Simulations of the Earth's Ultraviolet Airglow from a Geosynchronous Platform: Implications for Daytime Ionospheric Specification

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Introduction (1 of 2)

- The Naval Research Laboratory is simulating the Earth's airglow as viewed from geosynchronous platforms
  - Assess the required instrumental sensitivity and spatial resolution
  - Determine what types of ionospheric information are amenable to this approach
  - Prototype inversion approaches

- Focus on UV measurements at wavelengths below the O_2 absorption cut-off at ~180 nm
  - These measurements are only sensitive to the ionosphere and thermosphere
  - No contamination from atmospheric Rayleigh scattering or from terrestrial emissions such as anthropogenic sources, forest fires, and reflected moonlight

Introduction (2 of 2)

- Previous work on daytime and nightglow simulations from GEO showed that it is possible to extract ionospheric information during both nighttime and daytime

- We discuss our updated simulation software evaluate the accuracy and applicability of the approach

- What are we trying to learn?
  - What does the Earth's UV airglow look like from a geosynchronous platform?
    - How visible are the ionospheric gradients?
  - What ionospheric information can be inferred from the images?

Approach

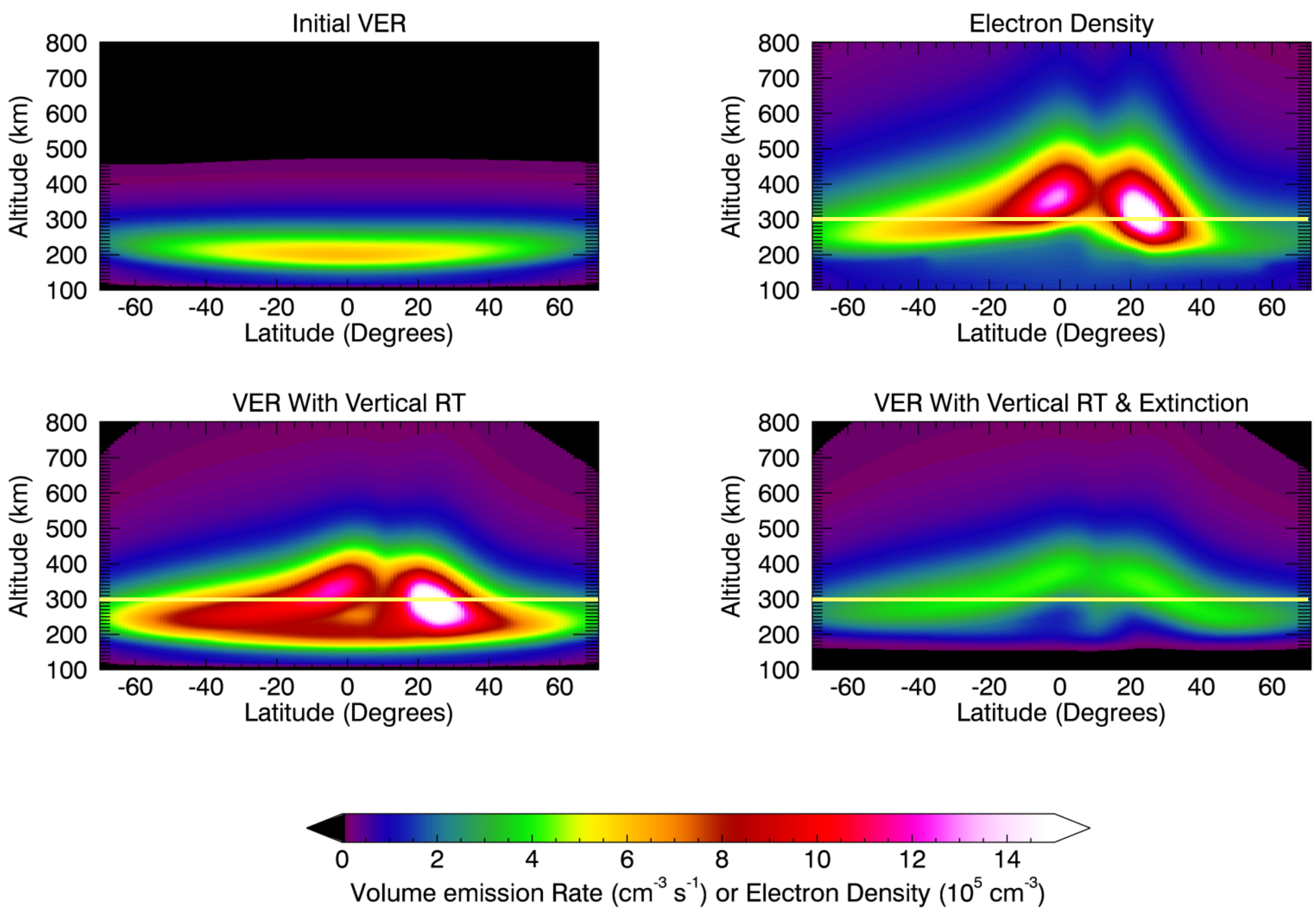
- Produce global electron and neutral densities
  - Neutral density: NRLMSISE-00
  - Ionospheric Density: IRI-2007
- Calculate total column densities to the Sun for each point in the latitude, longitude, and altitude grid
- Calculate the initial volume excitation/emission rates for the emissions
  - Parametrized version of Computational Physics' AURIC model to calculate photoelectron impact and photoionization excitation
- Perform radiation transport in the Complete Frequency Redistribution Approximation, if necessary
- Set up the scenario and perform the line-of-sight integrations
- Display images and analyze

Photon Production Mechanisms

- Photoelectron Impact:
  - $O + e^- \rightarrow O^*(^1S) + e^- \rightarrow O\ (^3P) + h\nu\ (115.2\ \text{nm}) + e^-$
- Photoionization-excitation:
  - $O + h\nu\ (\lambda < 44\ \text{nm}) \rightarrow O^{+*} + e^- \rightarrow O^+ + h\nu\ (83.4\ \text{nm}) + e^-$
- Photoelectron-impact excitation:
  - $O + e^{-*}\ (\text{En.} > 28\ \text{eV}) \rightarrow O^{+*} + 2e^- \rightarrow O^+ + h\nu\ (83.4\ \text{nm}) + 2e^-$
- Solar resonance fluorescence:
  - $O^+ + h\nu\ (83.4\ \text{nm}) \rightarrow O^{+*} \rightarrow O^+ + h\nu\ (83.4\ \text{nm})$
- Radiative recombination:
  - $O^+ + e^- \rightarrow O + h\nu\ (135.6\ \text{nm})$
- Mutual Neutralization:
  - $O^+ + O^- \rightarrow O + O^*(^5S) \rightarrow 2O\ (^3P) + h\nu\ (135.6\ \text{nm})$

