The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
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IAEA
International Atomic Energy Agency

2135-6

Second Workshop on Satellite Navigation Science and Technology for Africa

6 - 23 April 2010

Update on SCINDA Activities in Africa and Around the Globe

R. Caton
AFRL
Hansom
USA

AFRL

THE AIR FORCE RESEARCH LABORATORY

LEAD | DISCOVER | DEVELOP | DELIVER

An Update on SCINDA Activities in Africa and Around the Globe

April 2010

Ron Caton

Benjamin Heruska

Ionospheric Impacts on RF Systems

Space Vehicles Directorate

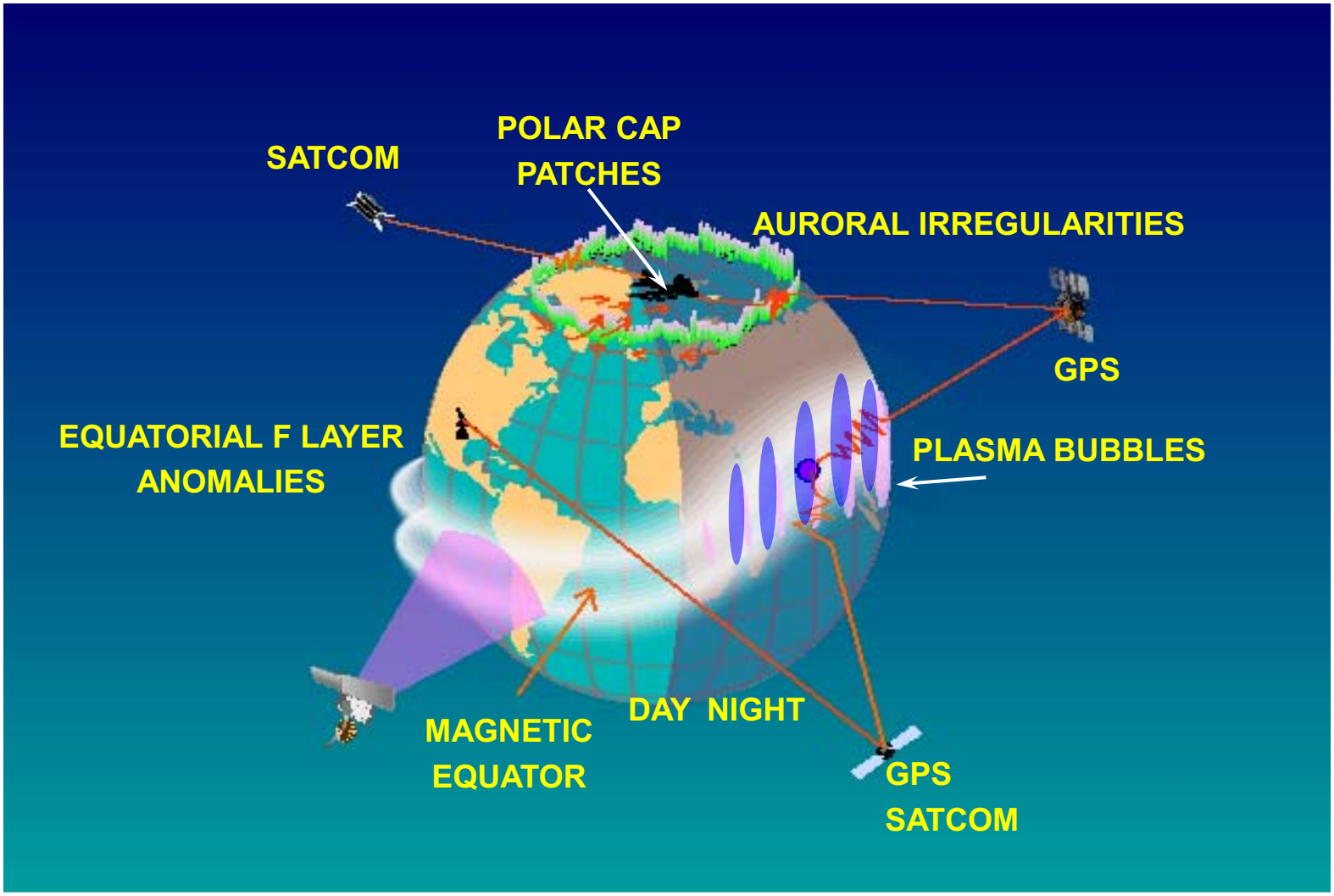
Air Force Research Laboratory

Principal Investigator – Dr. Keith Groves

Overview

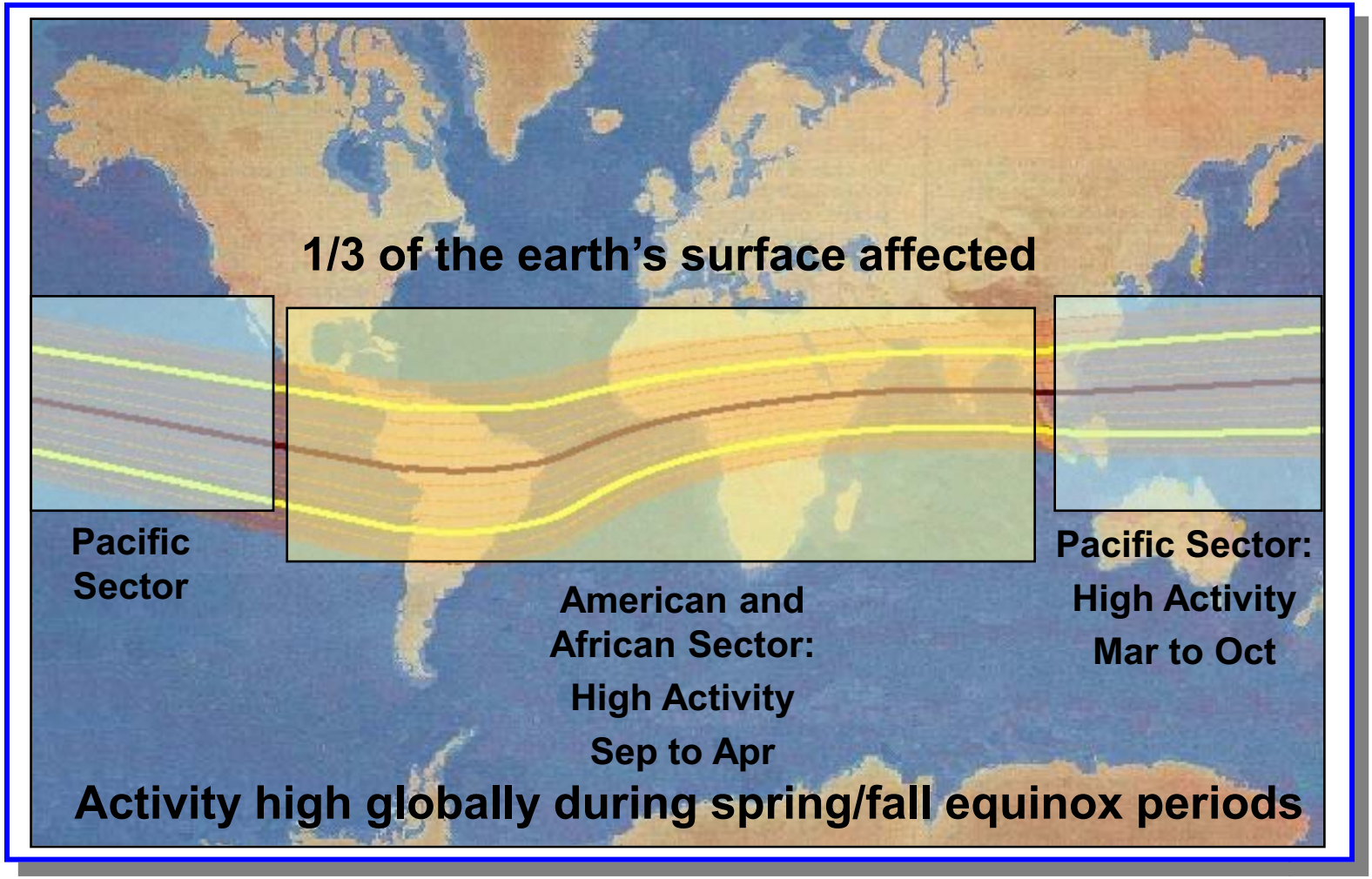
- What is scintillation?
- SCINDA concept and ionospheric specification
- Update on deployment of monitoring stations in the African sector
- Recent developments from the SCINDA team & opportunities for collaboration with African scientific community
- Summary

Disturbed Ionospheric Regions and Systems Affected by Scintillation



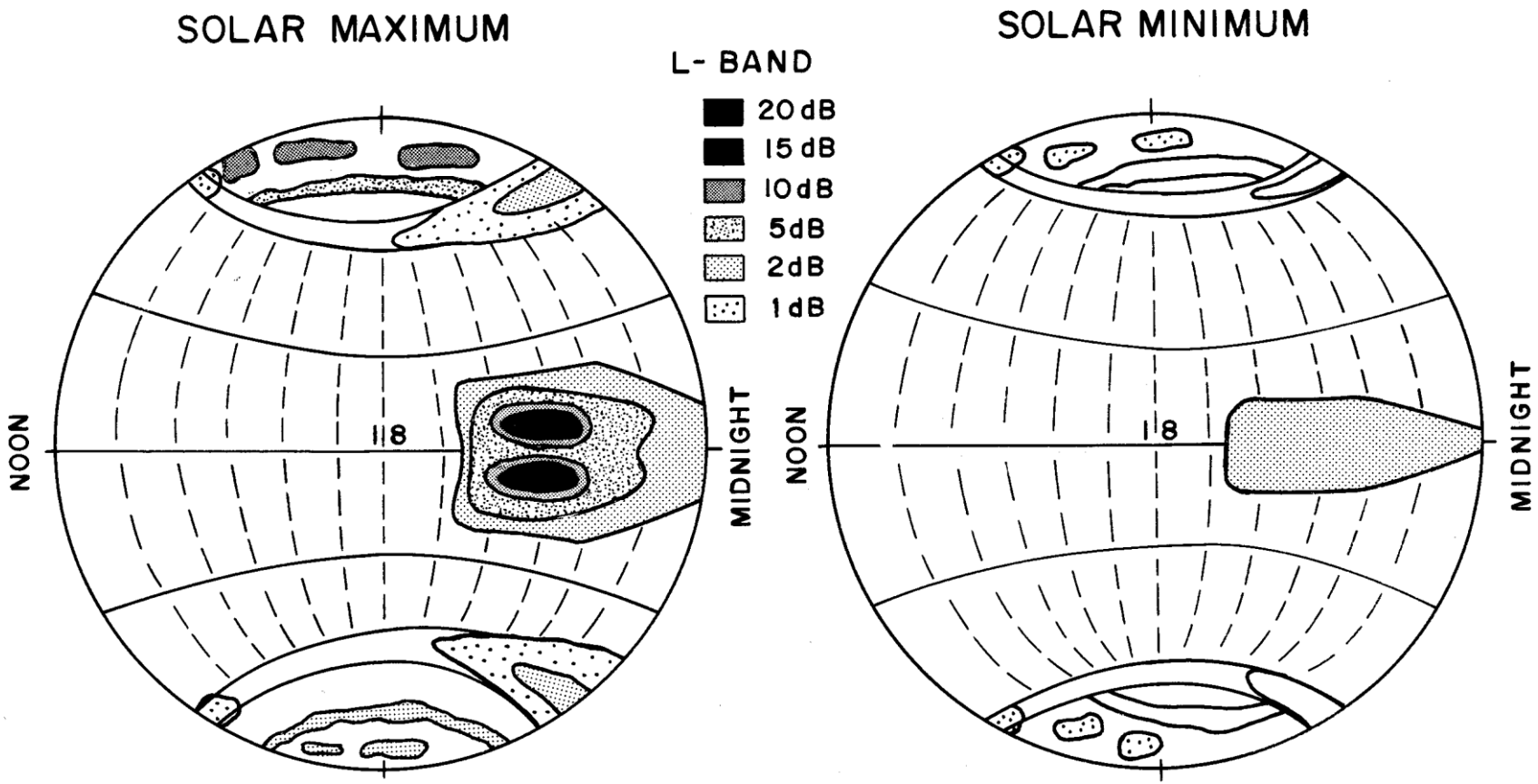
Equatorial Scintillation
Seasonal and Local Time Dependence

Equatorial scintillation generally occurs 2000 to 0300 LT in listed seasons



Global Morphology

"WORST CASE" FADING DEPTHS AT L-BAND



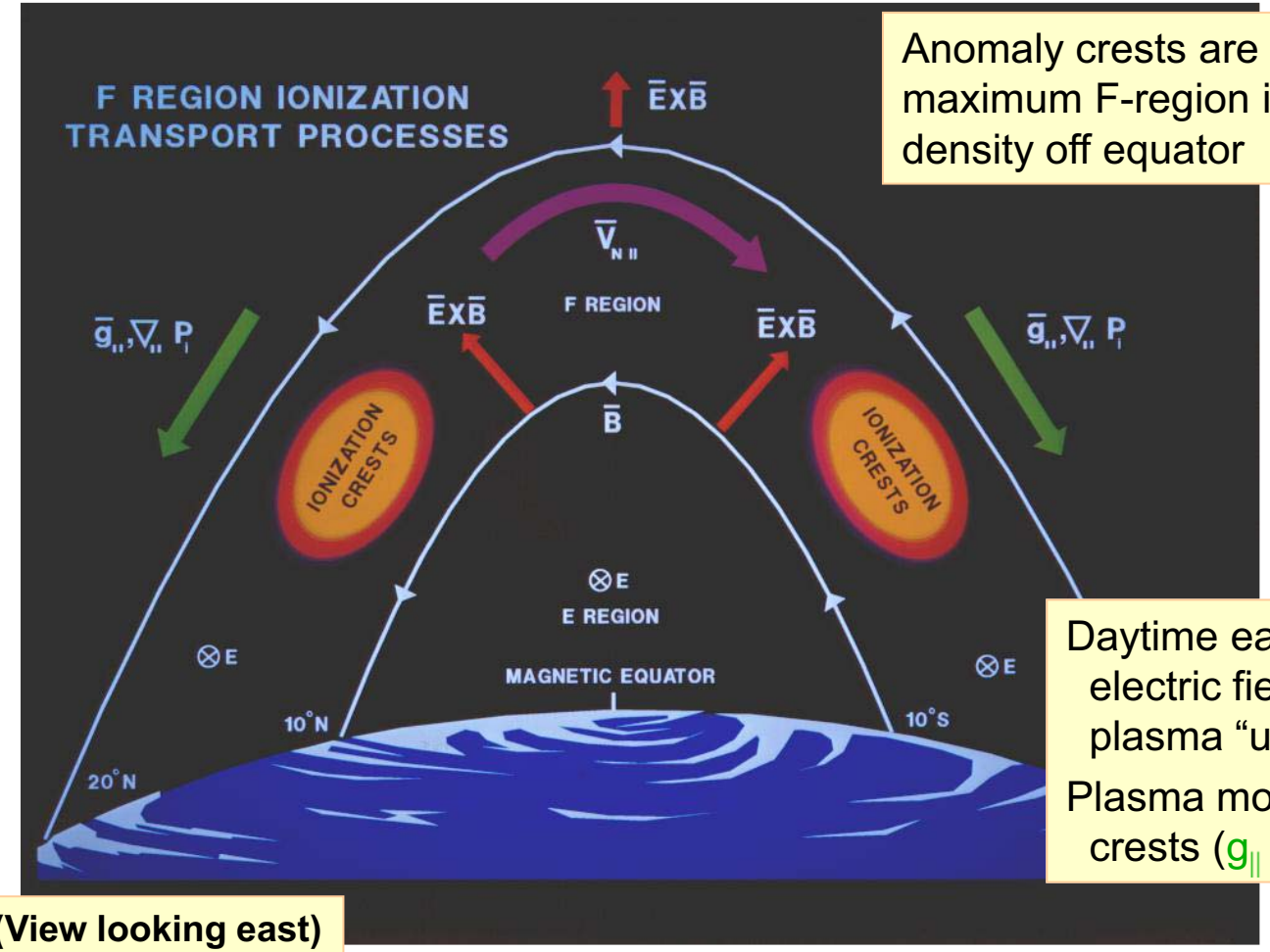
[After Basu, et al.]

What Are Equatorial Dynamics?

