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Ocean Remote Sensing by Oblique Incidence Sounding of the Ionosphere

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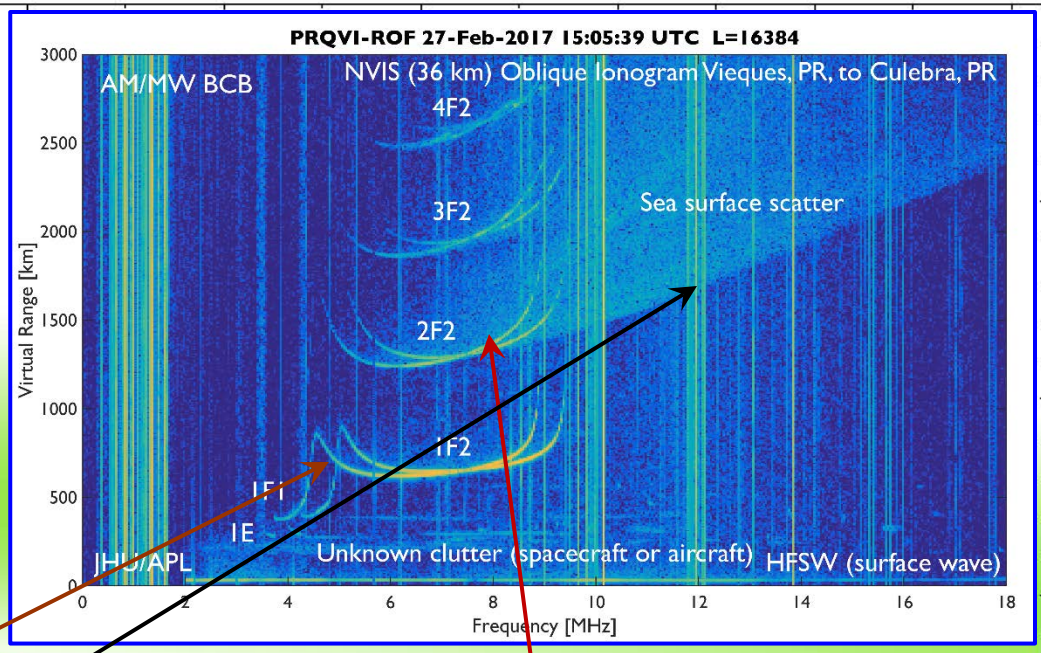
Ocean Surface HF Scatter Measurements

- Complementary Nature of HF Versus Microwaves
  - HF Sensitive to Swells While Microwaves Scatter from Capillary and Wind Waves
  - HF Waves Penetrate Rain with Much Less Attenuation than Microwaves
- Ocean Scatter in Oblique Ionograms and HF Satellite Sensing
- Ground-Ionosphere-Ocean-Satellite GIOS Technique
  - Skywave Illumination of Ocean Surface from Ground HF Transmitter
  - HF Signals Scattered to Satellite at Broad Range of Angles
  - Ocean Scatter Location Determined from Radar Range and Doppler
  - Data Products Include Wave Height Spectrum and Sea Ice Mapping
- Theory of Ocean Scatter and Ionosphere Propagation
  - Coherent (Specular) and Incoherent (Bragg) Scatter
  - Bistatic Sampling of Global Ocean Surface
  - Ray Tracing from Ground to Ionosphere to Ocean to Space (GIOS)
- Tests with Large Radar and Low-Earth-Orbit Satellite (ePOP)
  - Data Collected in April and August 2015
  - Interpretation of Range-Position-Intensity (RPI) Data
  - Ocean Wave Number Distribution of Meter-Scale Swells

1-Hop and 2-Hop Rays with Specular Reflection and Ocean Scatter

Quasi-Biquadradic Ionosphere Propagation Model for Oblique Ionogram Rays



Ionosphere

One-Hop

Surface Scatter

Two-Hop

Transmitter

Ocean Scatter

O-X Reflection

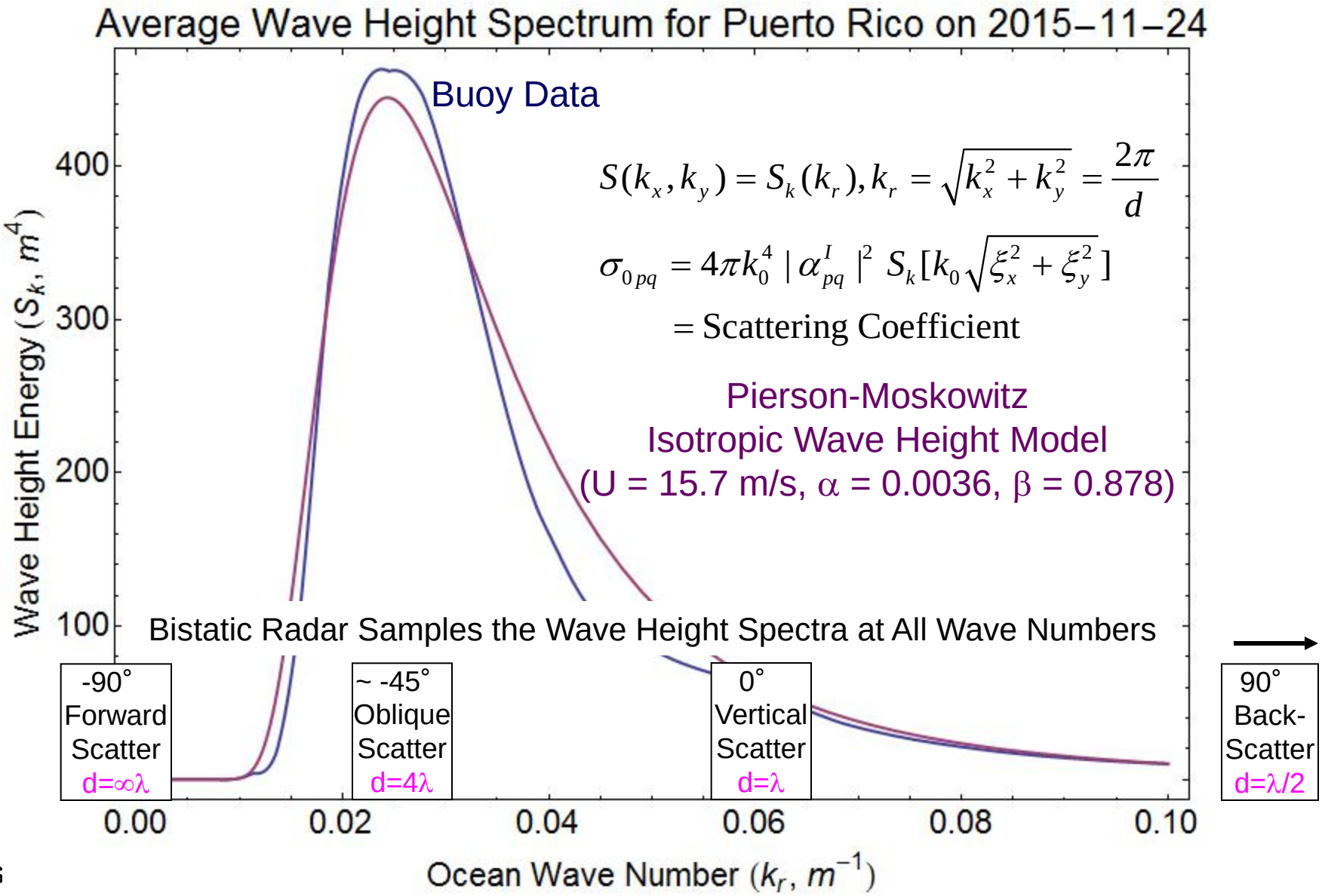
Receiver

Altitude (km)

Horizontal Distance (km)