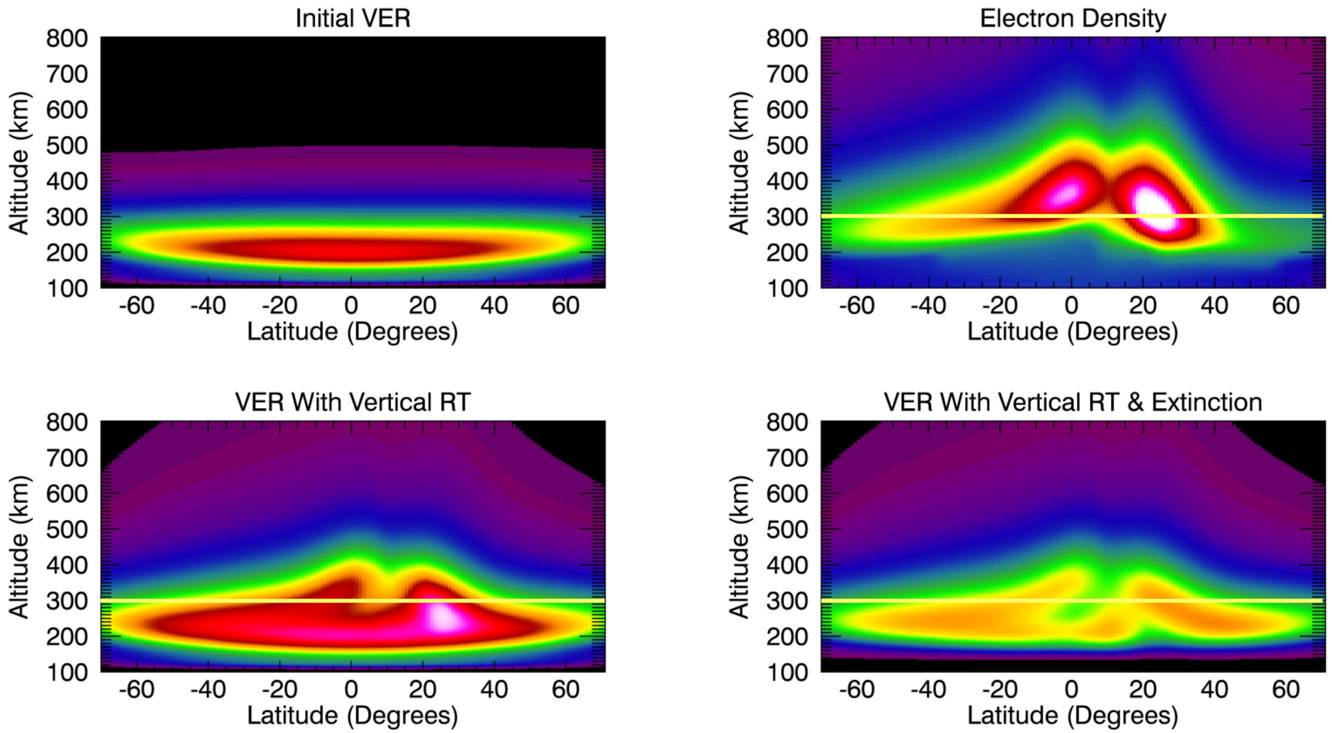
Radiation Transport: 83.4 nm

- Photons are created below ionosphere and scatter in the ionosphere and pick up the ionospheric signature; extinction limits the ***observed*** intensity



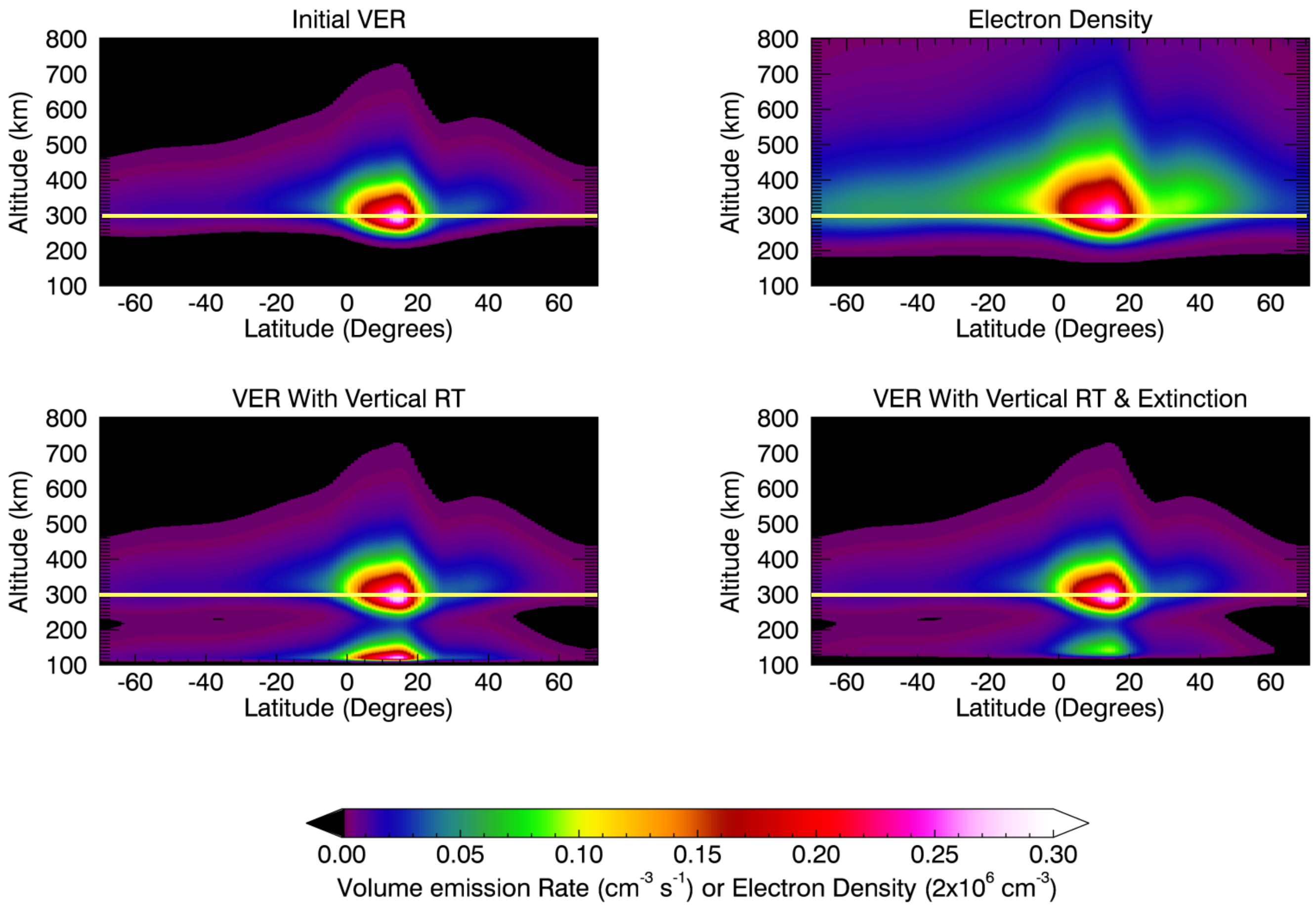
Radiation Transport: 83.2 nm

- More ionospheric information leaks through at the shortest wavelength, with the lowest optical depth



Radiation Transport: 135.6 nm

- Photons are created in the ionosphere and scatter below the ionosphere, but extinction primarily limits the *scattered* intensity



