Determination of Charged Particle Environment in Near-Earth Space with ICON-MIGHTI

Brenden G. Lech[1] (brendenlech@vt.edu) and Scott L. England[1]

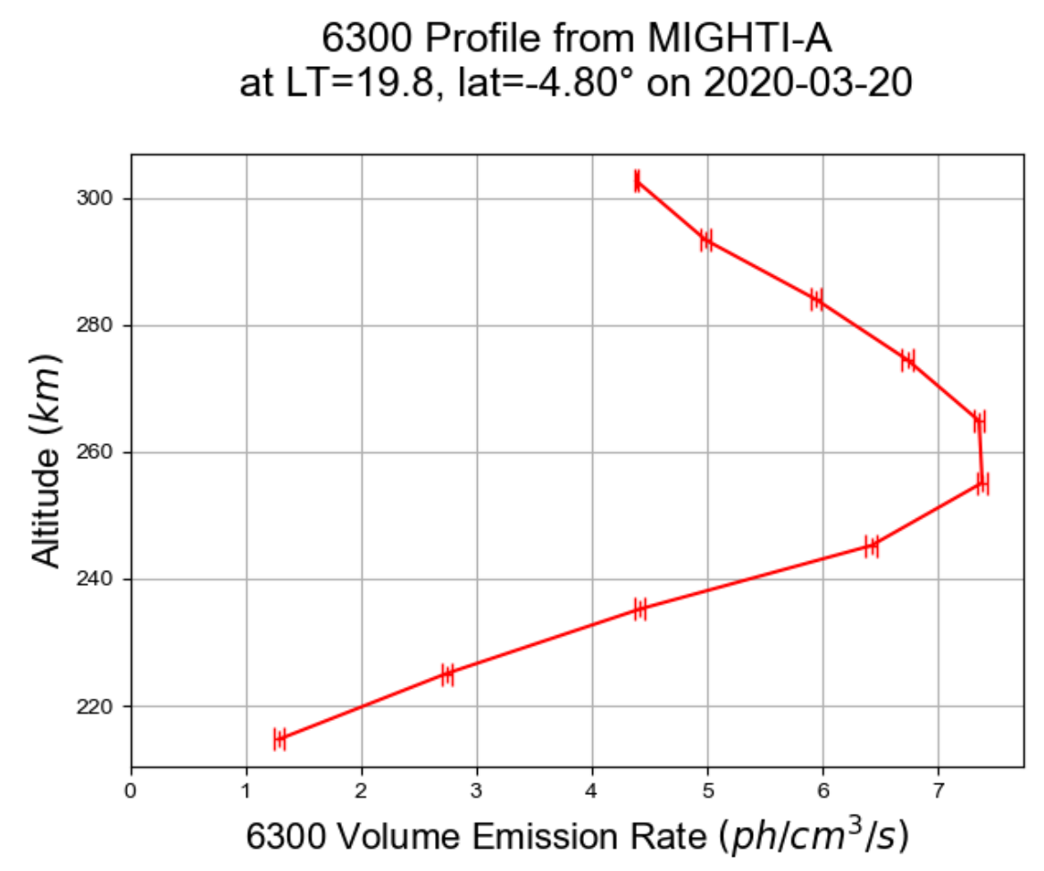
[1]Department of Aerospace and Ocean Engineering, Virginia Tech