Formation of Anomaly Region

Presence of anomaly crests strengthens off-equator scintillations

State of anomaly formation is indicative of equatorial dynamics



Anomaly crests are areas of maximum F-region ionization density off equator

Daytime eastward electric field (E) drives plasma "up" ($E \times B$)

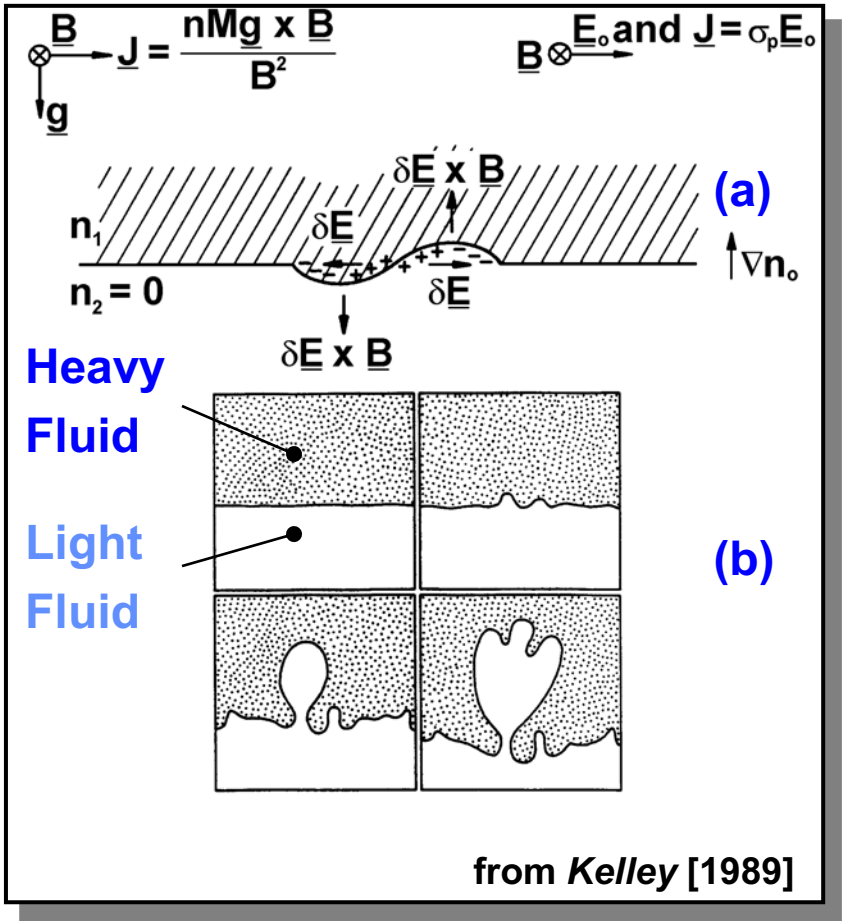
Plasma moves toward crests ($g_{||}$, $\nabla_{||}P_{||}$)

(View looking east)

What Is Instability Process?

Basic Plasma Instability

View along bottomside of ionosphere
(E-W section, looking N from equator)



Plasma supported by horizontal field lines against gravity is unstable

(a) Bottomside unstable to perturbations (density gradient against gravity)

(b) Analogy with fluid Rayleigh-Taylor instability

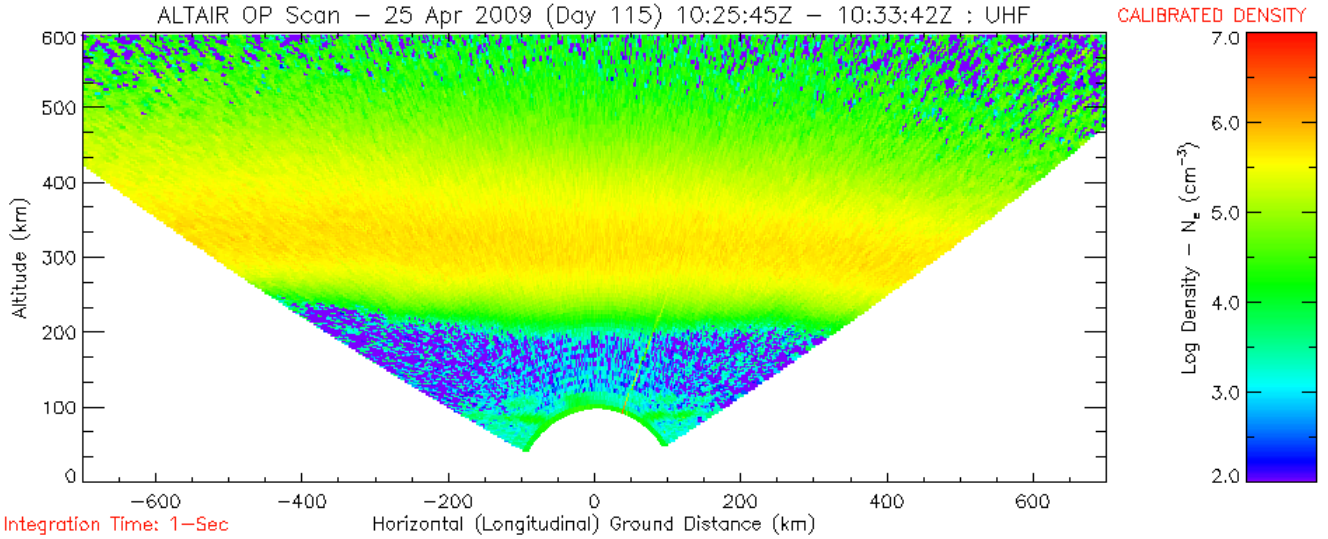
Perturbations start at large scales (100s km)

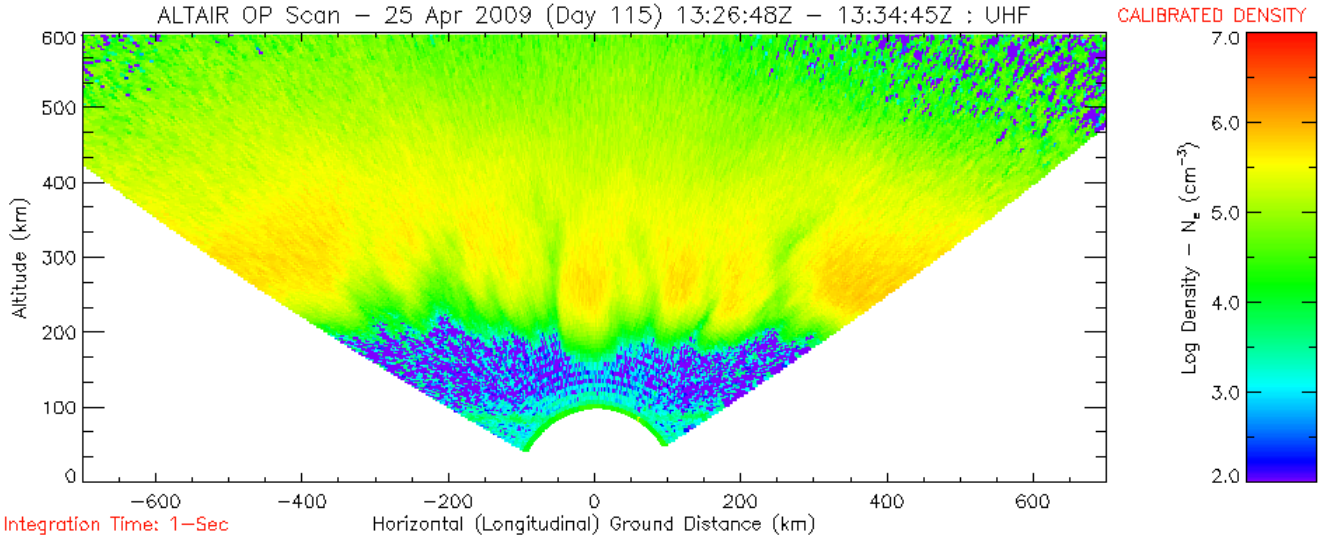
Cascade to smaller scales (200 km to 30 cm)