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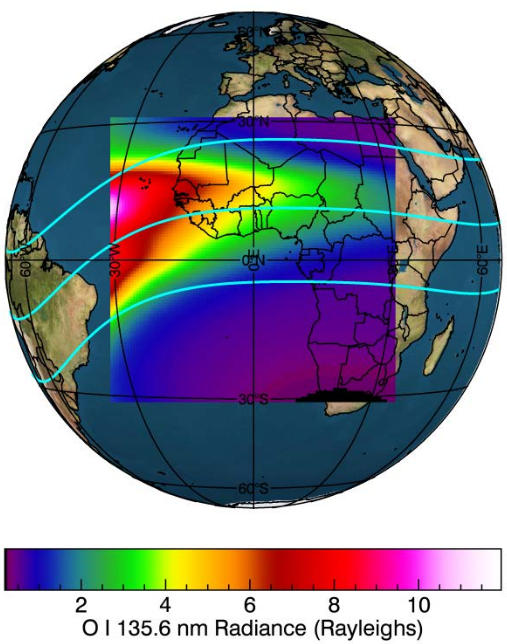
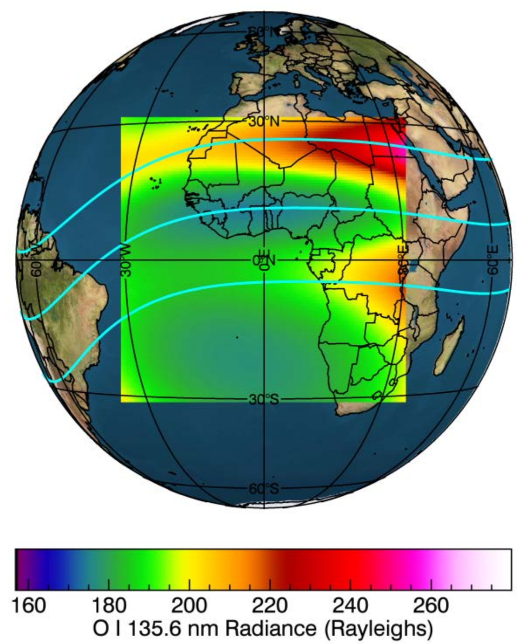
Case Studies & Observation Scenario

- Case 1: Daily variability
  - Date: March 21, 2017
  - Universal Times: Every 3 hours
  - Geophysical:
    - 10.7 cm flux and 81-day average = 78 SFU
    - A_p=8 nT

- Case 2: Solar Cycle Variability
  - Date: March 21, 2017
  - Universal Times: 12 UT
  - Geophysical:
    - 10.7 cm flux and 81-day average = 78, 140, 200 SFU
    - A_p=8 nT





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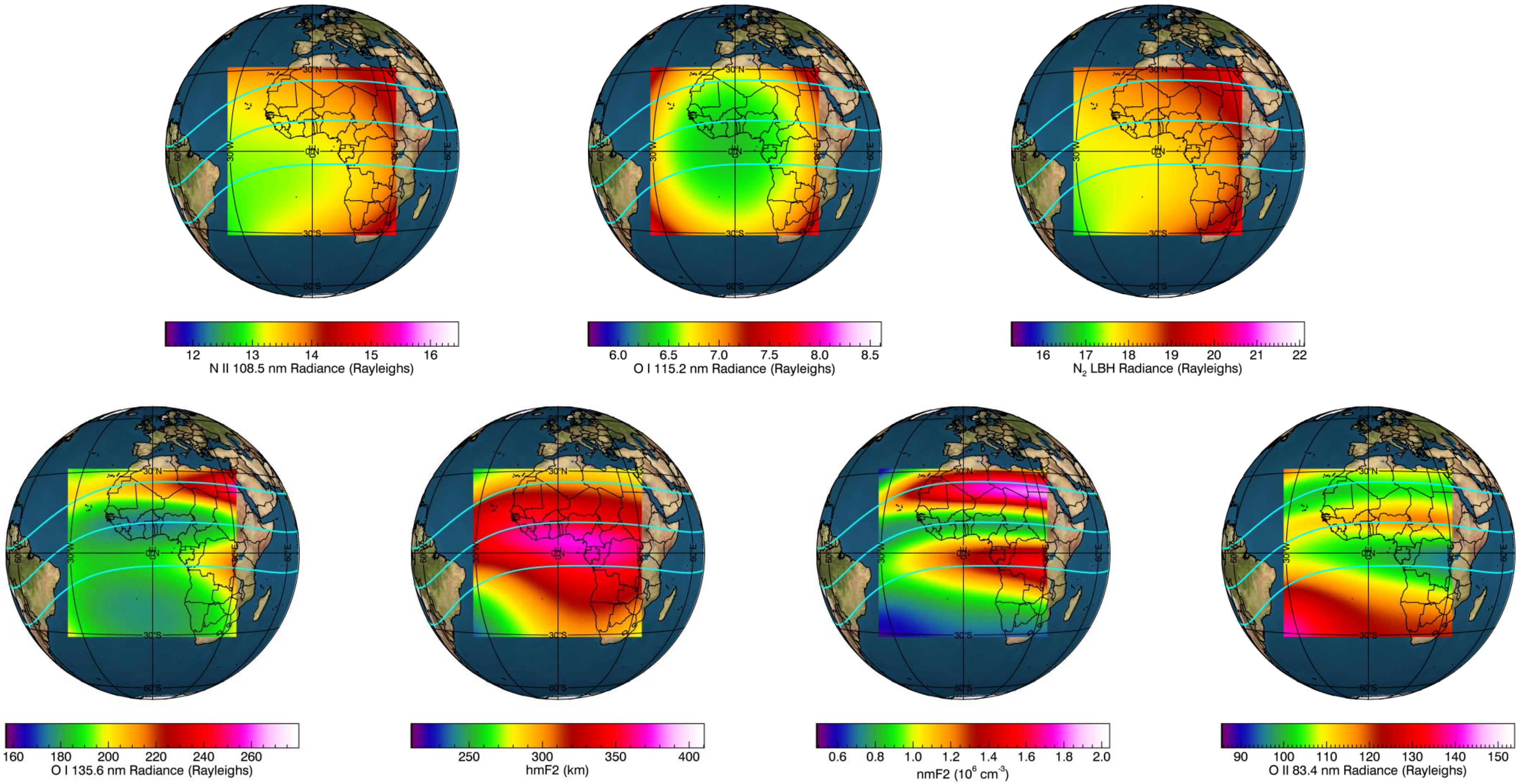
Airglow Scenes
12 UT, 10.7 flux=78 SFU

- Globe pictures of 83.4, 108.5, 115.2, 135.6, N_2 LBH 138.5 nm emissions & nmf2 & hmF2