Wave Height Wave Number Spectrum
Derived from Puerto Rico Wave Buoy Data

Source: http://www.ndbc.noaa.gov/station_page.php?station=XXXXX



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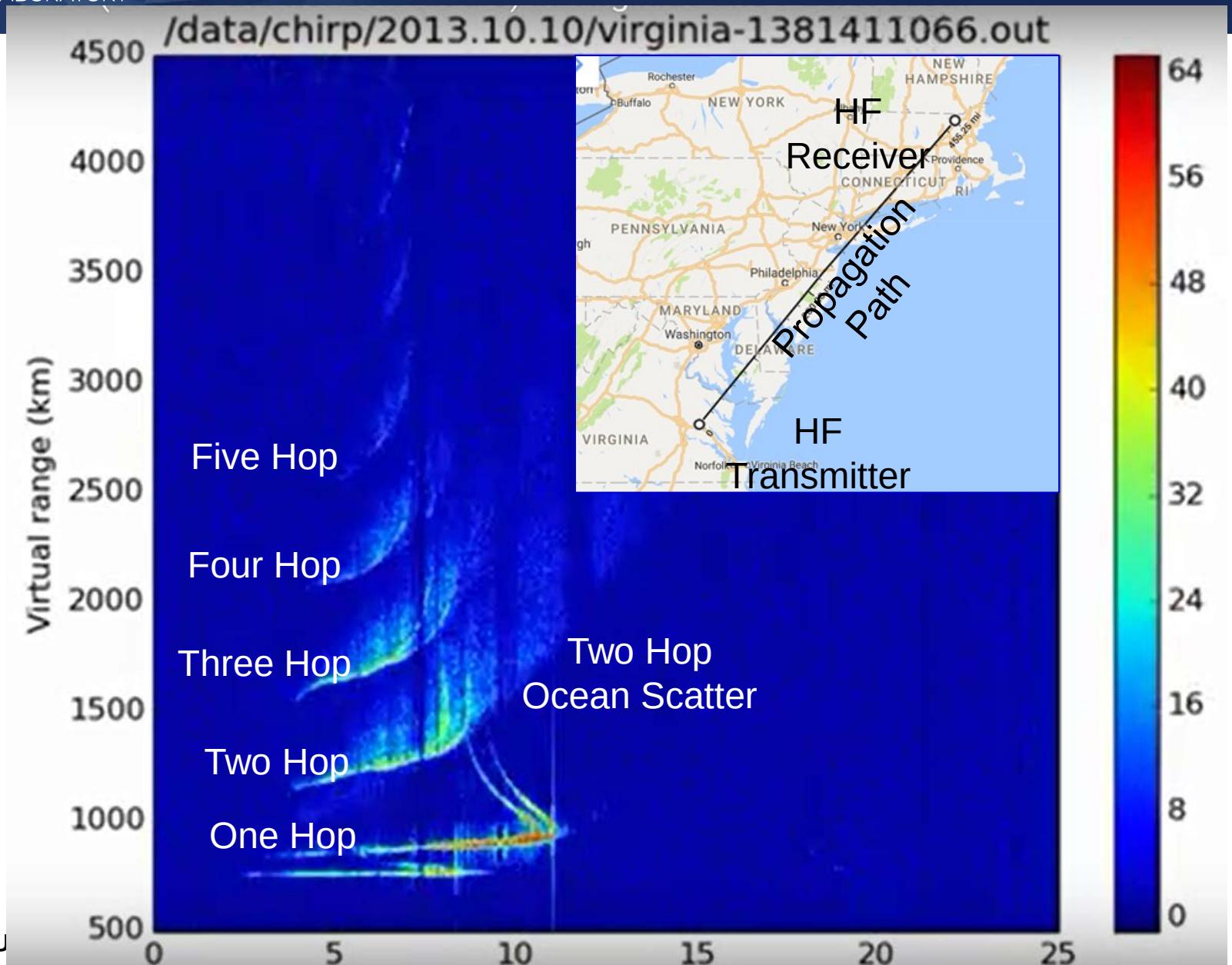
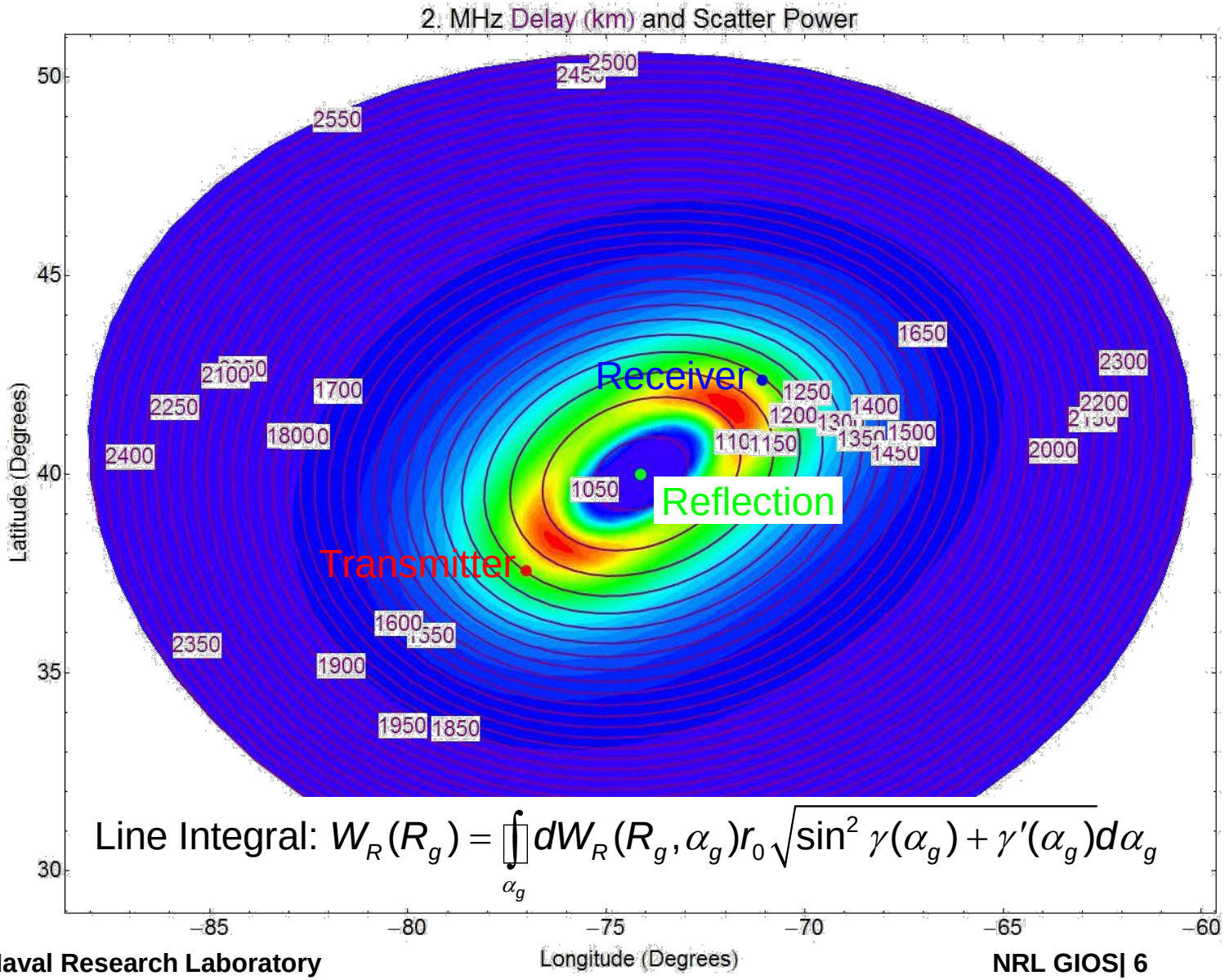
10 Oct 2013, 13:17:46 GMT HF Radar Scatter from the Ocean

