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Low-latitude Ionospheric Research using the CIRCE Mission

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Introduction

Objective: Provide space-based tomographic specification of electron density versus altitude and orbit phase angle derived from ultraviolet (UV) observations of the ionosphere with different viewing angles from multiple CubeSats

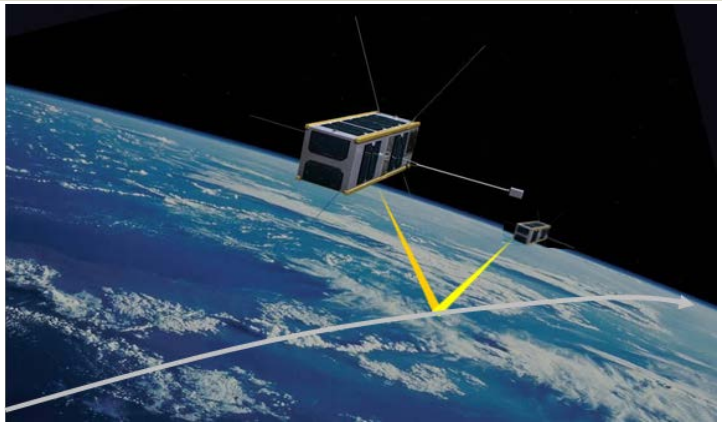

Figure. This shows an artist conception of the CIRCE spacecraft flying in tandem, sampling the same region of the ionosphere

Description:

- The experiment will consist of two 6U CubeSats
- Fly lead/trail in tandem in coplanar orbit to collect ionospheric measurements optimized for tomographic reconstruction
  - Four (2/CubeSat) Triple Tiny Ionospheric Photometers (Tri-TIP) UV 135.6 nm O^+ emission
  - Viewing geometry requires long baseline easily provided in orbit which also provides global coverage
- Potential launch via DoD Space Test Program
- Circular orbit ~650km, at low to mid-inclination preferred

- We present the mission concept, simulations illustrating the imaging capability of the sensor suite, and a range of science questions addressable using such a system

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CIRCE Science Questions

- **Equatorial Ionization Anomaly:**
  - What is the global latitude/altitude structure of the EIA?
  - What is driving EIA structure?
    - Which planetary waves are responsible?
    - Which tides are responsible?

- **Traveling Ionospheric Disturbances:**
  - Is it possible to image the altitude/latitude structure of Traveling Ionospheric Disturbances?
  - What is the global distribution of MSTIDs?
  - Is it possible to image the altitude/latitude structure of gravity-wave driven ionospheric perturbations?

- **Mid-latitude Trough**
  - Is it possible to image the altitude/latitude structure of mid-latitude ionospheric trough?
  - Are there additional ionospheric structures associated with the Mid-latitude Trough?

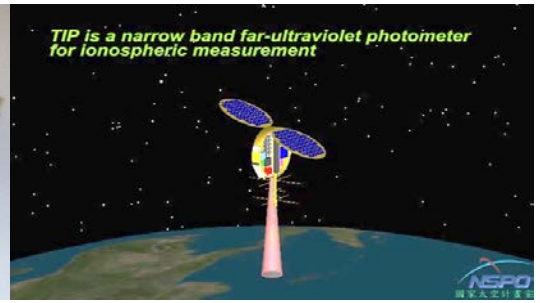
Heritage from TIP on COSMIC-1

Tiny Ionospheric Photometer (TIP)

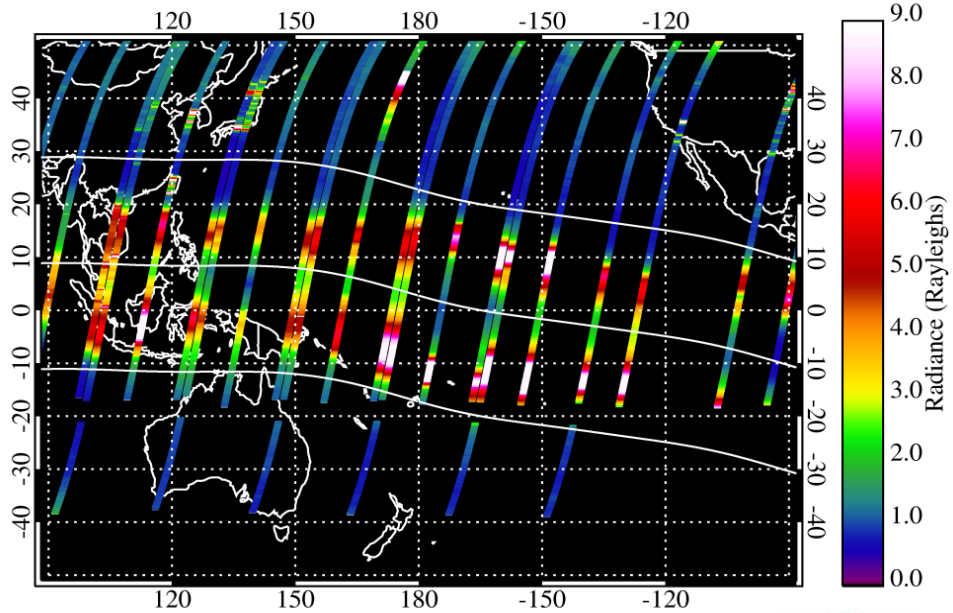
- Compact UV photometer
- Very high sensitivity
- Flew on COSMIC-1, operated from 2006-2010

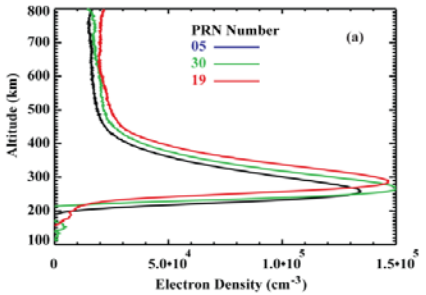
Measured 135.6 nm UV radiance

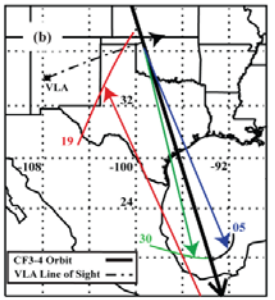
- Related to ionospheric electron density
- Used in conjunction with GOX RO data