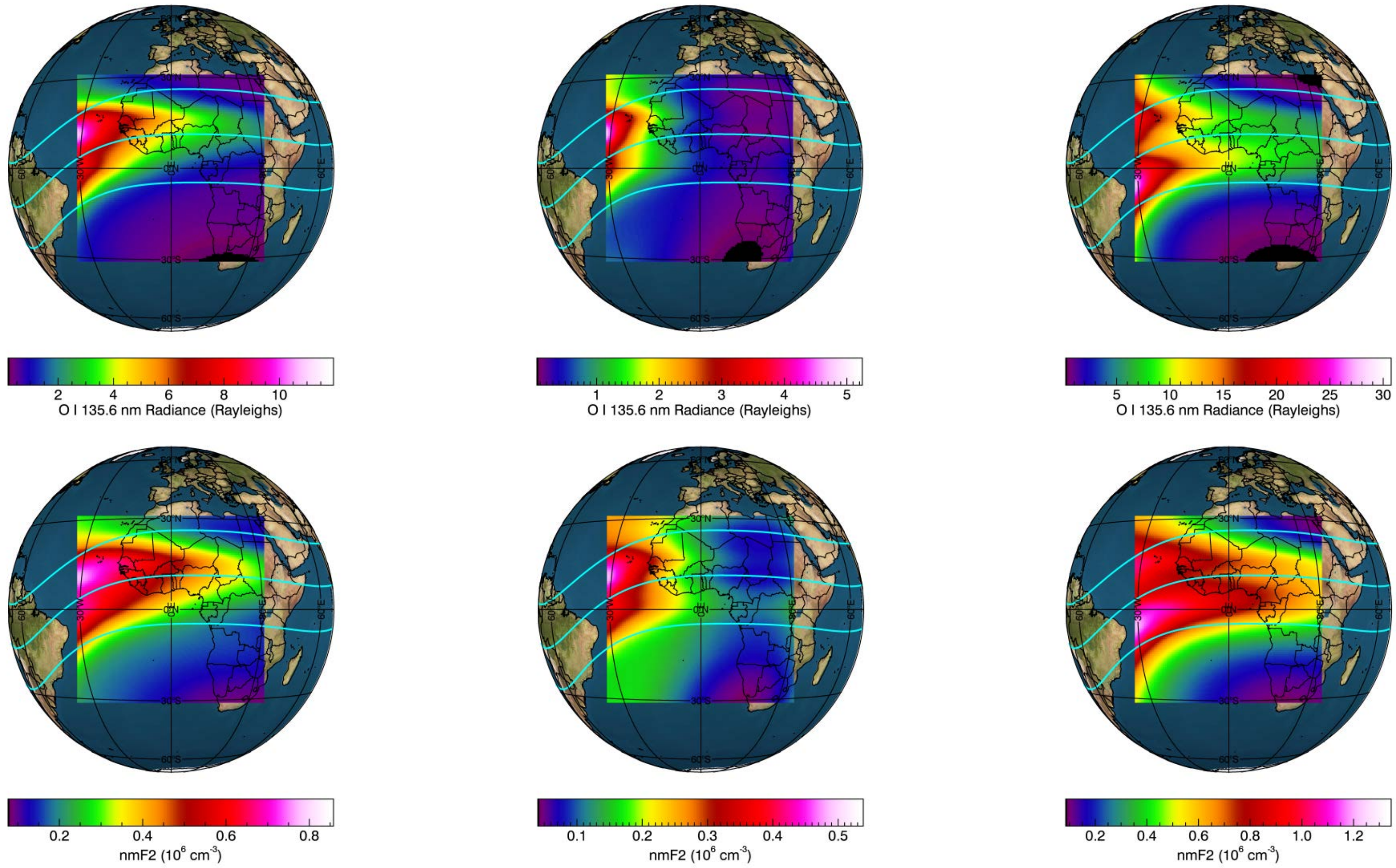


Nightglow Scenes:
0, 3, 21 UT, 10.7 flux=78 SFU

0 UT | 3 UT | 21 UT

135.6 nm

nmF2



Nighttime Ionospheric Parameters from 135.6 nm Sensing, 78 SFU

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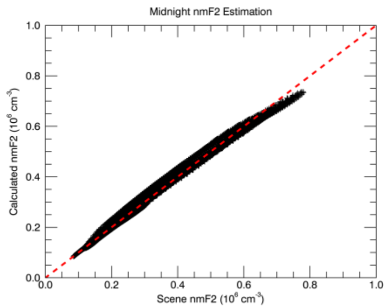
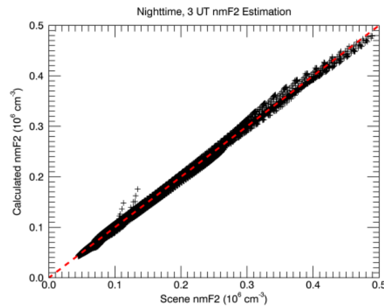