Virginia ROTHR WSBI Transmitter to USRP Receiver in Boston

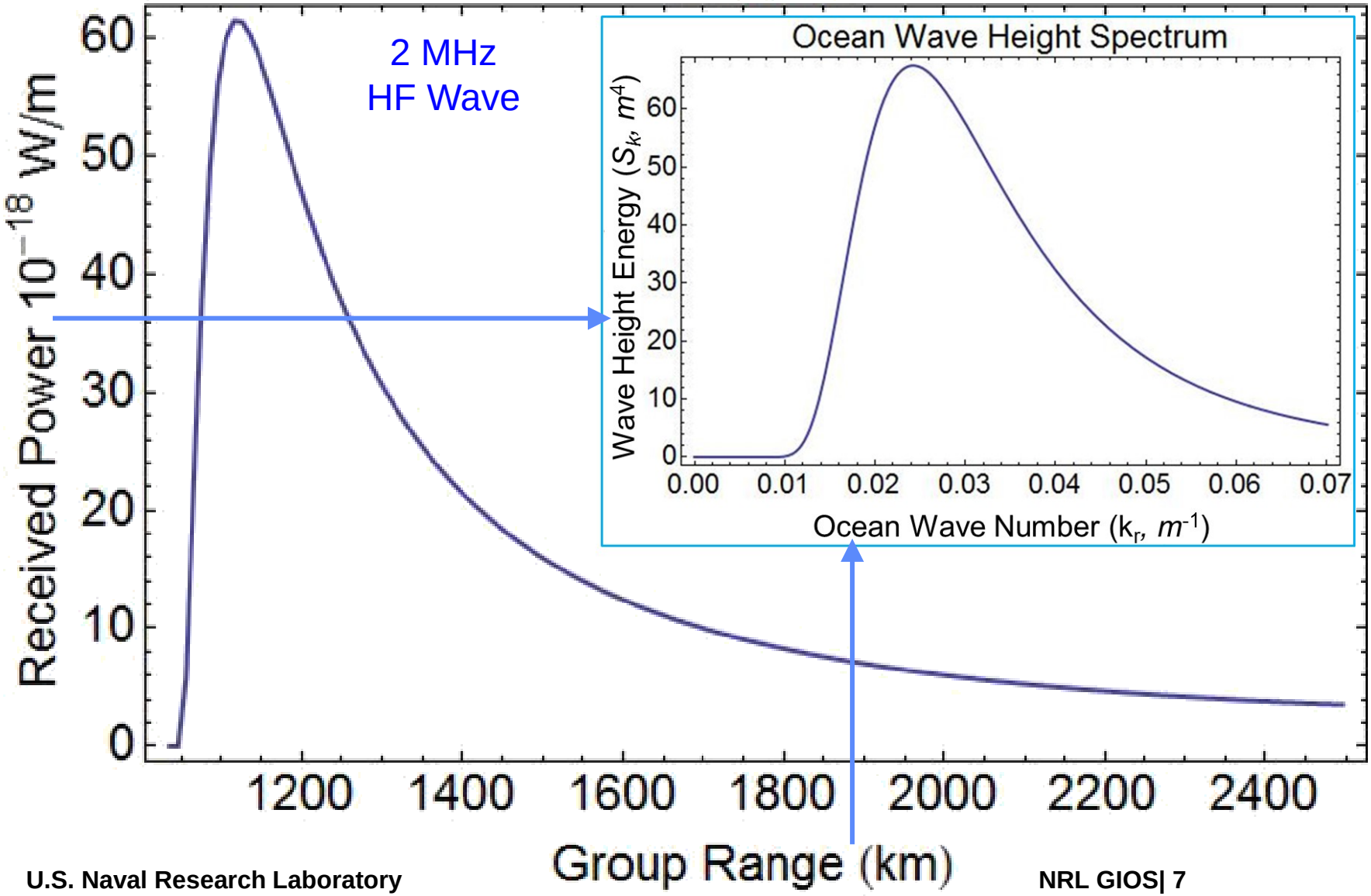


Group Range Contours Around Specular Reflection Point for HF Surface Scatter



Line Integral: $W_R(R_g) = \int_{\alpha_g} dW_R(R_g, \alpha_g) r_0 \sqrt{\sin^2 \gamma(\alpha_g) + \gamma'(\alpha_g)} d\alpha_g$

Ocean Wave Height Spectrum Derived from Scattered Signal Power Versus Range



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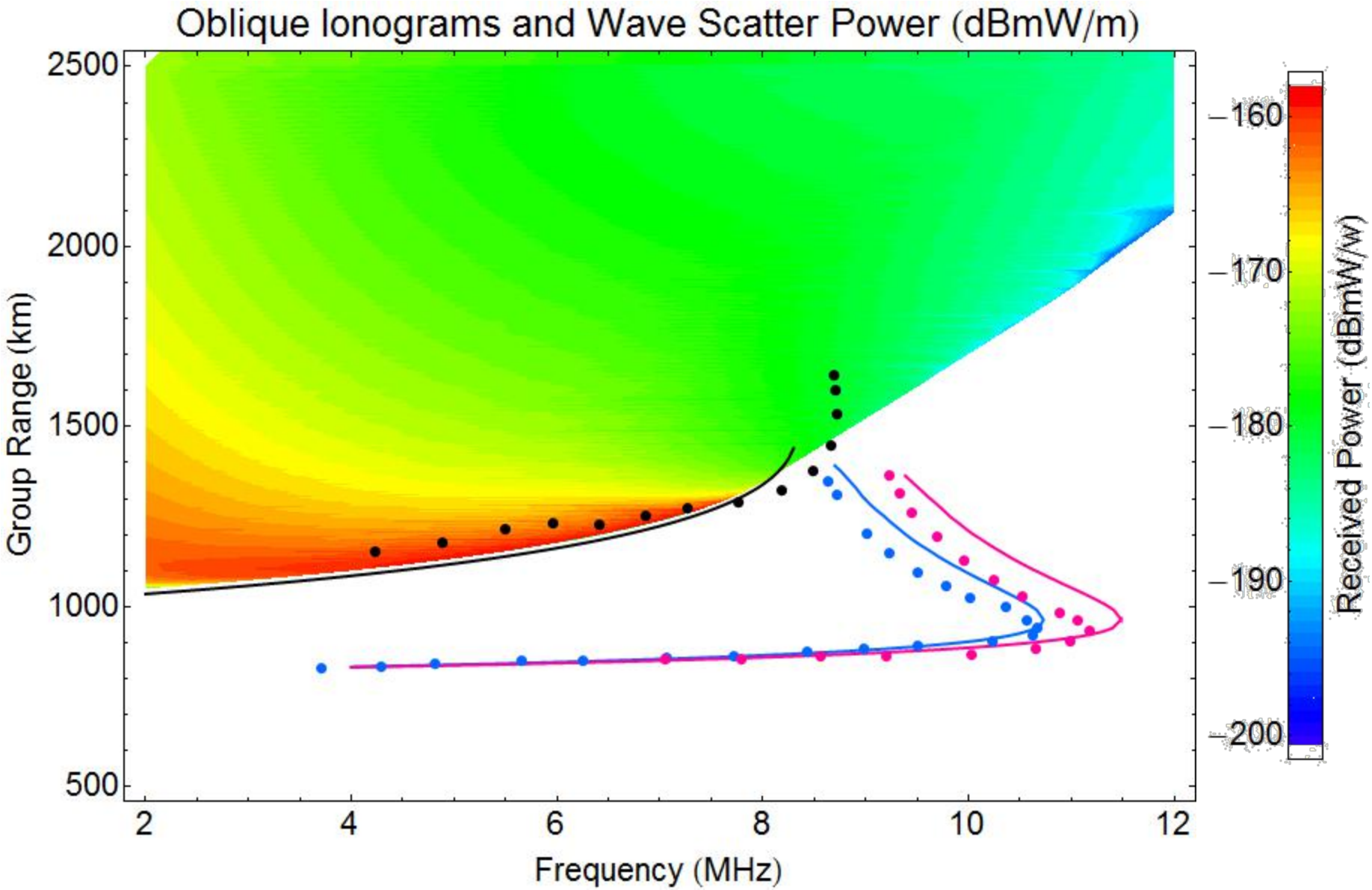
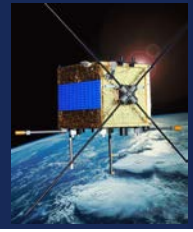
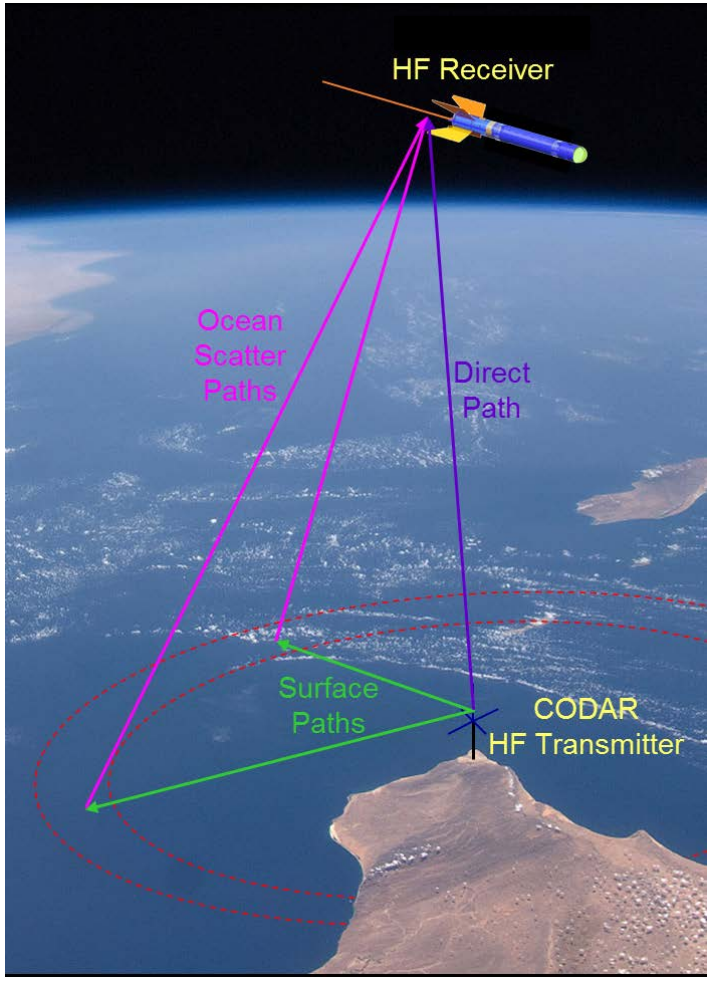
1-Hop and 2-Hop Oblique Ionogram Simulation with Ocean Scatter Power