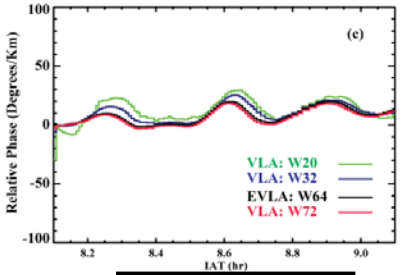


EIA September 2006

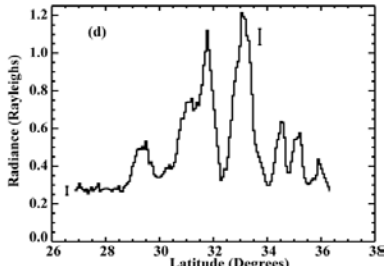








TID-VLA

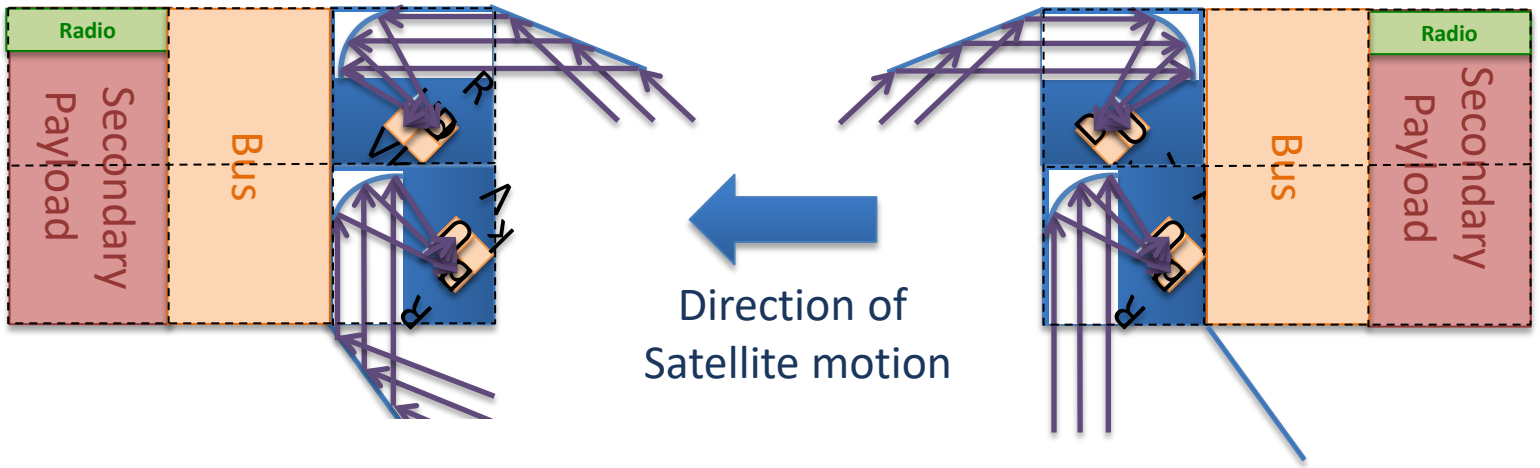


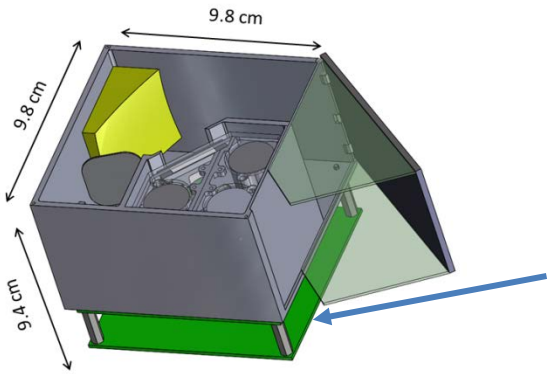
TID-TIP

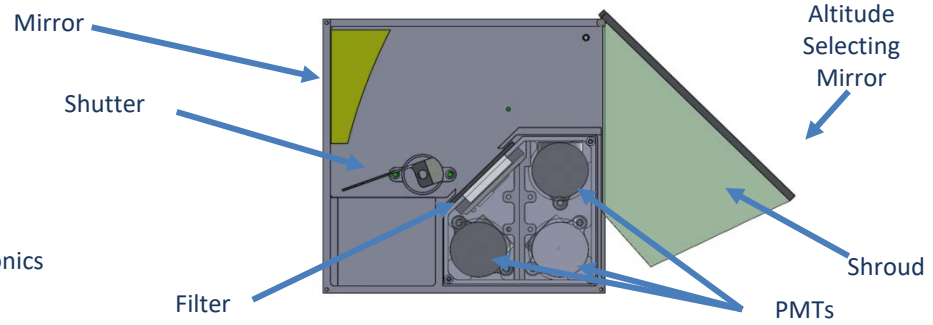
Experiment Configuration

Leading Satellite
Tri-TIP ≤2.25U, 7 W

Trailing Satellite
Tri-TIP ≤2.25U, 7 W







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CIRCE VERT Simulations

- The CIRCE concept of operations was tested by simulating measurements
  - Realistic viewing geometry & expected instrumental sensitivities ➔ Realistic instrumental noise superimposed
  - Full physics of ionospheric 135.6 nm nightglow simulated
    - Radiative recombination and mutual neutralization sources were included
    - Vertical radiation transport
    - Radiation transfer along the lines-of-sight included
- Inversions performed using newly developed Volume Emission Rate Tomography (VERT) code
  - Approach produces the Volume Emission Rate consistent with the measurements
  - General approach in that any photon emission can be interpreted in terms of Volume Emission Rate
  - Additional modeling may be needed to convert the Volume Emission Rate to physical quantities, such as electron density
  - Focus in this study is to infer the Volume Emission Rate
- Two scenarios tested
  - Polar orbit to test remote sensing of EIA morphology
  - Polar orbit to test sensing of ionospheric bubbles

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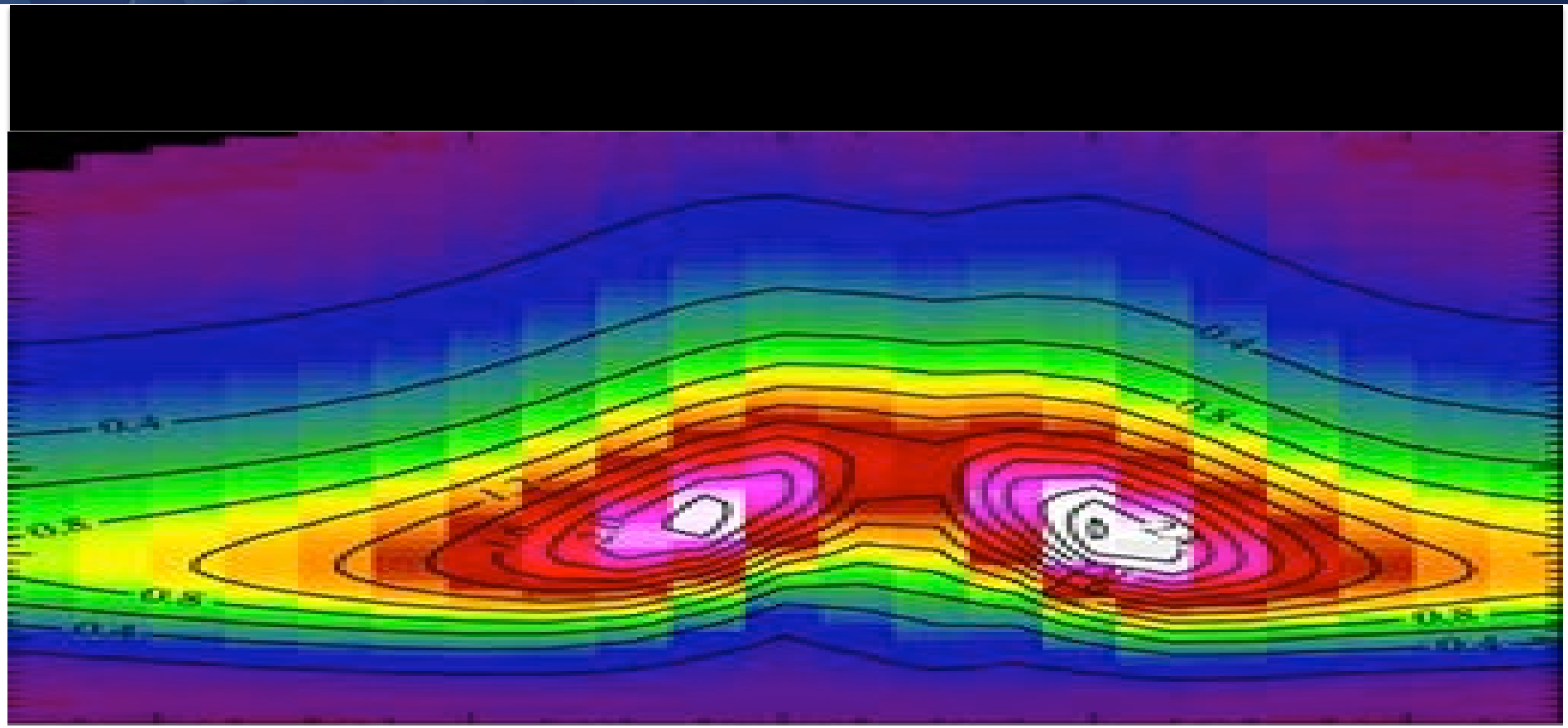
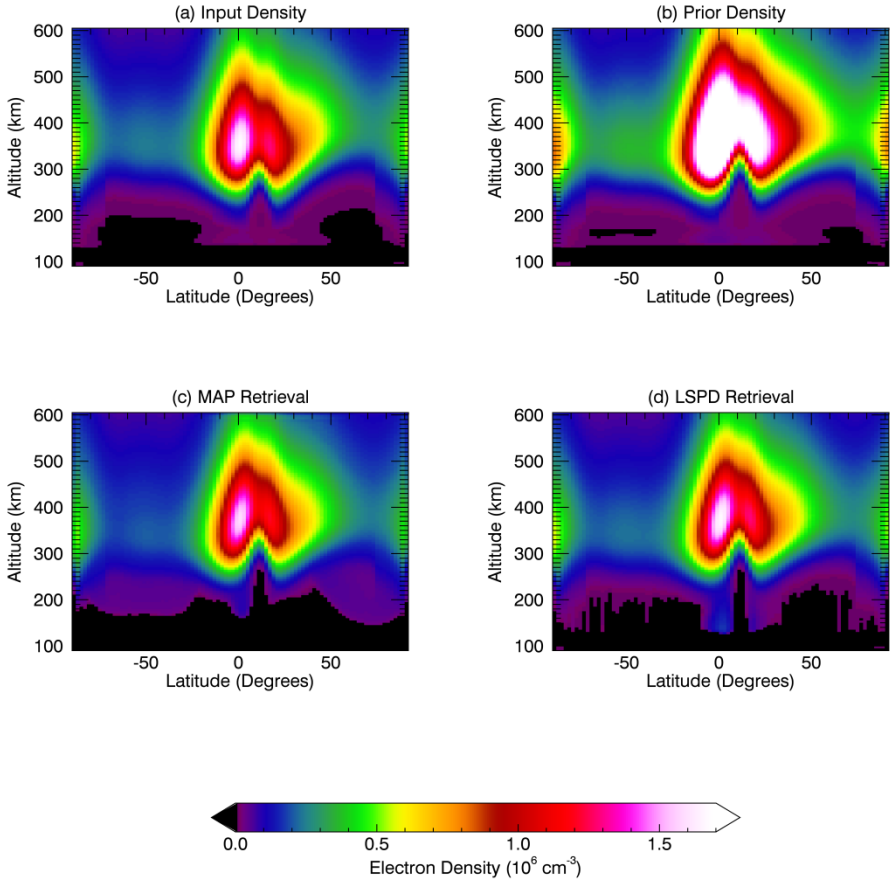
CIRCE Tomographic Lines of Sight