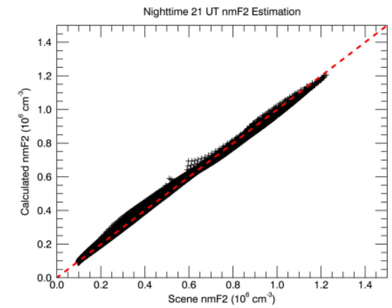
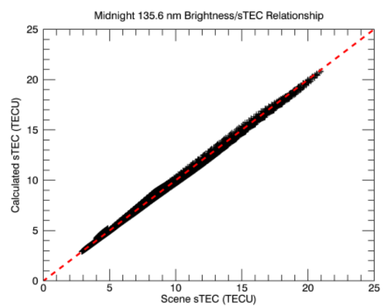
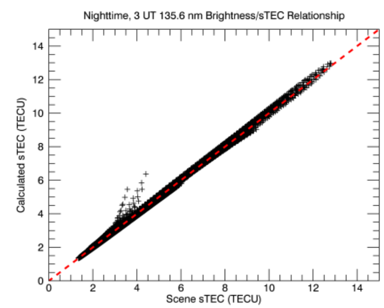
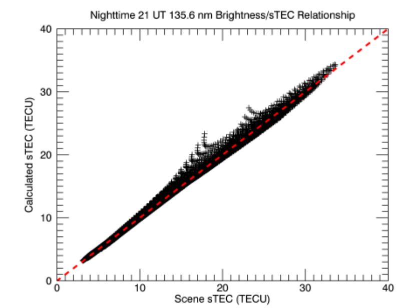
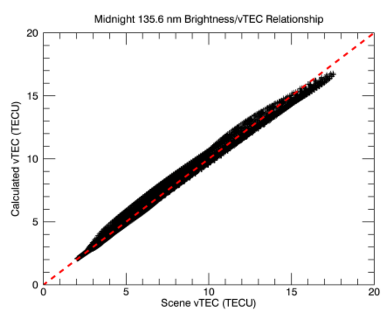
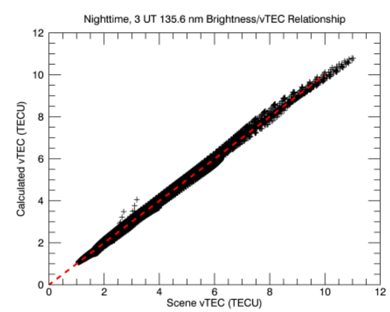
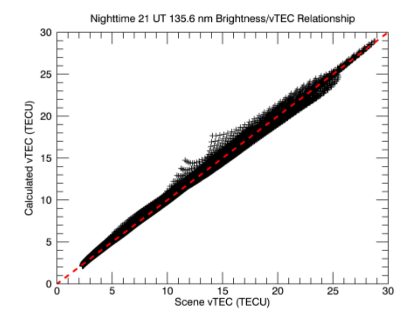
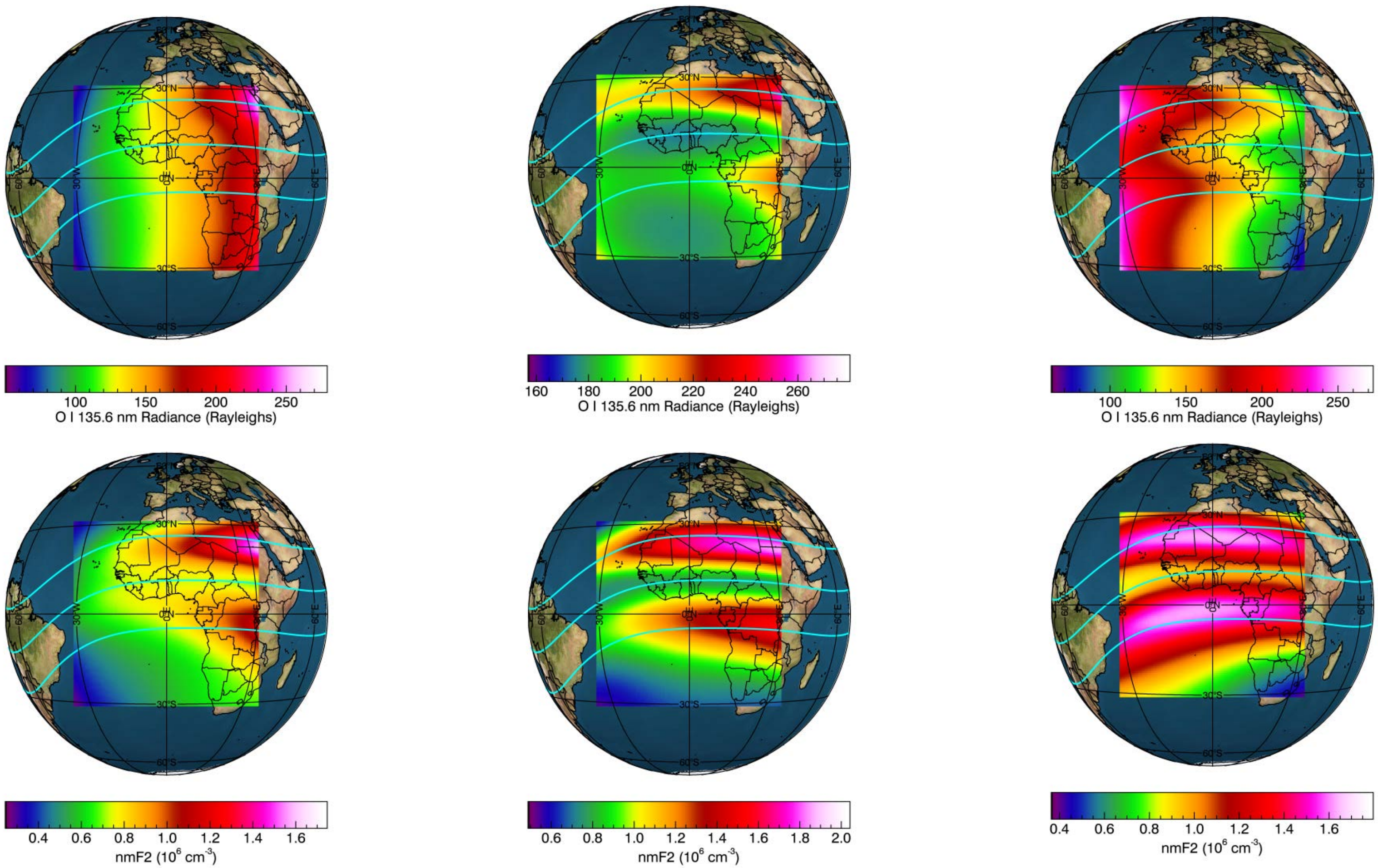
	0 UT	3 UT	21 UT
nmF2			
sTEC			
vTEC			