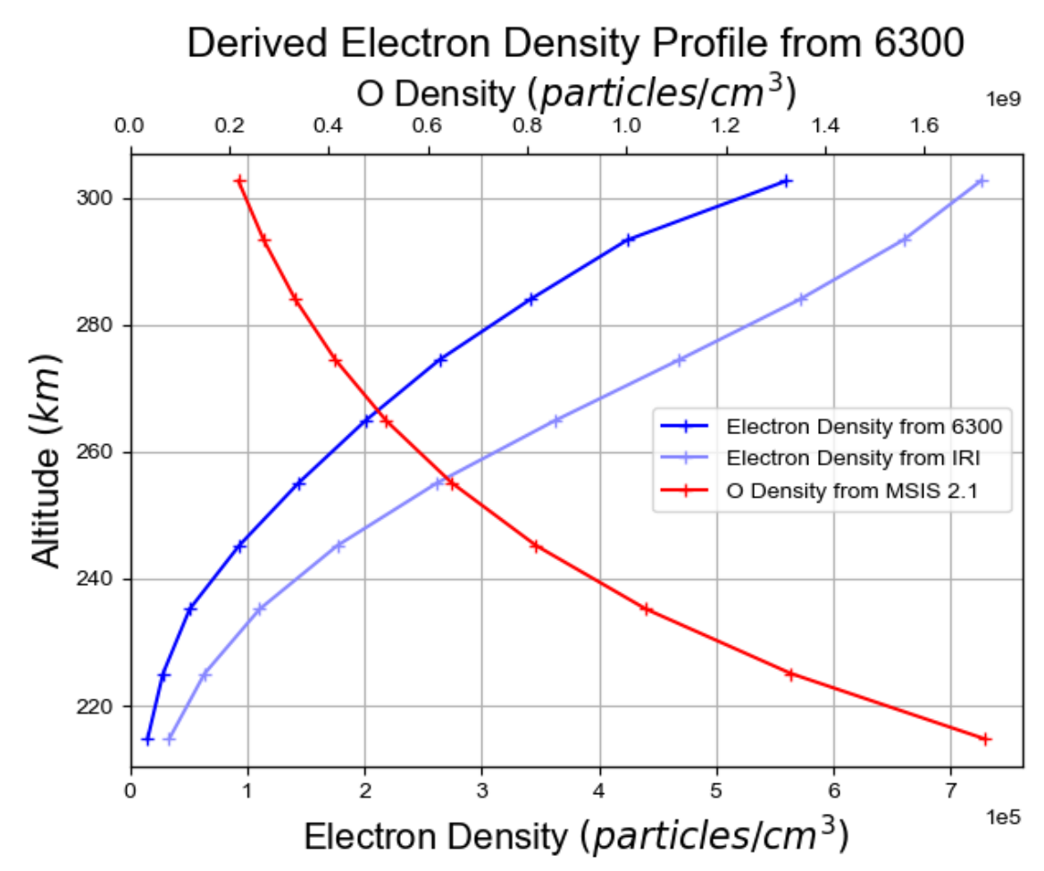
Abstract

The Ionospheric Connection Explorer (ICON) measures aspects of ionospheric behavior from LEO to identify the daytime and nighttime characteristics of the ionosphere, much of it related to ion density and velocity. However, comparatively less work has been done to cross-reference ICON's instruments' datasets to determine their consistency, where they may disagree, and where such apparent discrepancies may yield new science. Here, we begin by using the Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) to derive ion density measurements from 6300 emissions for comparison between MIGHTI-A and MIGHTI-B to develop a method of searching for ionospheric structuring in MIGHTI data. These instruments make measurements simultaneously in different locations, so comparisons are done on climatologies.

Motivation

The Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) is a pair of one-dimensional imaging interferometers oriented orthogonal to each other onboard the Ionospheric Connection Explorer (ICON) spacecraft, designed to provide low-latitude thermospheric wind and temperature measurements between 90km and 300km altitude. Horizontal wind measurements are derived through limb observations of red-line (6300Å) and green-line (5577Å) airglow. *(Englert et al., 2017)*