RADAR OBSERVATIONS

ALTAIR RADAR FACILITY

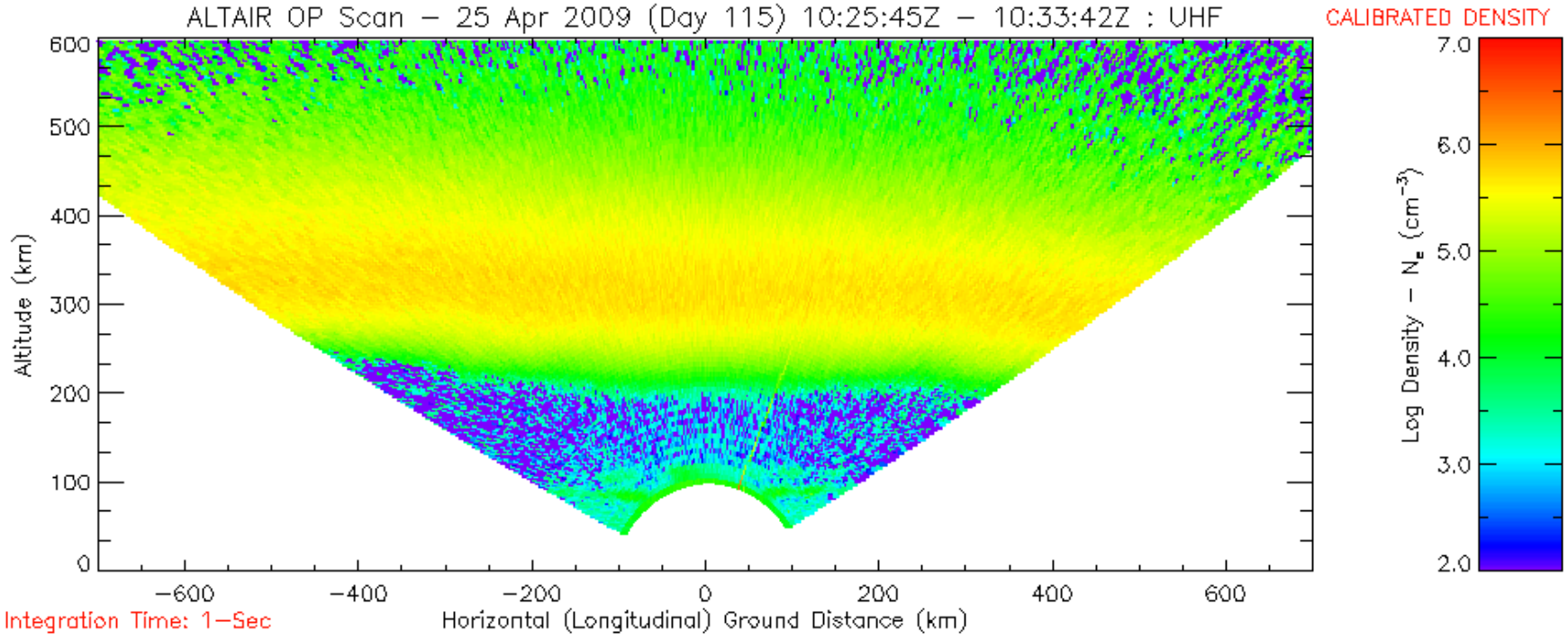
INCOHERENT RADAR SCANS



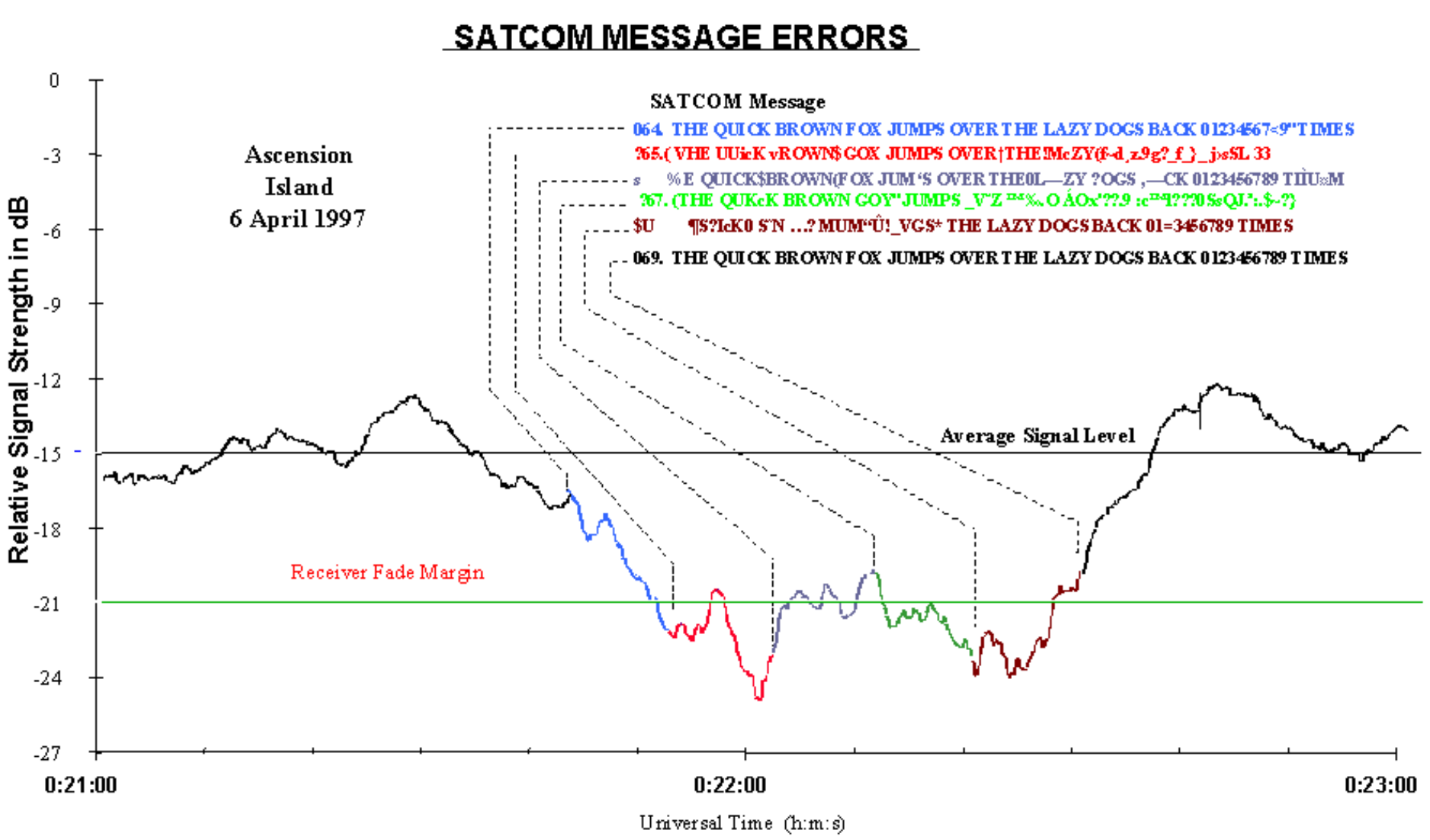


RADAR OBSERVATIONS

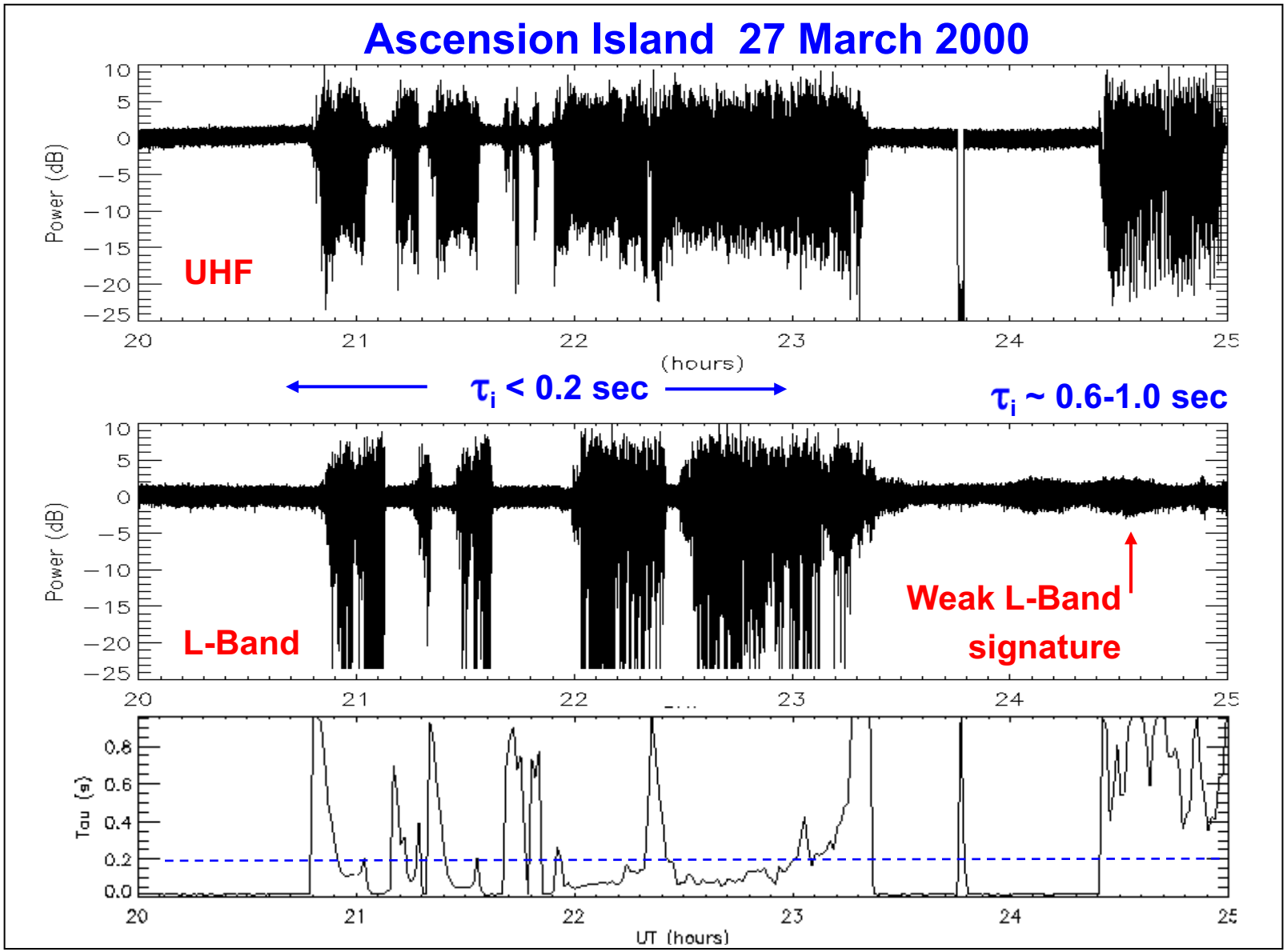
Time-Lapsed movie of ALTAIR SCANS



Scintillation Impacts on SATCOM
Real World Example

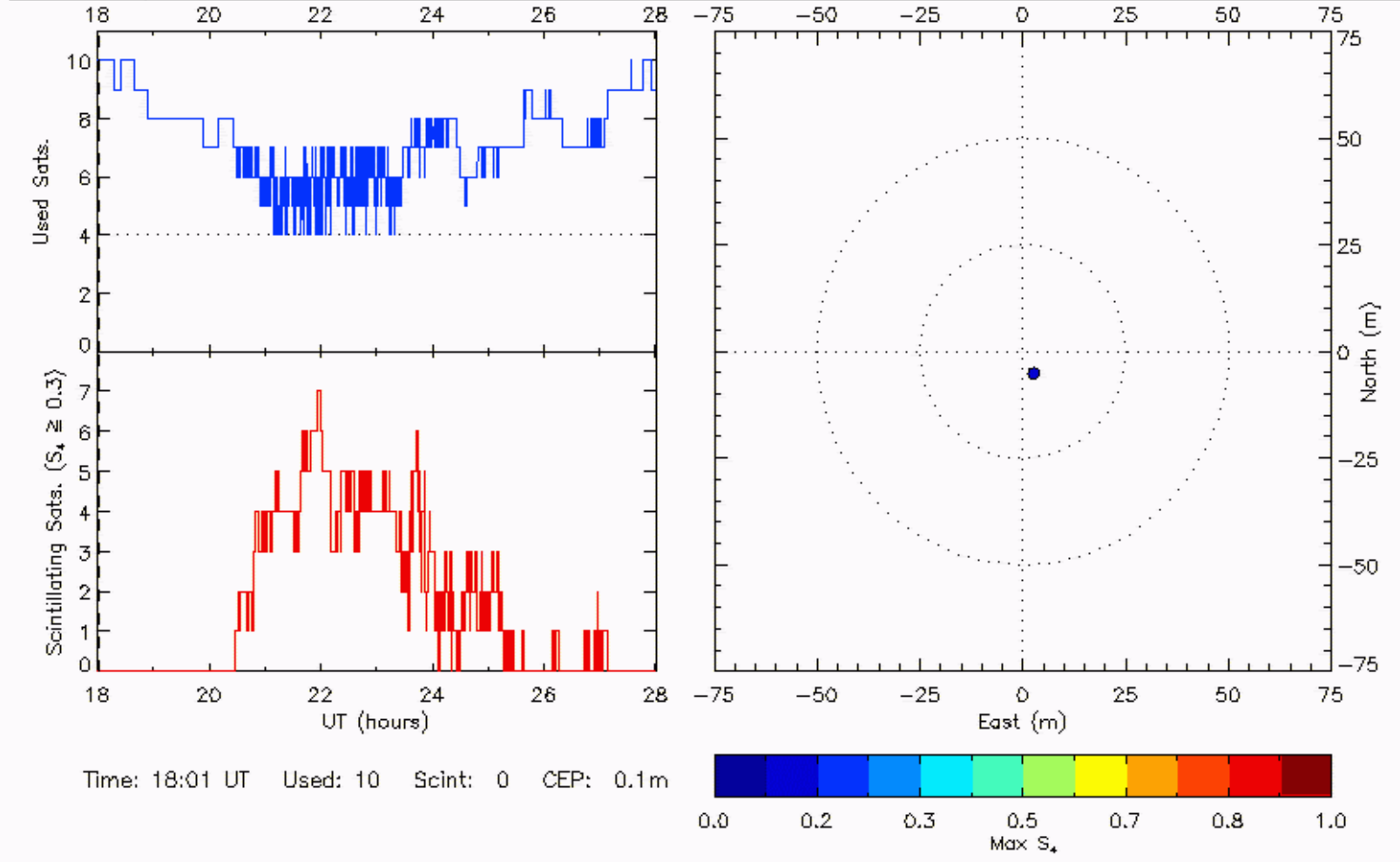


Scintillation Scale Size Decorrelation Time Parameter: τ_i



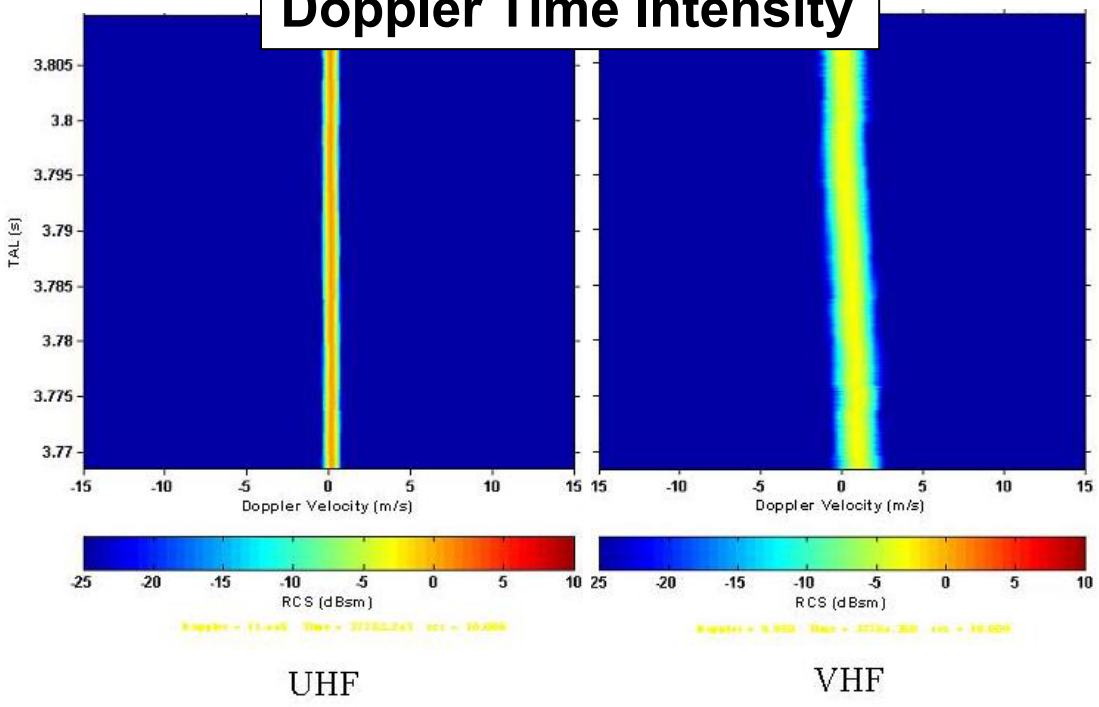
GPS Positioning Errors During Solar Max

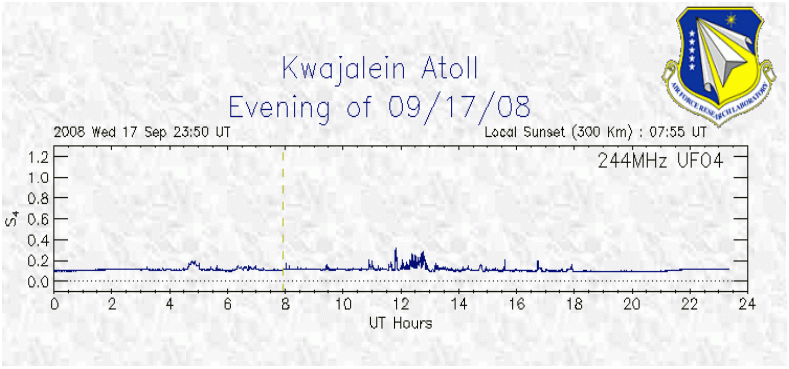
Scintillation can cause rapid fluctuations in GPS position fix;
Typical night from recent field experiments

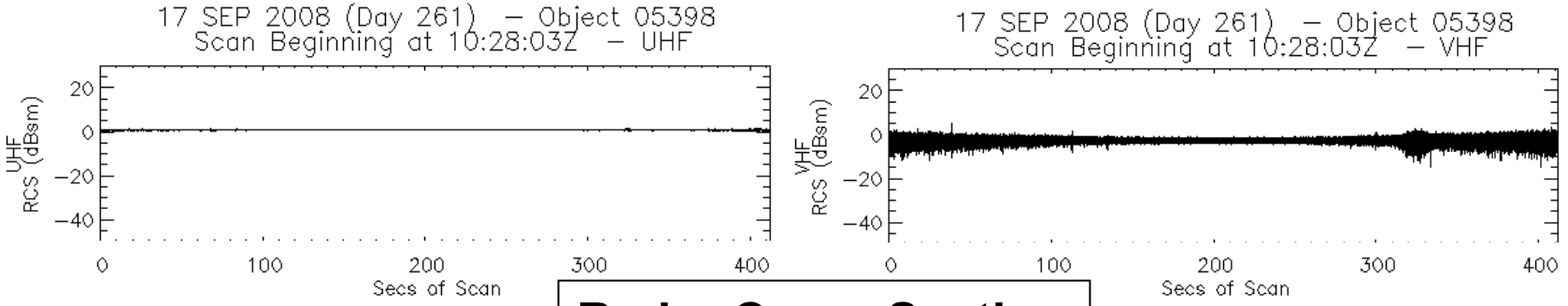


Scintillation Effects on RADAR Tracking

Doppler Time Intensity



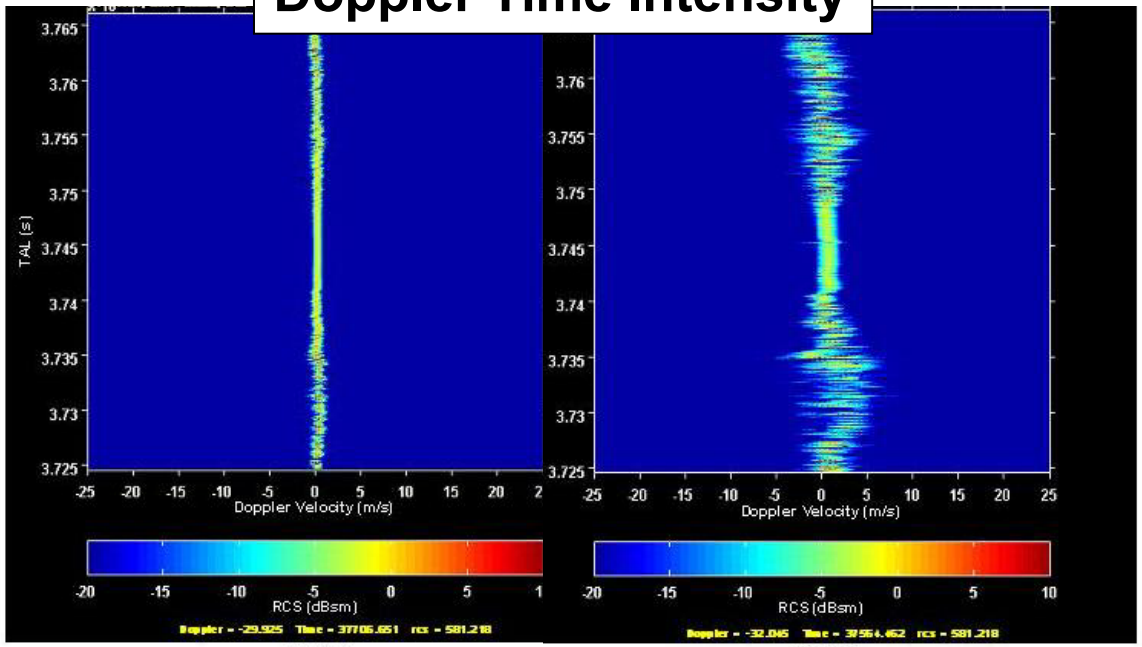


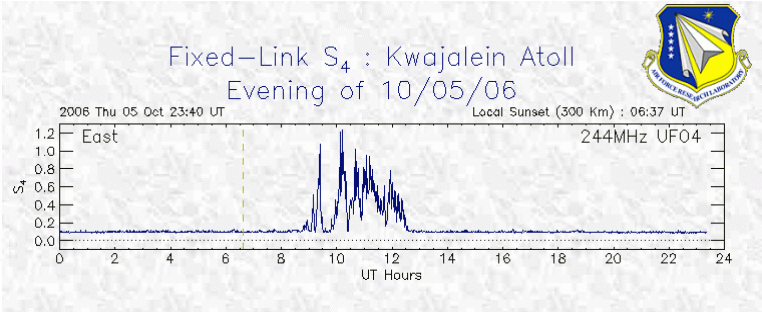


Radar Cross Section

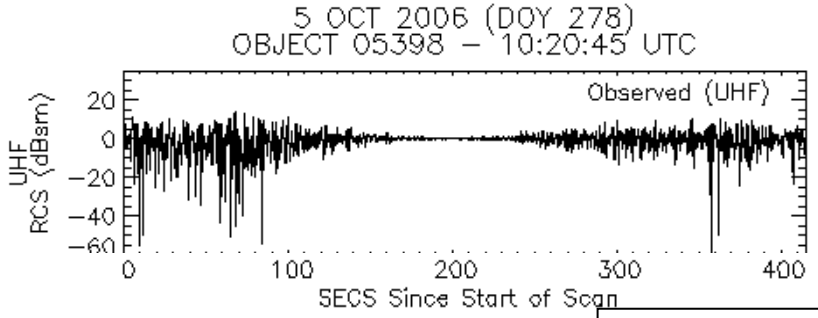
Scintillation Effects on RADAR Tracking

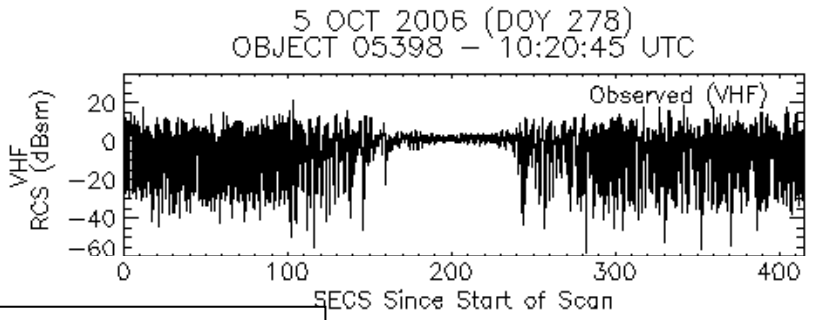
Doppler Time Intensity





Radar Track during scintillation event

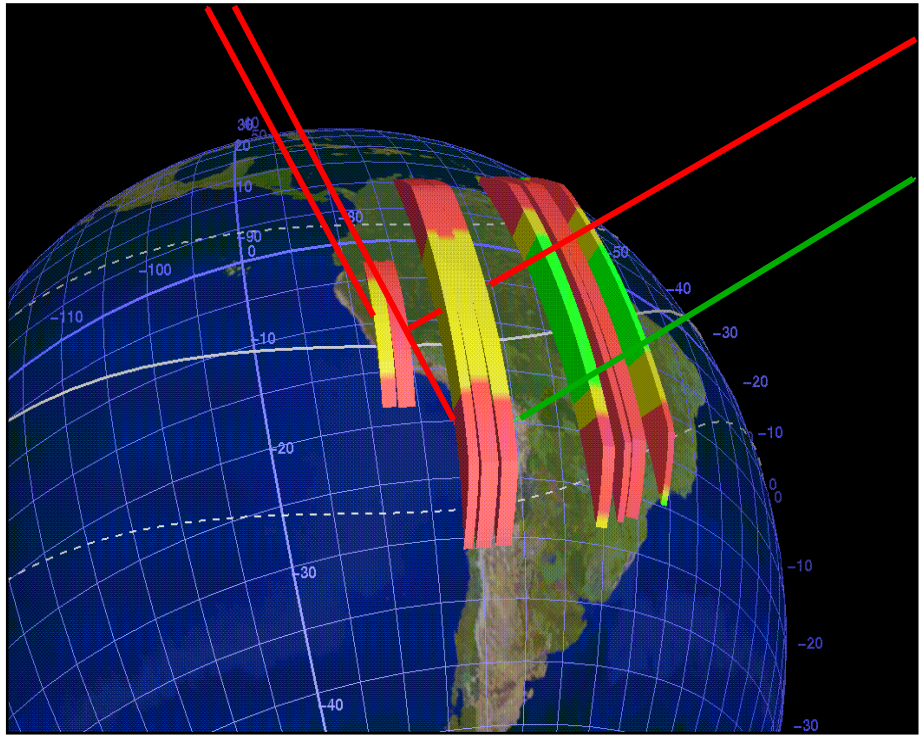




Radar Cross Section

SCINTILLATION NETWORK DECISION AID (SCINDA)