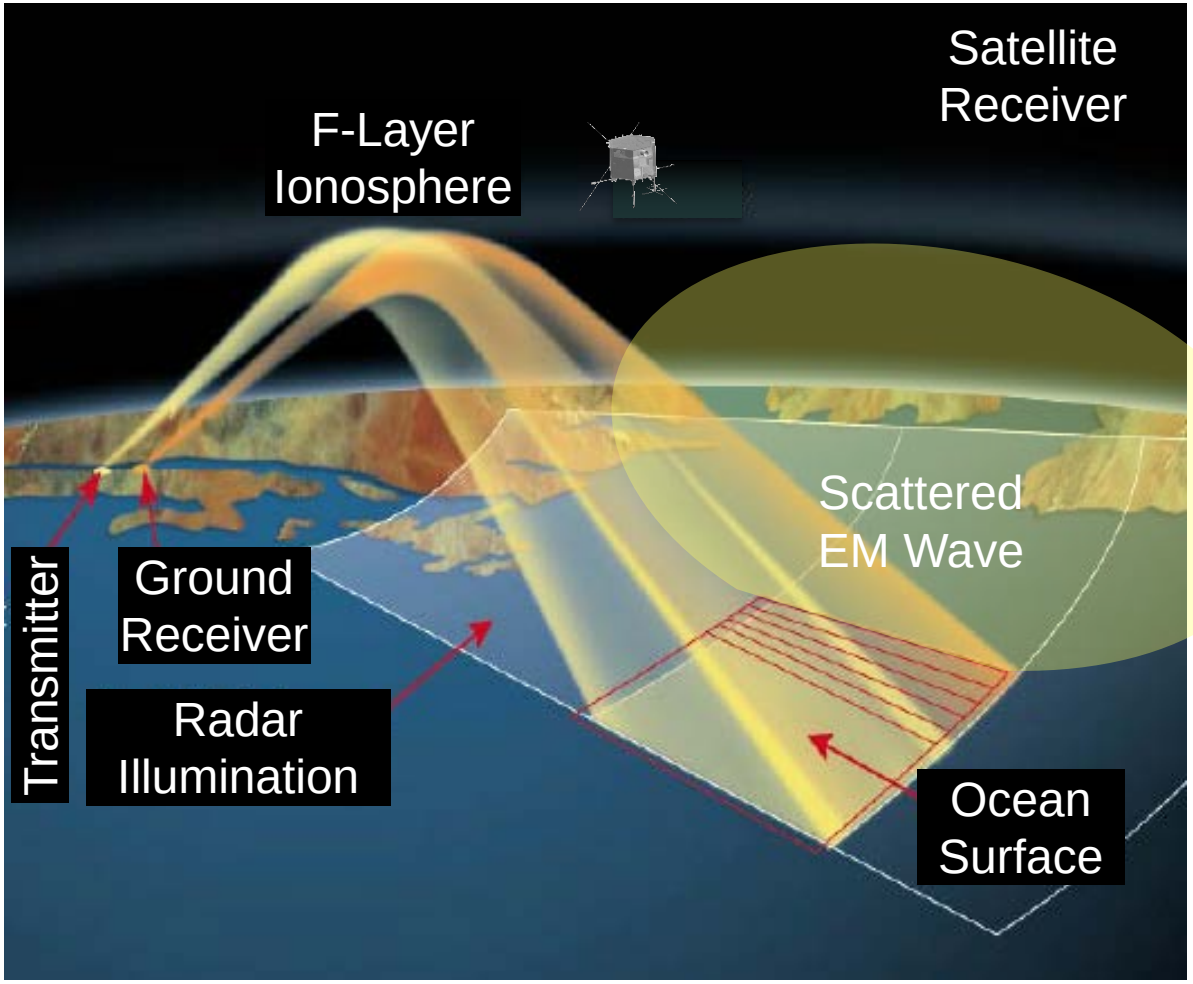
Ground Ionosphere Ocean Space
GIOS Ocean Science Experiments