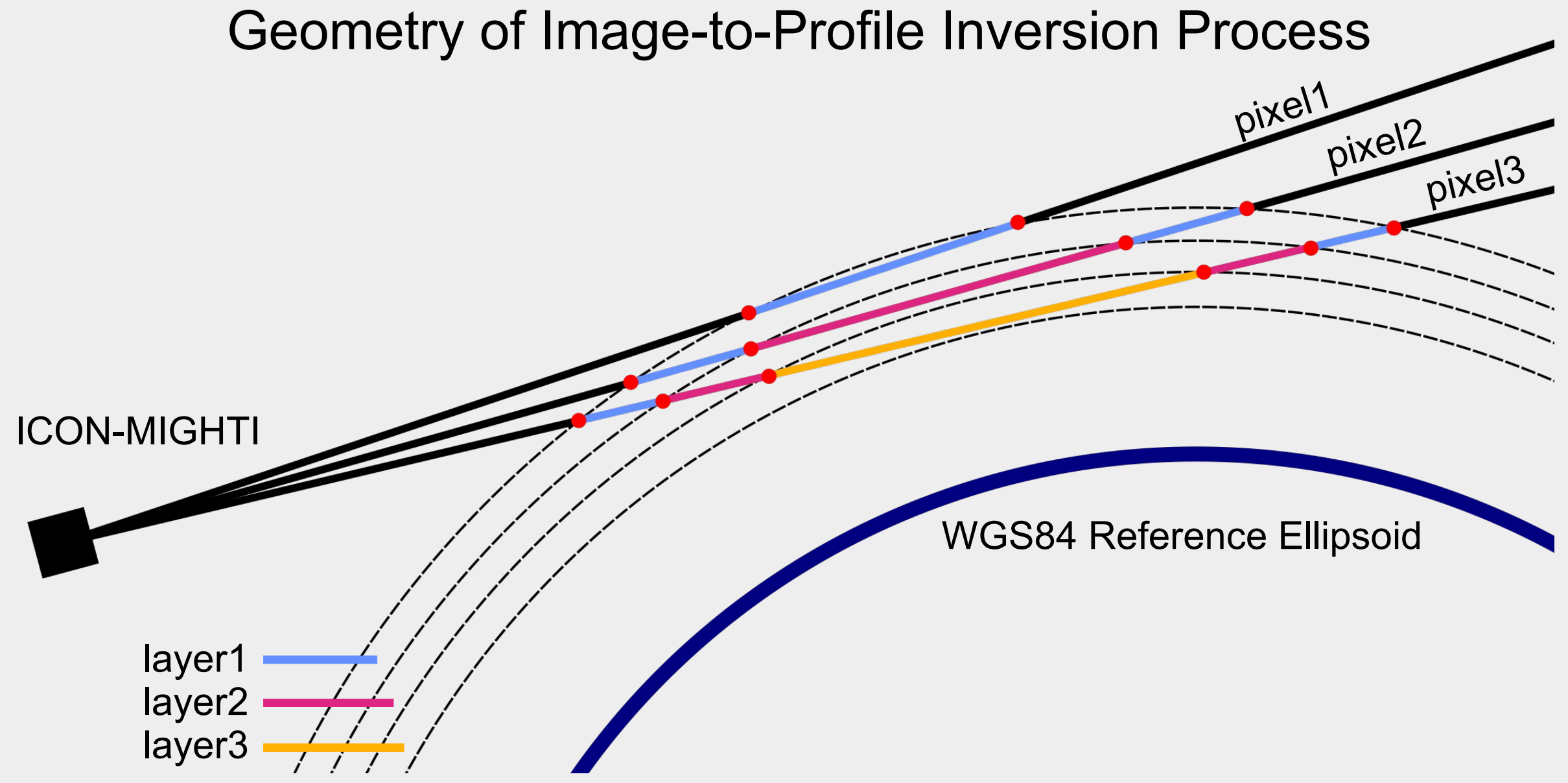
As 6300 photons are emitted by the decay of excited atomic oxygen from O(^{1}D) to O(^{3}P) and the O(^{1}D) production mechanisms rely on electron and ion density, 6300 emissions can provide an estimate of ionospheric conditions. Below is the equation describing the 6300 volume emission rate (VER). The main production mechanisms of O(^{1}D) are charge exchange of O$^+$ with O$_2$ and dissociative recombination of O$_2^+$ and e$^-$, while O(^{1}D) is quenched by collisions with N$_2$, O$_2$, and e$^-$ that result in it becoming O(^{3}P) without the emission of a 6300 photon.

$$V_{6300}=\frac{0.76\,\beta_1 k_1[O^+][O_2]}{1+\left(k_3[N_2]+k_4[O_2]+k_5[e^-]\right)/A_{1D}}$$

(Link and Cogger, 1988)

However, as MIGHTI's radial windspeed measurements rely on Doppler shift of emissions, MIGHTI was not calibrated for absolute emission brightness. This poses a challenge in using MIGHTI to measure absolute 6300 VER to derive ion density. Additionally, shot noise adds error that can be magnified by the inversion process used to derive an emission profile from the image.