135.6 nm Dayglow Scenes: 9, 12, 15 UT, 10.7 flux=78 SFU

9 UT | 12 UT | 15 UT

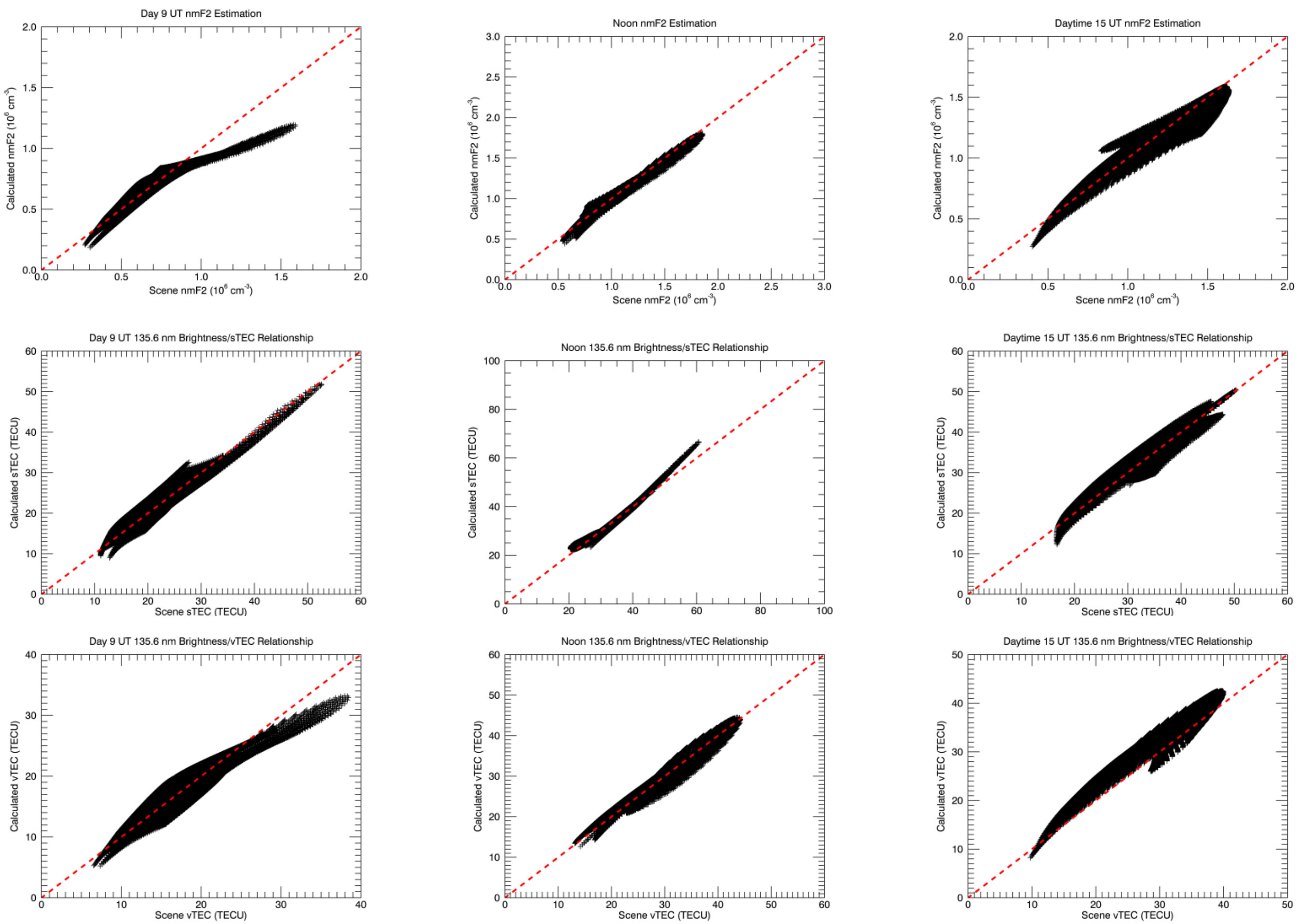
135.6 nm

nmF2

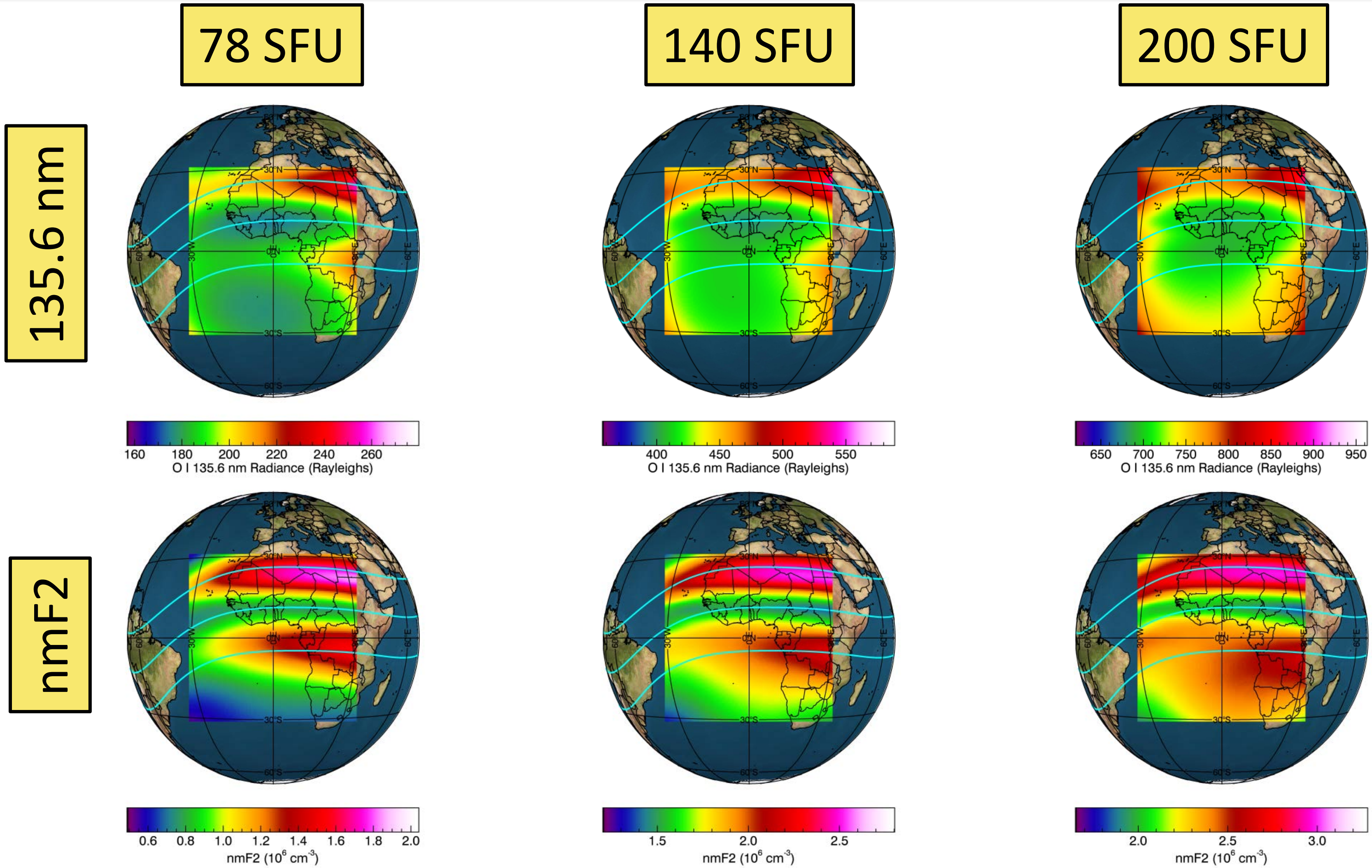