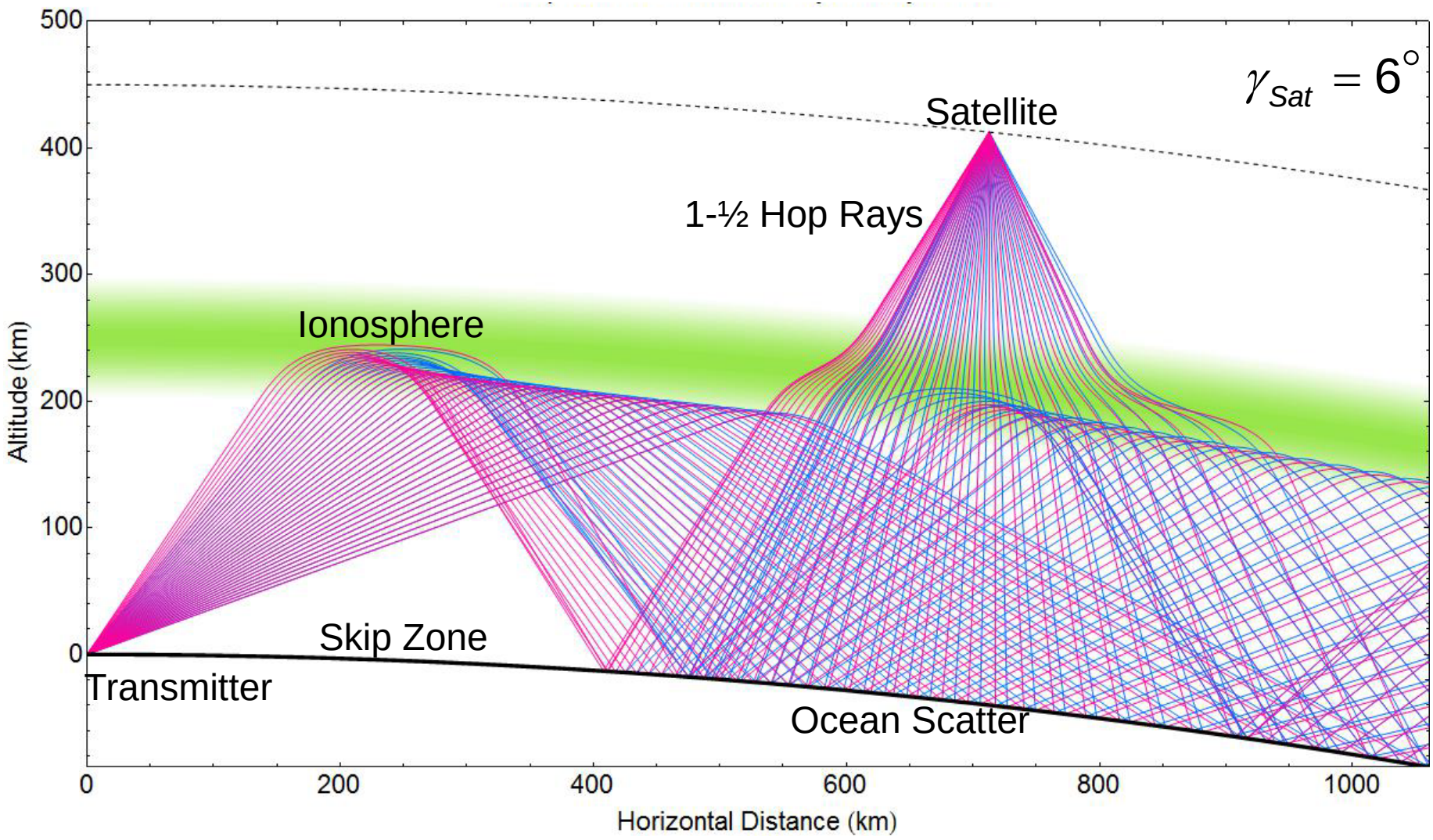
Bistatic HF Surface Radar Scatter



HF Radar Provides Sky Wave Ocean Illumination

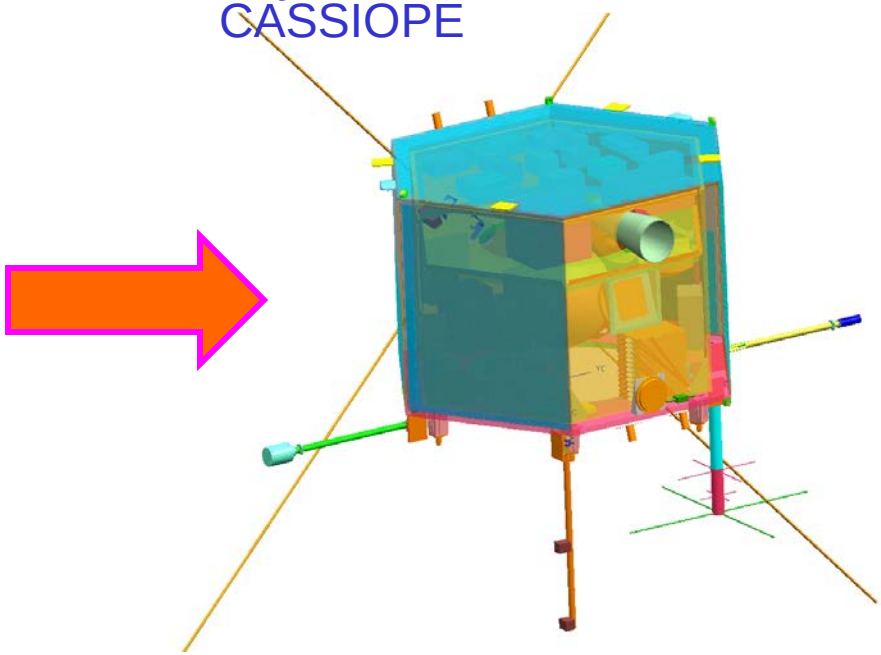


LHCP and RHCP Mode Rays for Ocean Scatter to a Satellite Through an F-Layer Profile with Spherical Stratification



US Navy HF OTH Radar (ROTHR) and Canadian ePOP Satellite Used for Ocean Observations

e-POP RRI Payload on CASSIOPE

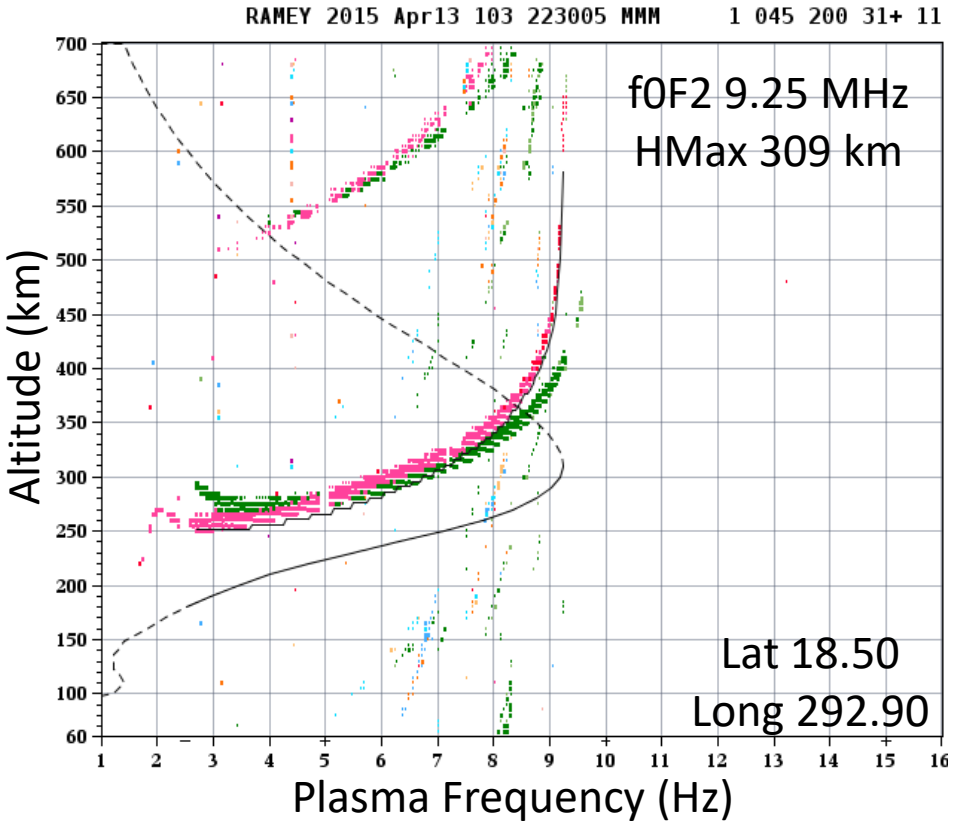


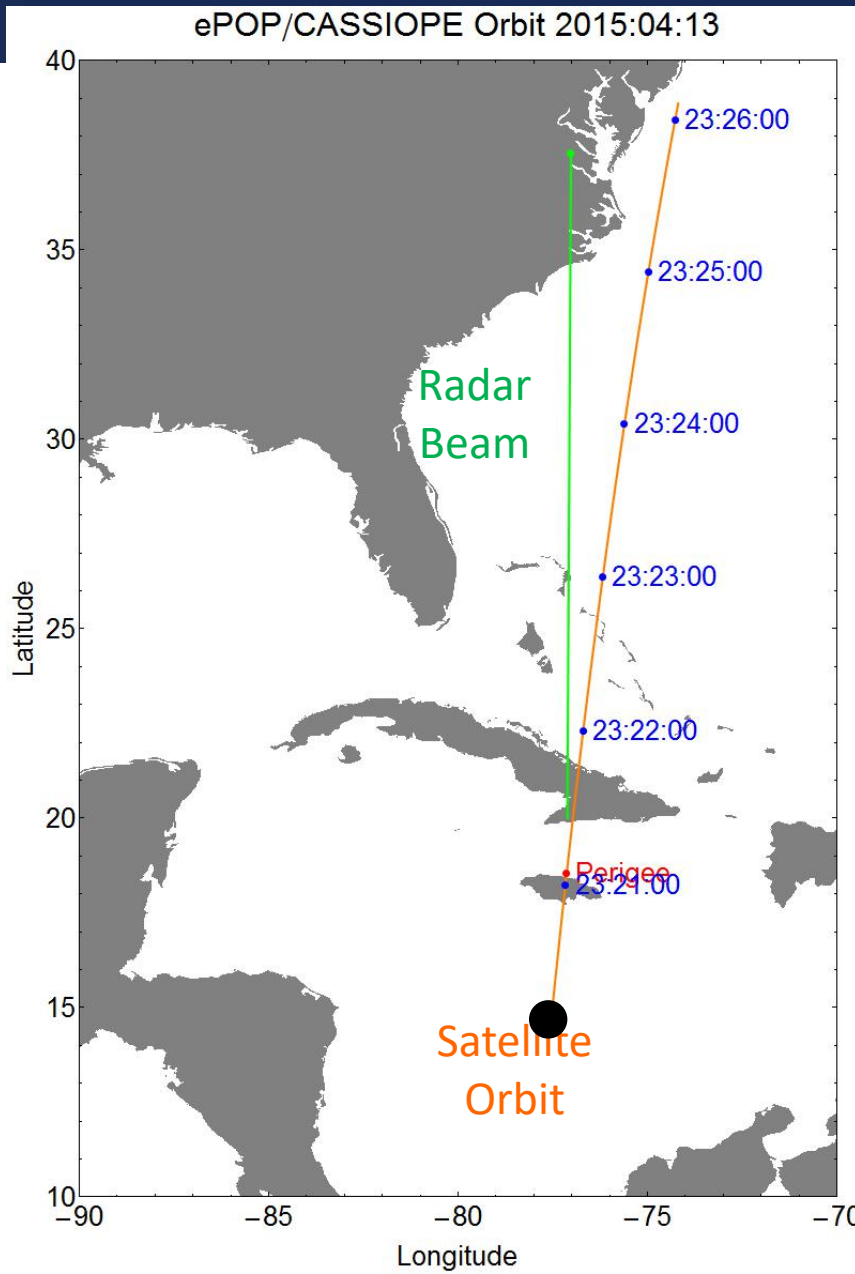
Relocatable Over the Horizon Radar (ROTHR) Operates from 5 to 30 MHz with 200 kW Transmitter and 10 Degree Beam