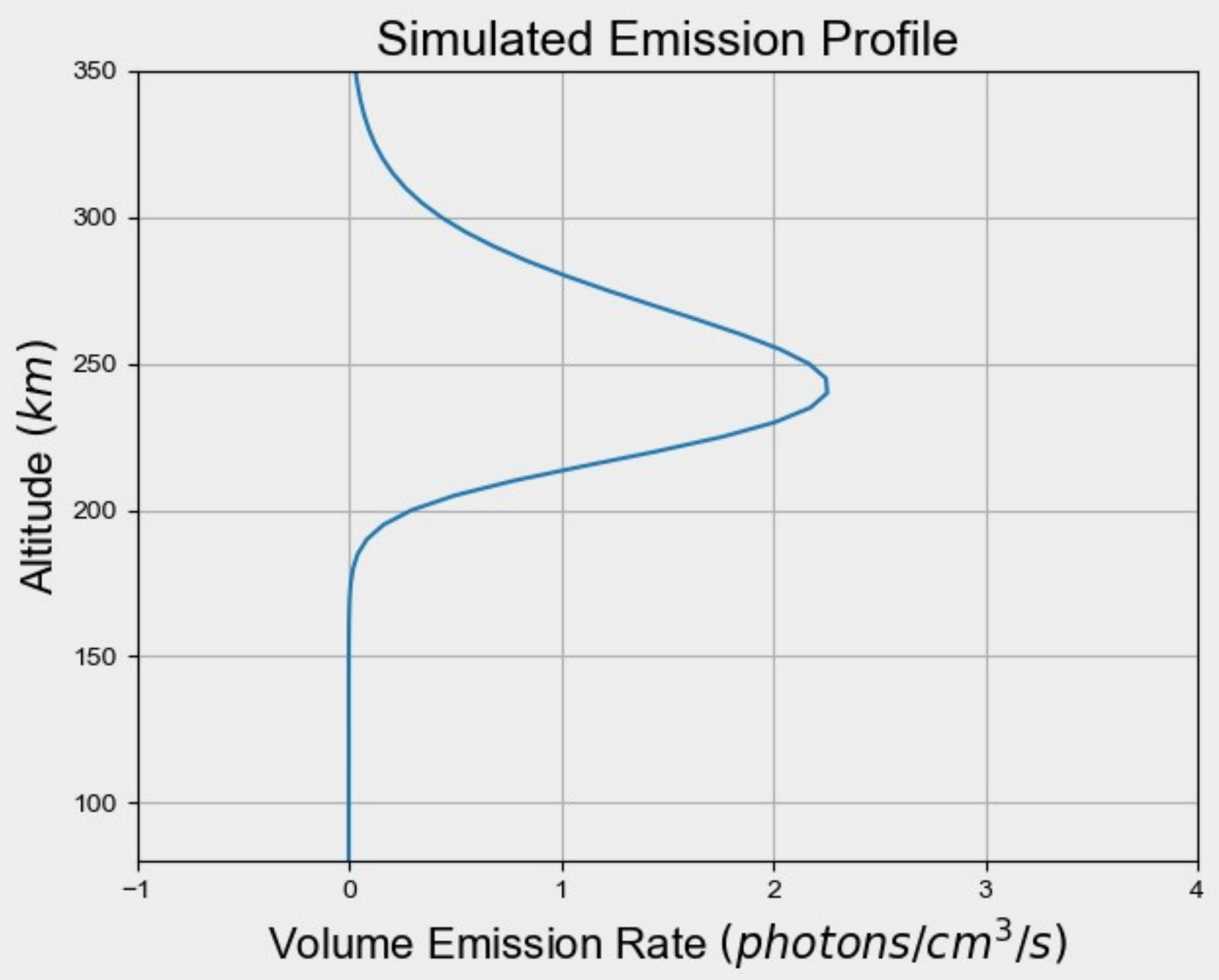
Geometry of Image-to-Profile Inversion Process

