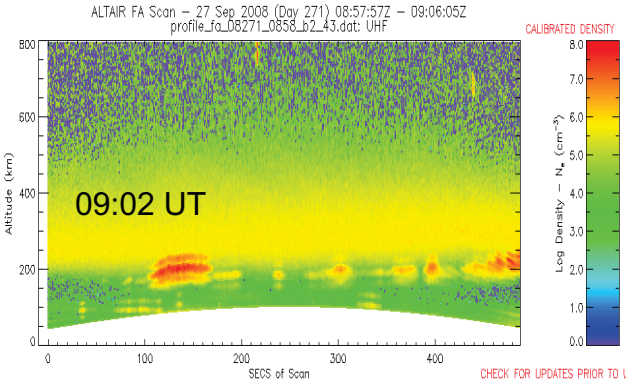


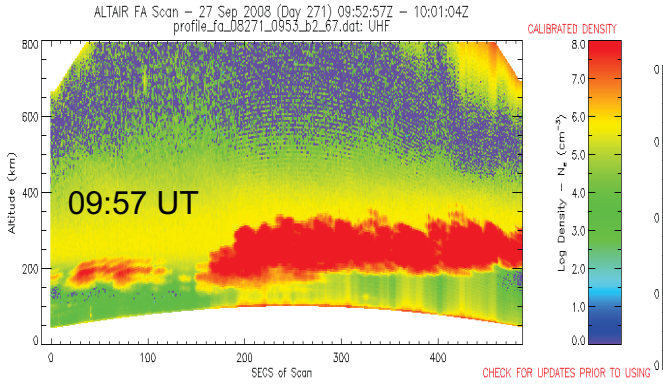


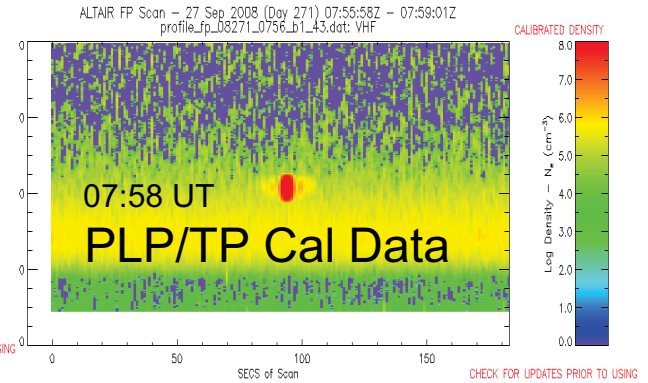




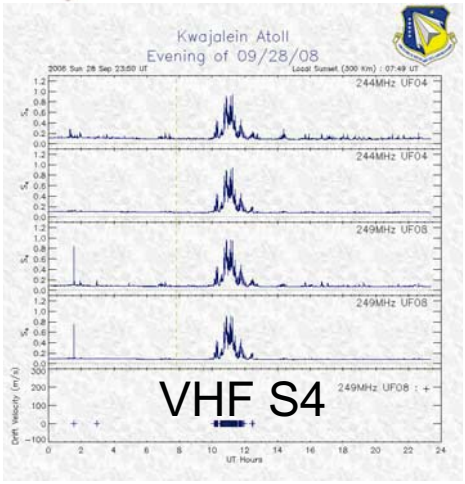


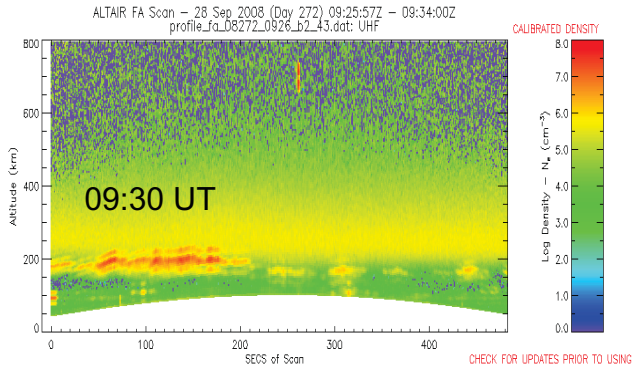


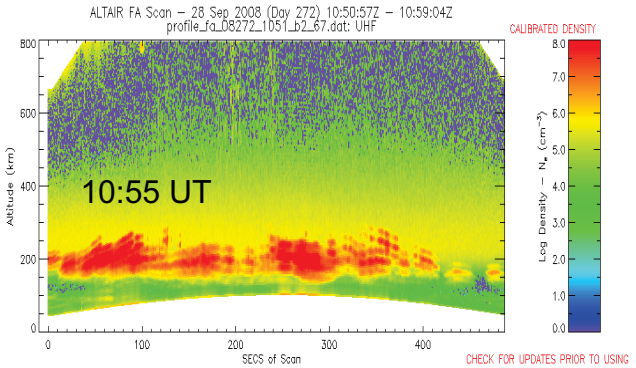


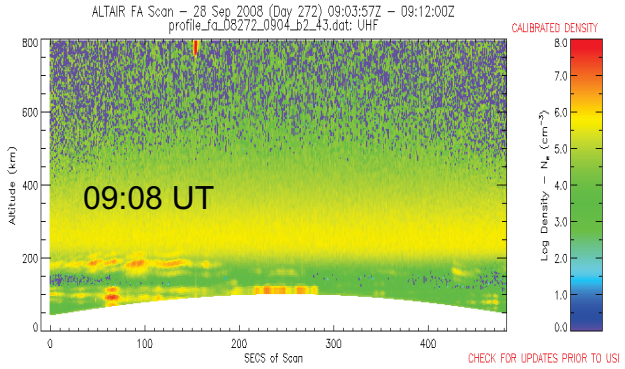


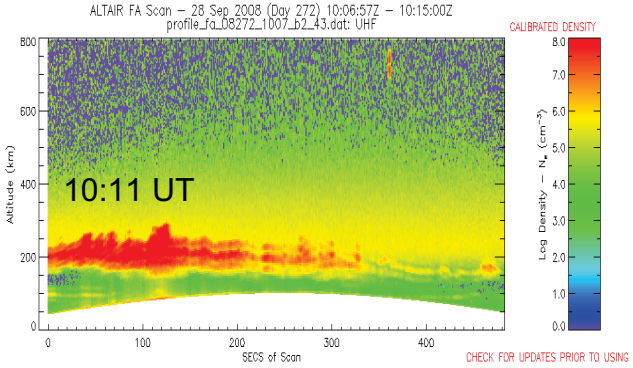
Common Observations
28 Sep 2008

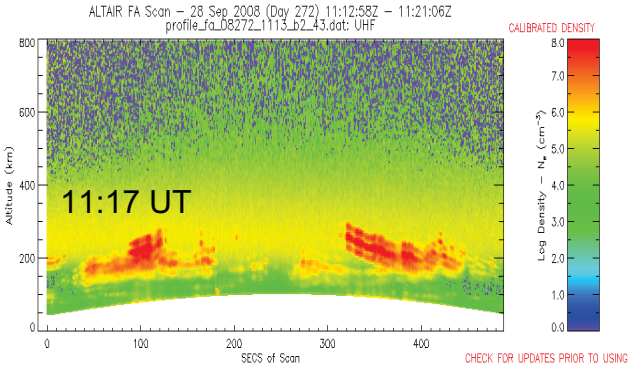


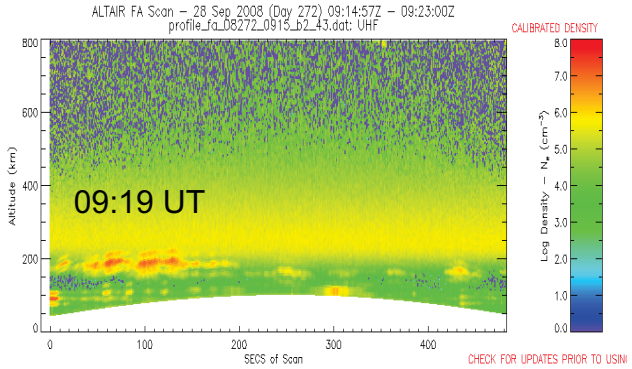


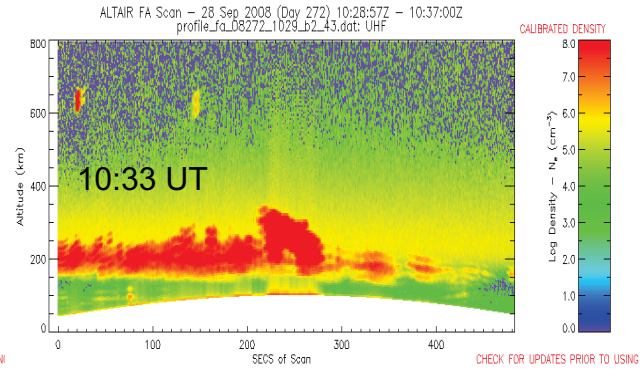


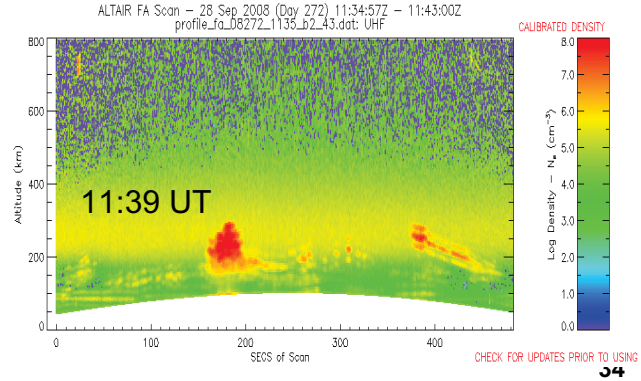


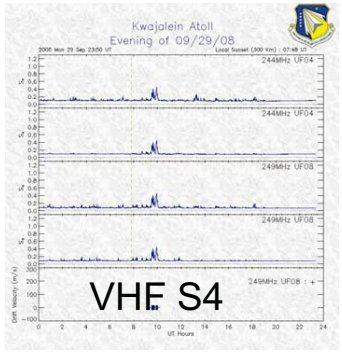




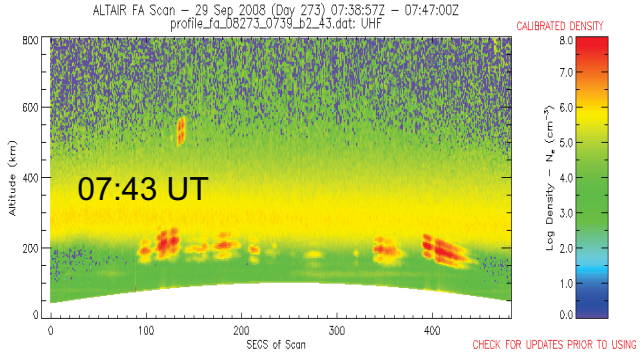


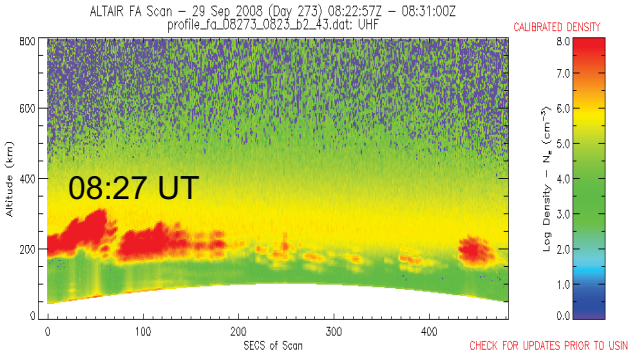


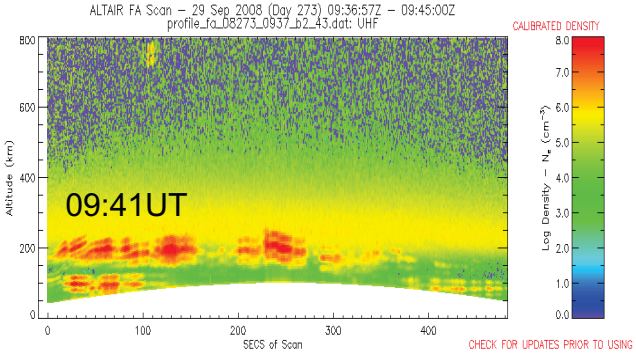


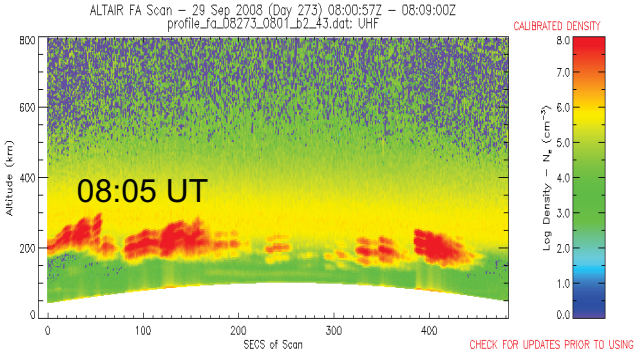


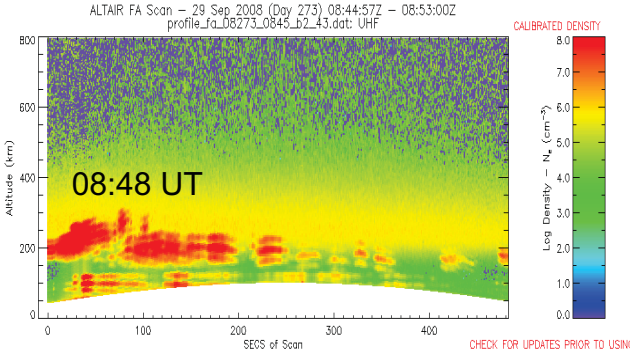
Common Observations
29 Sep 2008

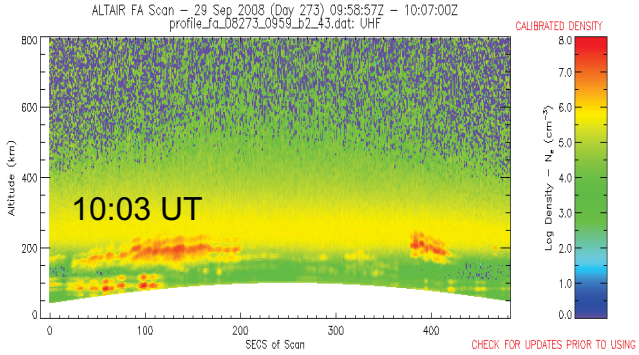


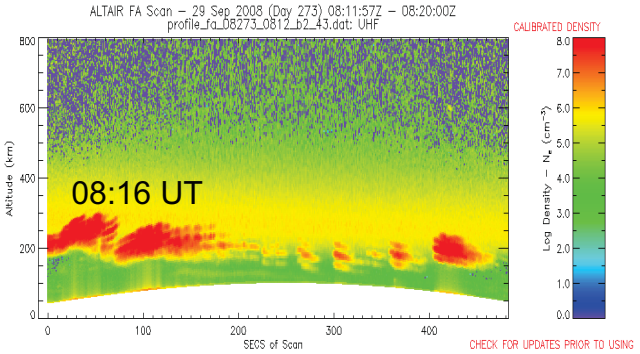


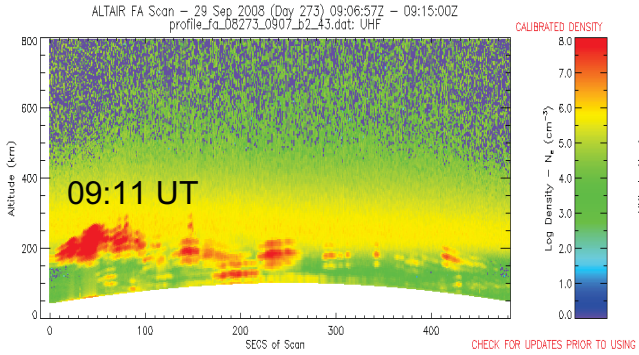


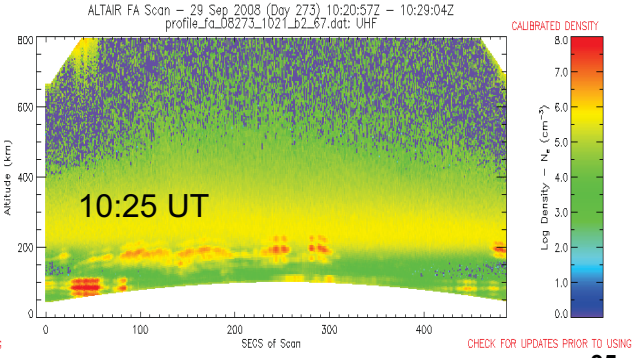