ePOP Radio Receiver Instrument (RRI) Covers DC to 18 MHz Using 6-m Dipoles

13 April 2015 Ionograms and ePOP Orbit

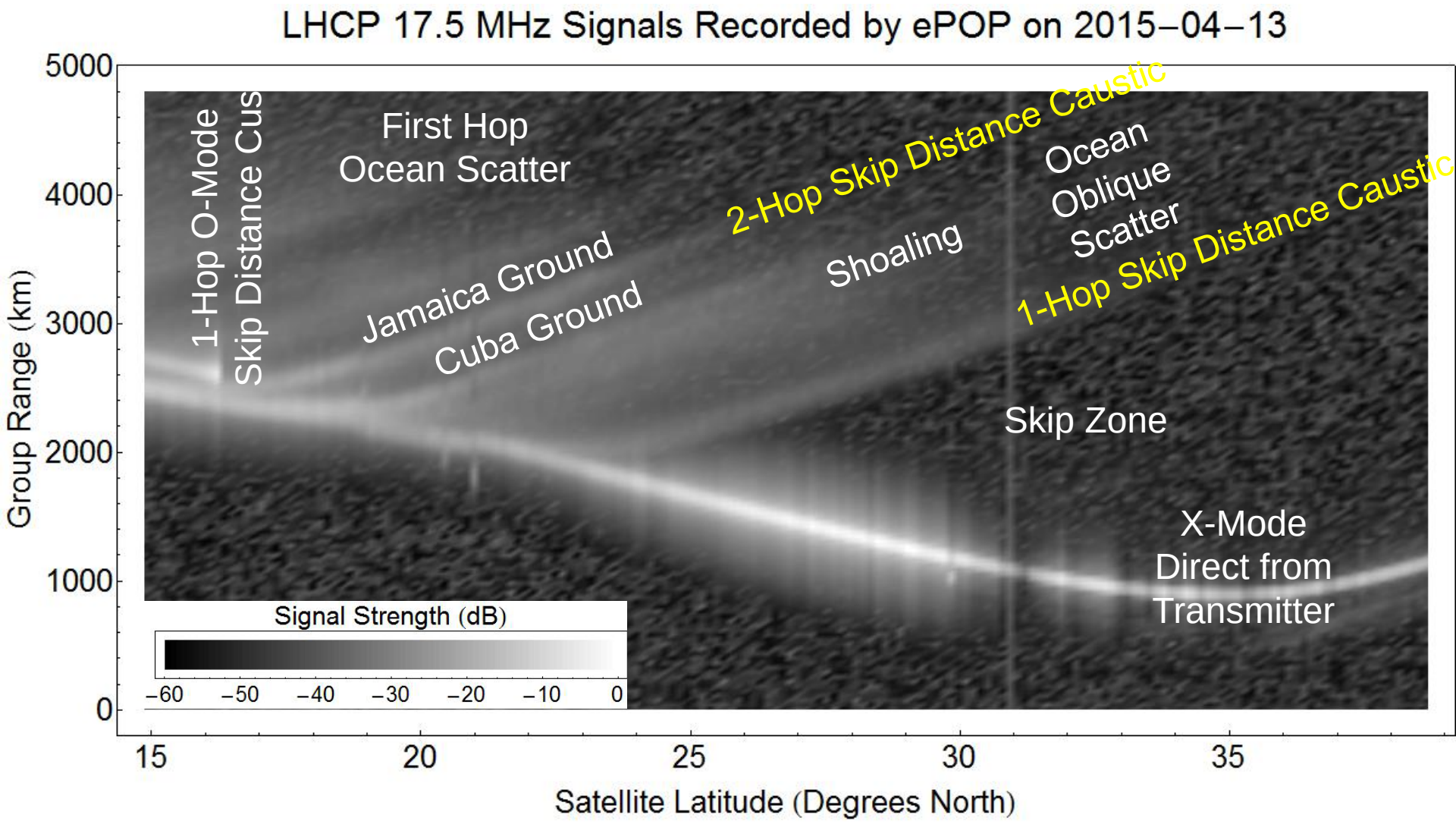
FMCW Transmissions from ROTHR/VA
at 17.5 MHz and Received by ePOP/RRI
- 62.5 Hz WRF
- 8.3 kHz Bandwidth