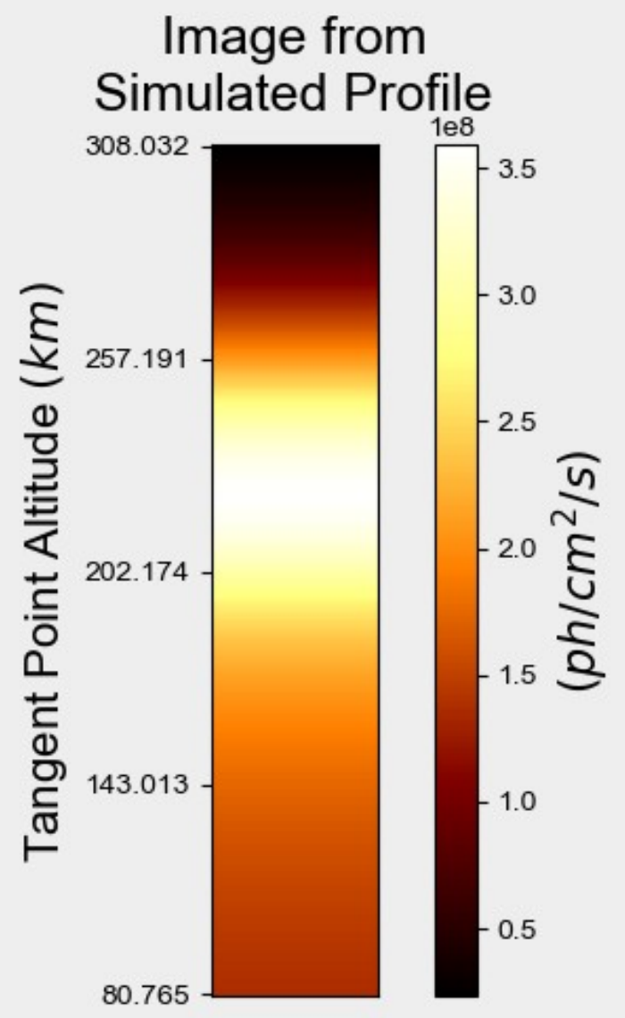


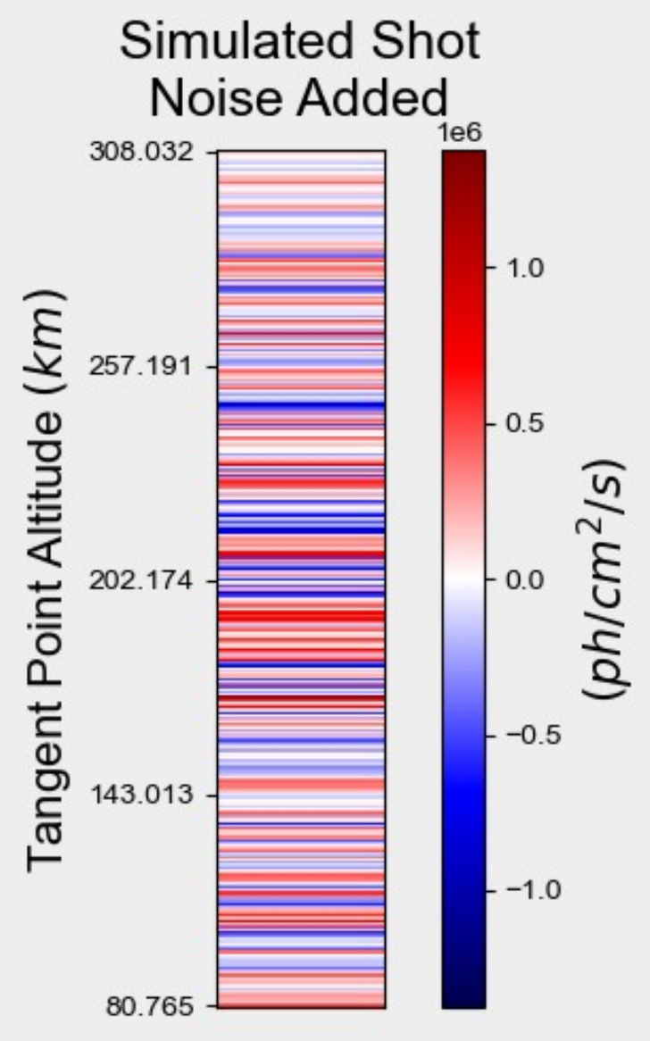
$$\begin{bmatrix} pixel_1 \\ pixel_2 \\ pixel_3 \end{bmatrix} = \begin{bmatrix} r_{1,1} & 0 & 0 \\ r_{2,1} & r_{2,2} & 0 \\ r_{3,1} & r_{3,2} & r_{3,3} \end{bmatrix} \begin{bmatrix} VER_{layer\,1} \\ VER_{layer\,2} \\ VER_{layer\,3} \end{bmatrix} \rightarrow \vec{I}=R*\vec{VER}$$