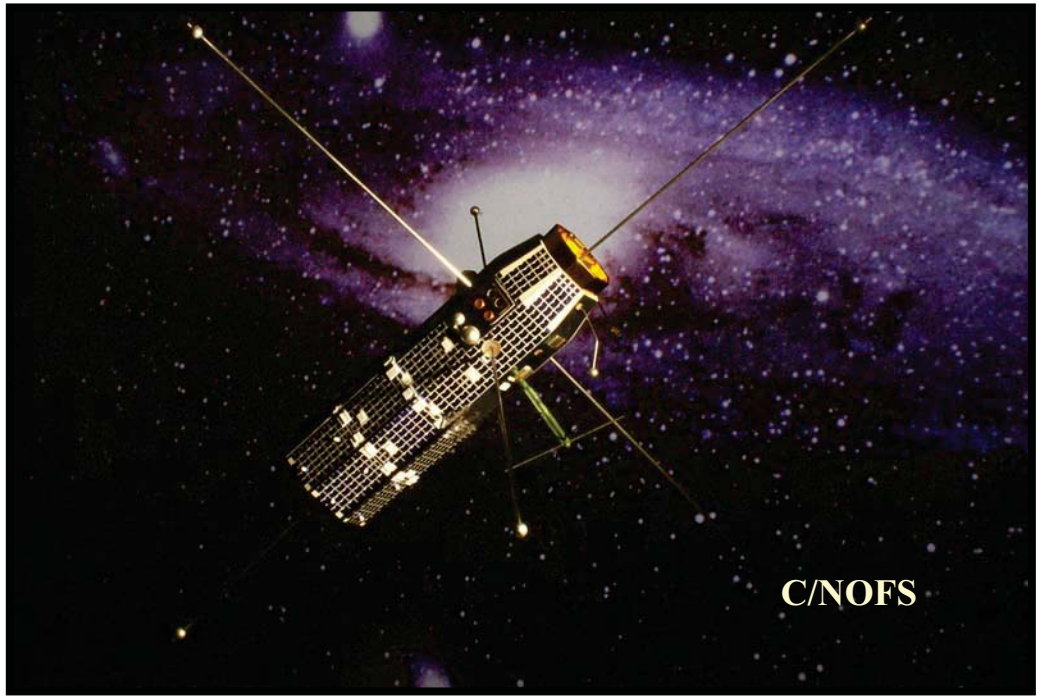




Communication/Navigation Outage Forecasting System

C/NOFS

First-ever system for continuous global scintillation forecasts of communication and navigation outages

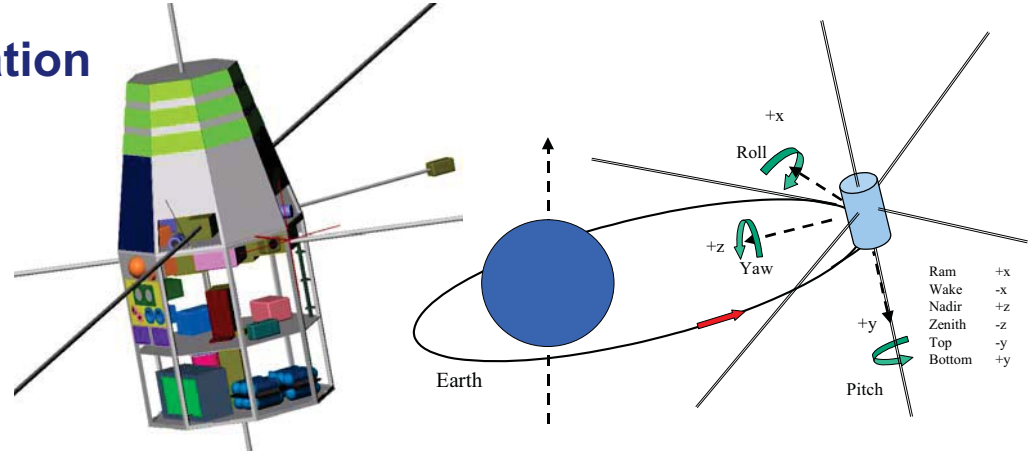


"Forecasting – long denigrated as a waste of time at best and a sin at worst – became a necessity" P. Bernstein, Against the Gods, 98

Communication/Navigation Outage Forecast System (C/NOFS)

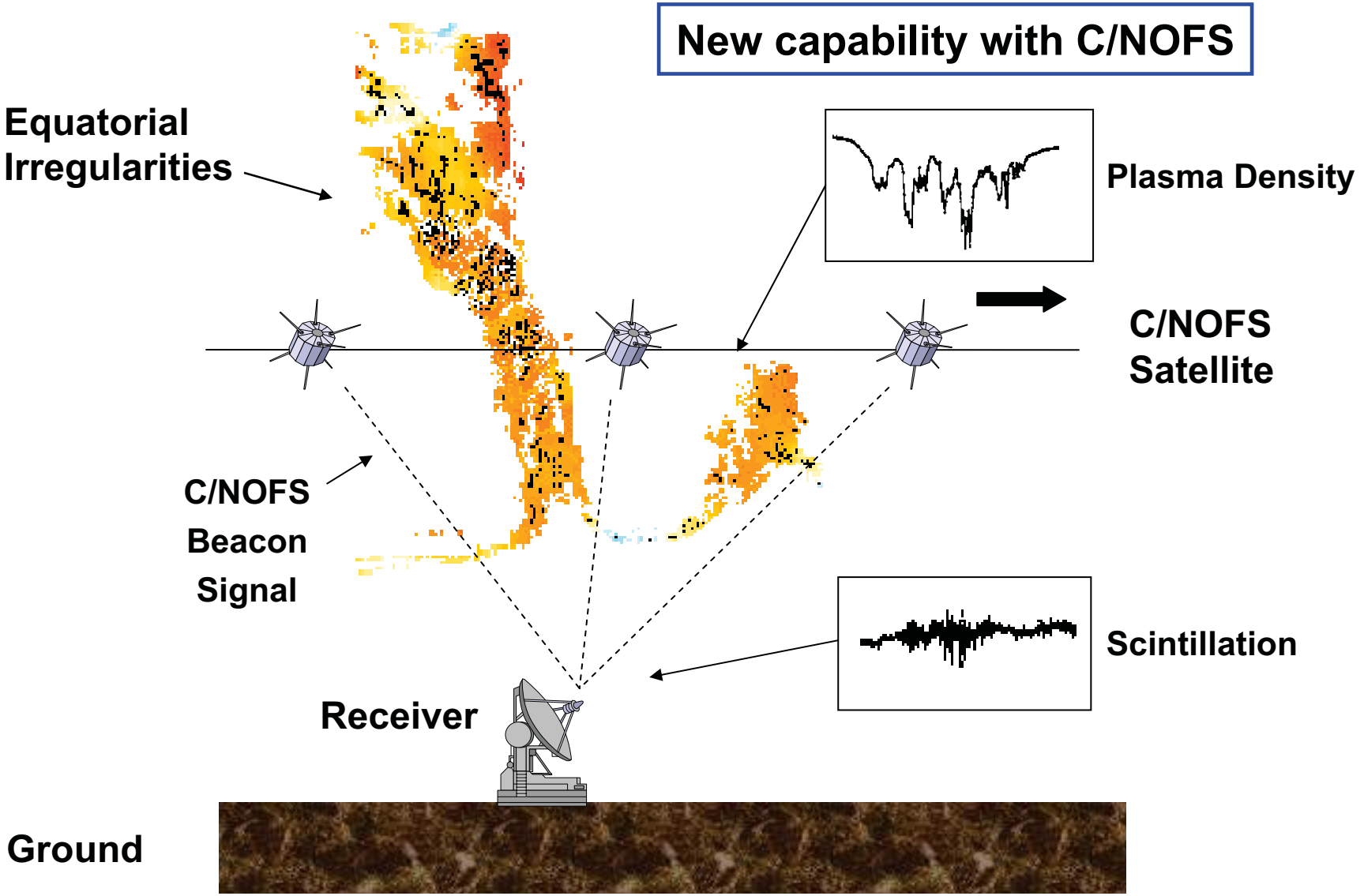
Advanced Concept Technical Demonstration to Forecast Scintillation

- **Satellite – low altitude / low inclination**
  - Inclination: 13 deg (target)
  - Elliptical orbit: 400 x 800 Km
- **Space Vehicle Payload**
  - GPS Occultation Receiver
  - Vector Electric Field Instrument
  - Planar Langmuir Probe
  - Ion Velocity Meter, Neutral Wind Meter
  - Multi-frequency radio beacon
- **Launched 14 Apr 2008**
- **System still in check-out phase; all sensors' operation nominal**
- **ALTAIR ionospheric data collection for sensor V&V already started**