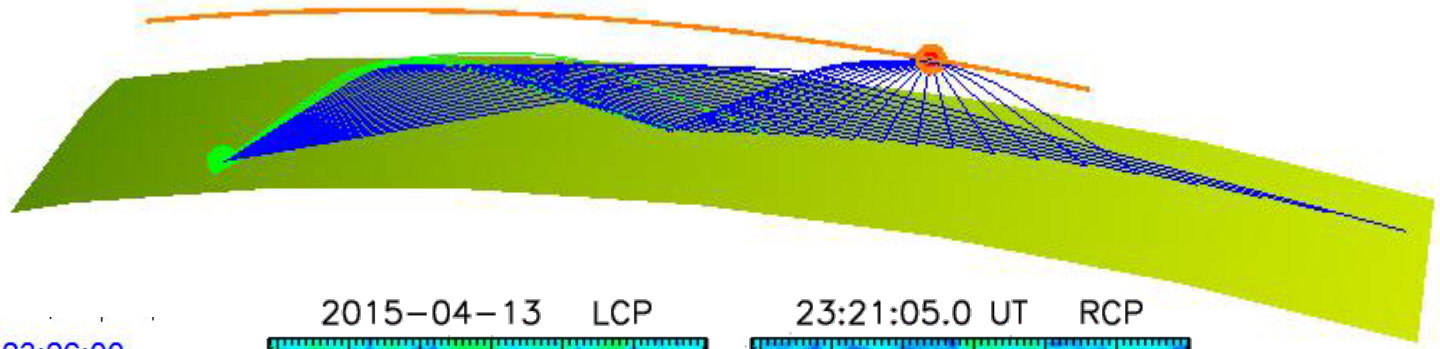


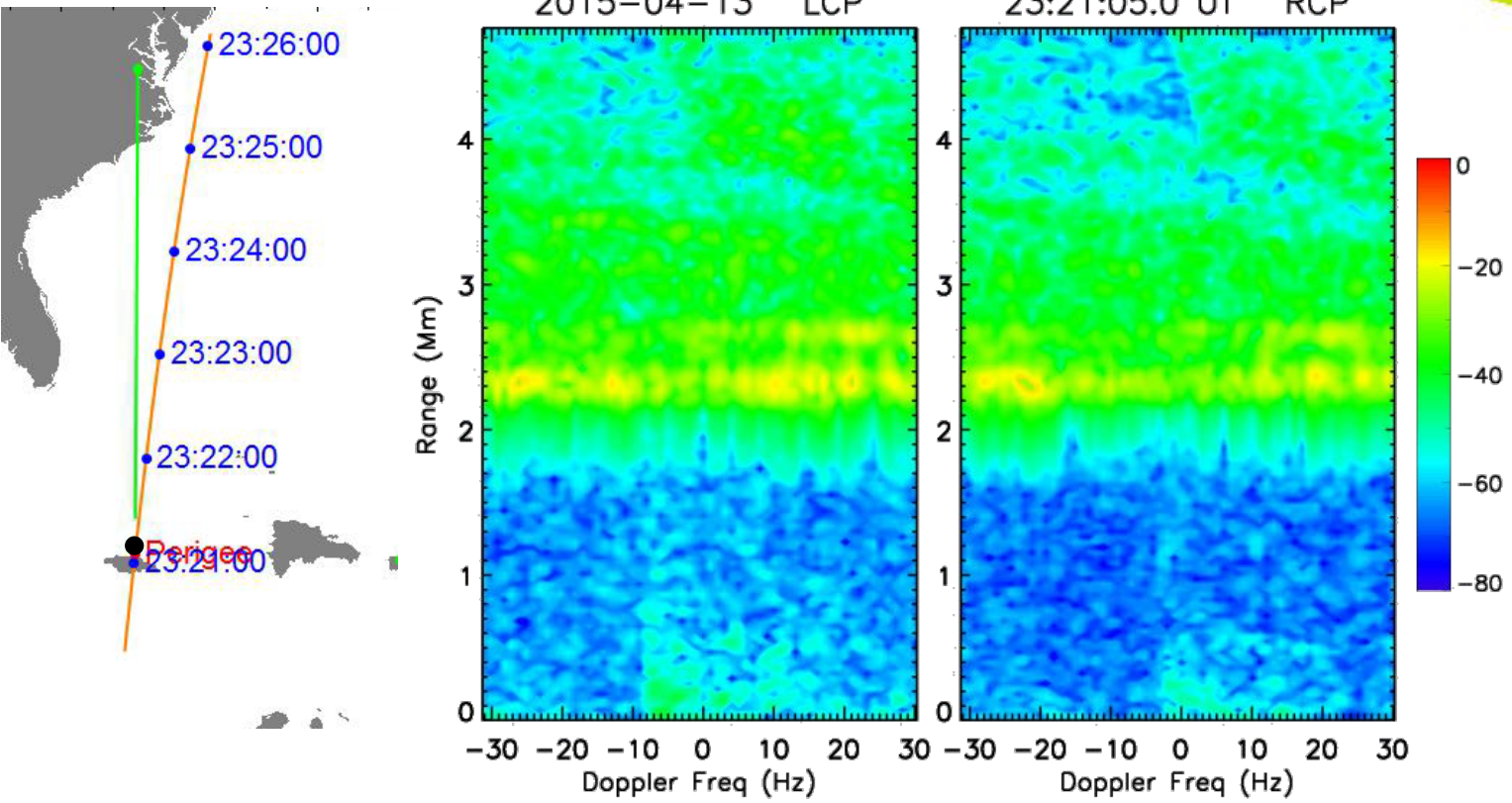
Range-Time Analysis of Radar Chirp

16 ms Chirp Period with 8.3 kHz Bandwidth

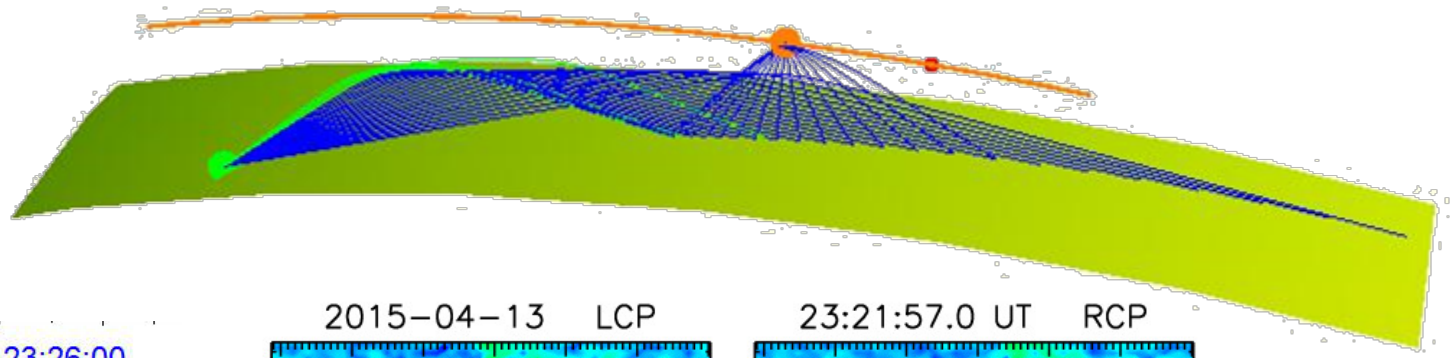


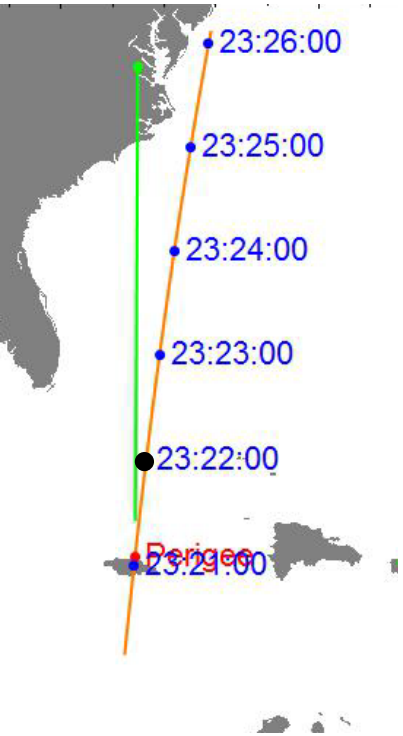
De-Chirped ePOP HF Data 13 April 2015, 23:21:05

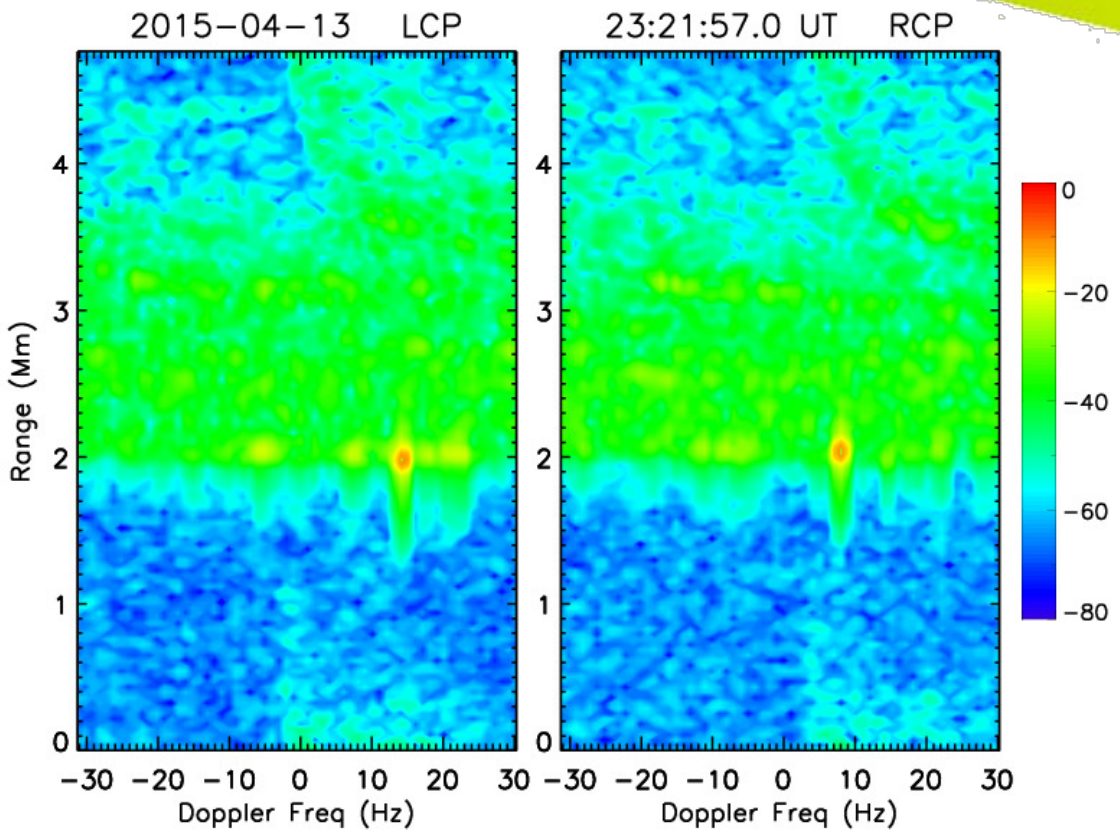




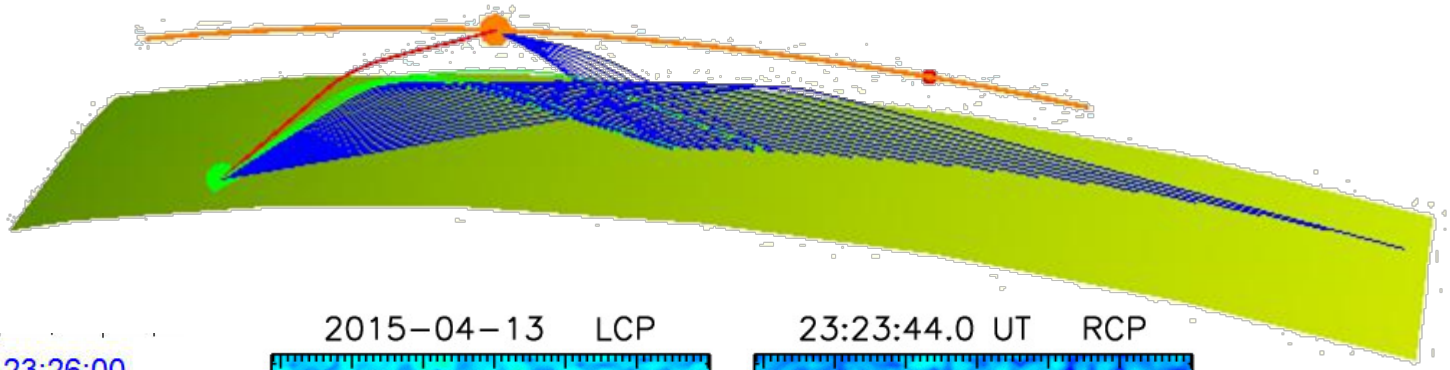
De-Chirped ePOP HF Data 13 April 2015, 23:21:57