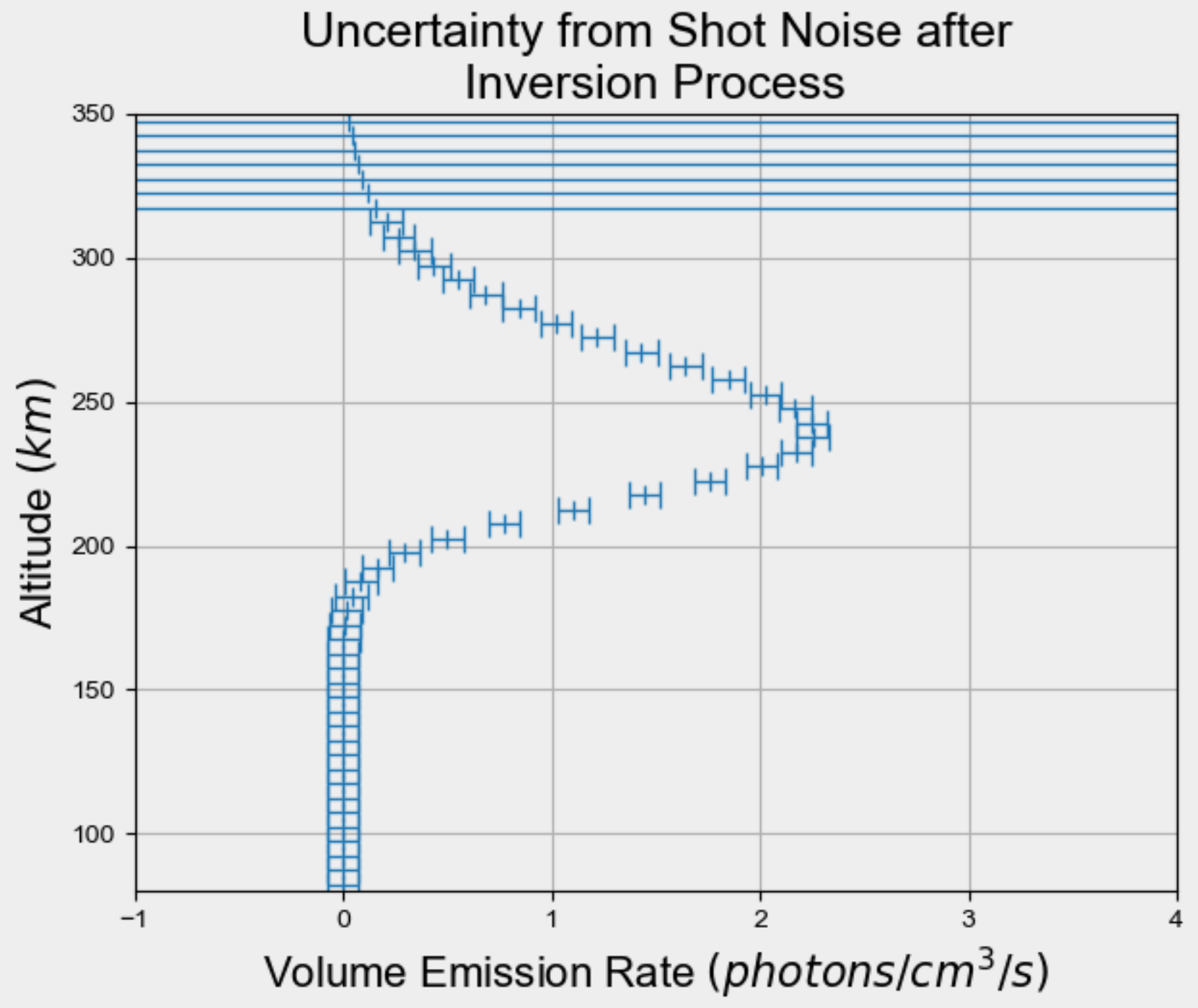
$$\vec{VER}=R^{-1}*\vec{I}$$

A Monte-Carlo simulation has been run to illustrate the effect of shot noise at different altitudes. A sample airglow profile is generated using PyGlow then converted to an image. Poisson noise is added to the image to simulate shot noise, then the profile is re-derived from the noisy image and compared with the true noiseless profile to estimate uncertainty added.