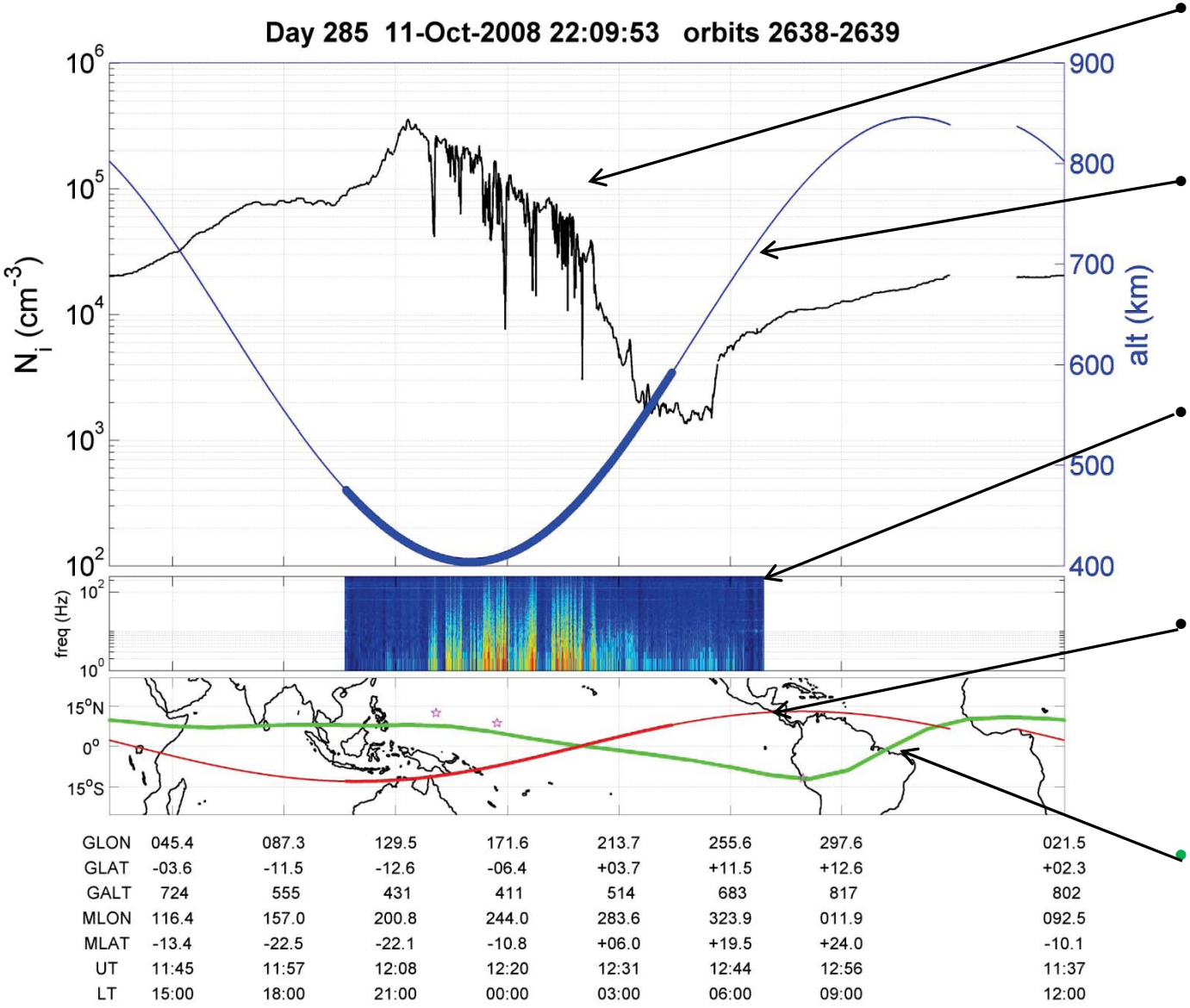


What Is "Calibration" Role?

Ground Measurements vs. In Situ



C/NOFS Planar Langmuir Probe (PLP) Electron Density Data



PLP in-situ densities

- 1 sec averages

Altitude

- Sunlight
- **Eclipse**

Spectrogram of PLP High Rate Data

- **0-256 Hz**

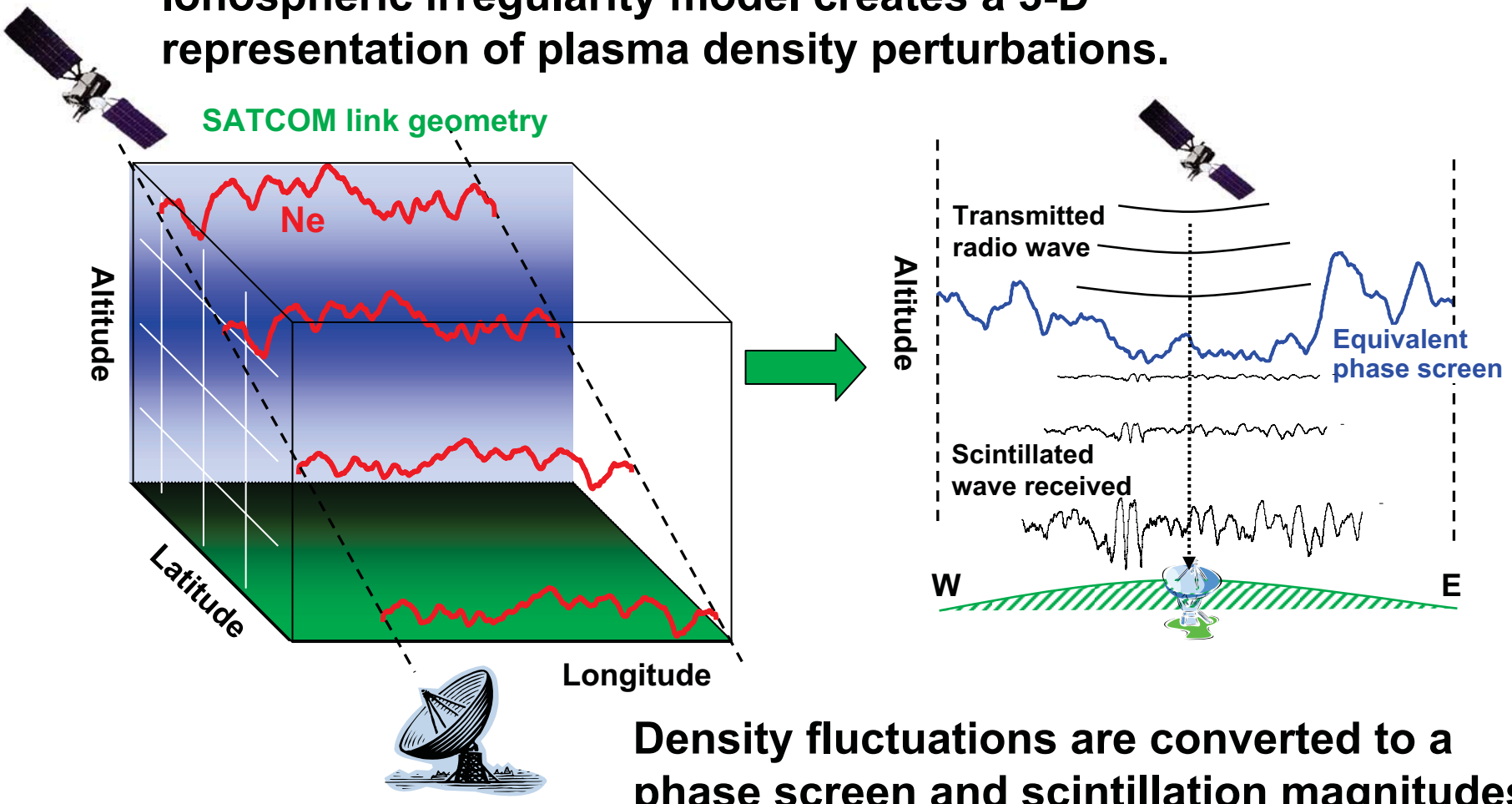
Ground Track

- Sunlight
- **Eclipse**

Magnetic Equator

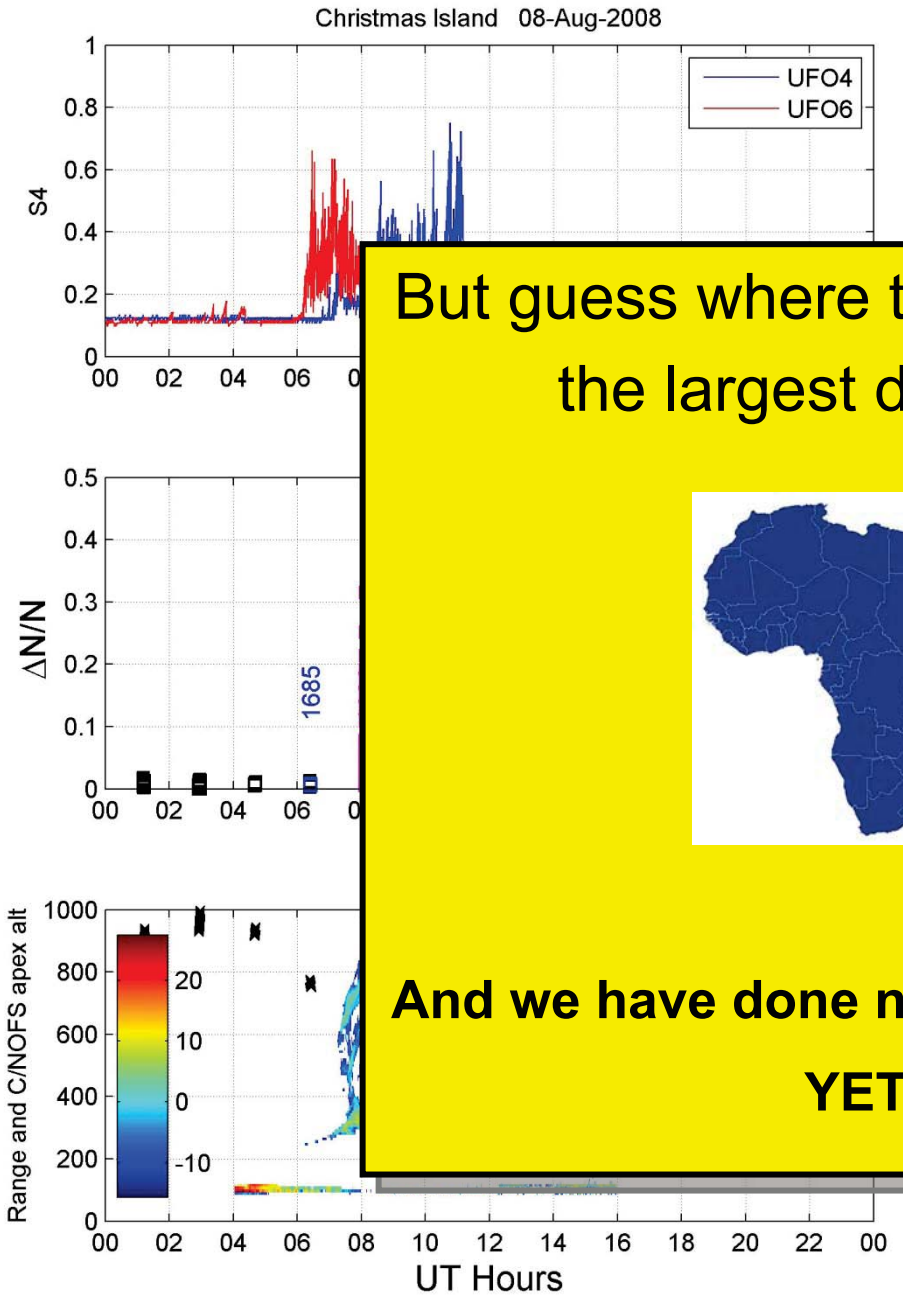
Space-Based Nowcasts
Phase Screen Scintillation Estimation

Ionospheric irregularity model creates a 3-D representation of plasma density perturbations.