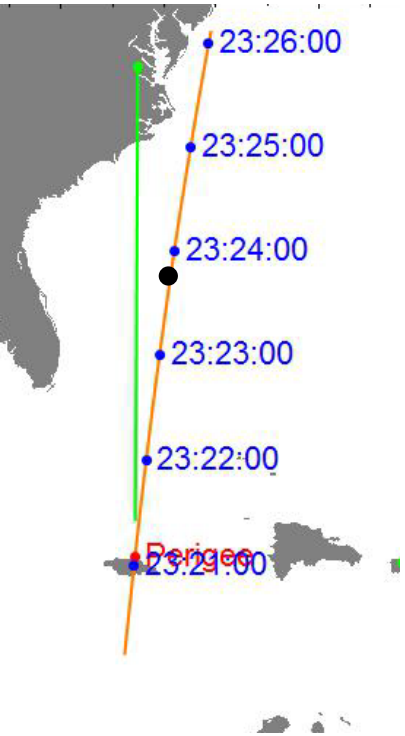


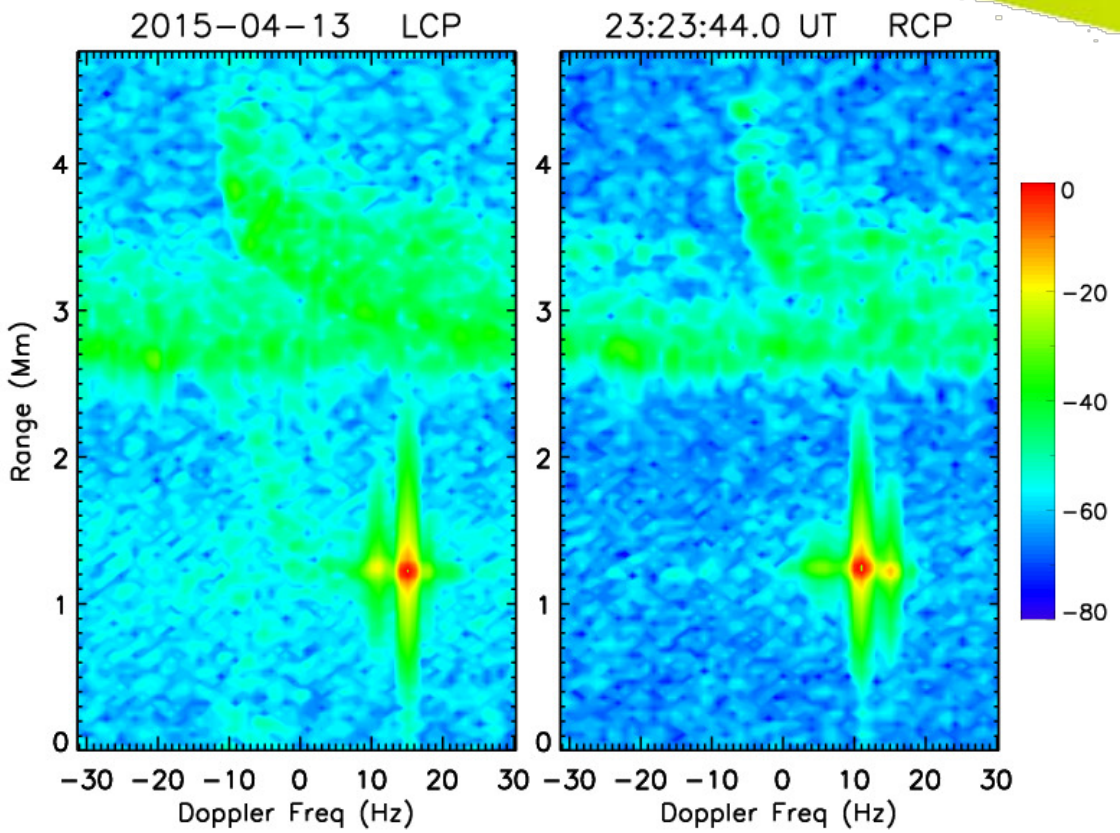




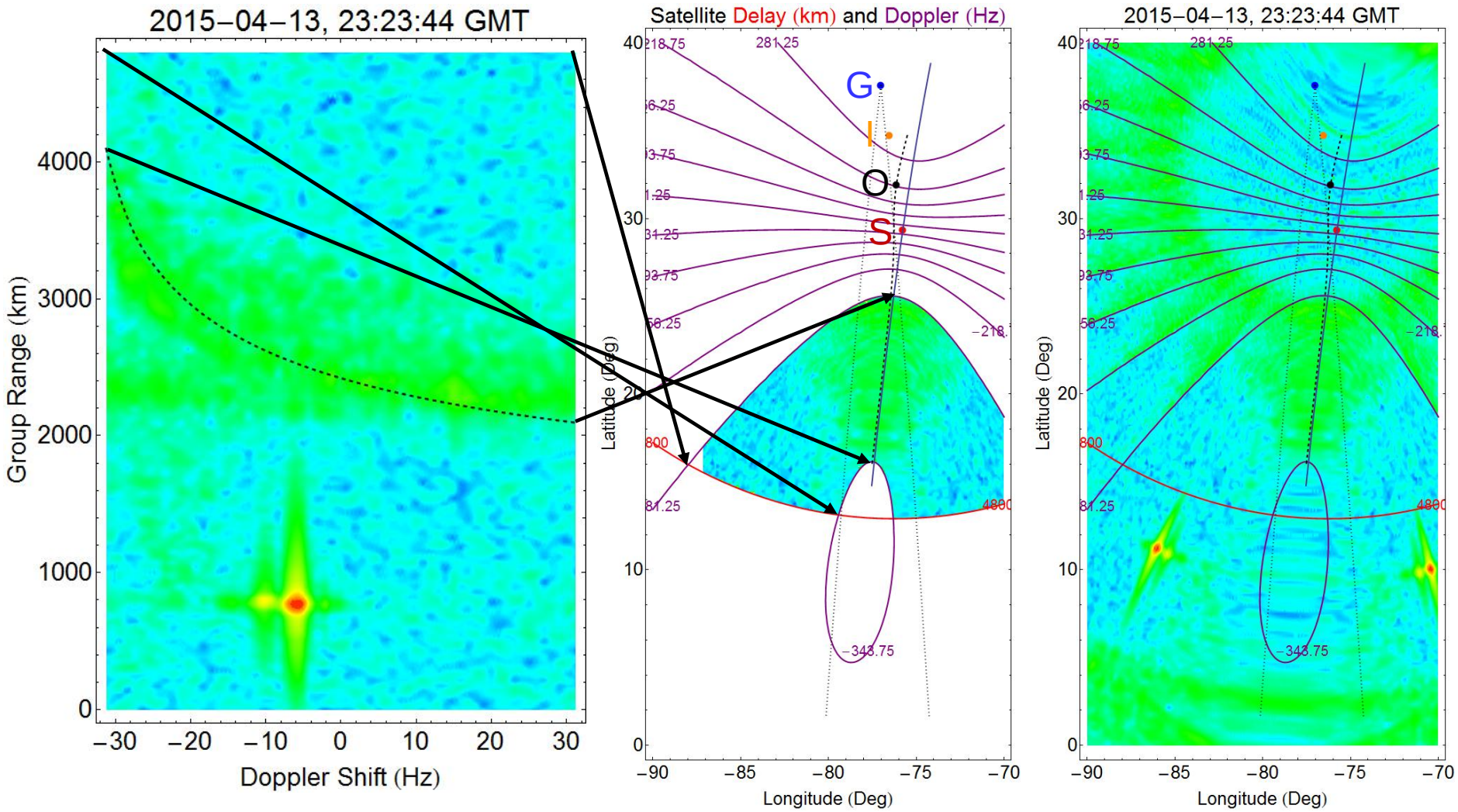
De-Chirped ePOP HF Data 13 April 2015, 23:23:44







HF Scatter Data Projection to Surface
13 April 2015, 23:23:44



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Bistatic HF Scatter for Ocean Remote Sensing Ground-Ionosphere-Ocean-Space (GIOS)

- Ground Transmitters for Ocean Illumination
  - Ocean HF Networks (CODAR, WERA)
  - Over the Horizon Radars (ROTHR, JORN, etc.)
  - HF Surface Radars (NRL HF SWR, etc.)
- HF Receivers Available on Ground and Space
  - Ground: Software Defined Receivers (USRP, SDR-IP)
  - Space: HF Receivers on Satellites: (ePOP-RRI, Other Launches)
- Fully Developed Propagation Theory
  - Ray Trace with Amplitudes Specified by Ray Tubes and Absorption
  - Ocean Scatter to Relate Scatter Coefficient to Surface Roughness
  - Doppler-Range Measurements Mapping to Surface Position
- Ionospheric Knowledge is Critical
  - Determines Ocean Illumination Region
  - Determines Satellite Range and Doppler Frequencies
  - Self Calibration with HF Direct Wave to Satellite
- Complements Other Ocean Measurements (CYGNSS, Buoys, Airplanes)