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

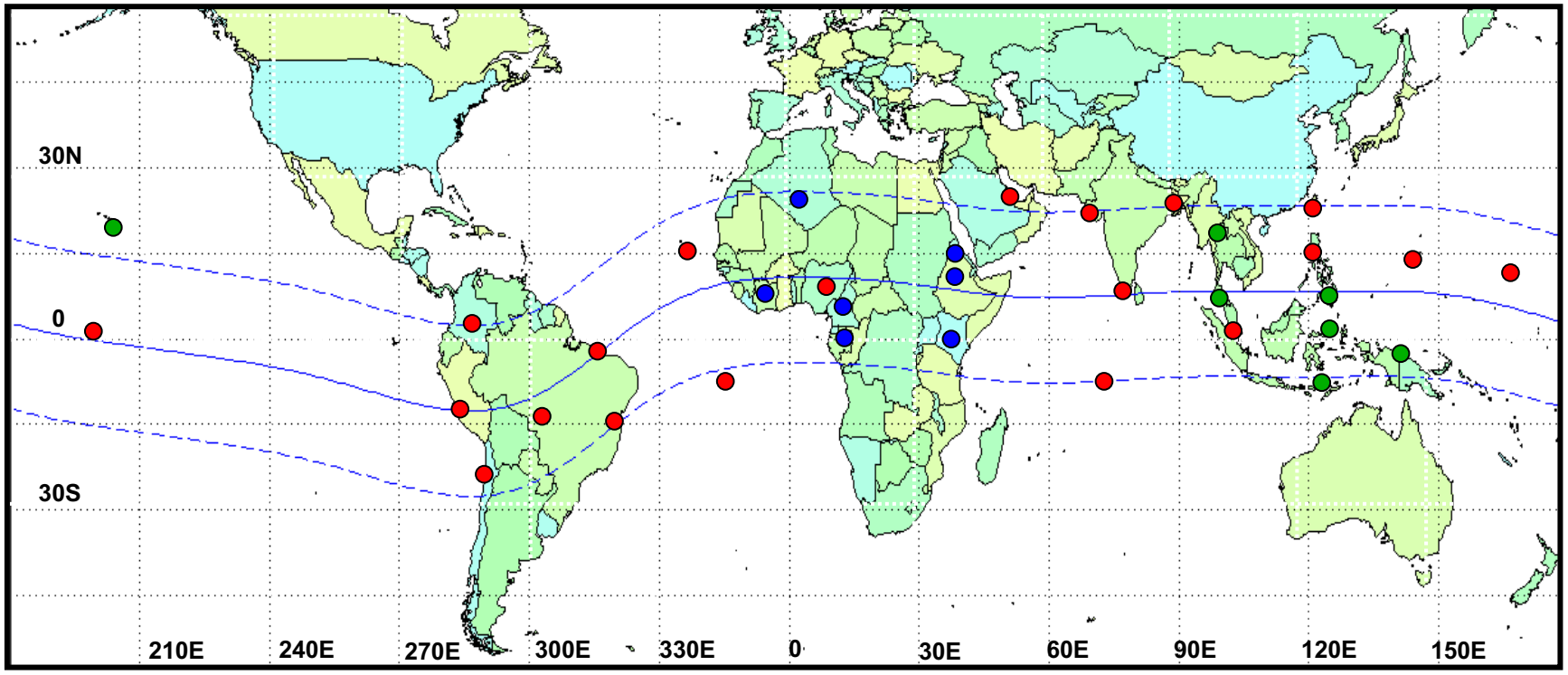


Real-time to 2-Hr Forecasts

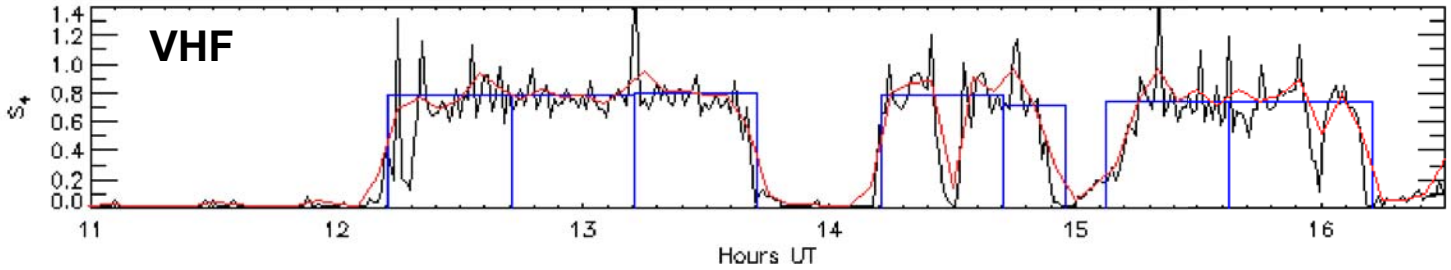
- **Ground-based sensor network**
  - **Passive UHF / L-band /GPS scintillation receivers**
  - **Measures scintillation intensity, eastward drift velocity, and TEC**
  - **Automated real-time data retrieval via internet**
- **Data supports research and space weather users**
  - **Understand on-set,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

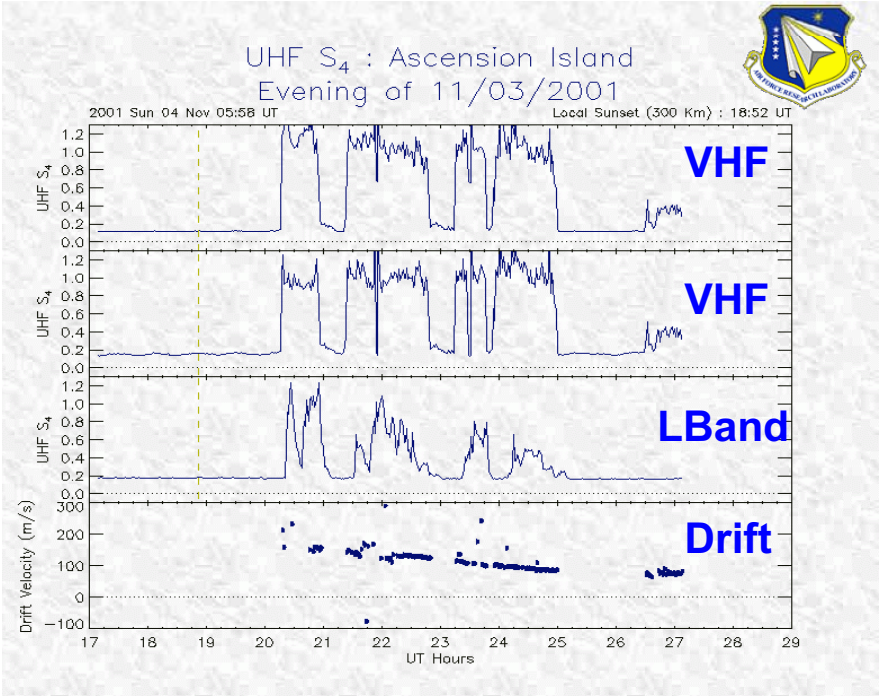
Global SCINDA Network

AFRL's Scintillation Network Decision Aid (SCINDA) network monitors GPS and geostationary UHF links over a widespread area in the equatorial region.



SCINDA Model & Products





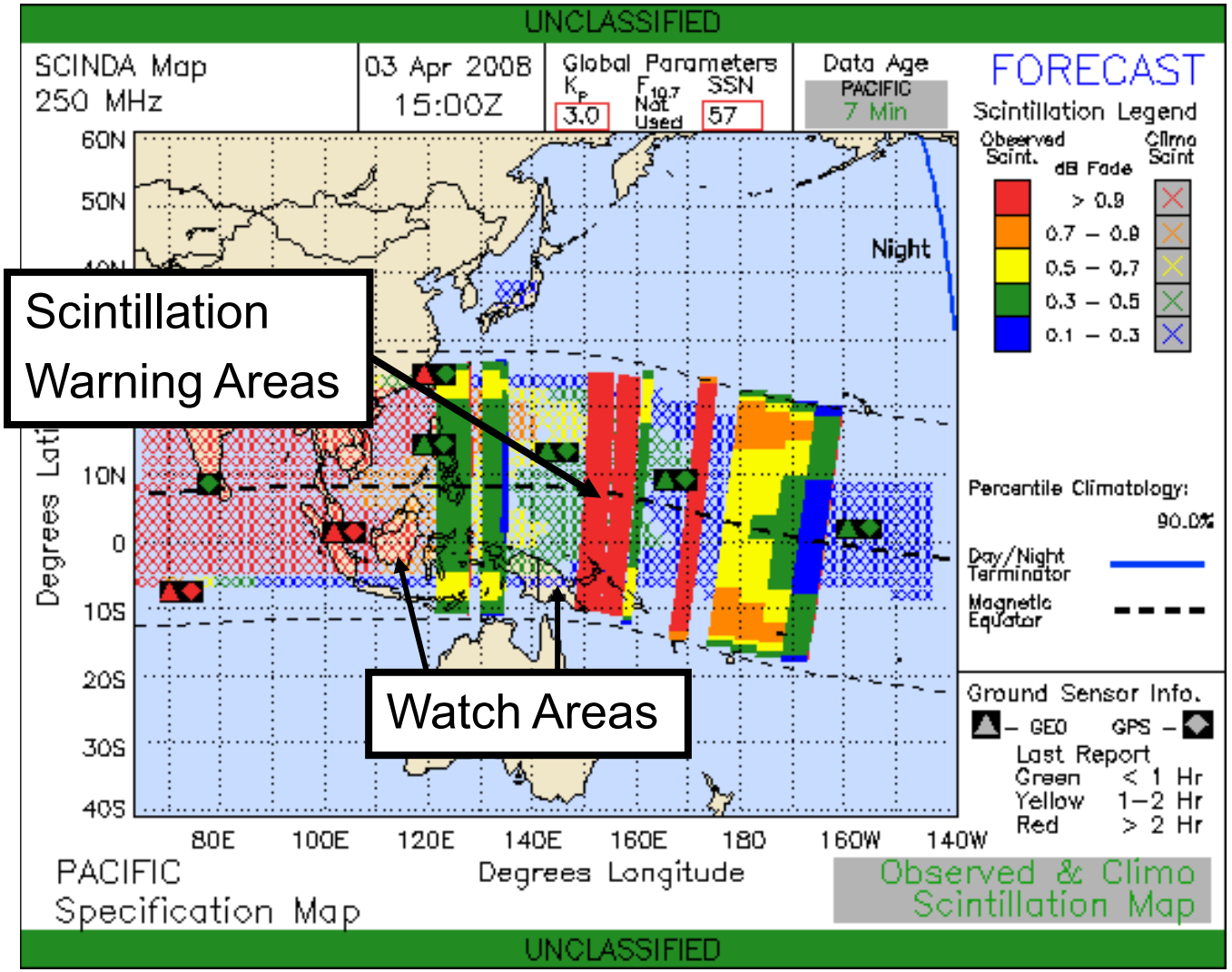
Groves, K.M., et al., Equatorial scintillation and systems support, *Radio Sci., 32,* 2047, 1997.

SCINDA Model

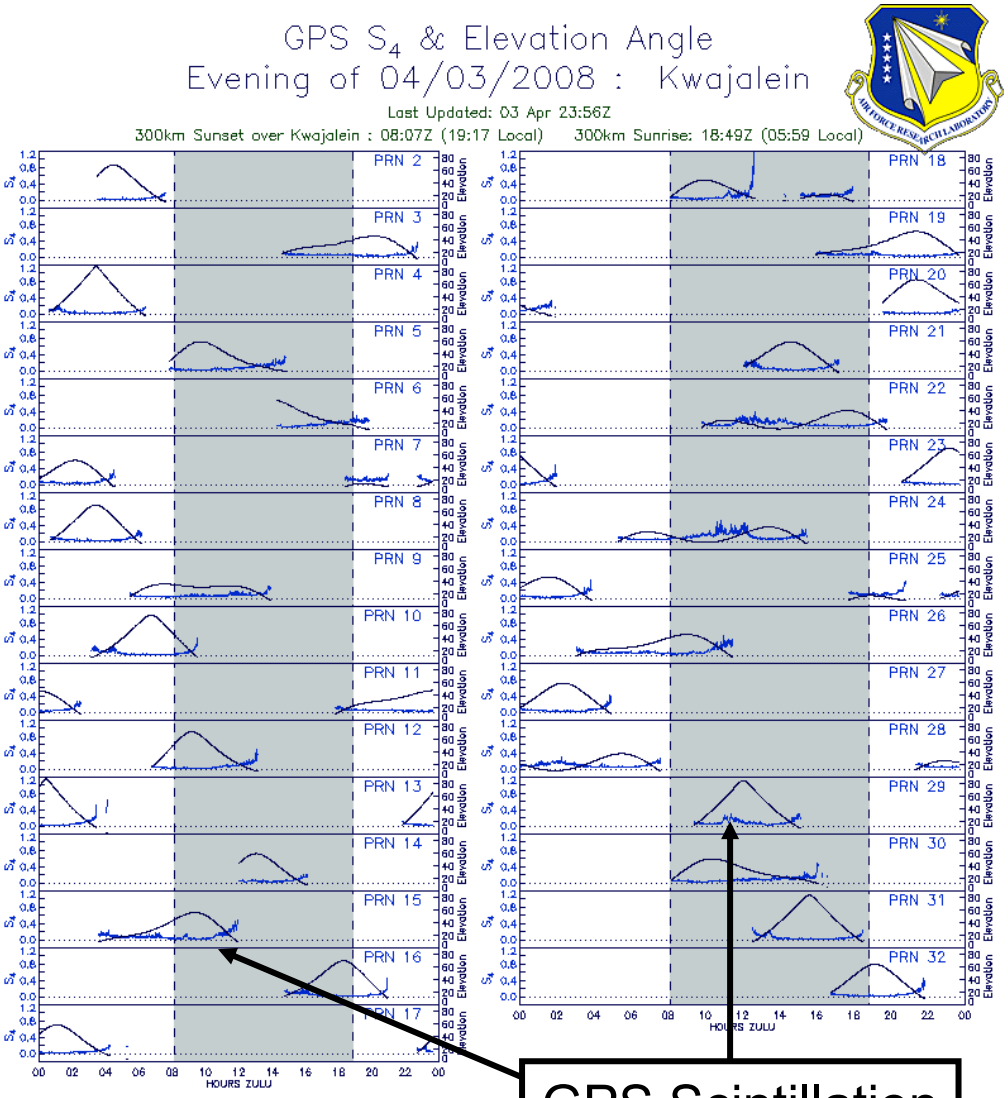
- Scintillation data collected in near real-time from global SCINDA network
- S_4 and ionospheric drift
- Smoothed data passed through Discrete Bubble Model (DSBMOD)
- Observed structures propagated with observed drift and decayed with empirical algorithm

Data-Driven Scintillation Map
Ionospheric Specification

SCINDA User Product Example for 250MHz

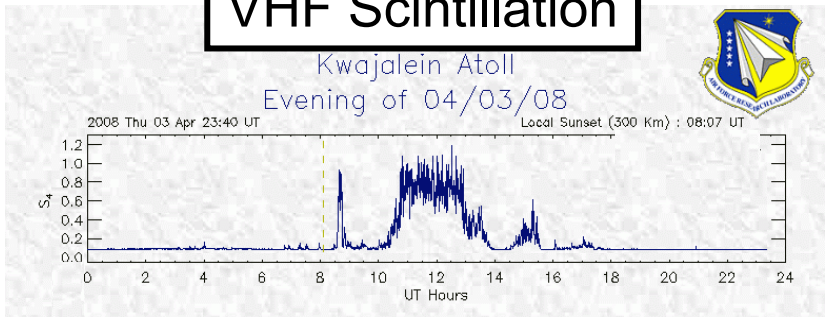


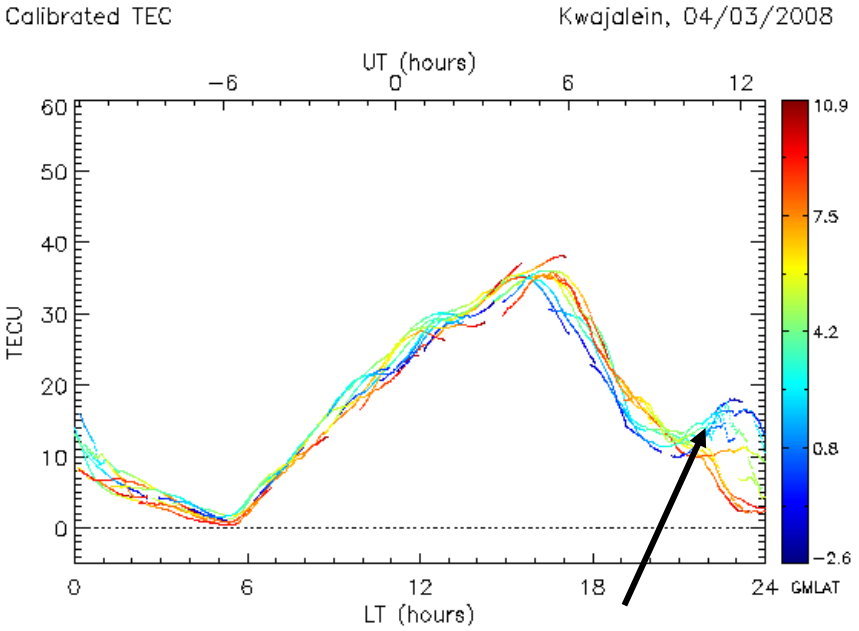
GPS Scintillation in Same Environment Much Weaker than VHF