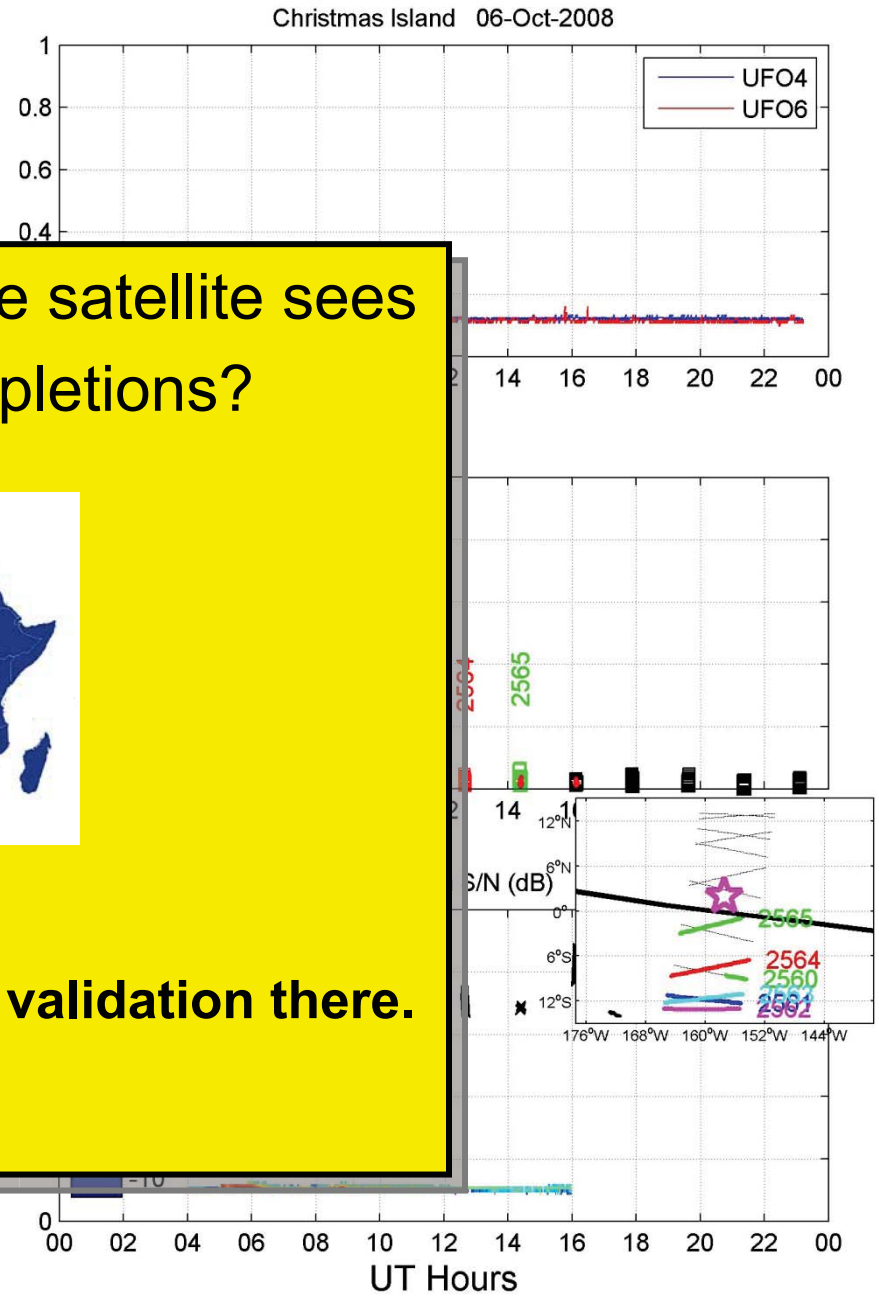


Density fluctuations are converted to a phase screen and scintillation magnitudes are estimated at desired frequencies along orbit trajectory

Agreement – Active Night



Agreement – Quiet Night

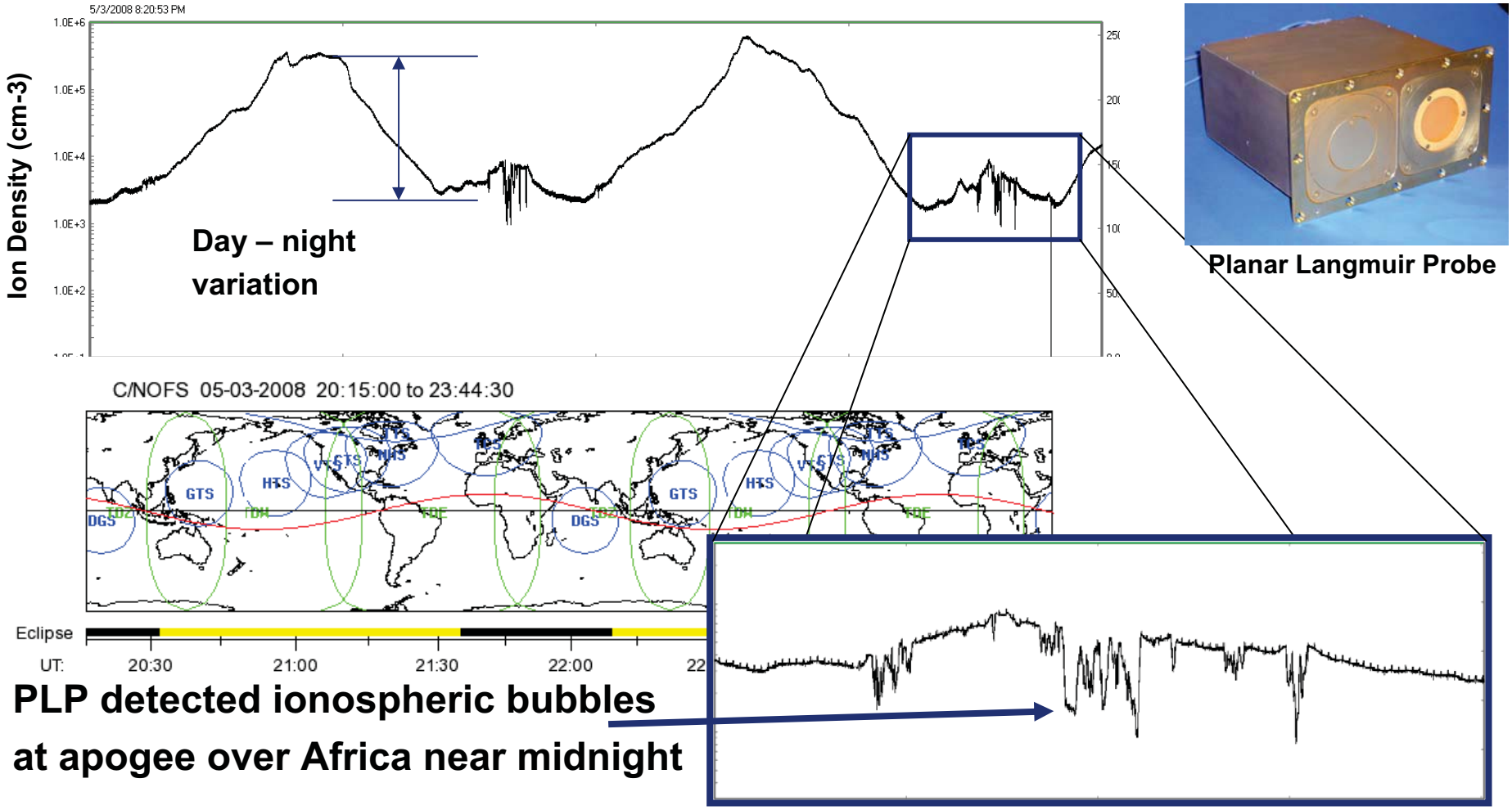


But guess where the satellite sees the largest depletions?

And we have done no validation there.

YET!

C/NOFS – Planar Langmuir Probe
First Detection of Ionospheric Bubbles



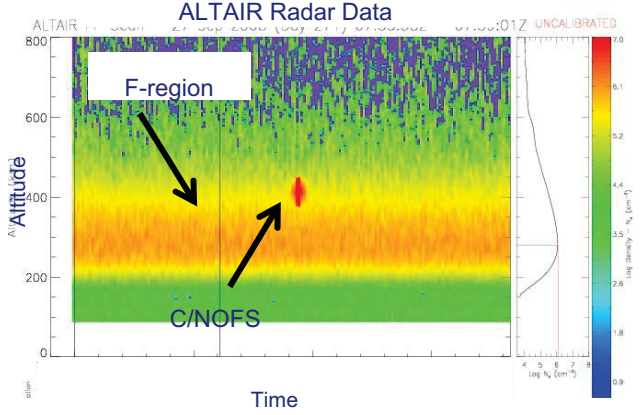
These ionospheric structures cause Com/Nav signal degradation and loss

C/NOFS Forecast Validation:
ALTAIR Campaign First Results

27 September 2008

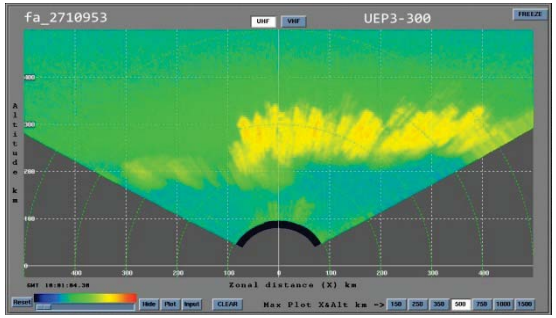
C/NOFS passed through F-region just after sunset; ideal forecast conditions

ALTAIR Radar Data

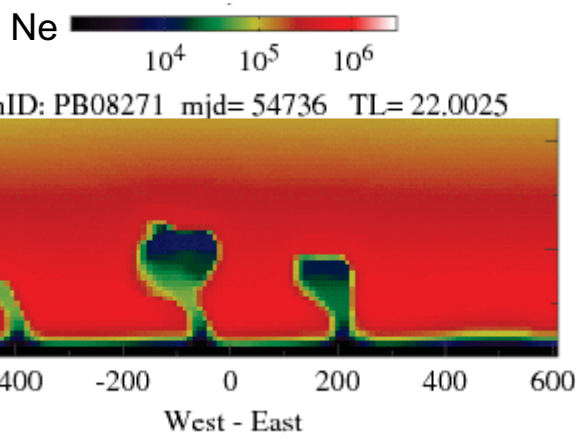


Preliminary results from forecast model run with *ground-based data only*

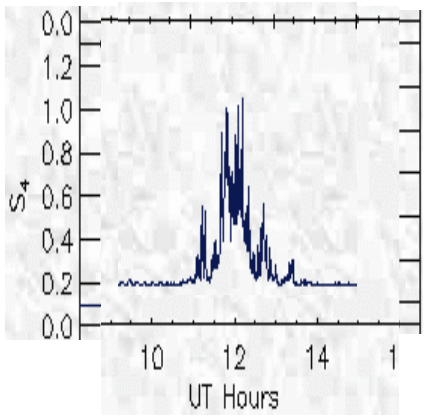
Actual Data



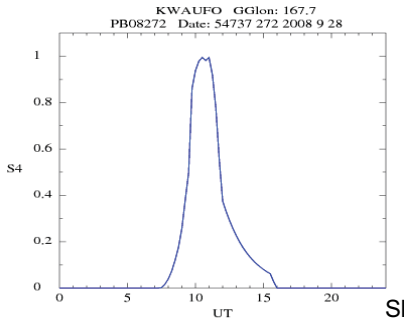
Forecast Model Results



Forecast instability consistent with data



UHF SATCOM scintillation levels predicted correctly

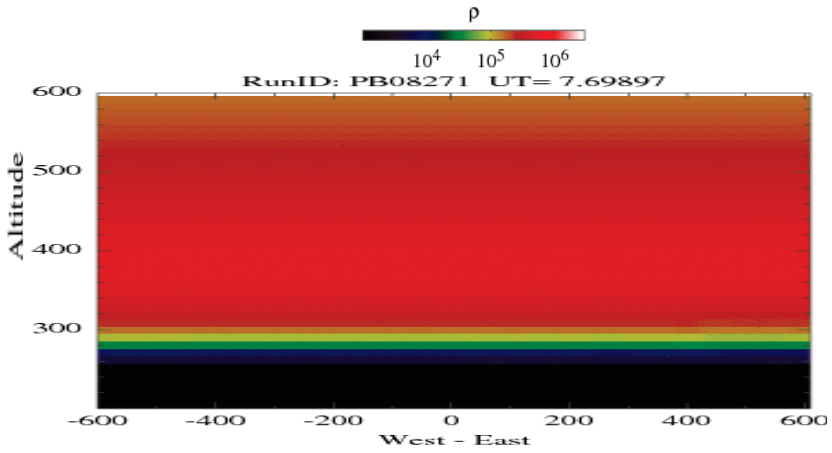


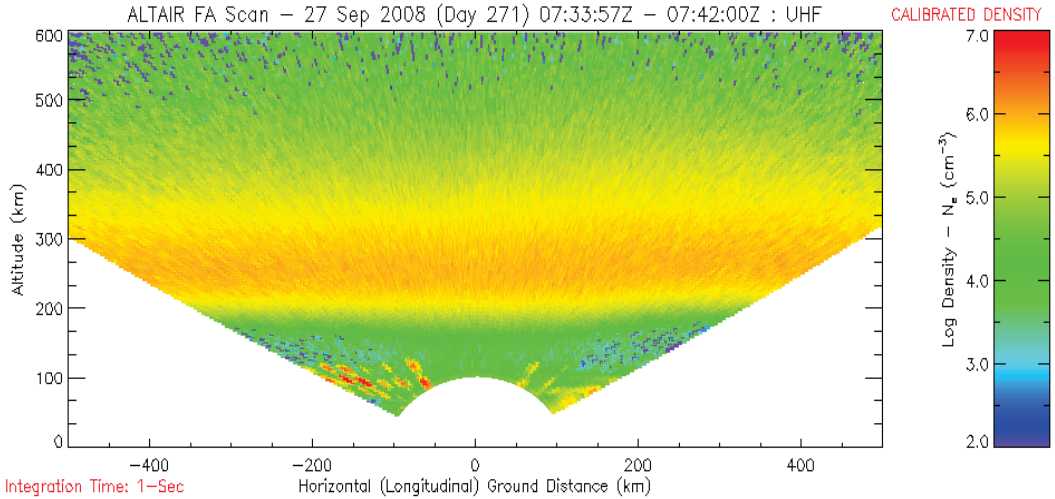
First case investigated promising!