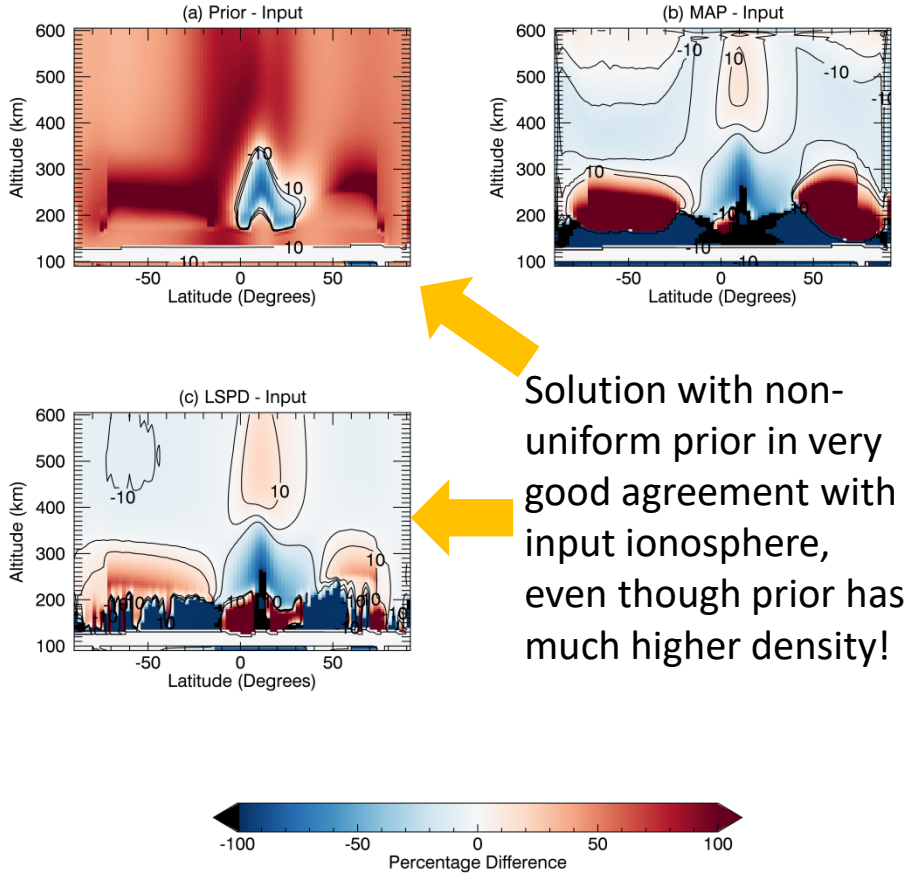
Lead: 90° deg down (nadir) & 45° degree down (wake)
Trail: 23° deg down (ram) & 45° deg down (ram)
Baseline separation: 250 km

Polar Simulation: 4-Look Directions

Electron Densities



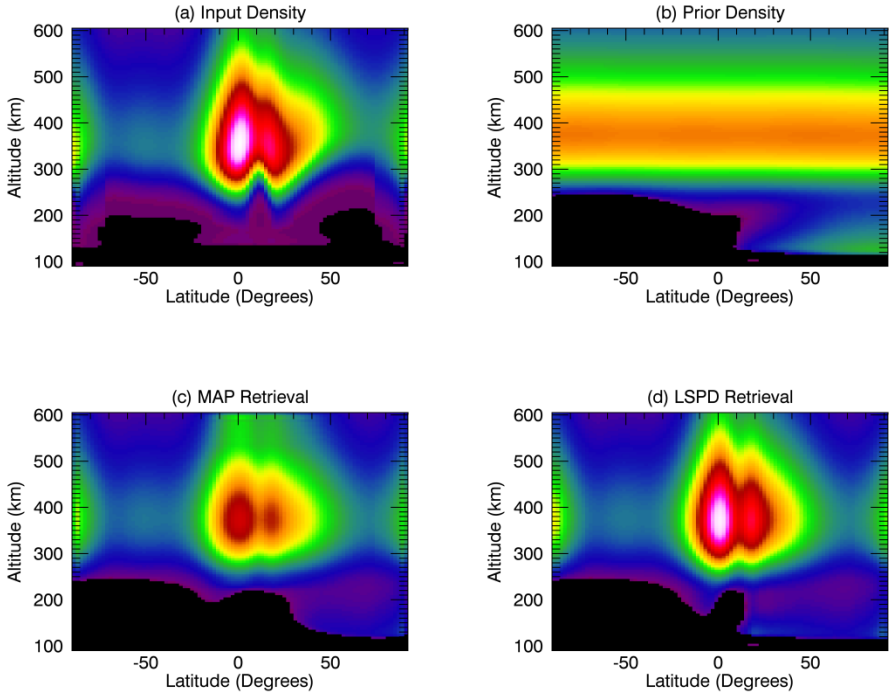
Percentage Difference

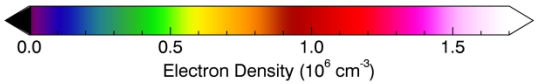


Solution with non-uniform prior in very good agreement with input ionosphere, even though prior has much higher density!