GPS Scintillation

VHF Scintillation

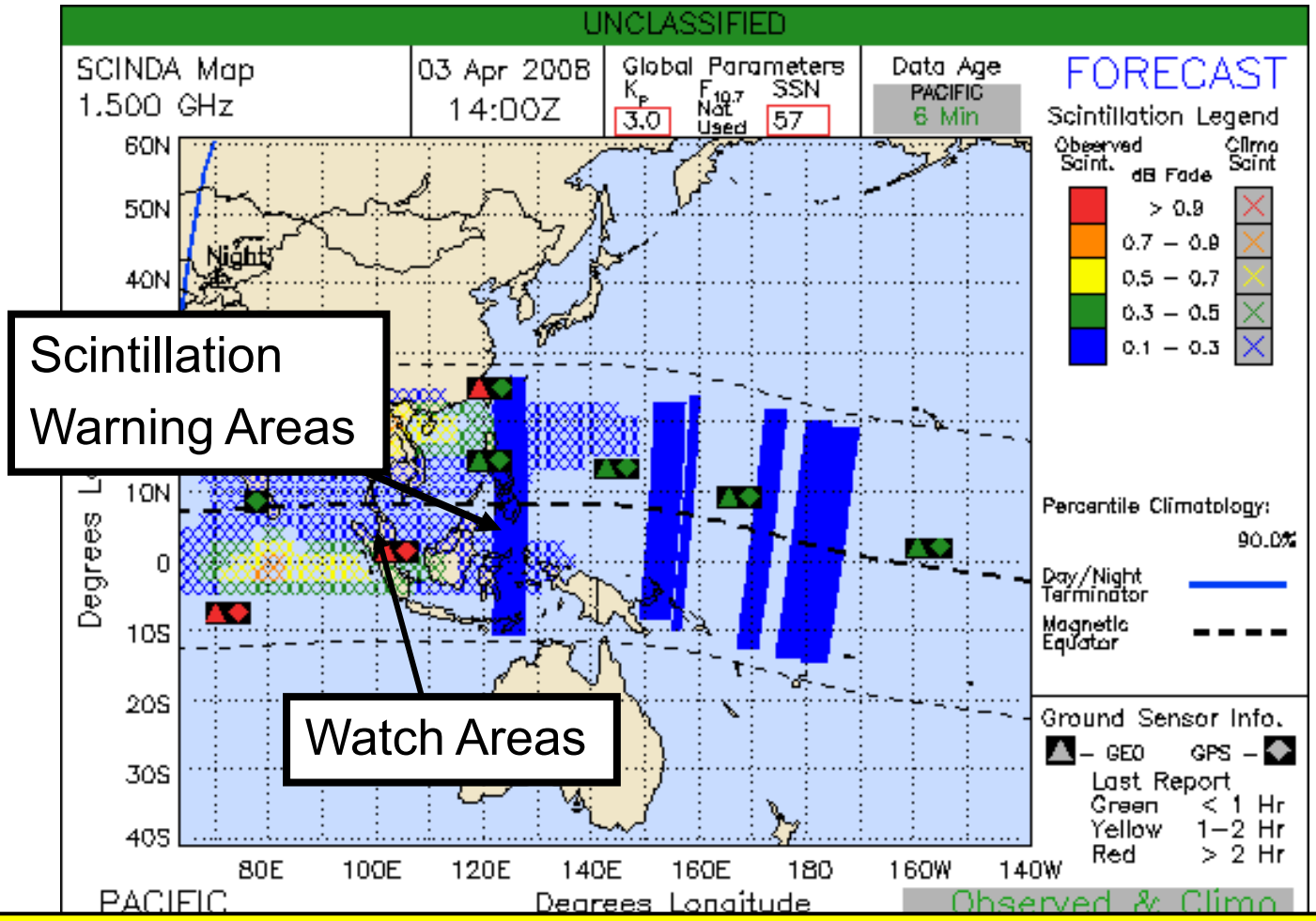




Latitude variation

Data-Driven Scintillation Map
Ionospheric Specification

SCINDA User Product Example for GPS



Modest Effects on GPS Frequencies During Solar Min

SCINDA Sensor Suite

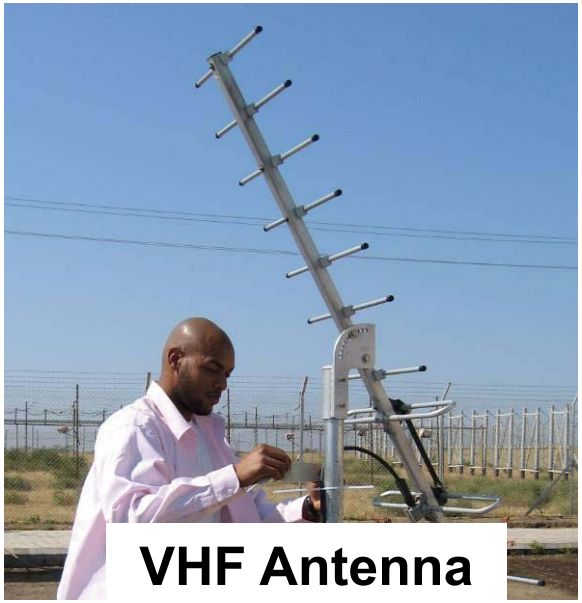
Tri-band Beacon System

Narrowband VHF Receiver

GSV4004B

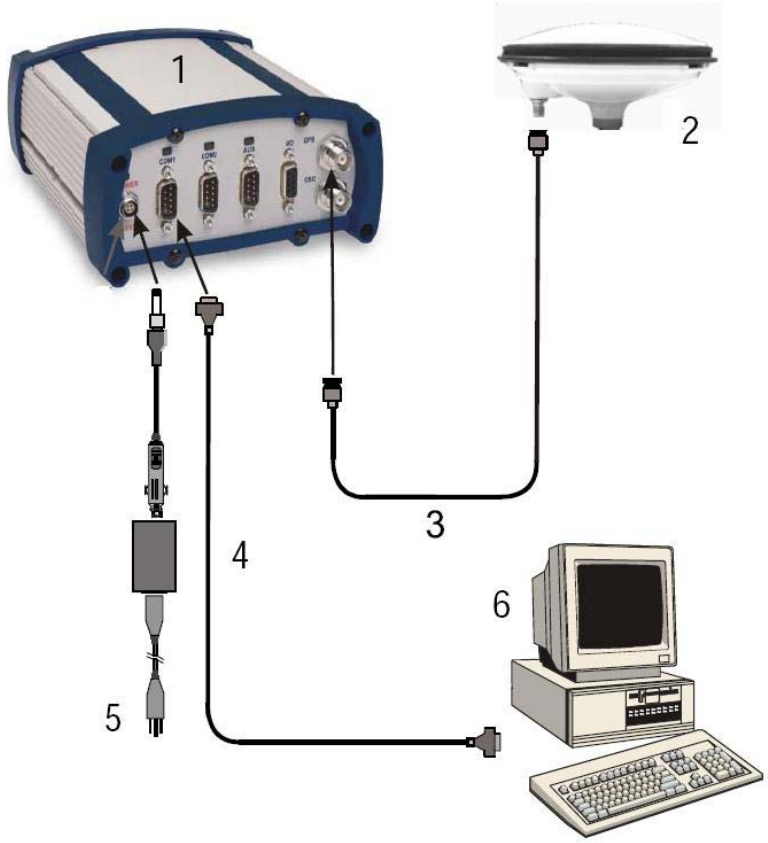
GPS Receiver

GPS Antenna



VHF Antenna

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

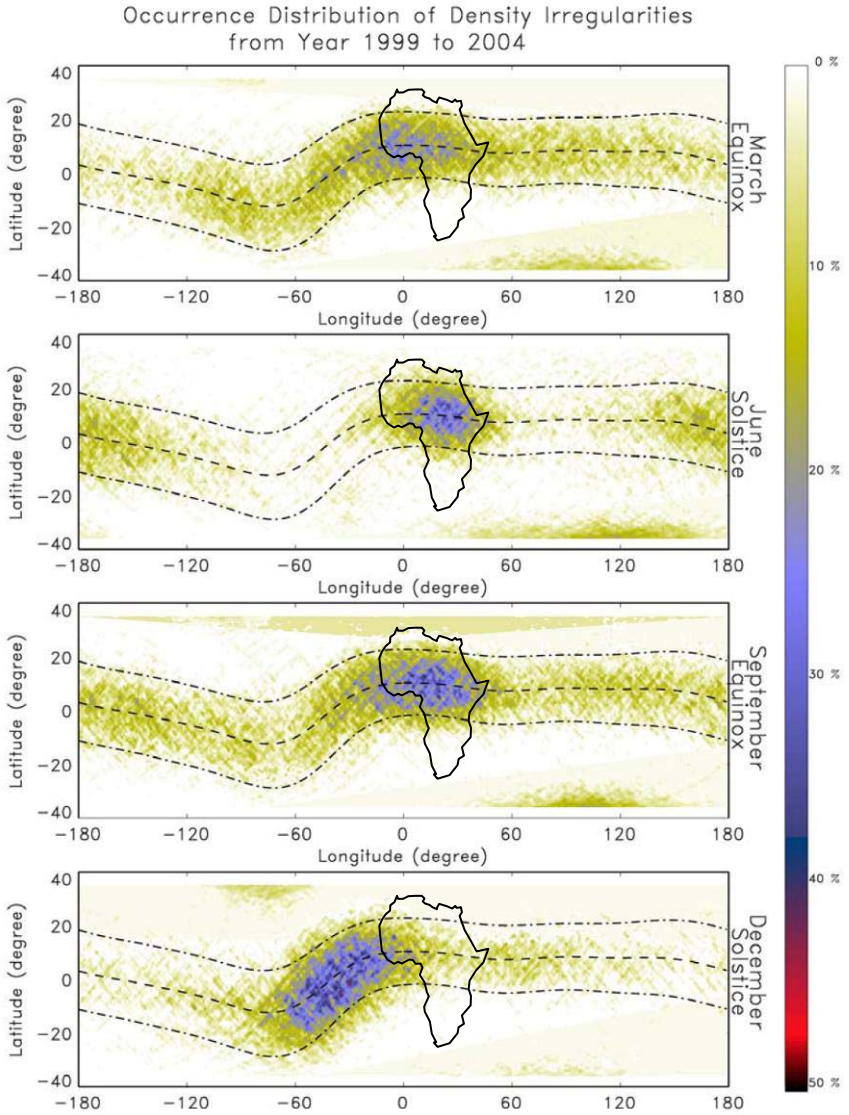
GPS Data Logging
What we measure: GPS System Outputs

- 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

Space Science across Africa

AFRL continues to pursue opportunities for collaboration with scientists in Africa & Asia

- 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/ISWI
- 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

Space Science in Africa

Recent meetings:

- Nigeria: National Nigerian Meeting on GNSS - November 2009
- Zambia: 3rd SCINDA IHY Workshop - June 2009
- Morocco: Workshop to Establish Scientific and Instrument Collaborations for Observing the Consequences of Space Weather - November 2009

Upcoming Meetings:

- Cairo: UN-NASA Workshop on the International Space Weather Initiative November 2010
- Kenya: Summer 2010
- Nigeria: Initiating GNSS curriculum at the African Regional Centre for Space Science and Technology Education

3rd SCINDA IHY Workshop Zambia

Hosted by the University of Zambia in collaboration with Hermanus Magnetic Observatory, South Africa

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

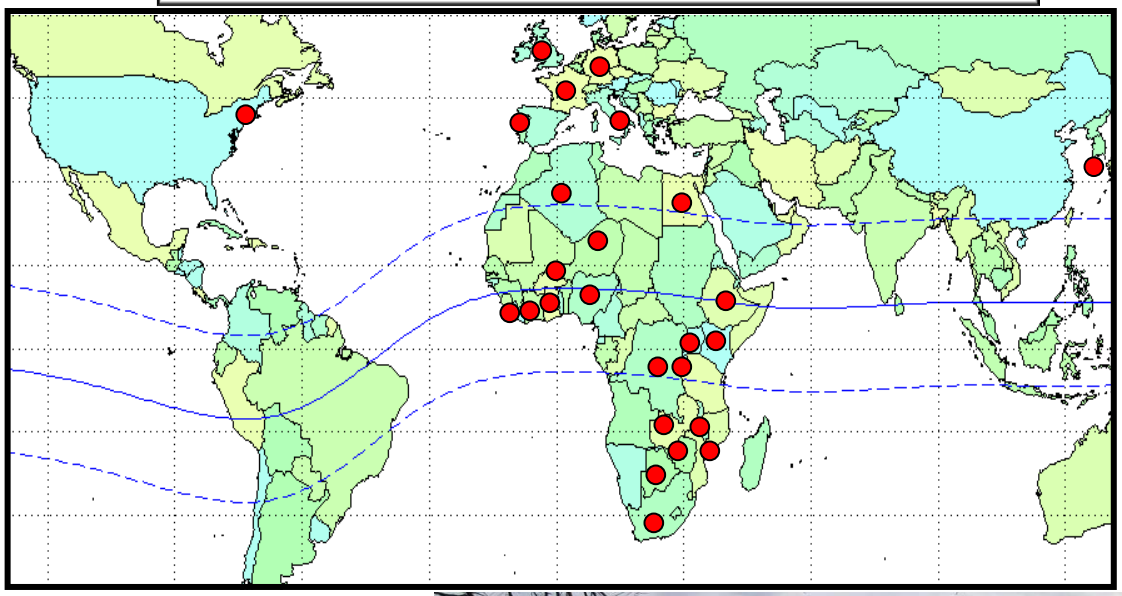
- Held June 2009 – 116 delegates from 27 nations including 79 representing 19 African countries
  - ~50 participants from 12 nations at 2007 IHY in Ethiopia
- Delivered 4 new SCINDA-GPS systems

3rd SCINDA IHY Workshop Zambia

- 24 Postgraduate Students
- 10 Undergraduate Students
- Attendees from:

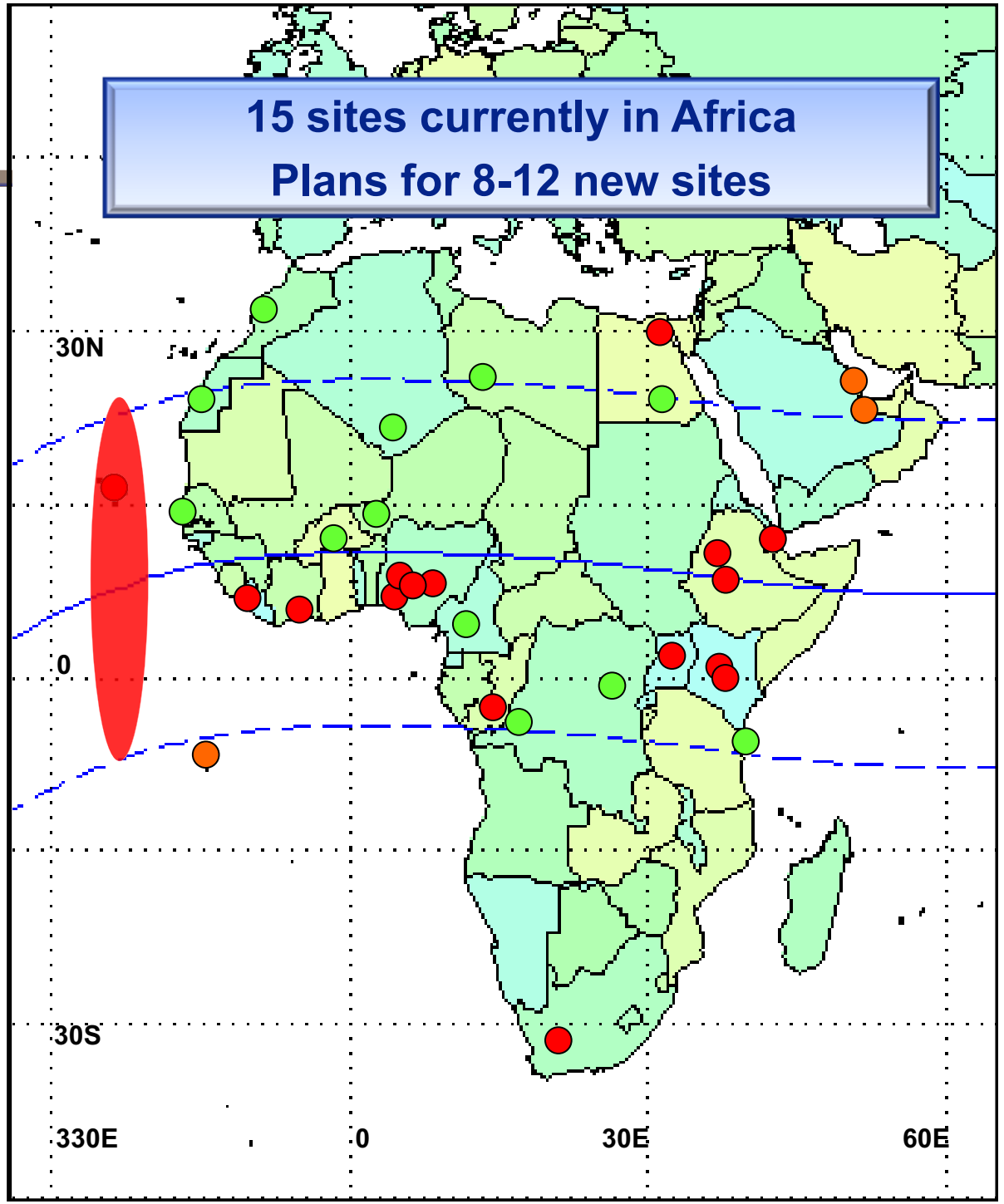
Algeria
Botswana
Burkina Faso
Congo DR
Czech Republic
Egypt
Ethiopia
France
Germany
Ghana
Italy
Ivory Coast
Japan
Kenya
Liberia
Malawi
Mozambique
Niger
Nigeria
Portugal
Rwanda
South Africa
Uganda
UK
USA
Zambia
Zimbabwe