C/NOFS Modeling and Forecasting

27 Sep 2008: A Quick Case Study

07:34 – 07:42 UT





C/NOFS Model Prediction

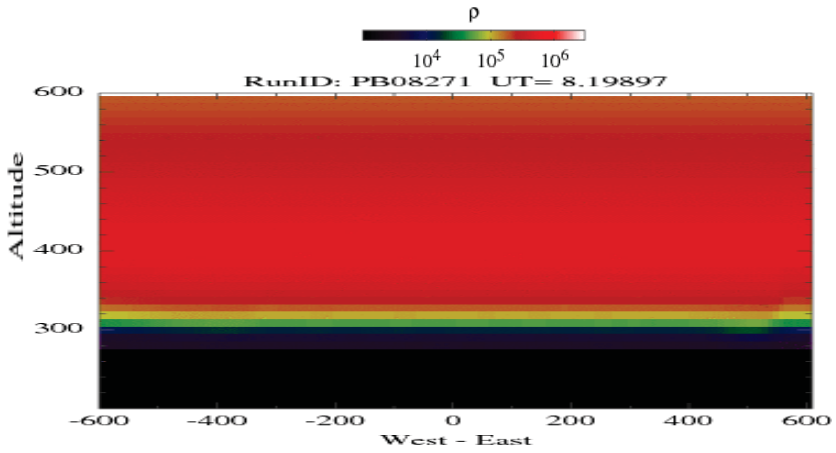
Climatological Inputs

ALTAIR UHF Radar Observations

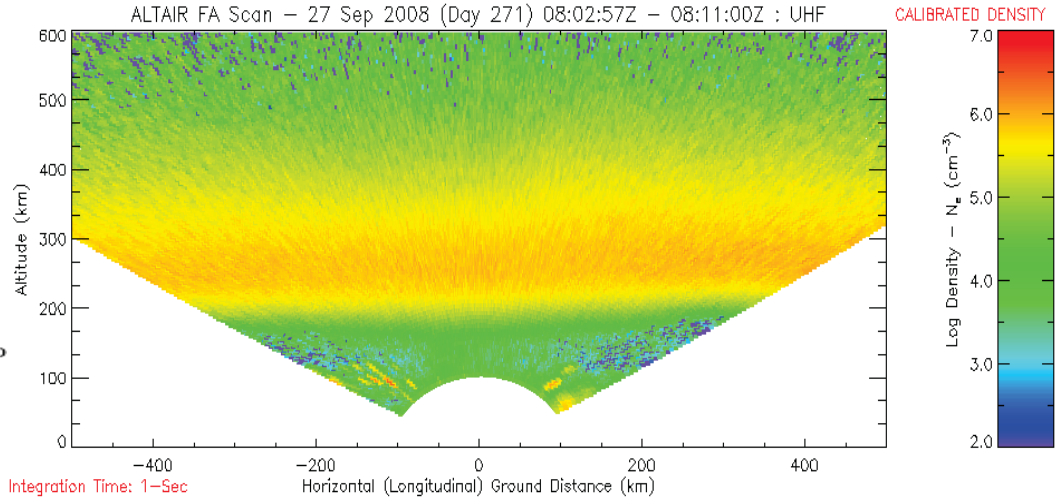
West to East Scan

Perpendicular to Magnetic Field

Kwajalein Atoll, Marshall Islands
27 Sep 2008



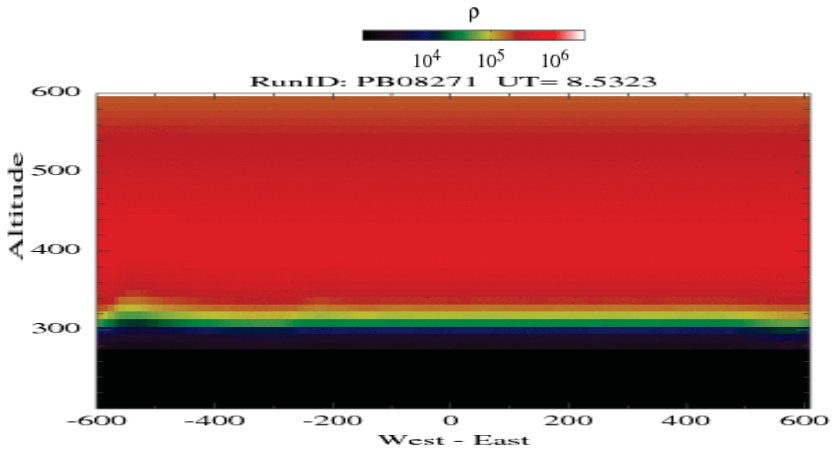
08:03 – 08:11 UT



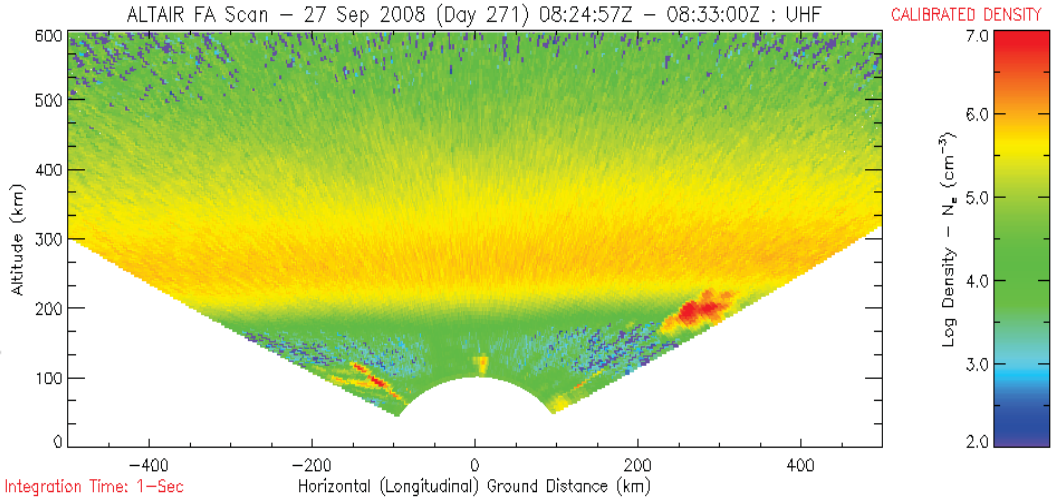
C/NOFS Model Prediction
Climatological Inputs

ALTAIR UHF Radar Observations
West to East Scan
Perpendicular to Magnetic Field

Kwajalein Atoll, Marshall Islands
27 Sep 2008



08:25 – 08:33 UT

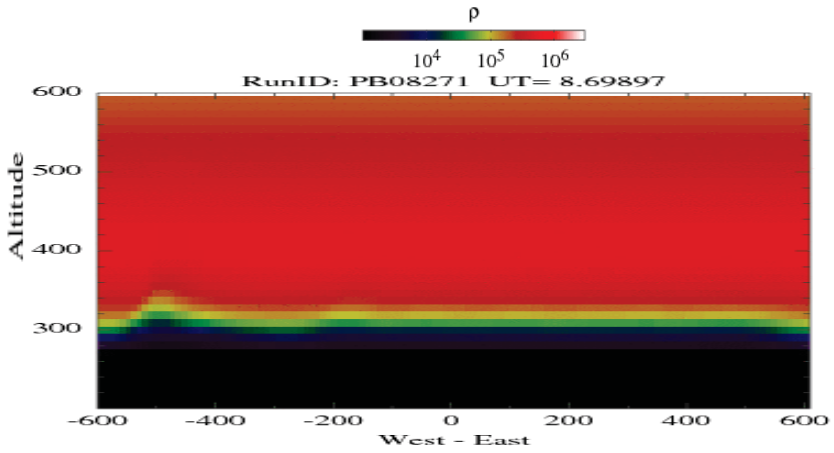


C/NOFS Model Prediction
Climatological Inputs

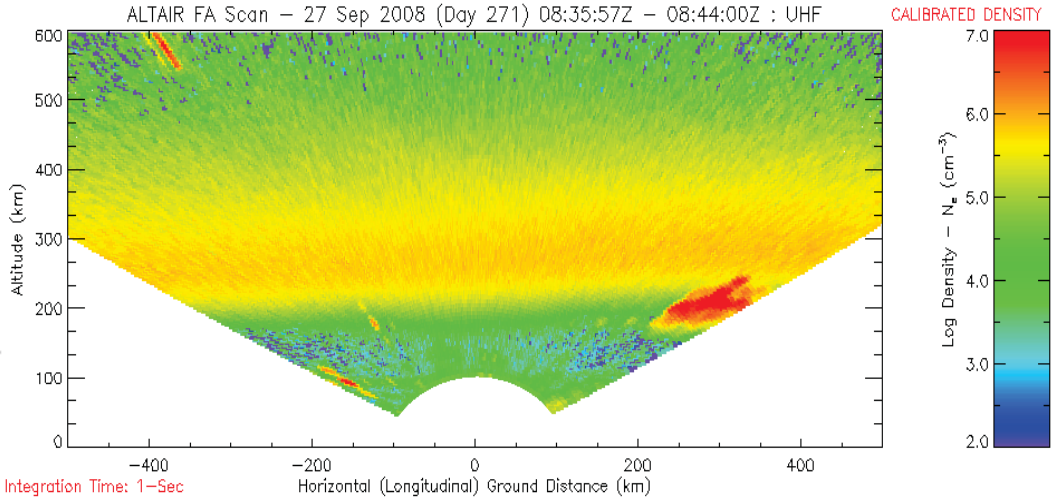
ALTAIR UHF Radar Observations
West to East Scan
Perpendicular to Magnetic Field

•Density irregularities are strongly field-aligned
•Radar experiences strong coherent echoes (Bragg backscatter) when operated in this geometry