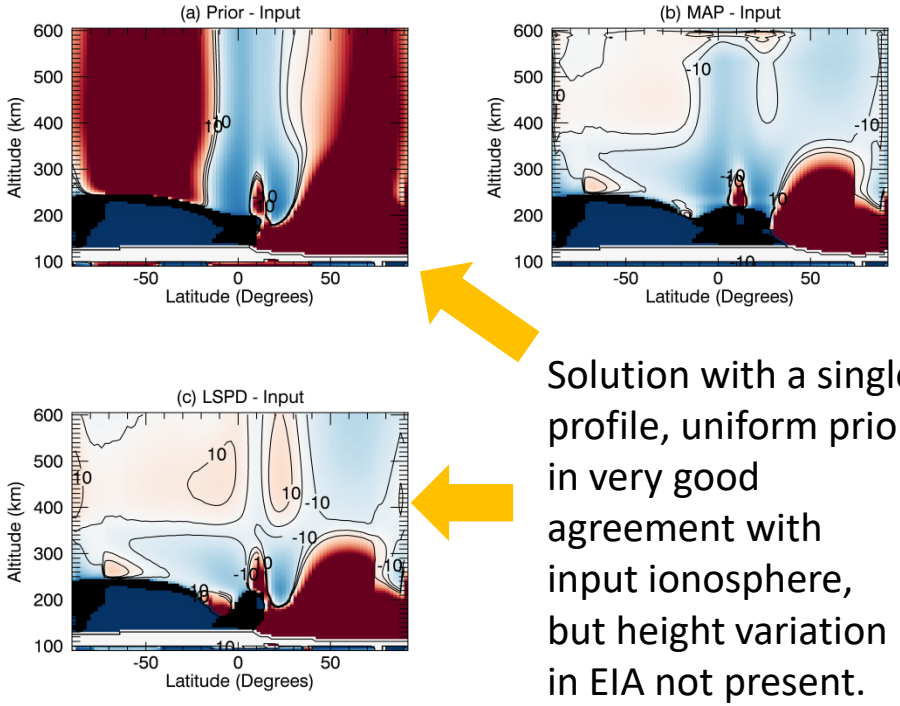
Polar Simulation: 4-Look Directions, Single Profile Prior

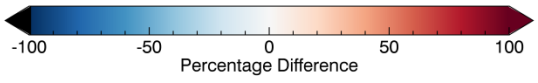
Electron Densities





Percentage Difference

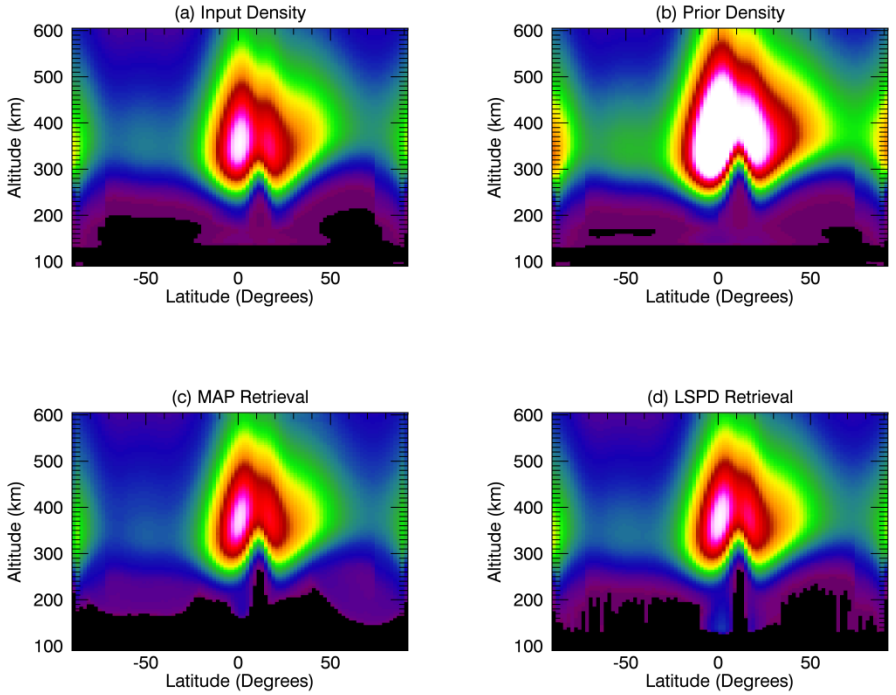


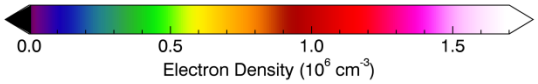


Solution with a single profile, uniform prior in very good agreement with input ionosphere, but height variation in EIA not present.

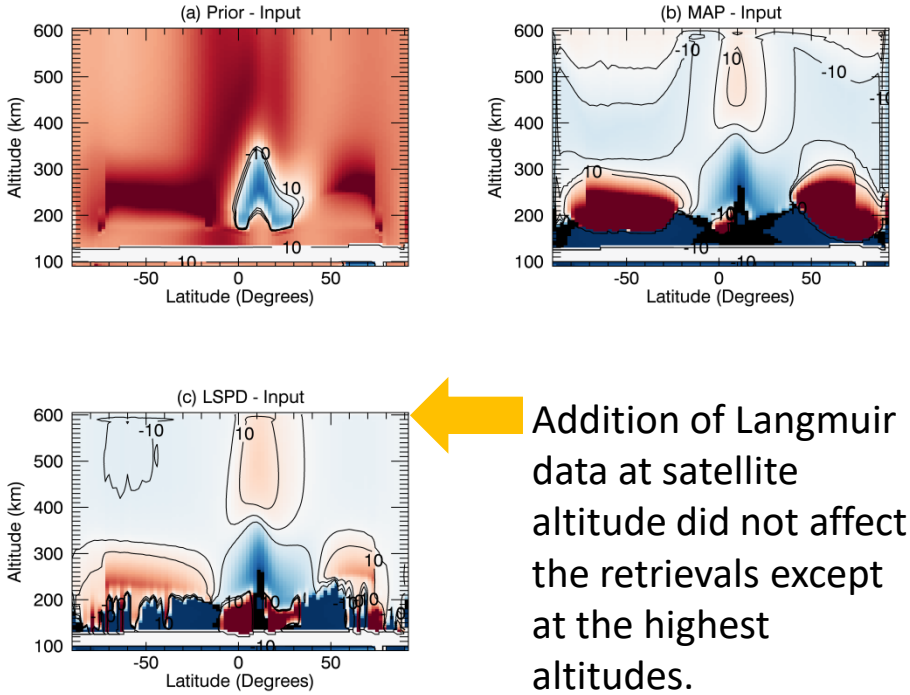
Polar Simulation: 4-Look Directions, Langmuir Probe