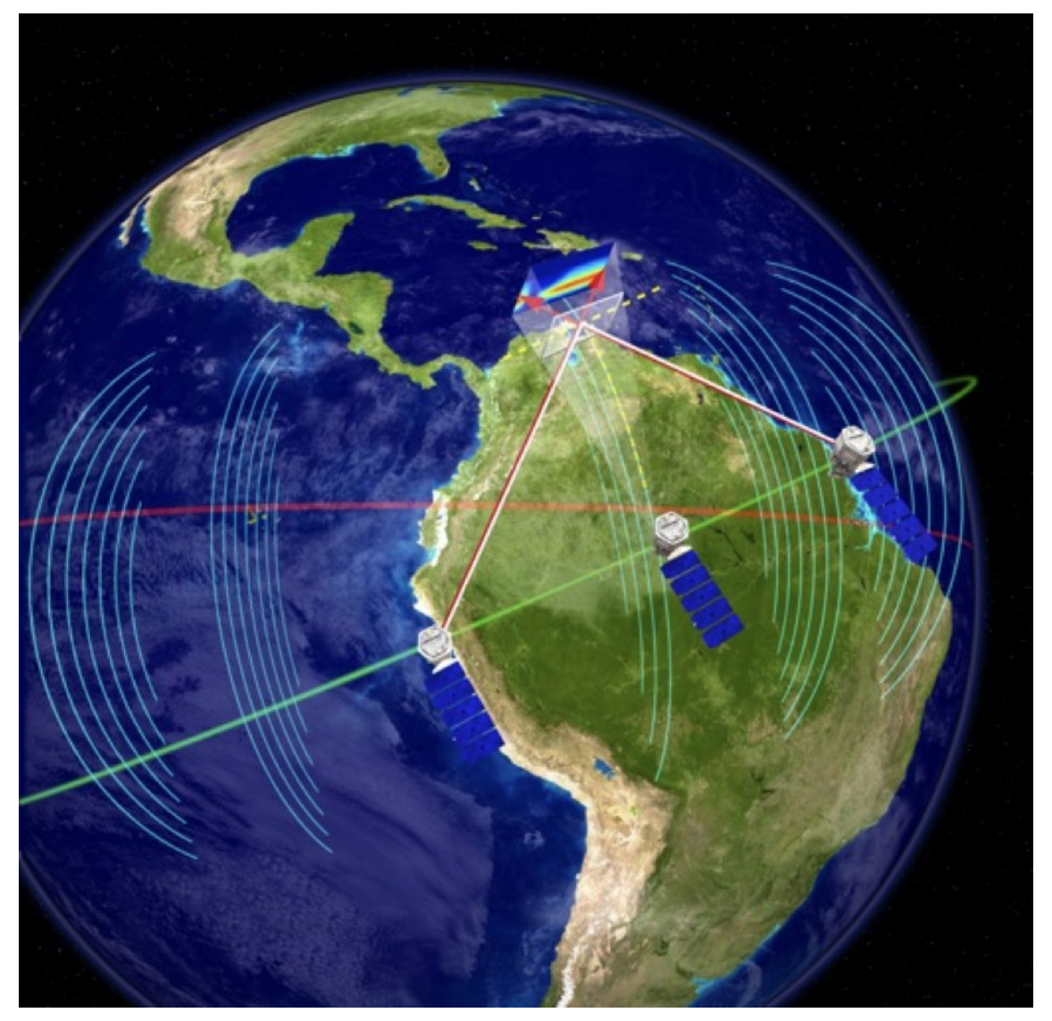