Kwajalein Atoll, Marshall Islands
27 Sep 2008



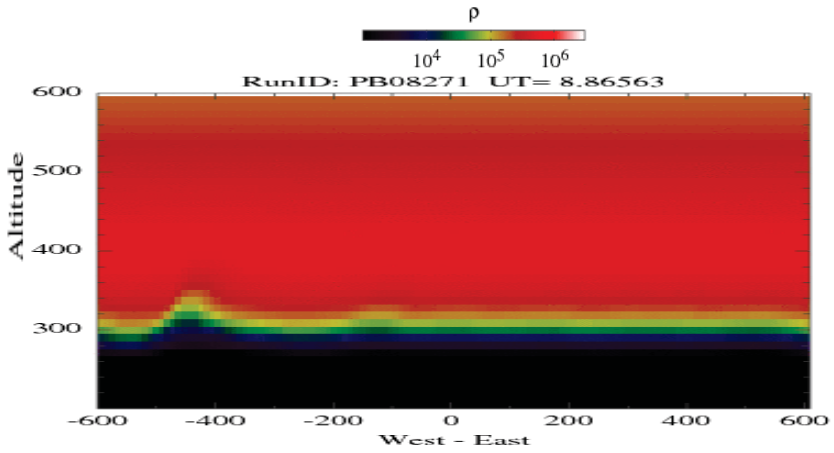
08:36– 08:44 UT



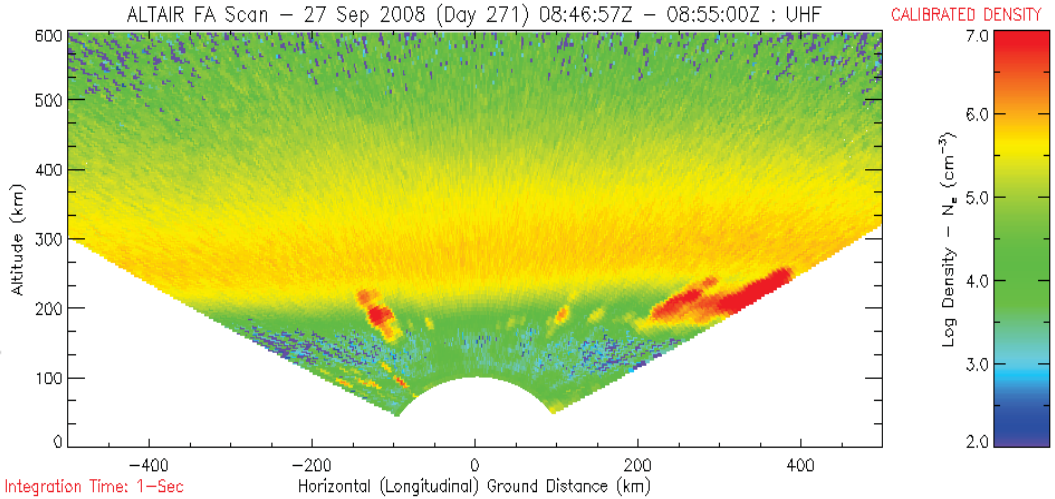
C/NOFS Model Prediction
Climatological Inputs

ALTAIR UHF Radar Observations
West to East Scan
Perpendicular to Magnetic Field

Kwajalein Atoll, Marshall Islands
27 Sep 2008



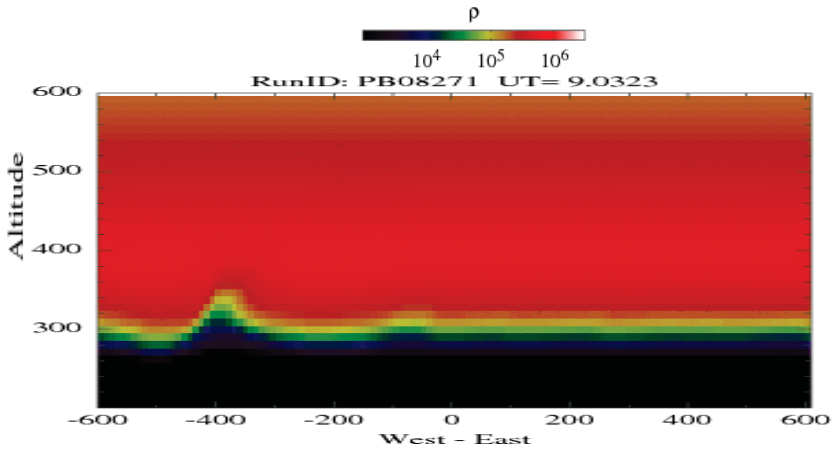
08:47 – 08:55 UT



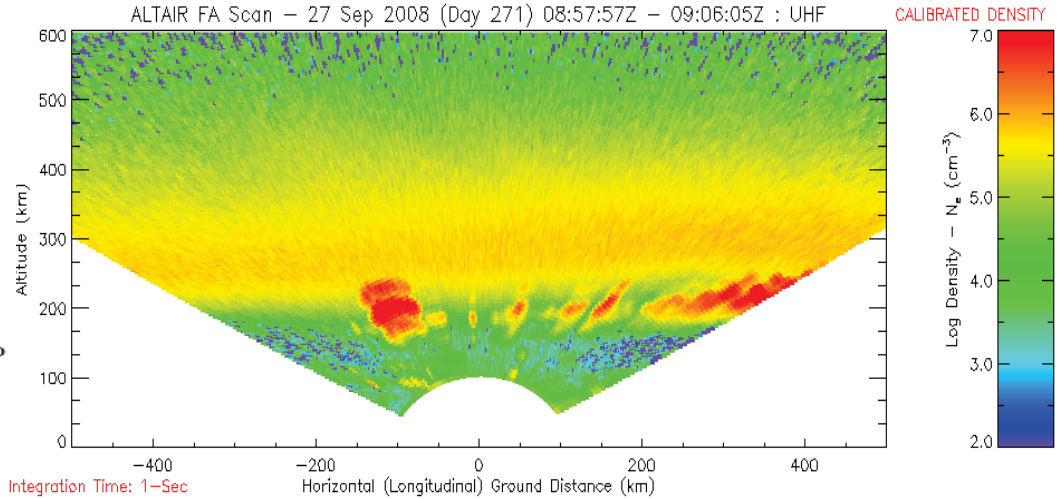
C/NOFS Model Prediction
Climatological Inputs

ALTAIR UHF Radar Observations
West to East Scan
Perpendicular to Magnetic Field

Kwajalein Atoll, Marshall Islands
27 Sep 2008



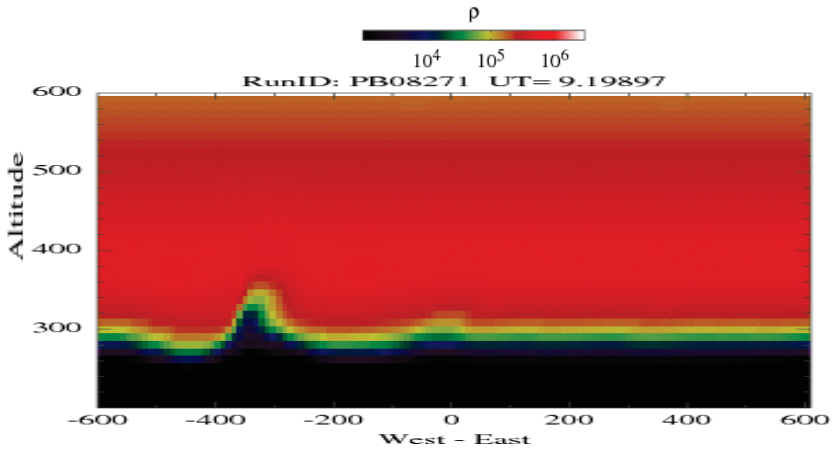
08:58 – 09:06 UT



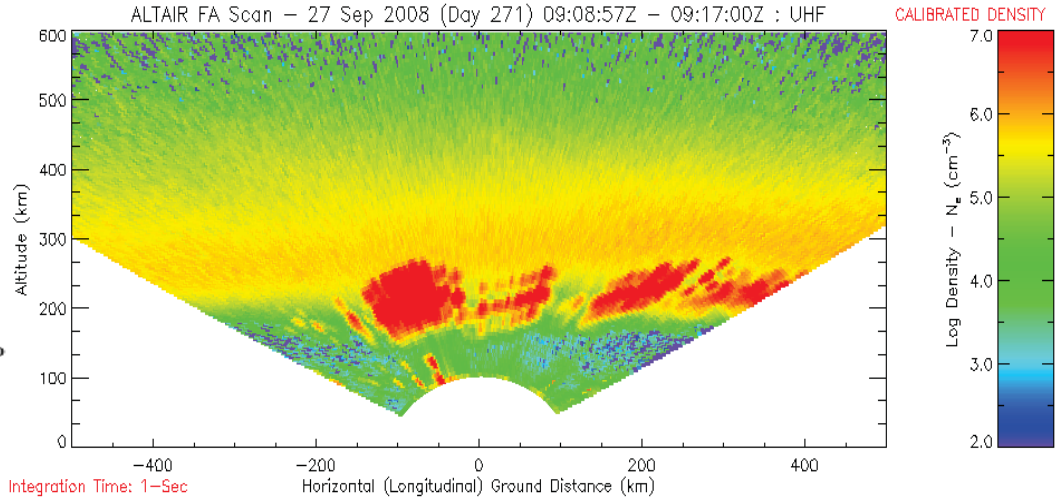
C/NOFS Model Prediction
Climatological Inputs

ALTAIR UHF Radar Observations
West to East Scan
Perpendicular to Magnetic Field

Kwajalein Atoll, Marshall Islands
27 Sep 2008



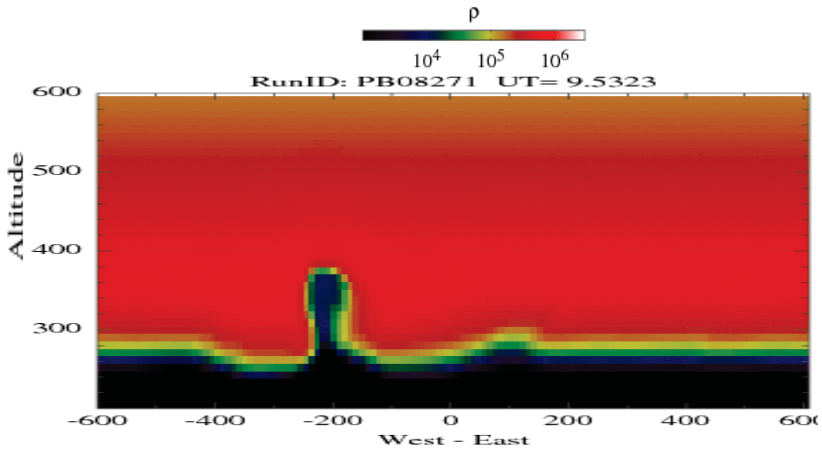
09:09 – 09:17 UT



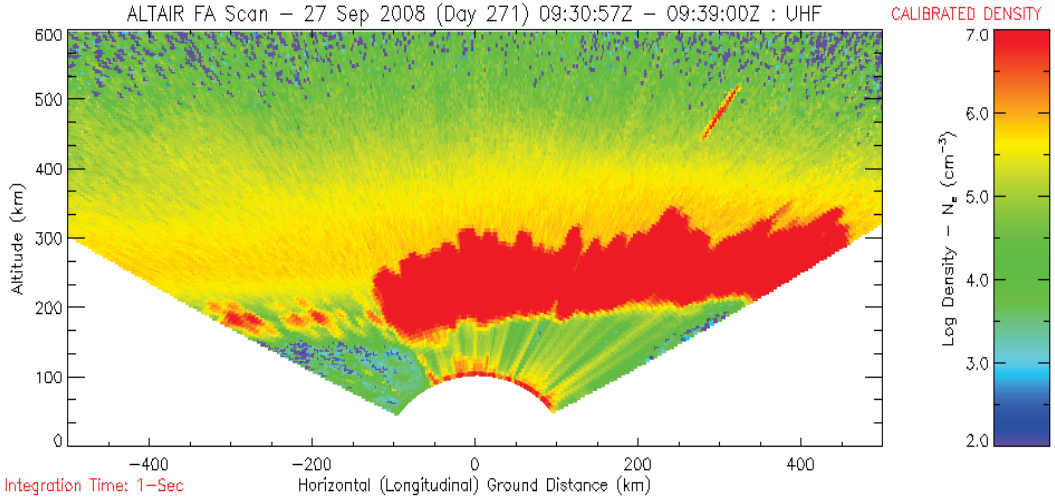
C/NOFS Model Prediction
Climatological Inputs