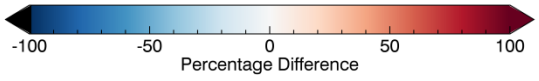
Electron Densities





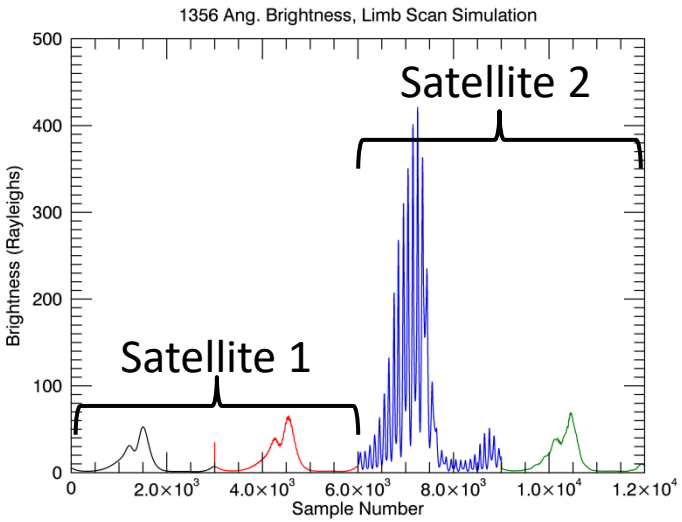
Percentage Difference

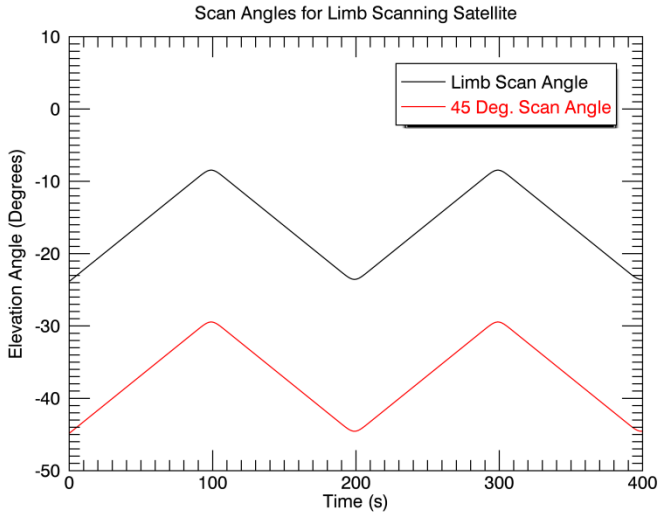




Addition of Langmuir data at satellite altitude did not affect the retrievals except at the highest altitudes.

Polar Simulation: 2-Look Directions, Limb Scanner

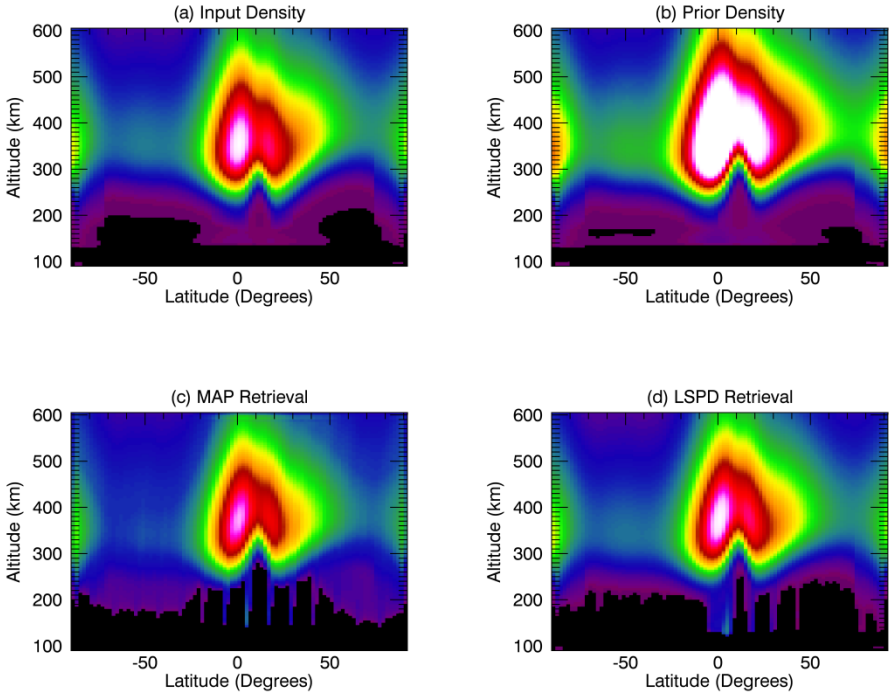


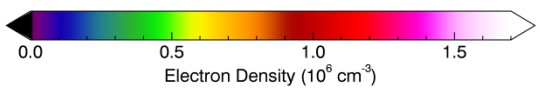


- Limb scan simulation assumes that satellite undergoes slow repeated slews
  - 100 s upward slew through 15°
  - Followed by 100 s downward slew through 15°
  - Top and bottom of scan slowed using 21 second Gaussian with 5 second HWHM
  - The scanning persists throughout nighttime portion of orbit
- Other options have been considered
  - Imaging detectors
  - Scan mirror
  - Scanning slit along long-axis of photocathode
    - Instrument oriented 90° WRT other instruments
  - These will be re-visited if limb-scanning of vehicle cannot be accomplished

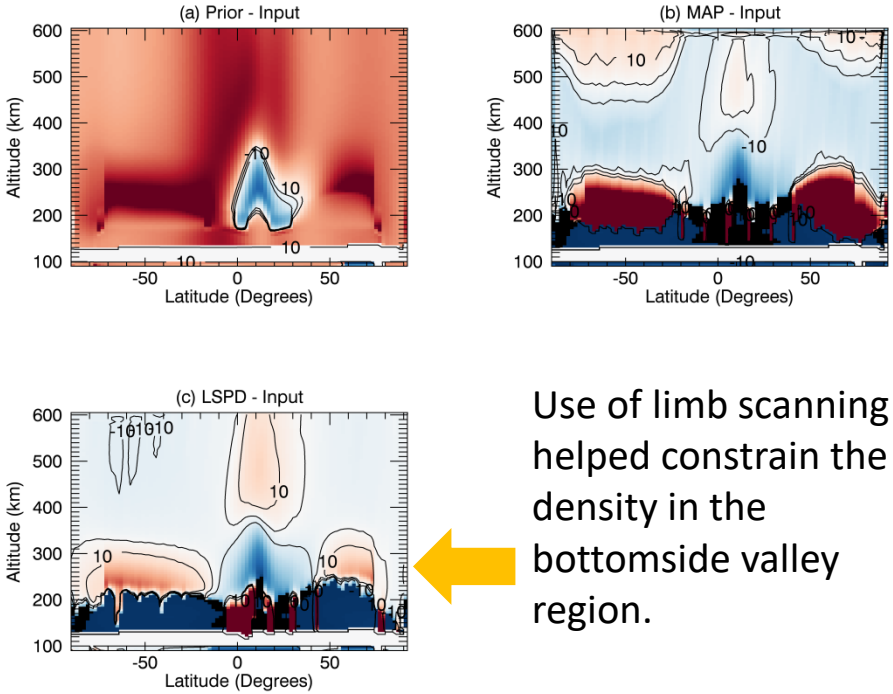
Polar Simulation: 2-Look Directions, Limb-scanner