Daytime Ionospheric Parameters from 135.6 nm Sensing, 78 SFU

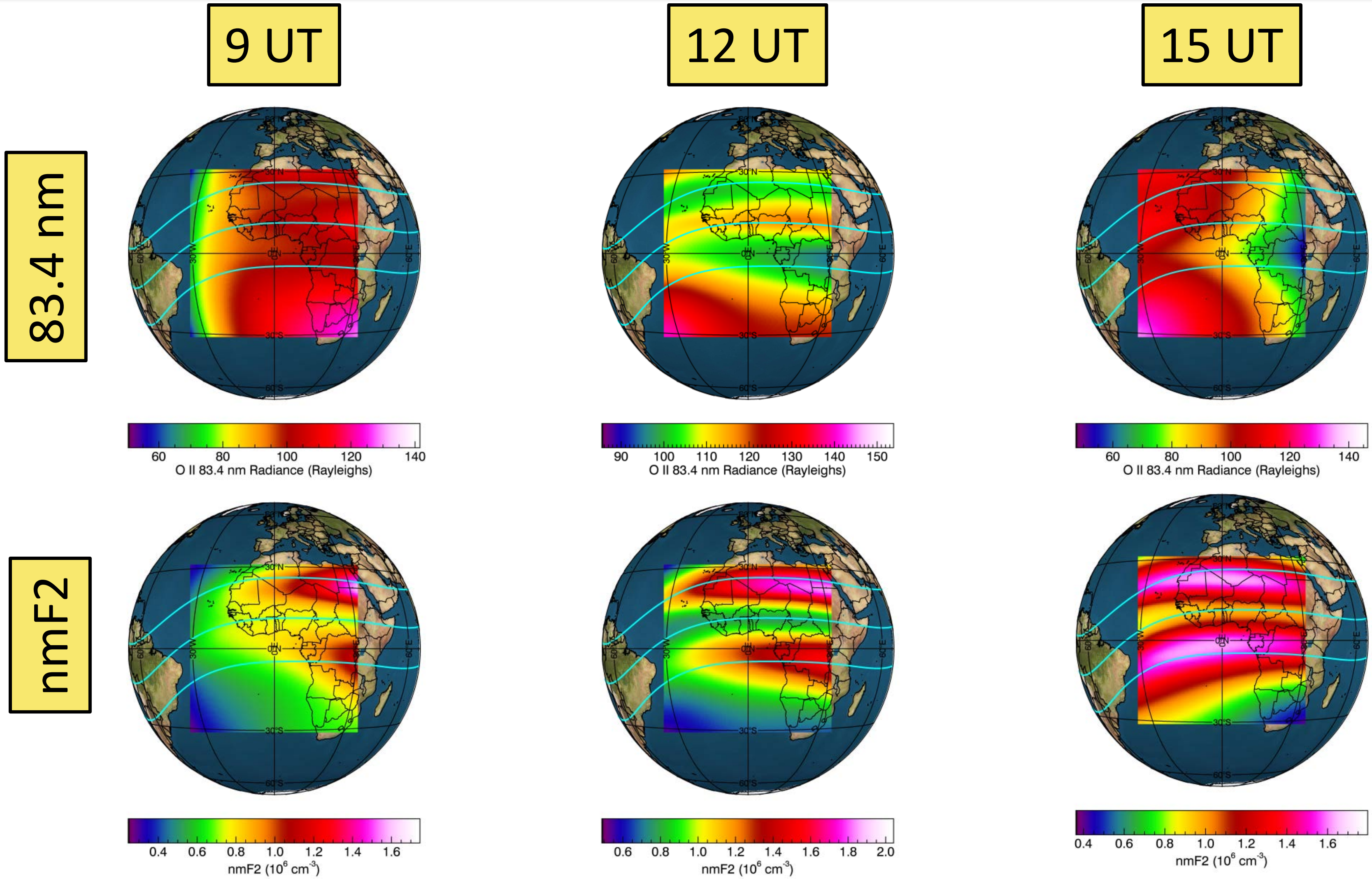
	9 UT	12 UT	15 UT
nmF2			
sTEC			
vTEC			



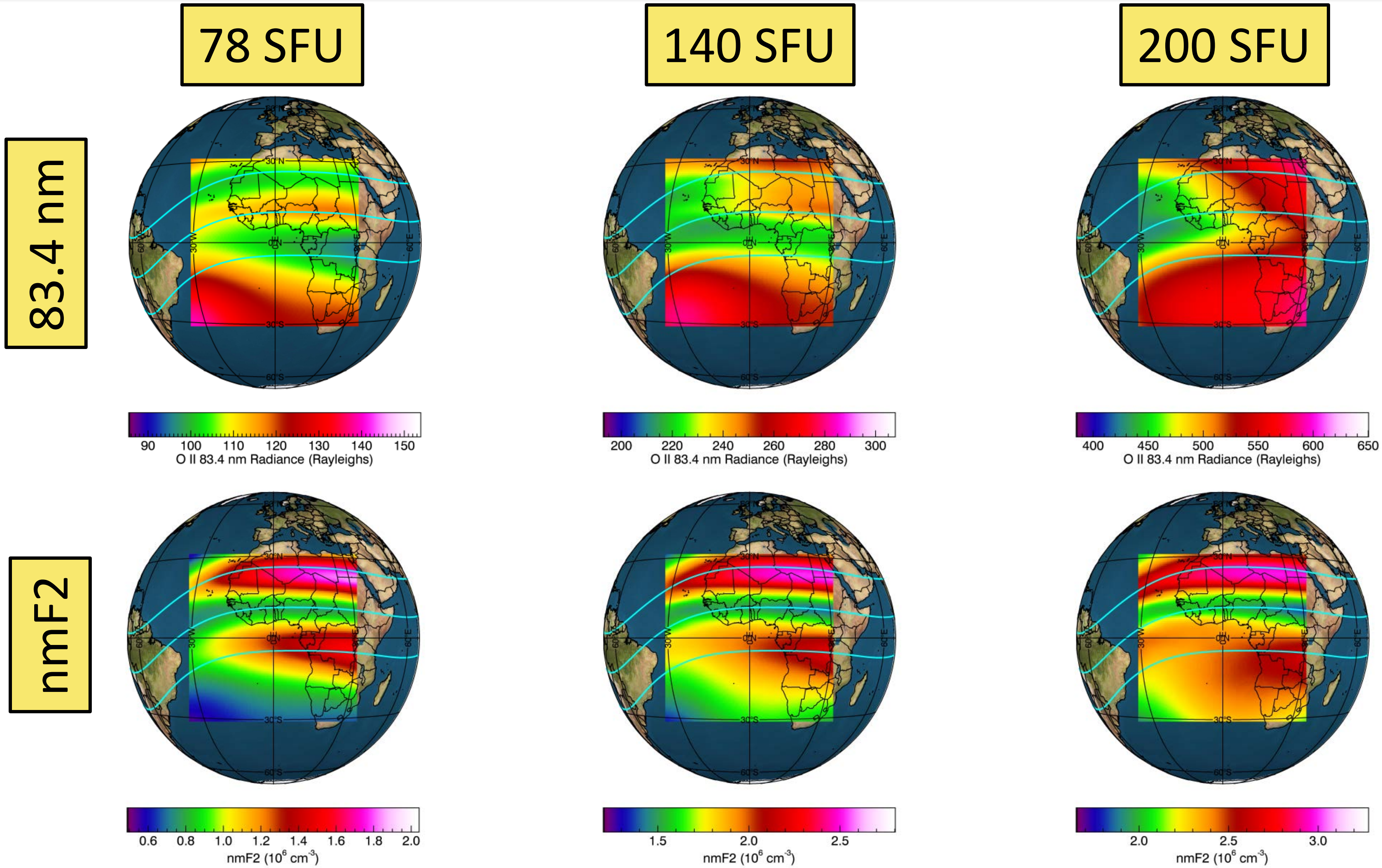
135.6 nm Dayglow Emission & nmF2 vs 10.7 cm Flux