ALTAIR UHF Radar Observations
West to East Scan
Perpendicular to Magnetic Field

Kwajalein Atoll, Marshall Islands
27 Sep 2008



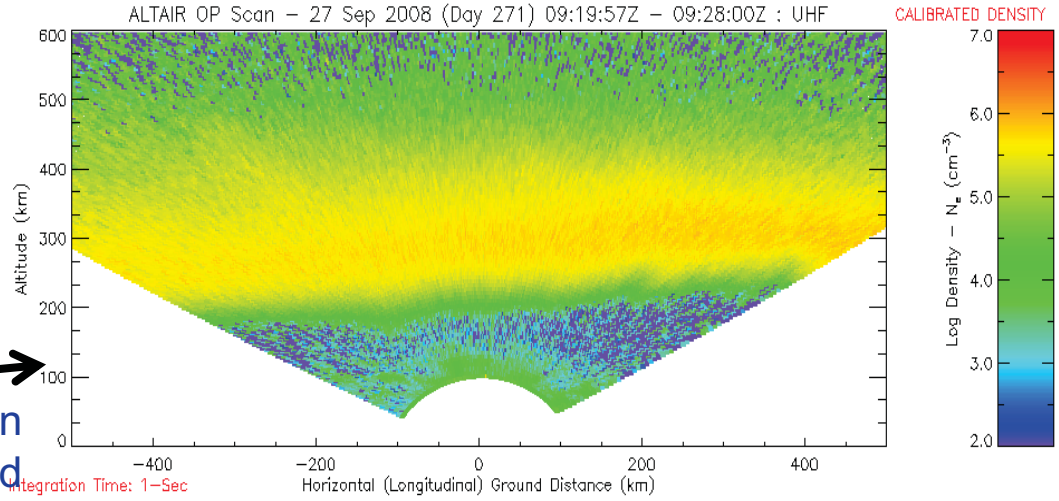
09:19 – 09:39 UT



Two views of the same phenomenon

1.Strong coherent scatter from meter-scale field-aligned irregularities

2.Weak incoherent scatter from ionized gas viewed off-perpendicular



West to East Scan
6° off-perpendicular to Magnetic Field

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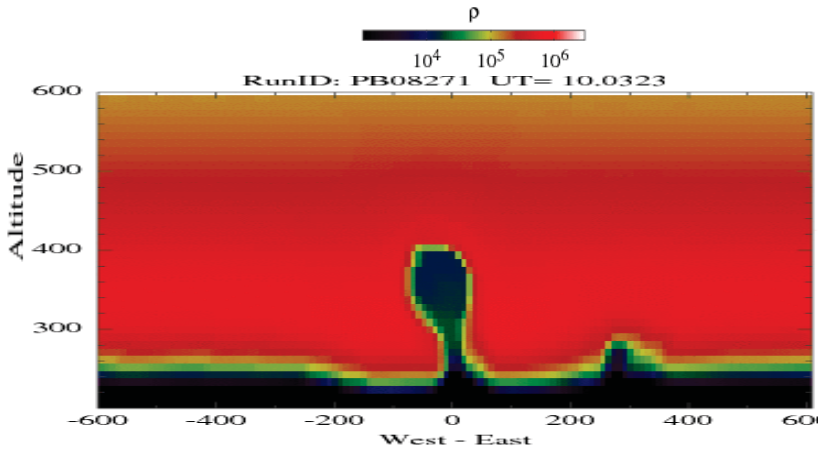
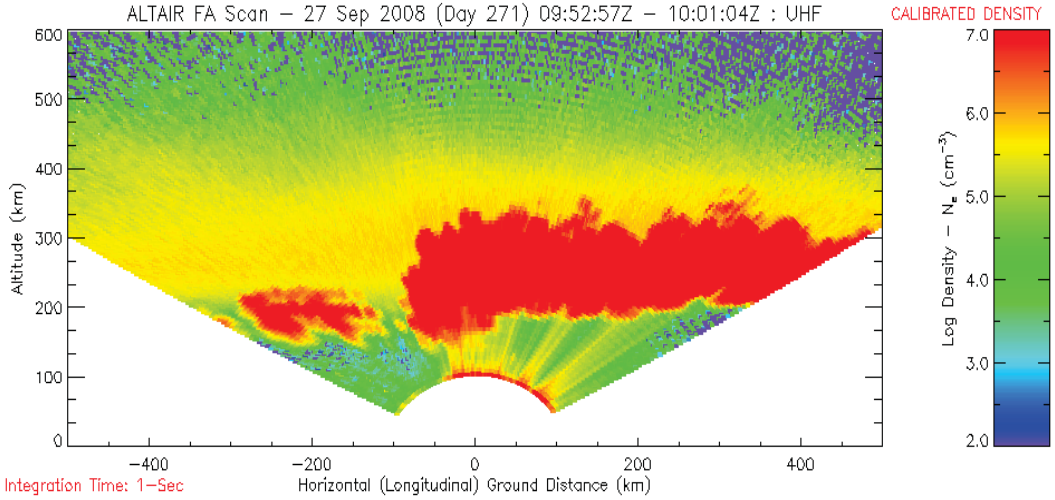
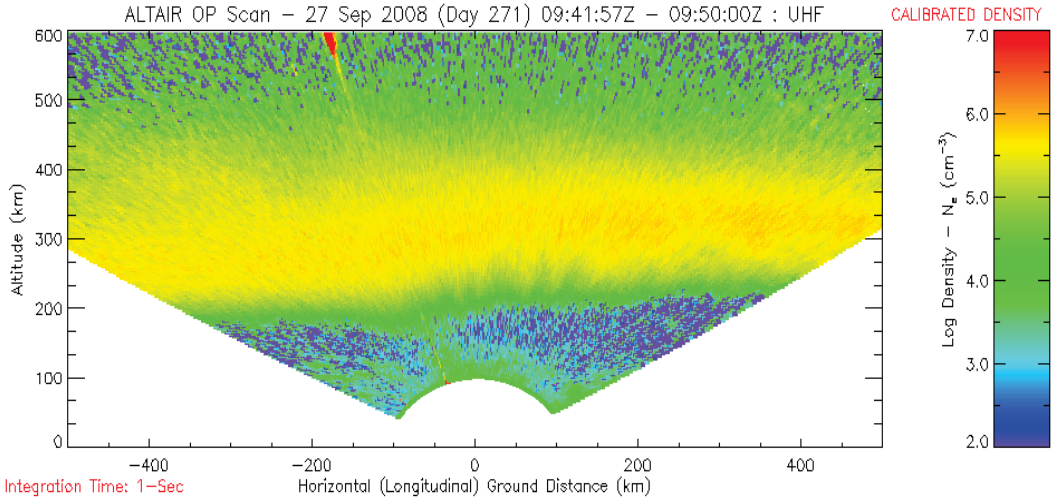


09:41 – 10:01 UT





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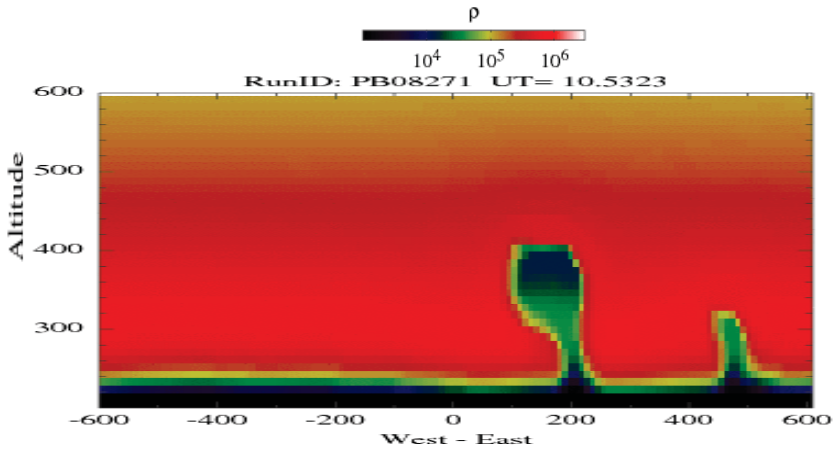
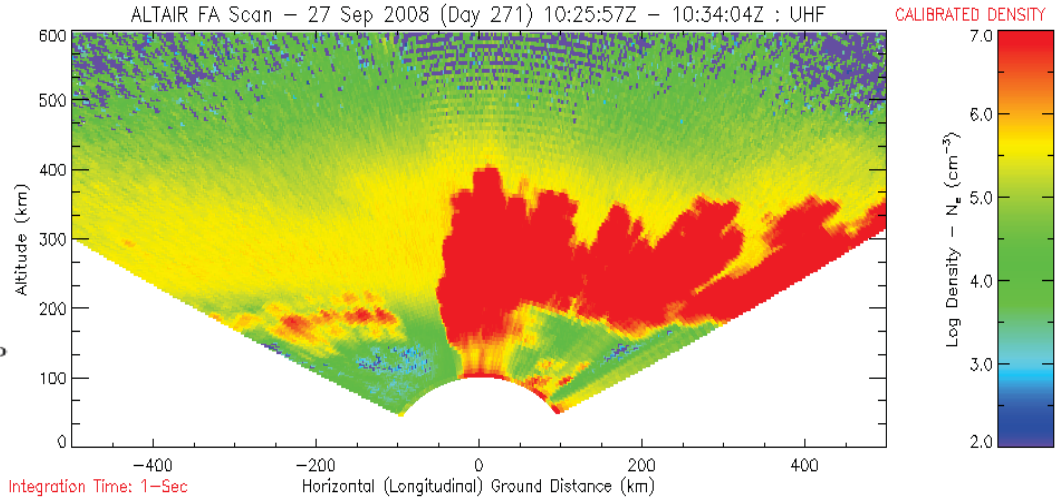
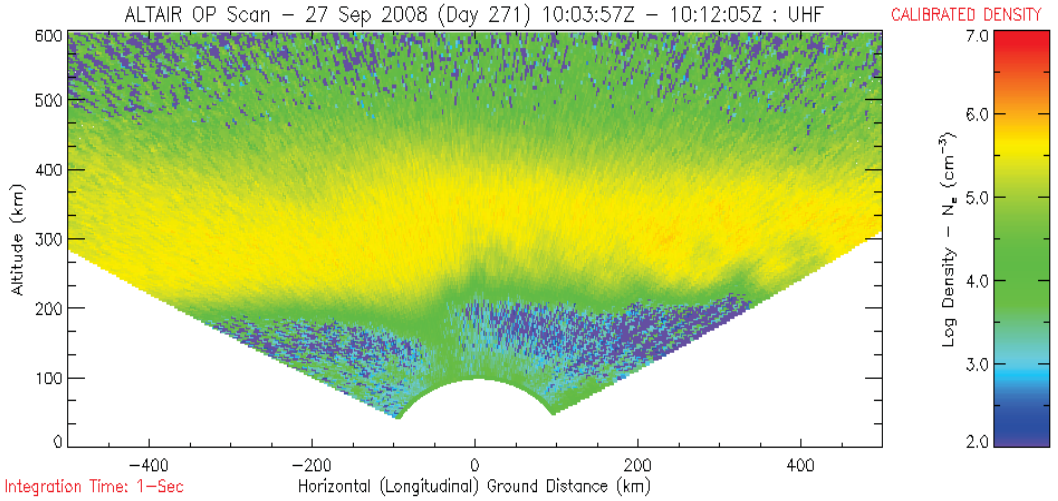


10:04 – 10:34 UT





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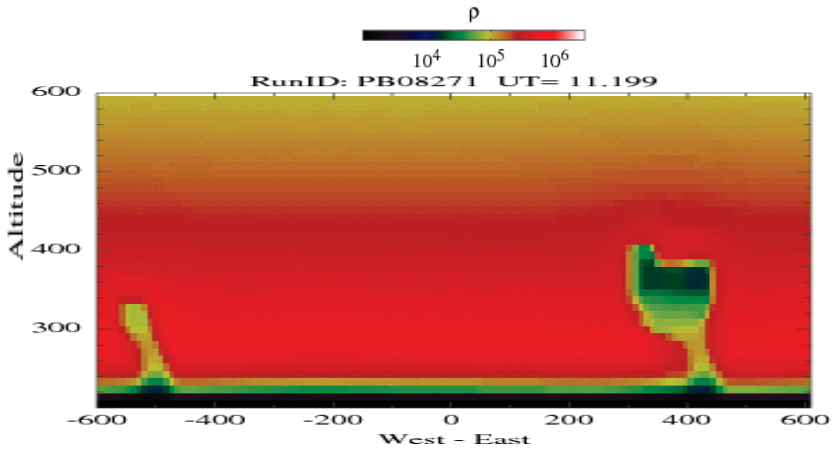
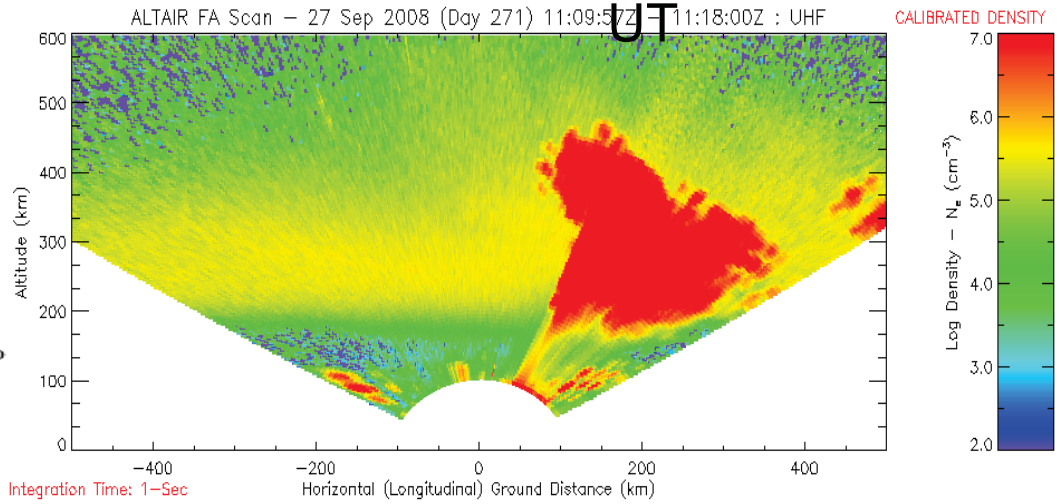
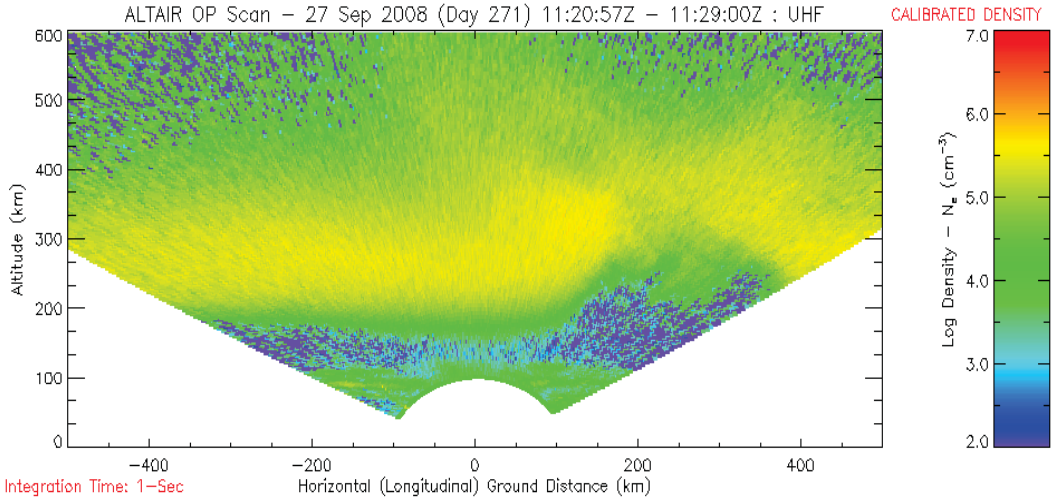