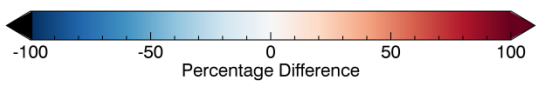
Electron Densities





Percentage Difference

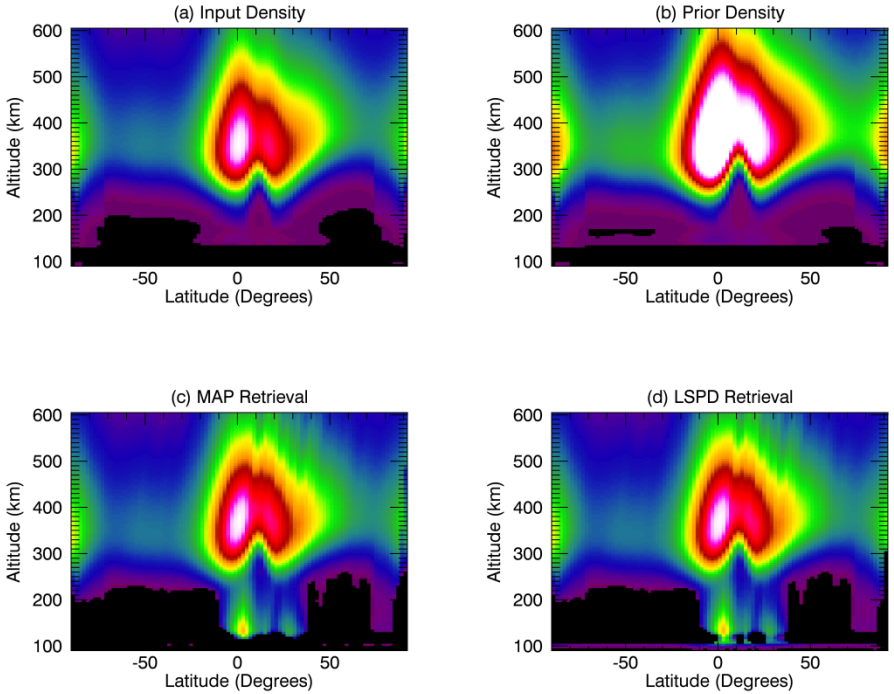


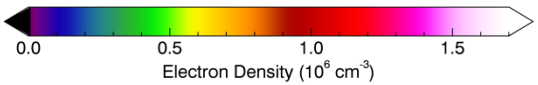


Use of limb scanning helped constrain the density in the bottomside valley region.

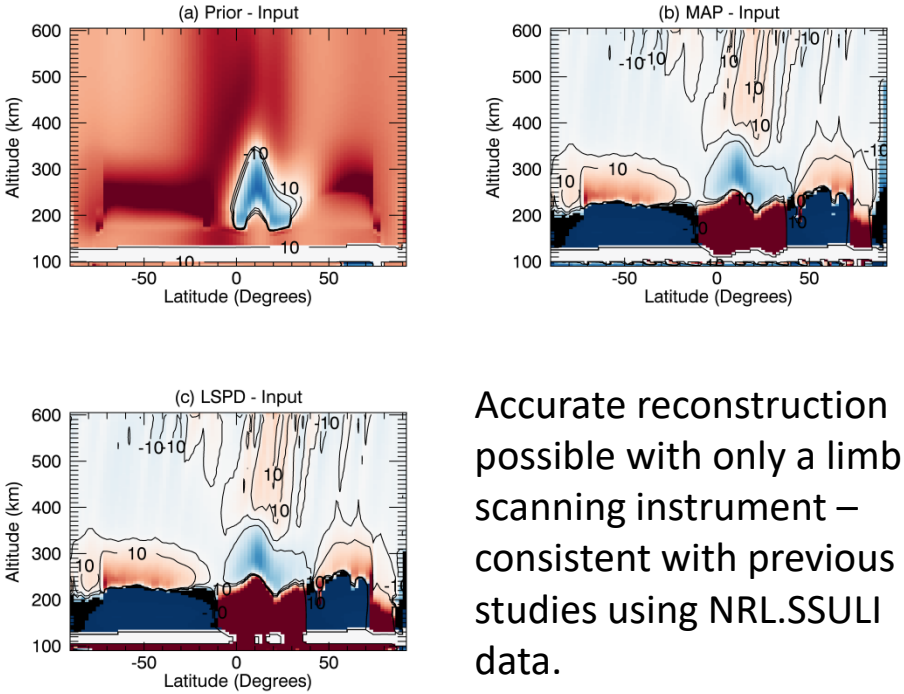
Polar Simulation: Limb-scanner Only

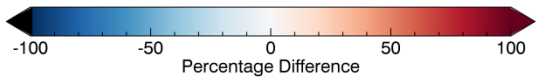
Electron Densities





Percentage Difference

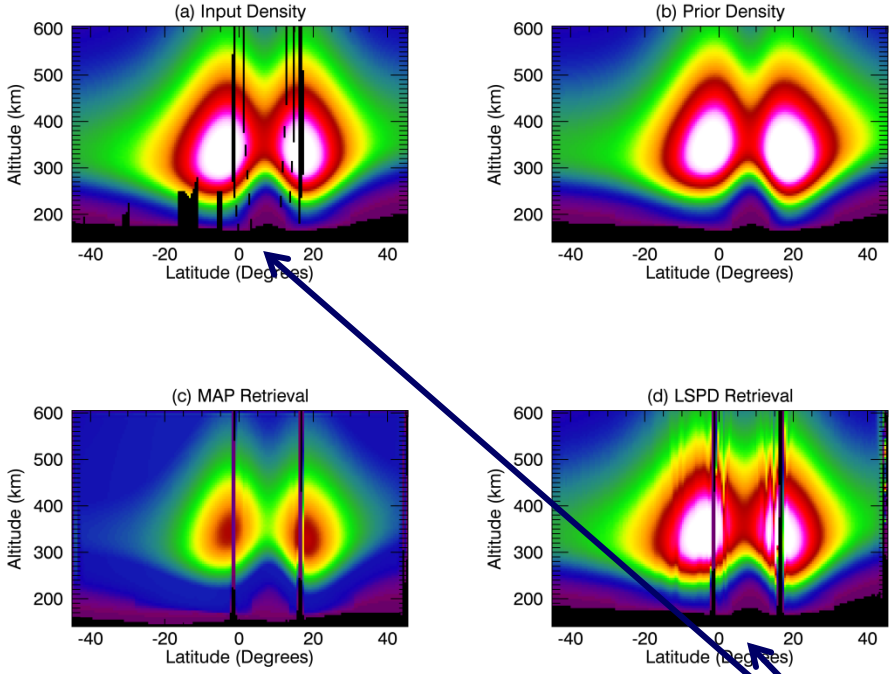




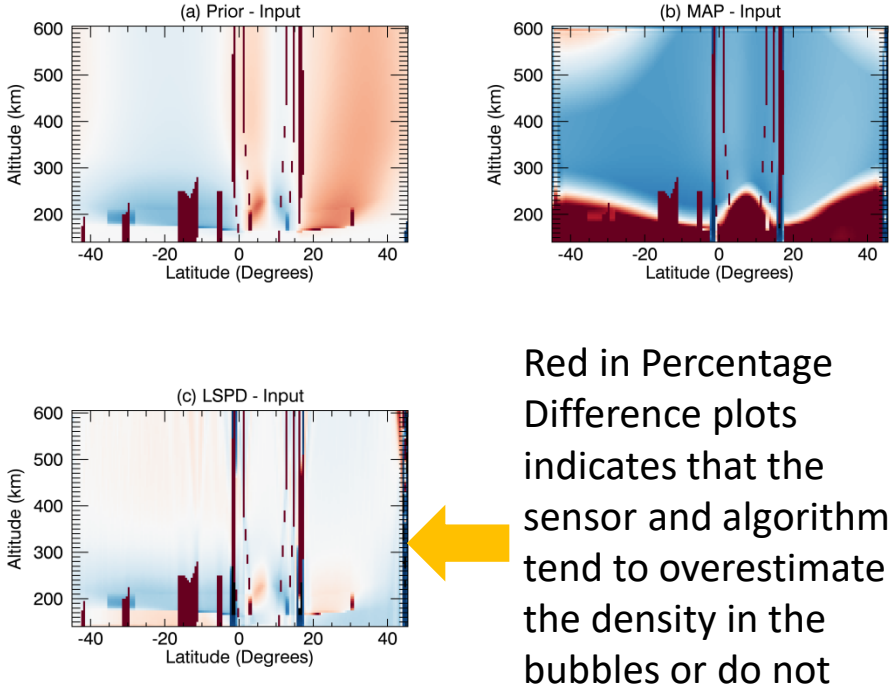
Accurate reconstruction possible with only a limb scanning instrument – consistent with previous studies using NRL.SSULI data.