IHY Attendees from 27 Countries



SCINDA in Africa

- Large regional gap in the center of Africa
- Bubble may persist to horn of Africa
- A goal is to increase coverage in central African gap



- **Pre-2006 SCINDA sites**
- **Existing IHY Sites**
- **Potential IHY Sites 2010**

Active SCINDA / AFRICA Ground Stations

Station	GPS Age (minutes)	GPS Operational Percentage (week/month)
Abidjan	66	78% 73% 4% 4% 18% 23%
Akure	> 24 hrs	0% 0% 0% 0% 100% 100%
Ascension Island	21	99% 53% 1% 1% 0% 46%
Bahirdar	52	88% 85% 10% 6% 2% 9%
Cape Verde	> 24 hrs	86% 92% 0% 0% 14% 8%
Kampala	> 24 hrs	37% 44% 1% 1% 62% 55%
Lagos	34	86% 81% 6% 3% 7% 16%
Nairobi	7	99% 67% 1% 2% 0% 31%
Nsukka	> 24 hrs	89% 49% 4% 9% 7% 41%

Legend

- < 60 minutes
- 60 - 120 minutes
- > 120 minutes

Coming soon:

- Illorin, Nigeria
- Cairo, Egypt
- Brazzaville, Congo

Proposed/Potential Sites:

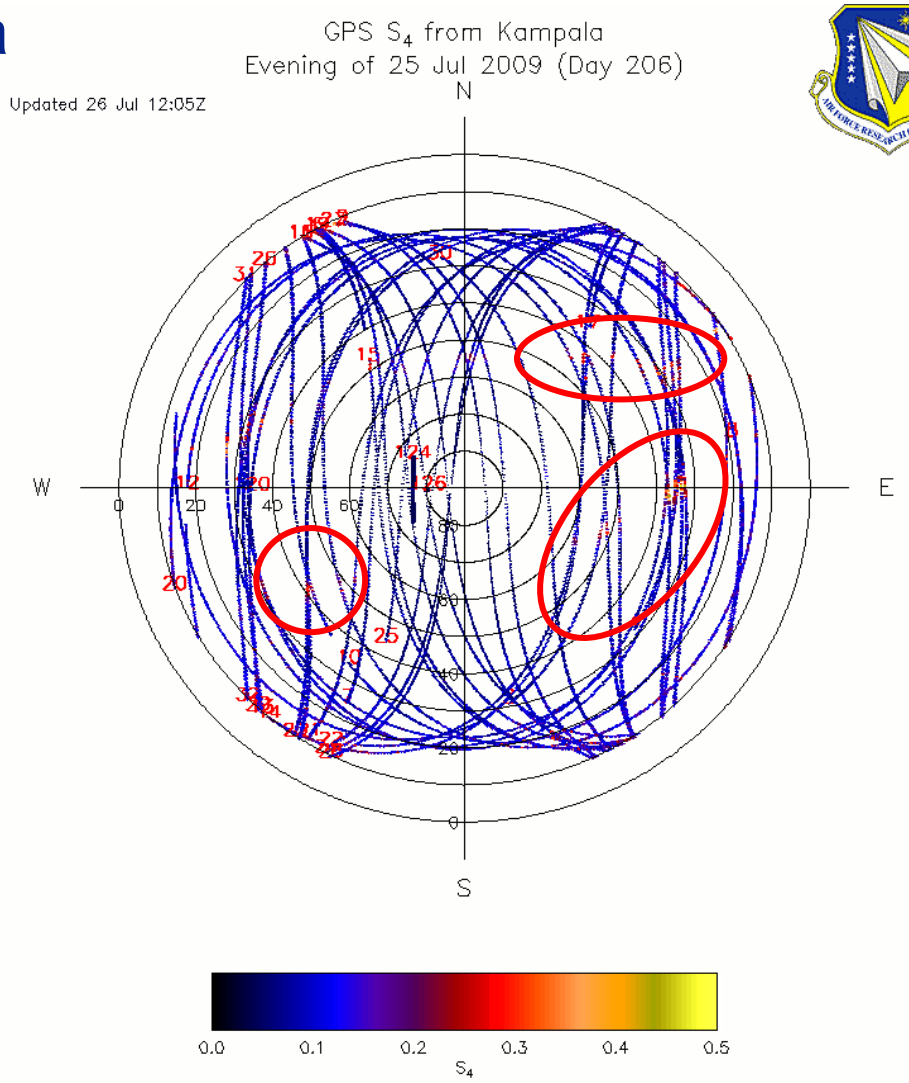
- Morocco
- Burkina Faso
- HMO, South Africa
- DRC
- Libya
- Nairobi, Nigeria
- Niger
- Senegal
- Algeria
- Tanzania
- Timbuktu
- Cameroon

From SCINDA Website on 03 Feb 2010

New Sites in 2009

Dr. Florence Mutonyi D'ujanga
Makerere University
Kampala, Uganda

Initial install – issues with multipath



New Sites in 2009

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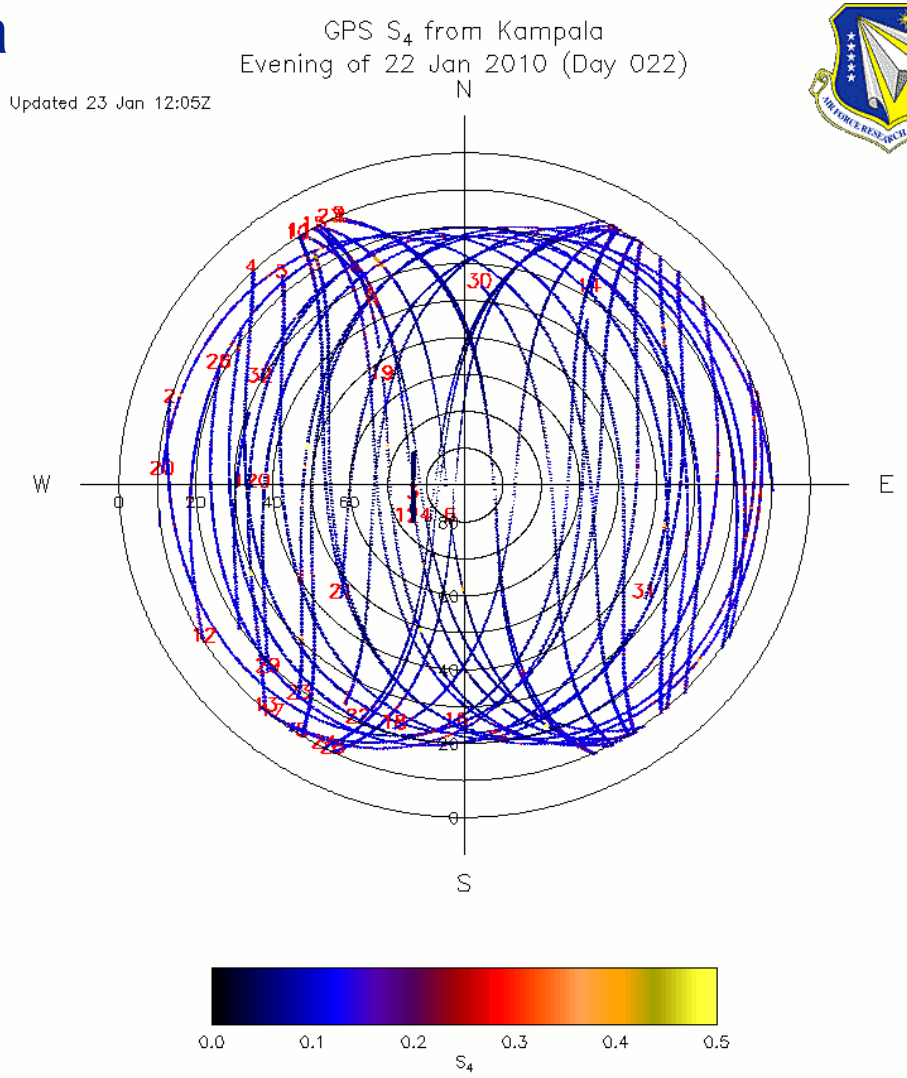


Much improved multipath environment

New Sites Expected by June 2010

Yaounde, Cameroon
Dr. Guemene Dountio
Dr. Cesar Mbane

Congo Brazzaville
Dr. Dinga Bienvenue

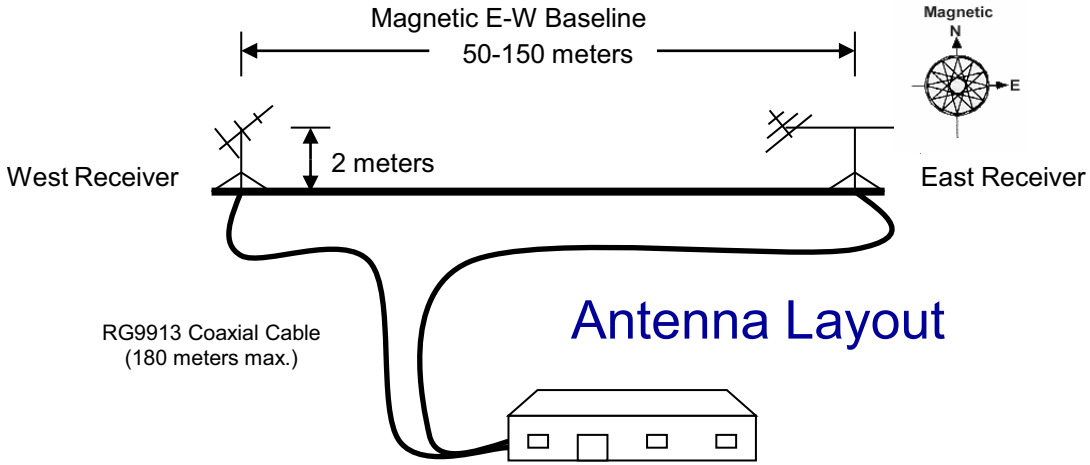
- Provides coverage in important Central African area

Expanded Opportunities
VHF & Tri-Band Receivers

Tri-Band Beacon System

Narrowband VHF Receiver

Plans to supplement existing SCINDA sites with VHF and Tri-Band systems

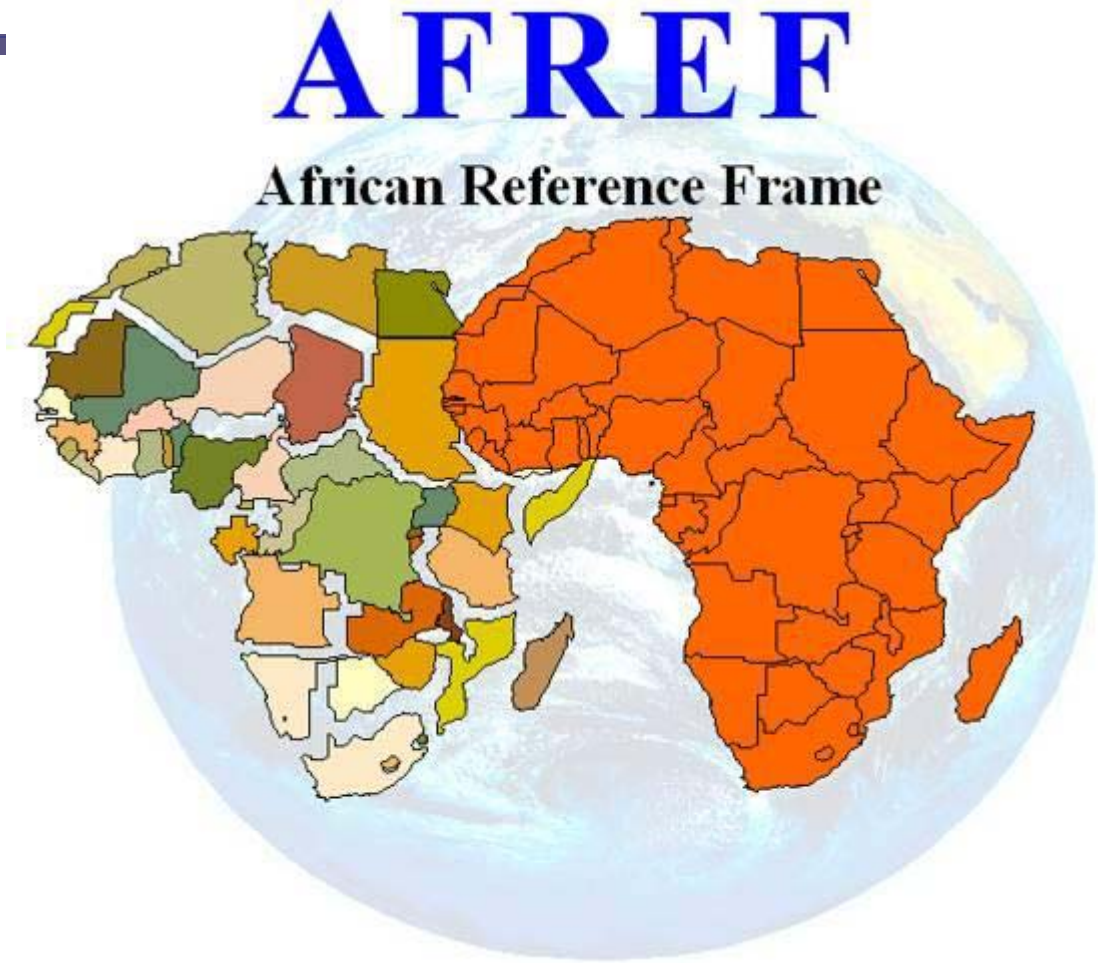


Antenna Layout

VHF Antenna

AFREF

African Reference Frame

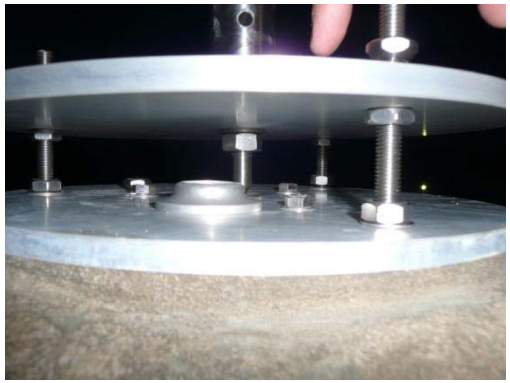


African initiative to unify the different datums

Continuing to collaborate with Dr. Rui Manuel da Silva Fernandes

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

On-Going Projects with the AFRL SCINDA Team

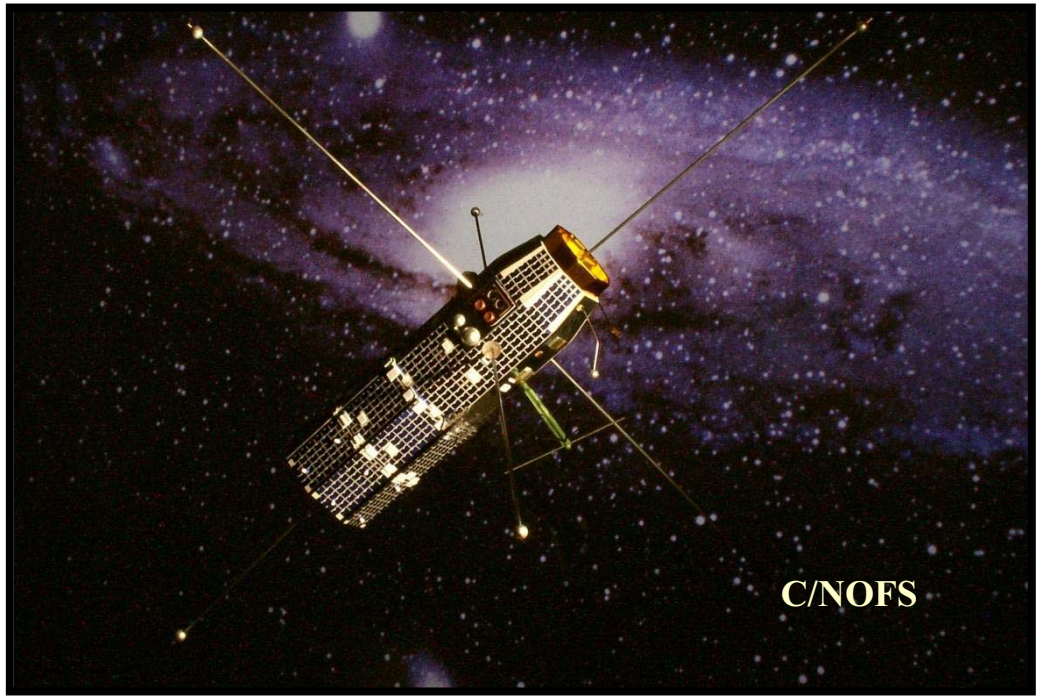
- *C/NOFS*
  - *GPS Occultation*
  - *Beacon Measurements*