83.4 nm Dayglow Scenes: 9, 12, 15 UT, 10.7 flux=78 SFU



83.4 nm Emission & nmF2 vs 10.7 cm Flux

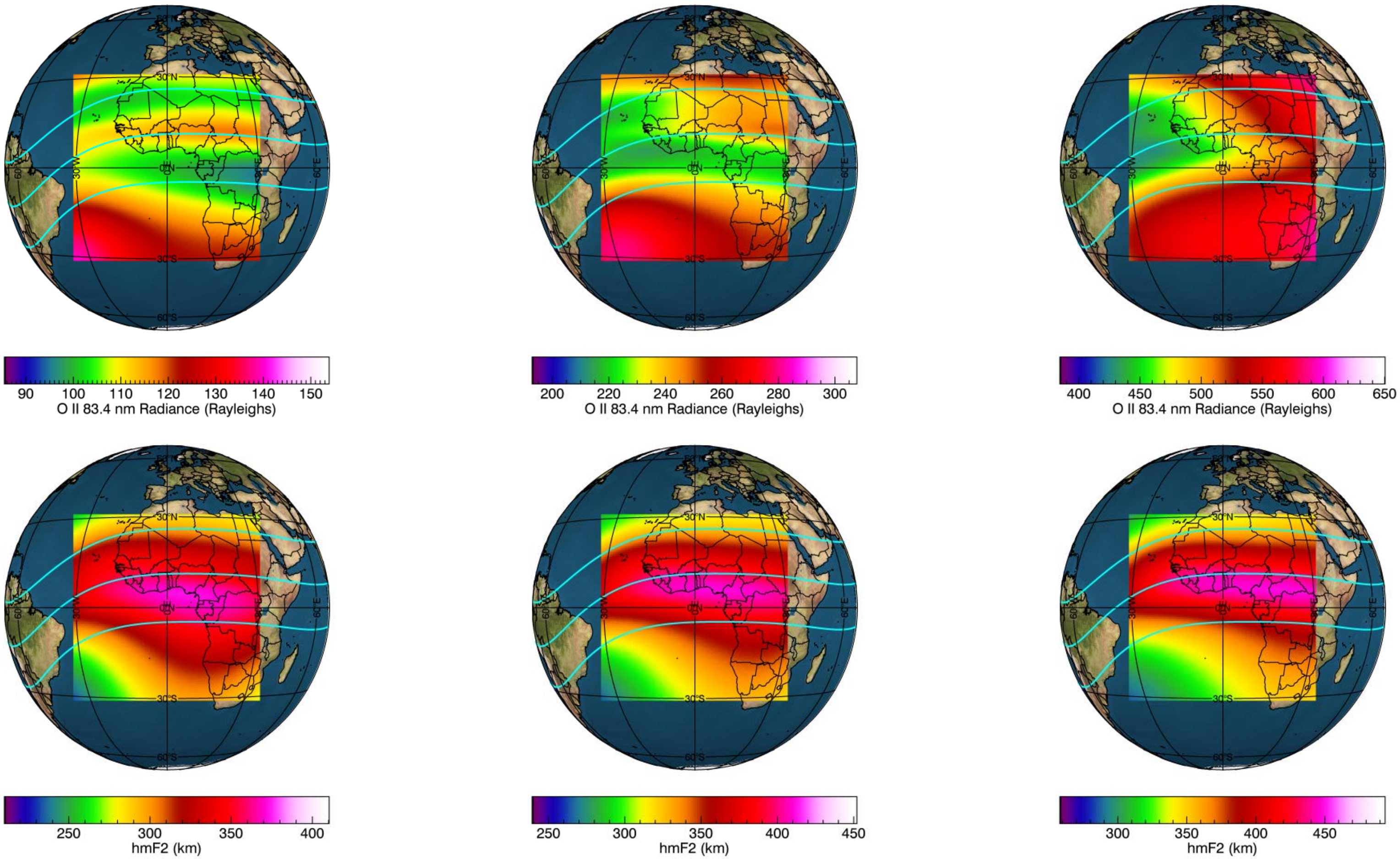


83.4 nm Emission & hmF2 vs 10.7 cm Flux

78 SFU | 140 SFU | 200 SFU

83.4 nm

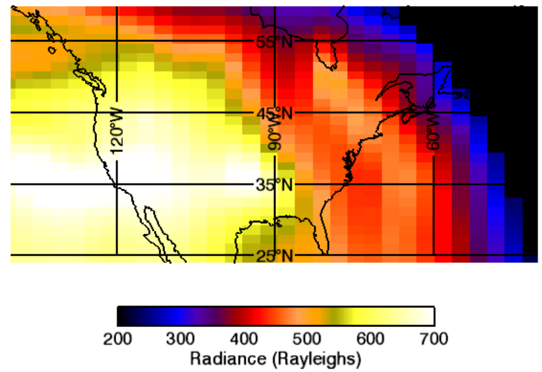
hmF2



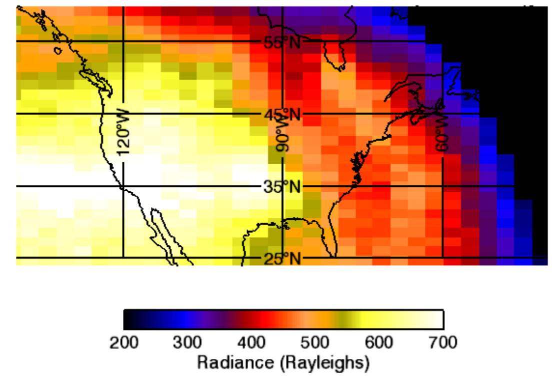
83.4 nm Emission & Ionospheric Sensing

- During a previous study, we showed that it is possible to invert 83.4 nm images and infer the peak electron density
- Those simulations were of a difficult SED plume over the US
  - Date and Time: November 20, 2003 at 20:00 UT
  - $a_p = 100$
  - 10.7 cm Solar Flux and 81-day average = 150 Solar Flux Units

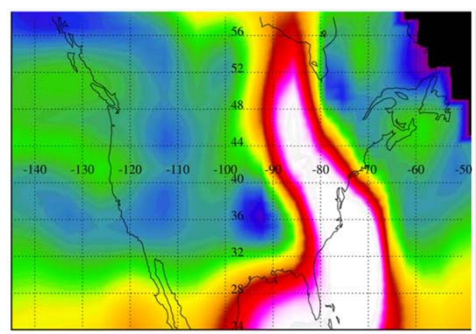
SED 83.4 nm Radiance Without Noise



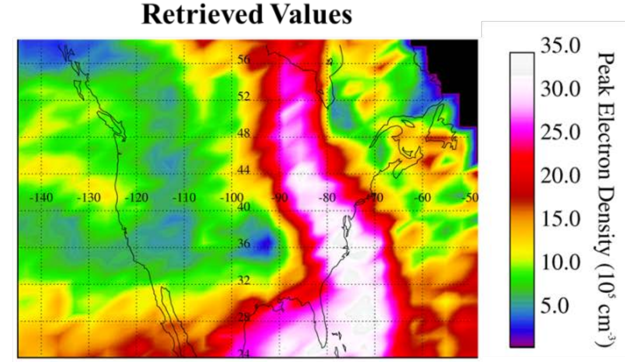
SED 83.4 nm Radiance With Shot Noise



Peak Electron Density GAIM SED



Peak Electron Density Retrieved Values



Summary

- We presented an overview of a software suite being developed at the NRL
  - Used to simulate airglow scenes under a variety of scenarios
  - Focused on simulations of airglow as seen from a geosynchronous imager

- Our approach entails
  - Modeling of the airglow excitation mechanisms
  - Radiation transport & transfer
  - A variety of ionospheric and thermospheric models can be used for the simulations

- We presented imagery at a variety of Local Times and over a Solar Cycle
  - Showed simple power-law relationships between the 135.6 nm emission and the STEC, vTEC , and nmF2
  - Showed images of the 83.4 nm emission demonstrating the difficulty of interpreting that emission
  - Mentioned previous work that could be updated to invert the 83.4 nm emission

Backup Slides

O I 135.6 nm: Radiation Transport

- The 1356 Å emission is a doublet and is scattered by atomic oxygen and absorbed by molecular oxygen:
  - O: Resonant Scattering redistributes the photons in altitude
    - O + hν (1356, 1358 Å) $\rightarrow$ O + hν (1356, 1358 Å), Cross-section: $\sigma = 2.499 \times 10^{-18}$ cm^2 (1356); $\sigma = 1.242 \times 10^{-18}$ cm^2 (1358)
  - O_2: Absorption removes photons
    - O_2 + hν(1356, 1358 Å) $\rightarrow$ 2O, Cross-section: $\sigma = 7.20 \times 10^{-18}$ cm^2 (1356); $\sigma = 7.15 \times 10^{-18}$ cm^2 (1358)

- Integral version of the radiation transport equation in the plane-parallel Complete Frequency Redistribution approximation:

$$\varepsilon(z) = \varepsilon_0(z) + n_O(z)\sigma \int_{z_{\min}}^{z_{\max}} \varepsilon(z') H\big(|\tau(z) - \tau(z')|, |t(z) - t(z')|\big) dz' \quad \begin{cases} \tau(z) = \sigma \int_z^{\infty} n_O(z') dz' \\ t(z) = \sigma_{O_2}^{abs} \int_z^{\infty} n_{O_2}(z') dz' \end{cases}$$

Holstein H function → $H(\tau, t) = \dfrac{1}{2\sqrt{\pi}} \int e^{-2x^2} E_1\left(\tau e^{-x^2} + t\right) dx$

O I 135.6 nm: Radiation Transfer

- Once the photons are created and then scattered or redistributed in altitude, one needs to model the transfer of that radiation to the observer for observation:

$$I_{1356} = 10^{-6} \sum \int_0^{\infty} T\left(\left| \tau\left(z(s) - \tau^s\left(z(s=0)\right)\right) \right|, \left| t^s\left(z(s)\right) - t^s\left(z(s=0)\right) \right| \right) \; \varepsilon\left(z(s)\right) ds$$

- The function, T, is the Holstein t-function:

  - ***x*** is the width of the spectral line in Doppler units

$$T(\tau, t) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-x^2} \exp(-\tau e^{-x^2} + t) dx$$

Radiation Transport

- The 83.4 nm and 135.6 nm emissions require radiation transport calculations to properly model the scenes
- For example, the 83.4 nm photons are primarily created at low altitudes
  - The upward traveling photons are resonantly scattered several times before being lost
    - This results in an enhancement of the volume emission rate in the F-region ionosphere
  - But scattering out of the observer's line-of-sight limits the overall emission intensity
- Proper radiation transfer modeling is required to simulate and interpret these emissions

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Daytime Ionospheric Parameters from 135.6 nm Sensing vs 10.7 Flux