Bubble Simulation: 4-Look Directions

Electron Densities



Percentage Difference

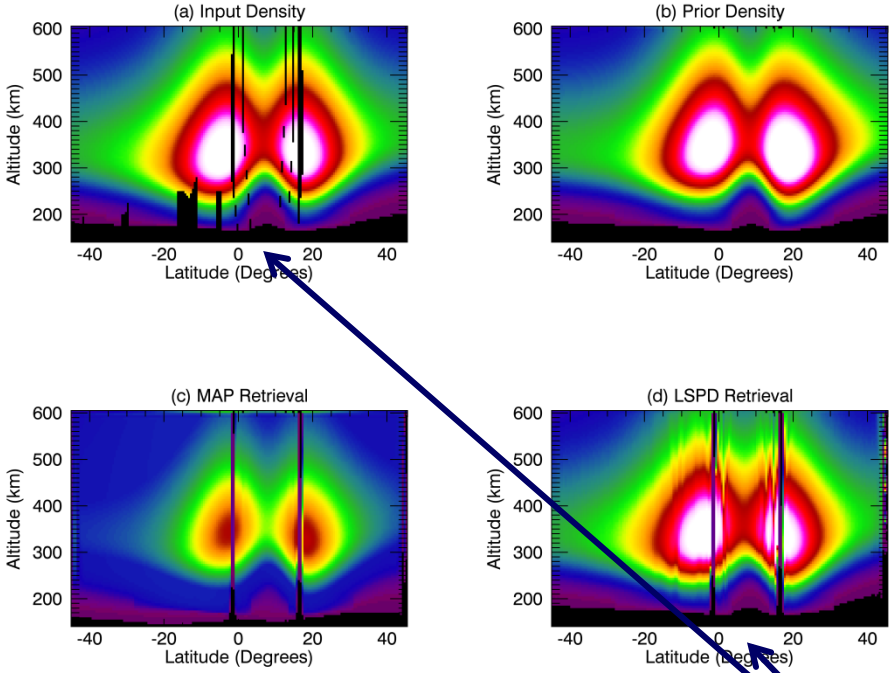


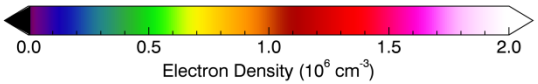
Red in Percentage Difference plots indicates that the sensor and algorithm tend to overestimate the density in the bubbles or do not capture them.

Bubbles not well captured.

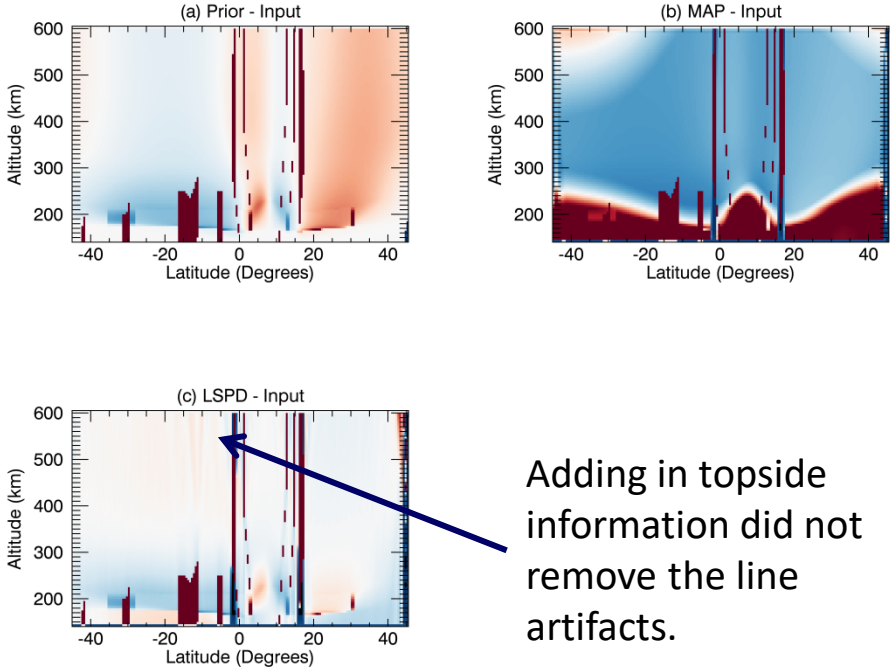
Bubble Simulation: 4-Look Directions, Langmuir Probe

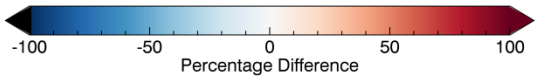
Electron Densities





Percentage Difference





Adding in topside information did not remove the line artifacts.

Bubbles still not well captured.

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Summary

- The CIRCE concept of operations and a preliminary demonstration of mission effectiveness were presented
  - Realistic viewing geometry, with expected instrumental sensitivities & realistic noise was superimposed
  - Full physics of ionospheric 135.6 nm nightglow simulated
  - Radiative recombination and mutual neutralization sources were included
  - Vertical radiation transport (except in bubble simulation)
  - Radiation transfer along the lines-of-sight included
  - Inversions use newly developed Volume Emission Rate Tomography (VERT) code
- CIRCE mission is able to retrieve the ionospheric structure given a reasonable prior ionosphere
  - Ionospheric morphology is well-captured
  - Small-scale structures such as ionospheric bubbles are also observable

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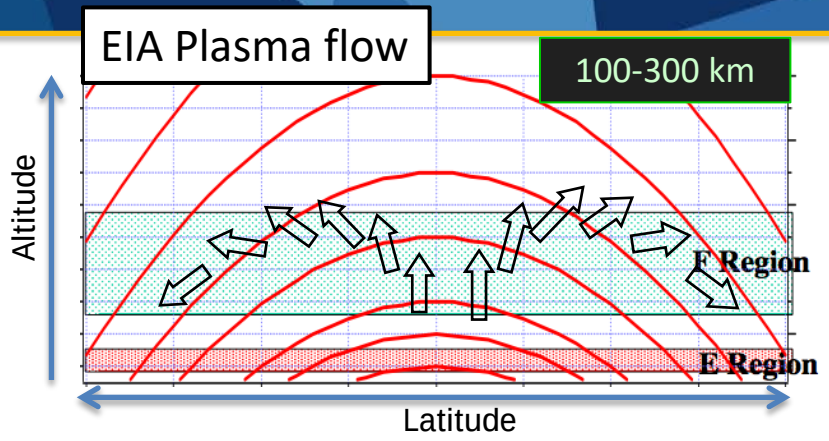
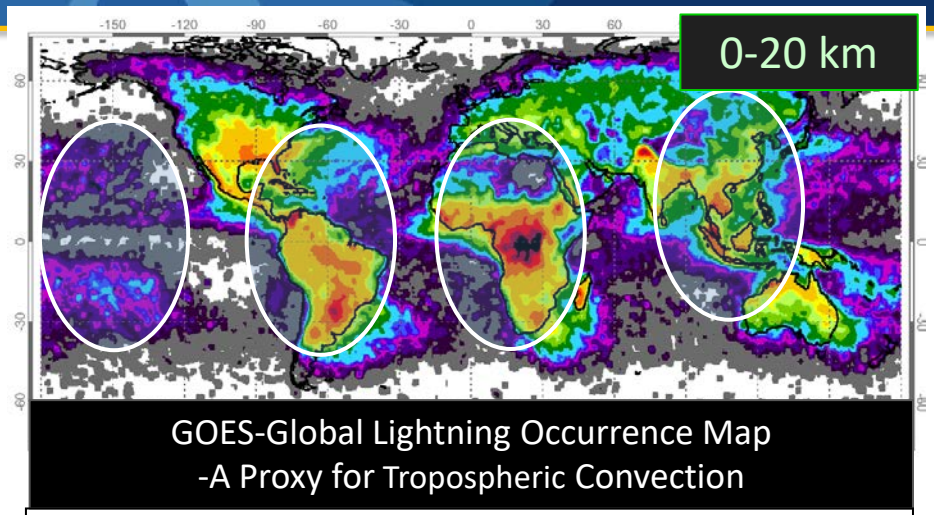
Backup slides