- *Phase Screen Simulations*

Communication/Navigation Outage Forecasting System

C/NOFS

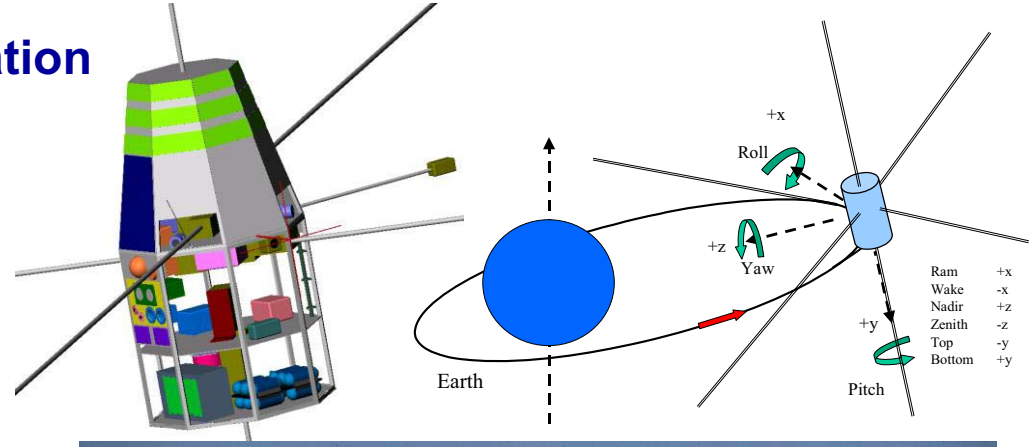
First-ever system for continuous global scintillation forecasts of communication and navigation outages



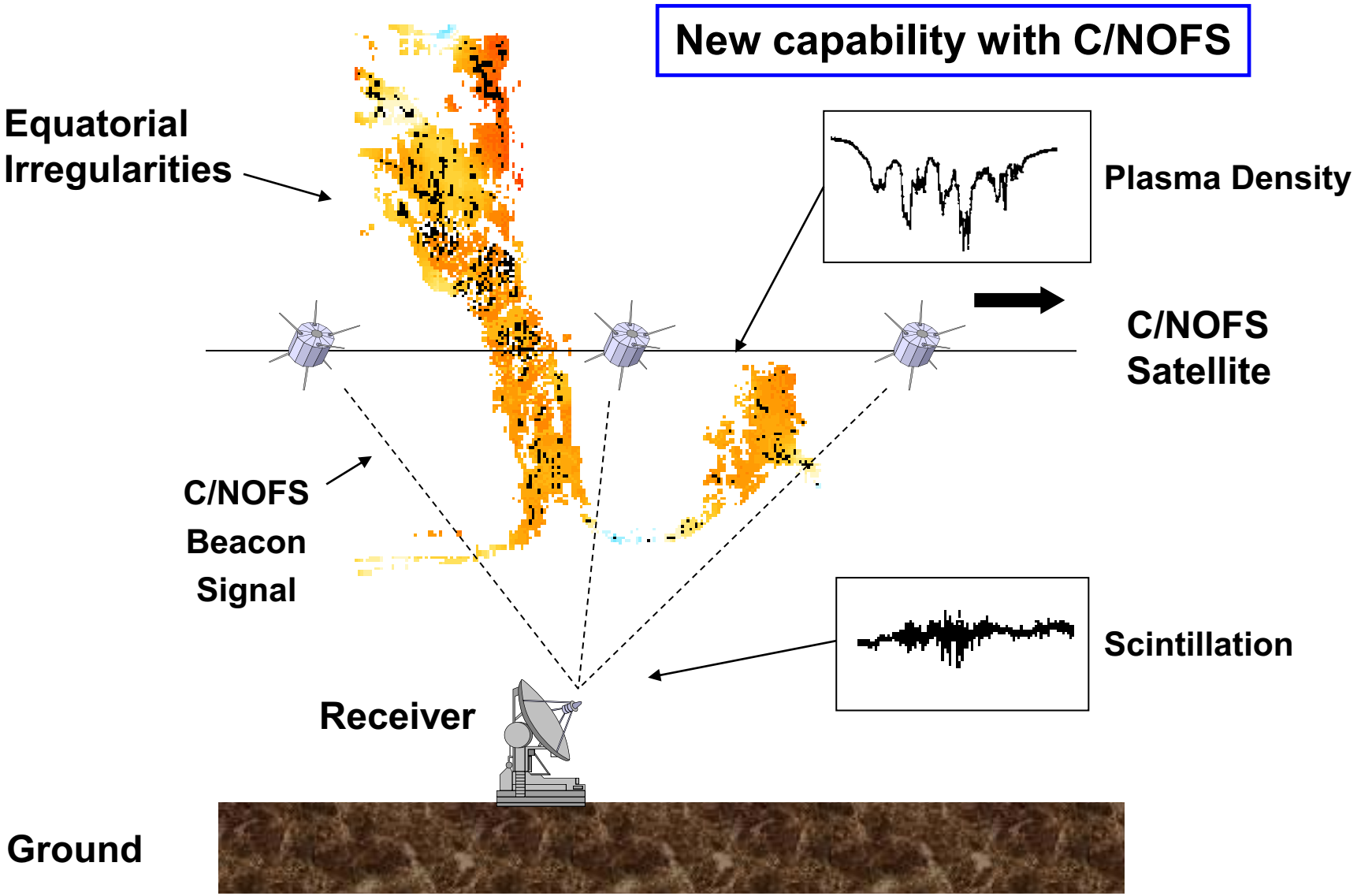
Communication/Navigation Outage Forecasting System

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**

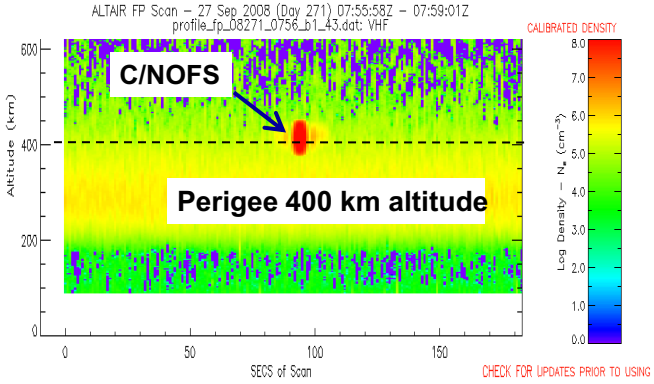


Ground Measurements vs. *In Situ*



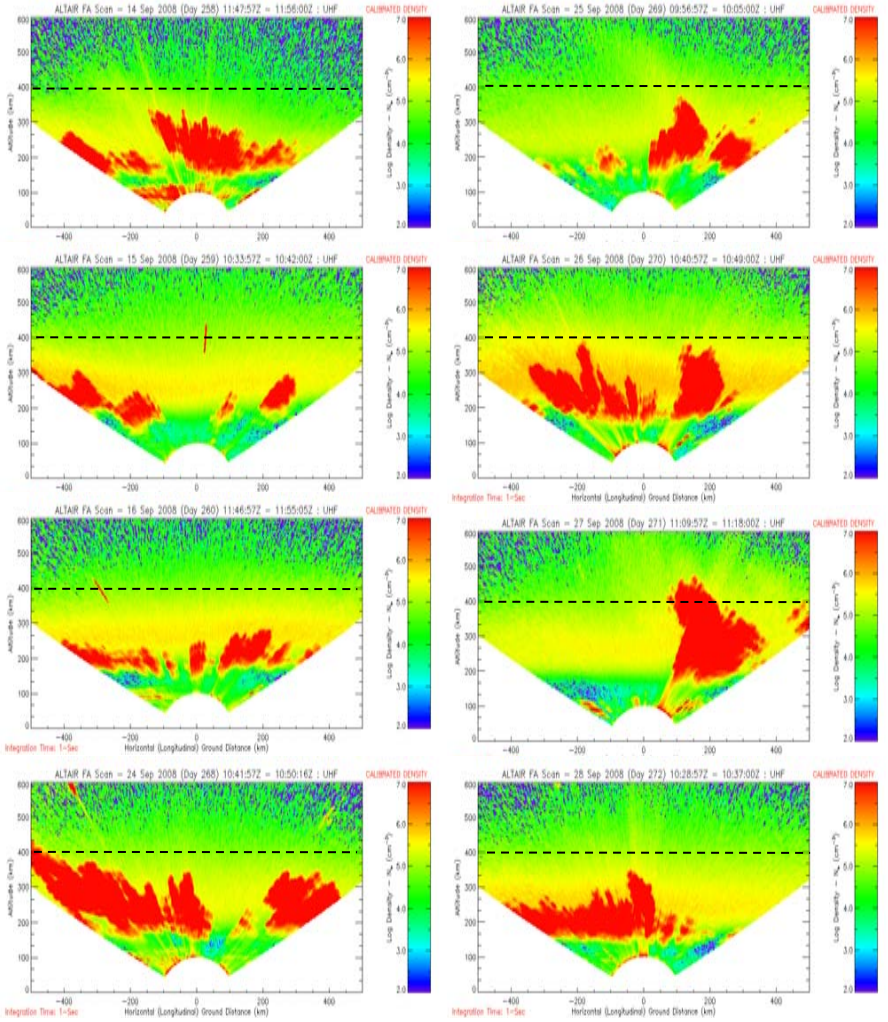
2008 C/NOFS Campaign

- During solar minimum ionospheric disturbances are weakly driven
  - Less frequent and slow to develop with limited altitude extent
- Even at perigee, C/NOFS In-Situ observations can “miss” active regions

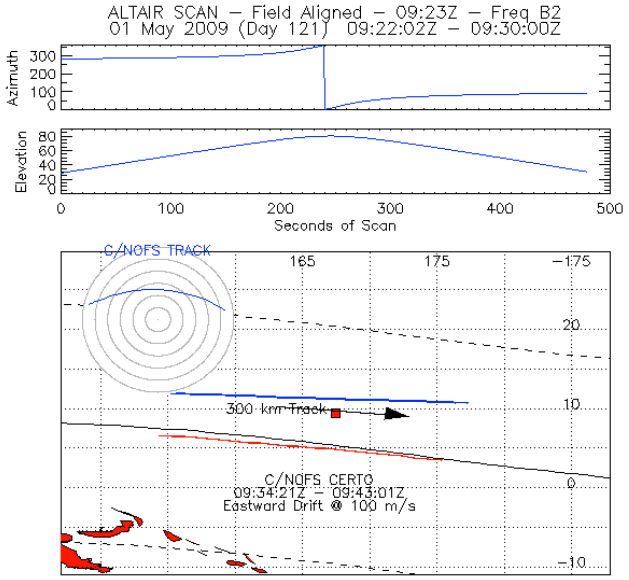


Active nights - Kwajalein Atoll

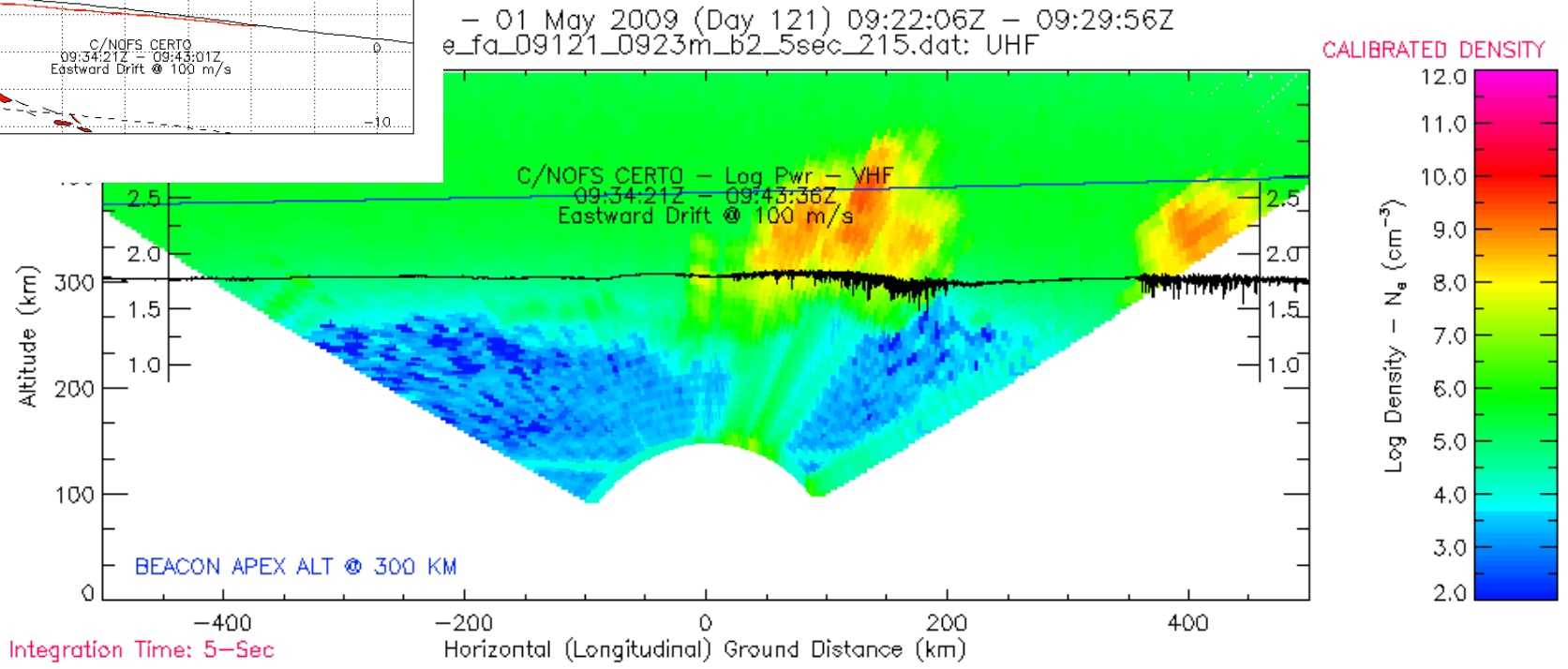
14-29 September 2008



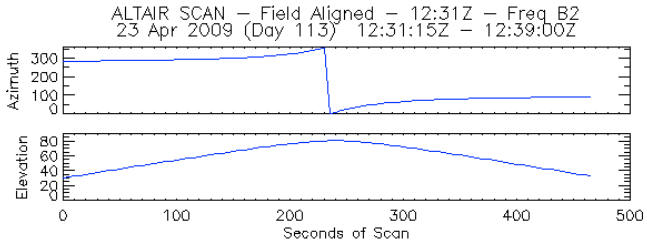
C/NOFS CERTO & ALTAIR

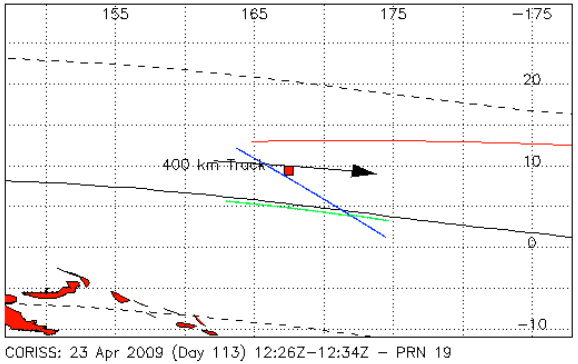


- Beacon data from C/NOFS overflights of the Kwajalein Atoll – data mapped into apex
- Scintillation observed on beacon signal when turbulent structures reach sufficiently dense regions in the ionosphere