11:10 – 11:30 UT

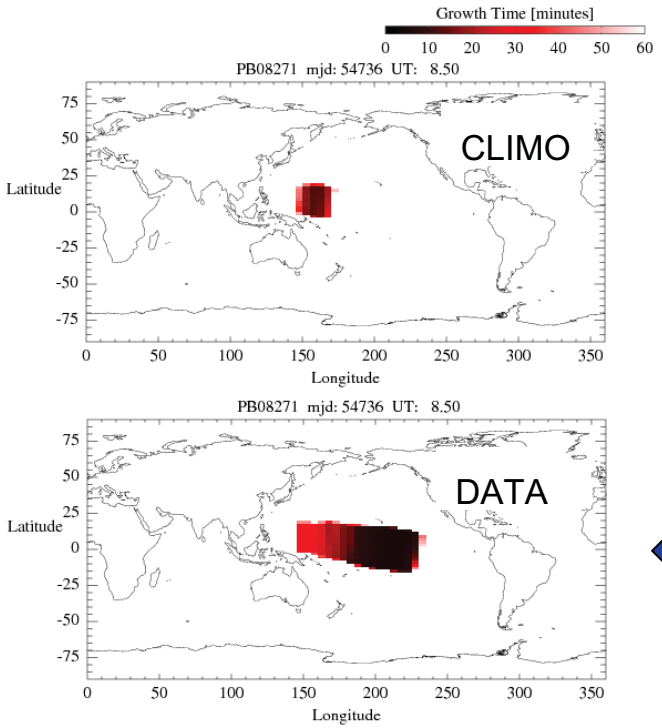


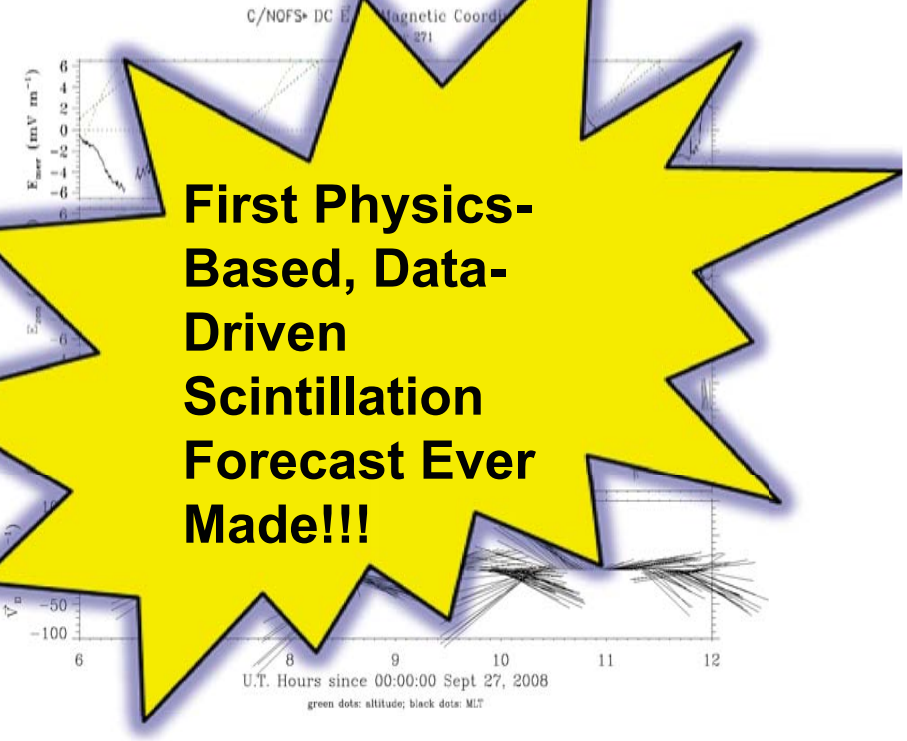
- Uplift and bottom-side irregularities eventually result in large plume structure blossoming into topside ionosphere with associated turbulence and scintillation



C/NOFS Scintillation Forecast

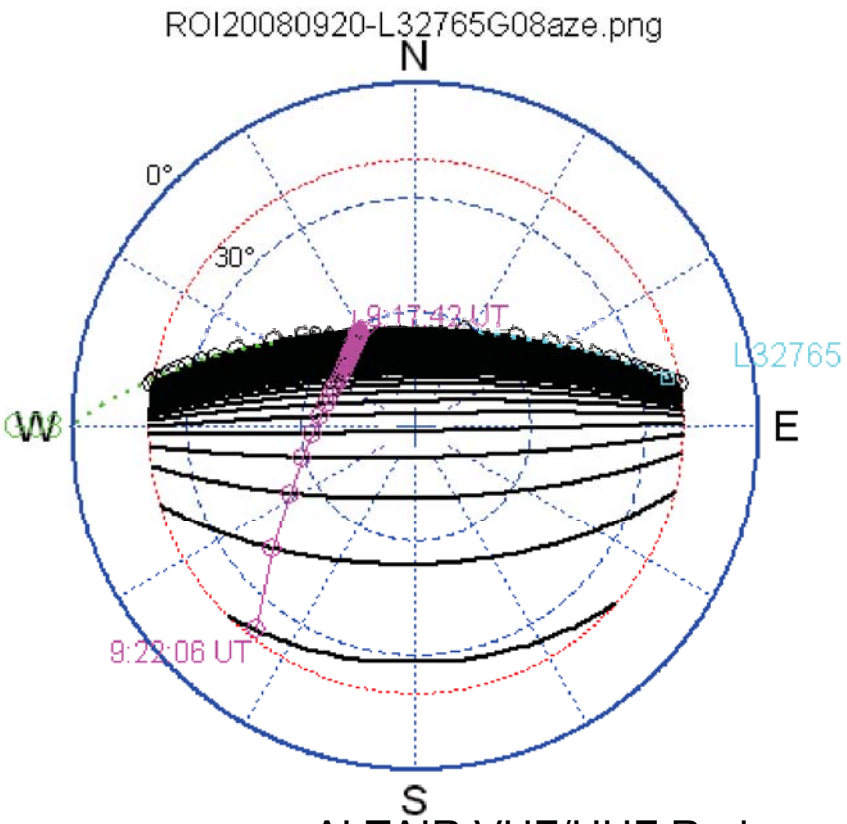
- **Data-driven prediction for Day 271 suggest stronger development than climatological results, consistent with observations**





Very early results look promising…BUT a lot remains to be learned

New Horizon with Space-Based Radio Occultation Techniques

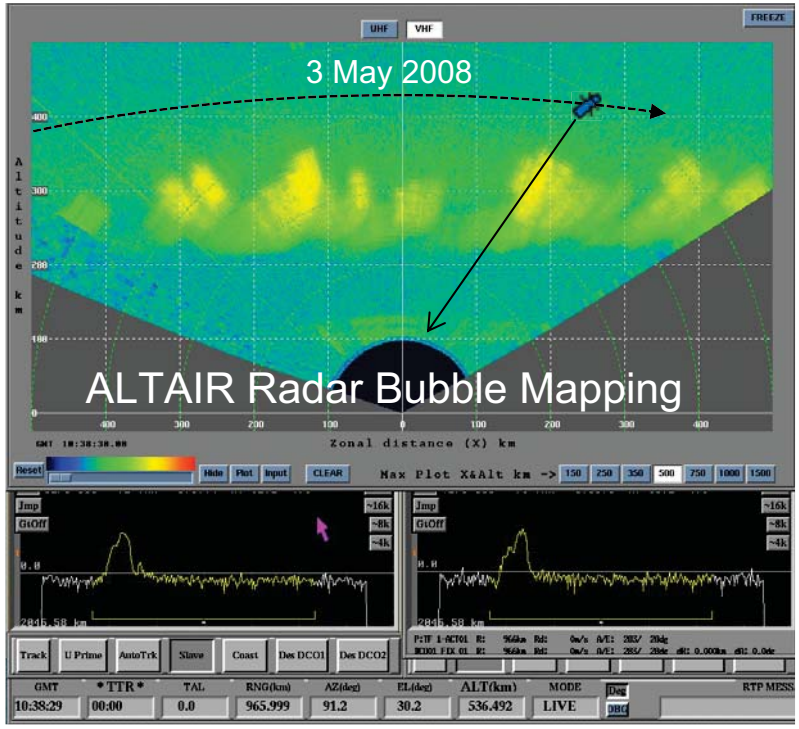


ALTAIR VHF/UHF Radar

- C/NOFS occultation geometries favorable for complete characterization with ground-based GPS
- Data can be provided for specific passes known in advance
- Can also be used for scintillation detection
- Numerous good opportunities will occur in the equatorial zone

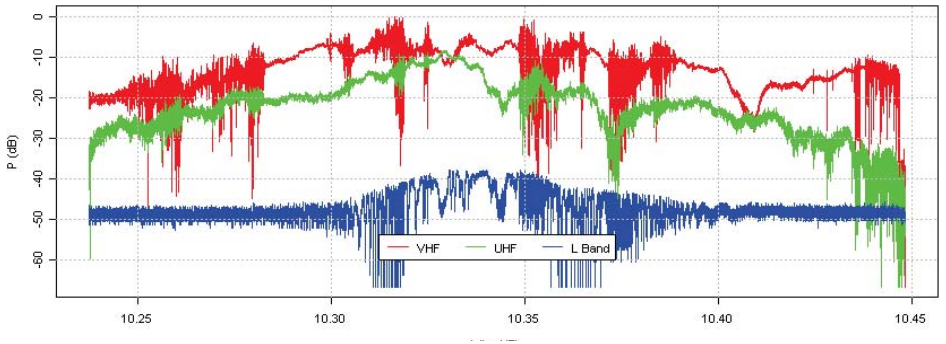
- Combining ground- and space-based GPS observations promises to be an effective characterization technique

CERTO Beacon



ALTAIR VHF/UHF Radar

C/NOFS Tri-band beacon signals



- Direct comparison of ionospheric structure observed with radar and deduced from C/NOFS beacon signal
- Physics-based model applied to test forecast capability
- Requires ground-based tri-band beacon receiver
- COSMIC & other satellites transmit similar signals

SCINDA Summary

- SCINDA provides robust state-of-the-art sensors for ionospheric characterization (irregularities, TEC)
  - Goal is to ensure good coverage across Africa for next solar max
- Project has phased approach to:
  - Establish “macro-scale” coverage in equatorial belt
  - Develop small-scale arrays for detailed characterization
  - Expand coverage to mid-latitude for magnetic storms
- Combining ground- and space-based data facilitates better characterization & development of improved techniques
- Please see us if you are interested in participating—opportunities for research collaboration & hosting sensors