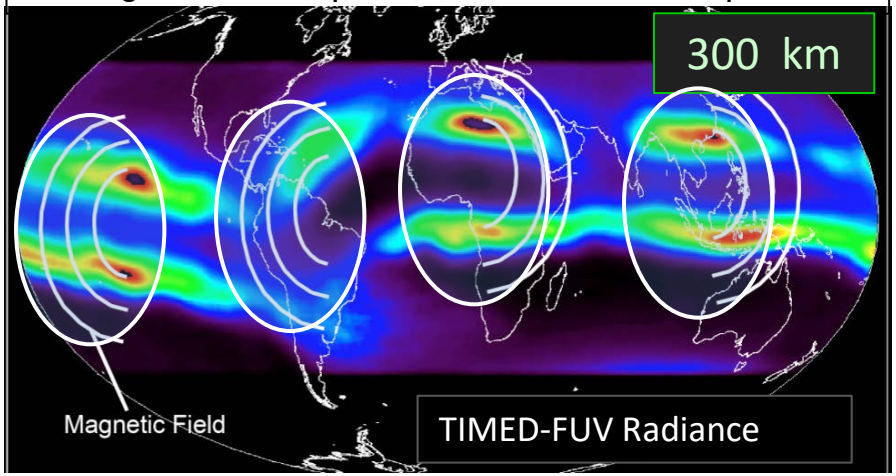
Equatorial Ionization Anomaly (EIA) -Morphological Drivers-



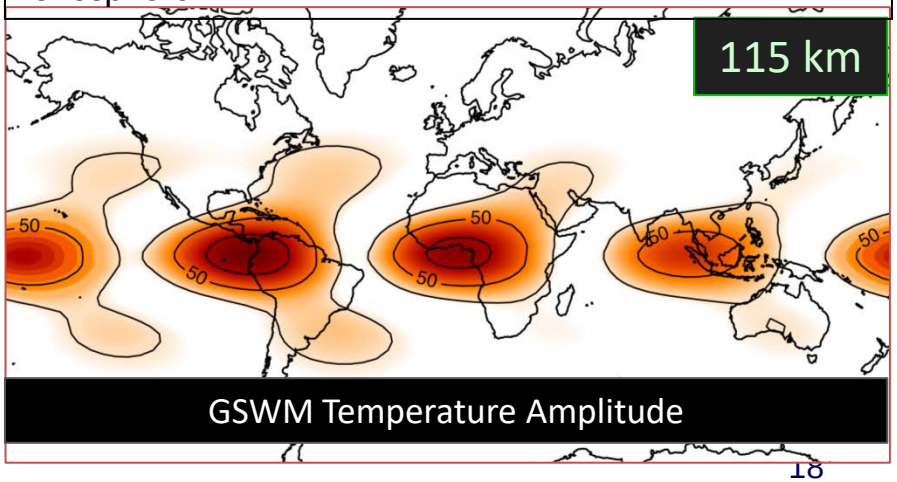


GOES-Global Lightning Occurrence Map
-A Proxy for Tropospheric Convection

Planetary wind dynamo – Ionospheric plasma production is intensified by strong neutral winds, making dense ionospheric bands about the equator.

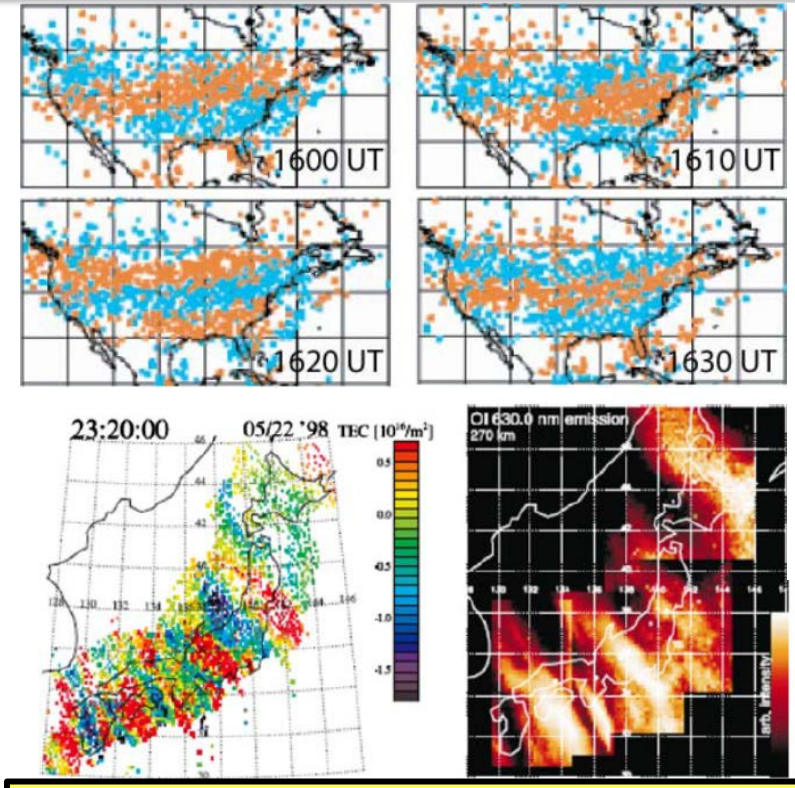


Planetary weather – Tropical weather systems produce global-scale atmospheric waves at the equator that travel upward to drive winds in the lower ionosphere.



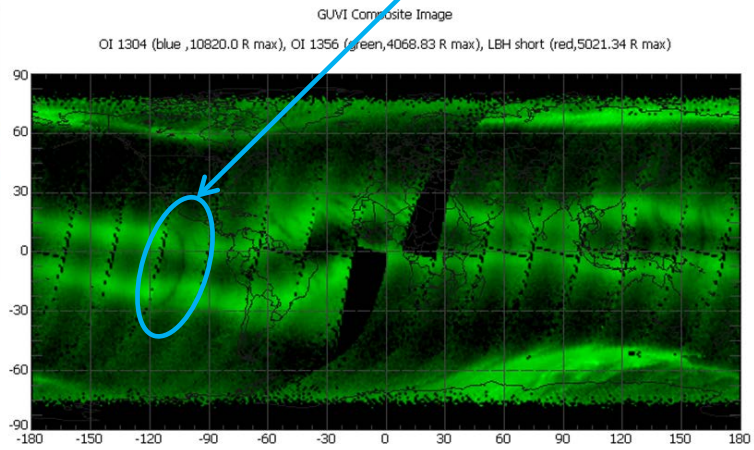
GSWM Temperature Amplitude

Ionospheric Bubbles and Traveling Ionospheric Disturbances



Traveling Ionospheric Disturbances

Bubbles and depletions



Night Ionosphere (TIMED/GUVI data)