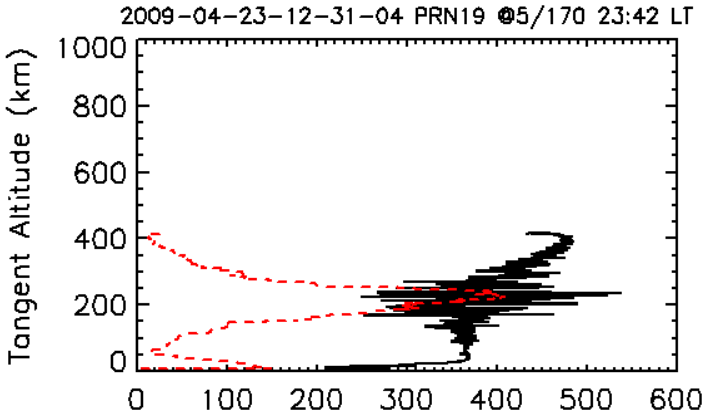


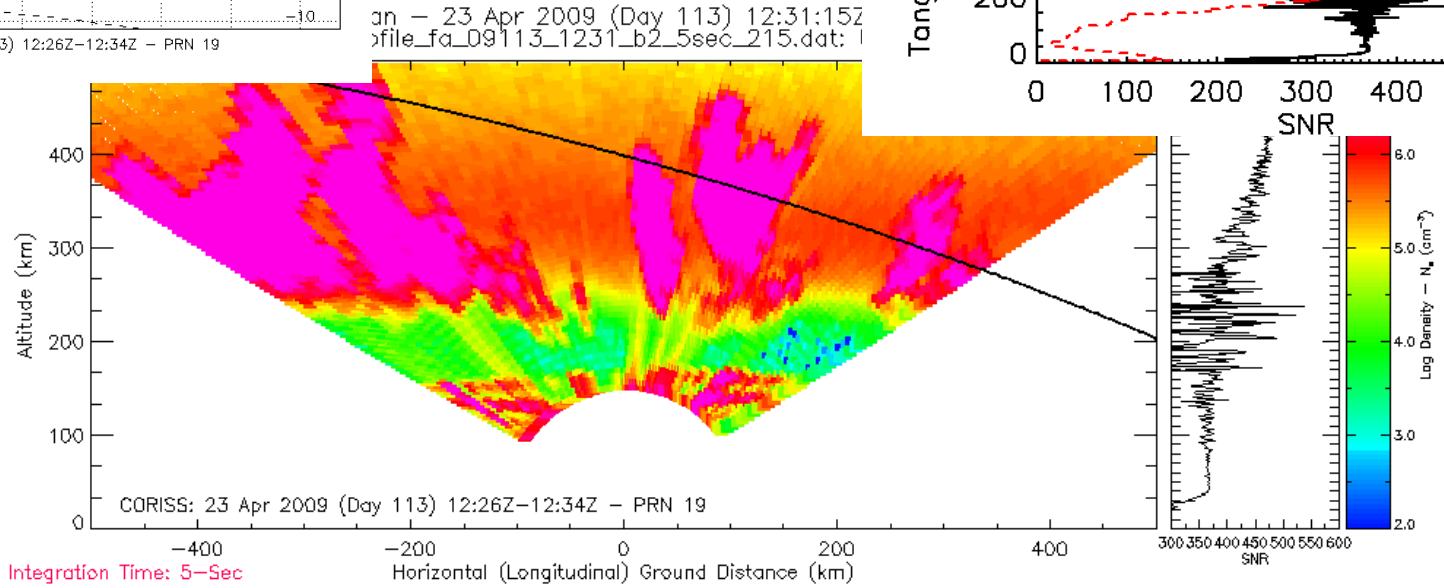
C/NOFS GPS Occultation





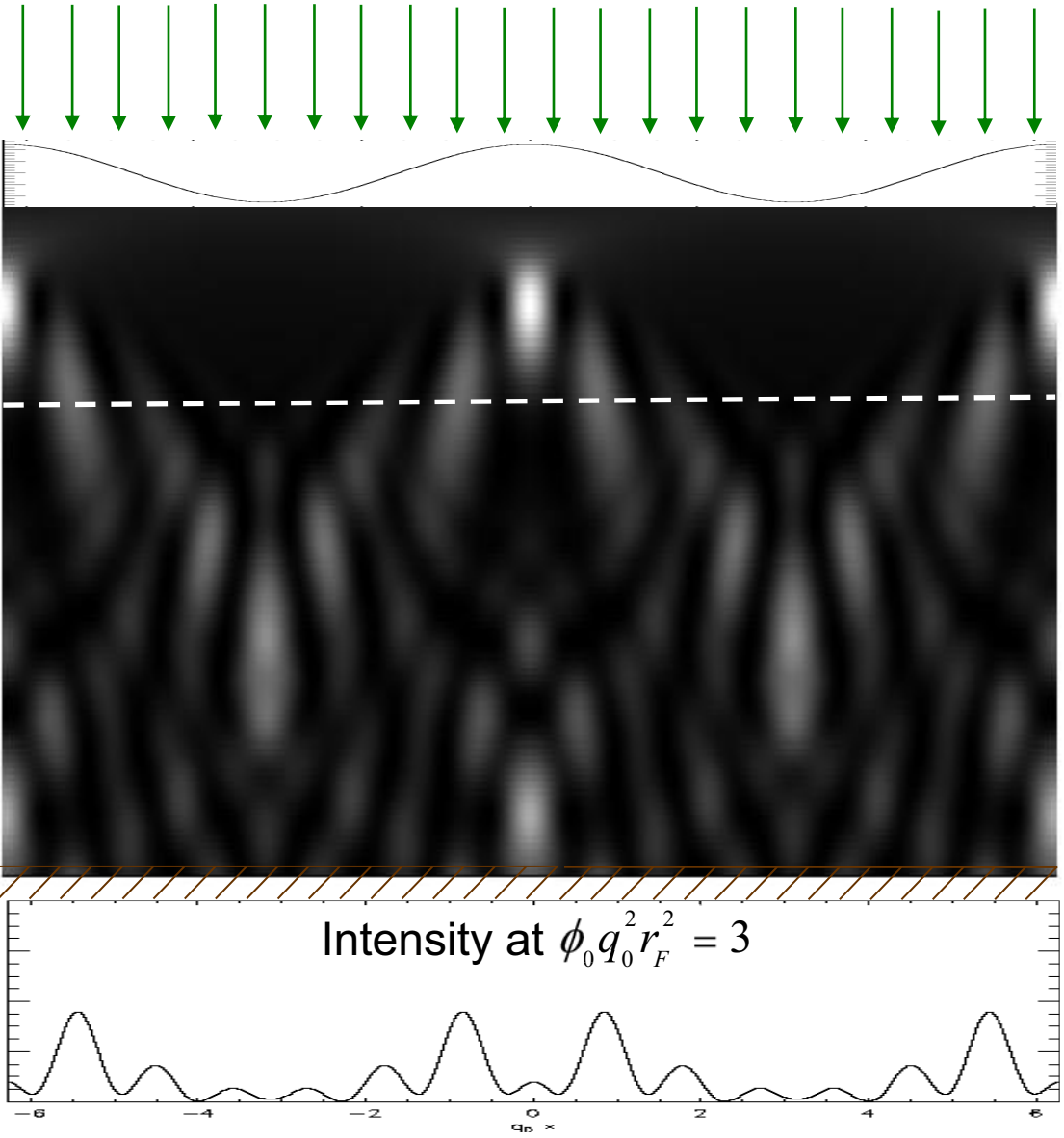
- GPS Occultation Data from CORISS
- Using ALTAIR to help develop algorithm to pinpoint scintillating region in ionosphere





Phase Screen Simulations

Plane Wave



Phase Screen

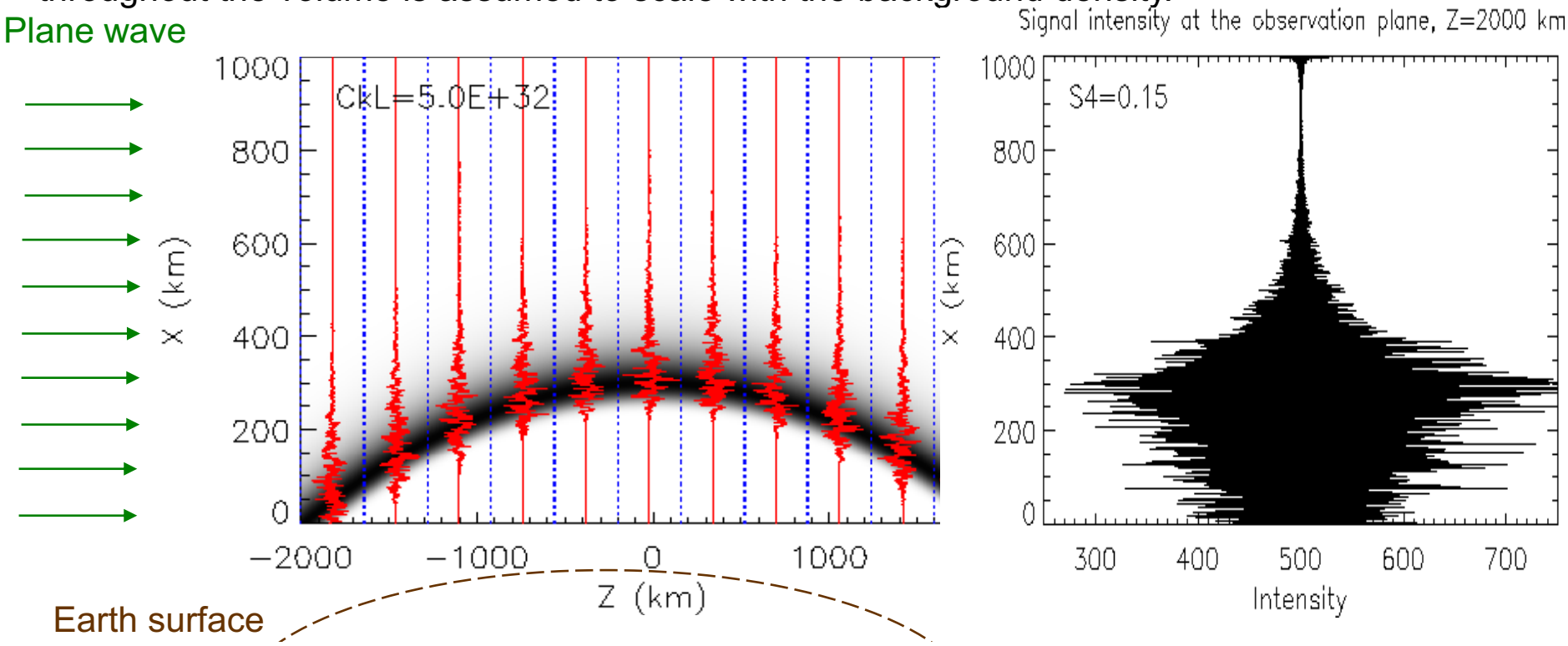
Focal distance

Propagation

Ground

Phase Screen Simulations
Occultation Geometry

We specify the background electron density as a Chapman layer. Irregularity strength (RMS ΔN) throughout the volume is assumed to scale with the background density.

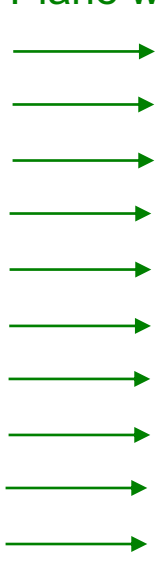


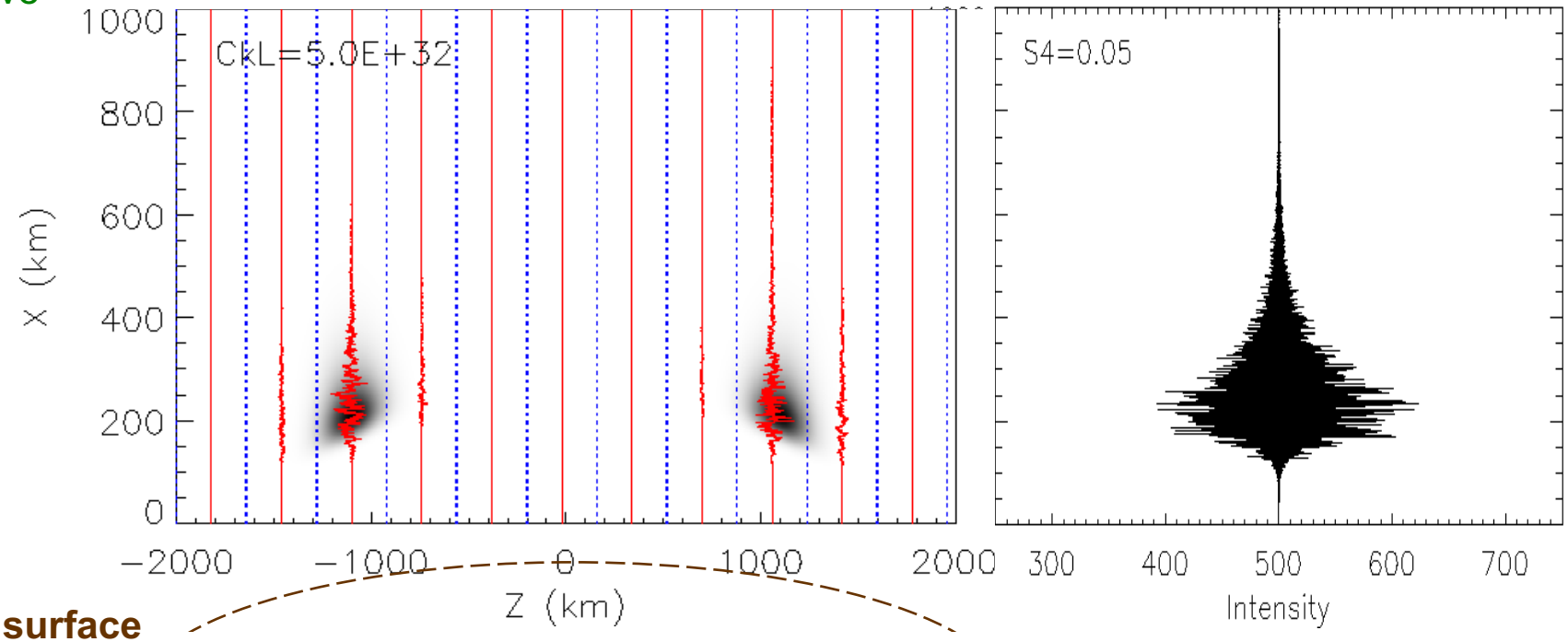
Signal intensity at the observation plane is computed by propagating through multiple phase screens oriented normal to the raypath. The phase in each screen (shown in red) is computed by integrating the density fluctuations between adjacent blue dashed lines.

Scattering is strongest at the ionospheric peak height (HmF2), but also occurs at much lower apparent altitudes due to Earth curvature effects.

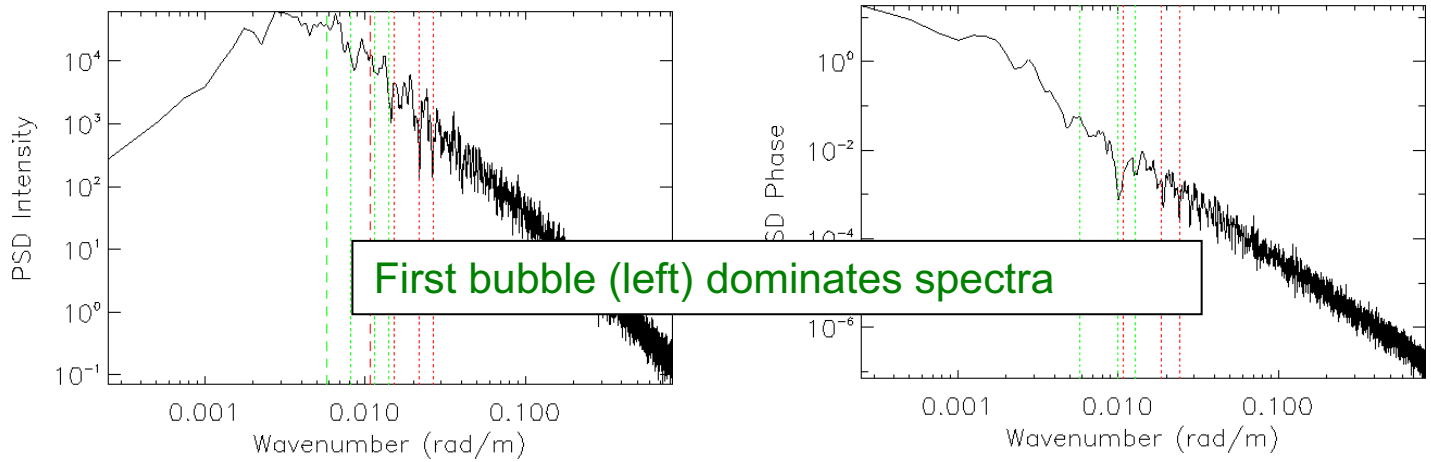
Phase Screen Simulations
Occultation Geometry– Multiple Bubbles

Plane wave





Earth surface



First bubble (left) dominates spectra

SCINDA Summary

- SCINDA provides robust state-of-the-art sensors for ionospheric characterization (irregularities, TEC)
  - Well on the way to meeting our goal of ensure good coverage across Africa for next solar max
  - Coverage in African sector expanded exponentially in last 3 years
- Combining ground- and space-based data facilitates better characterization & development of improved techniques
- AFRL SCINDA team continues to expand space weather tool set in collaboration with African scientists
- Please see us if you are interested in participating — opportunities for research collaboration & hosting sensors