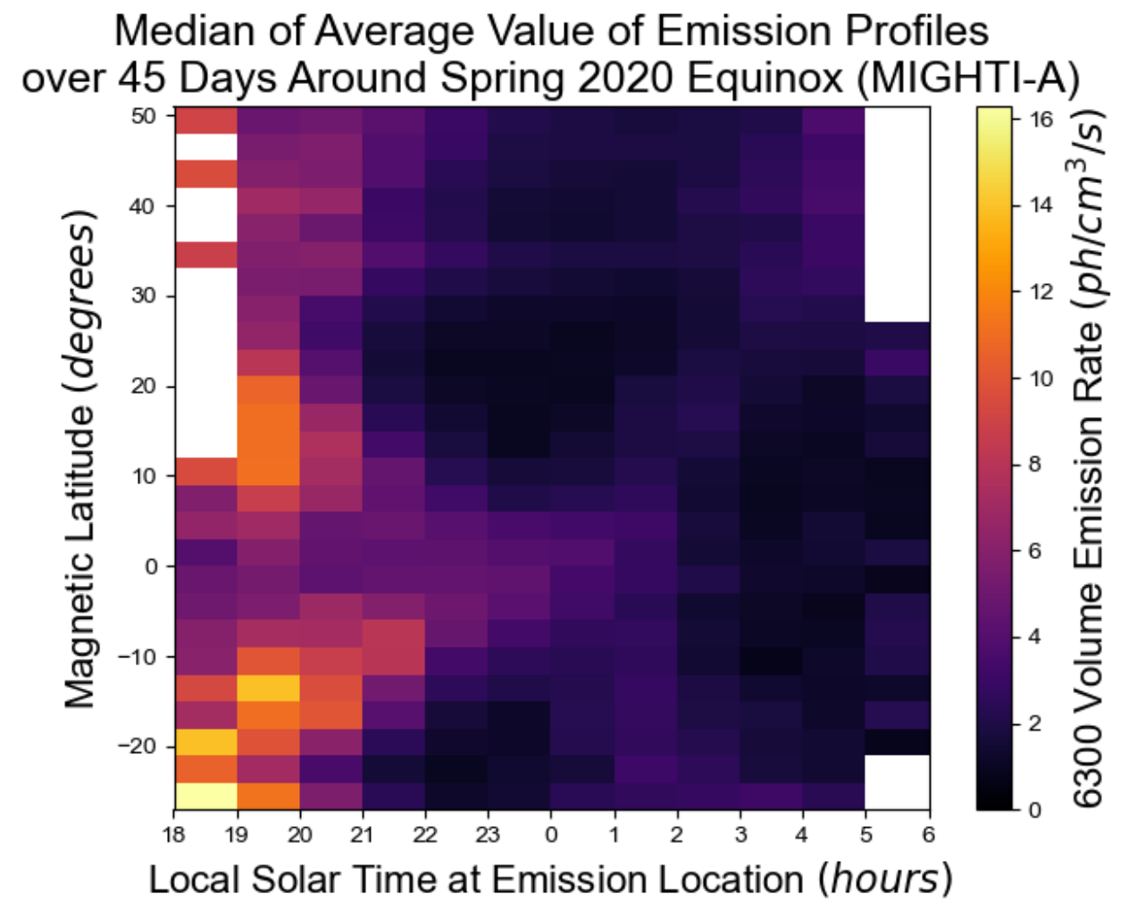


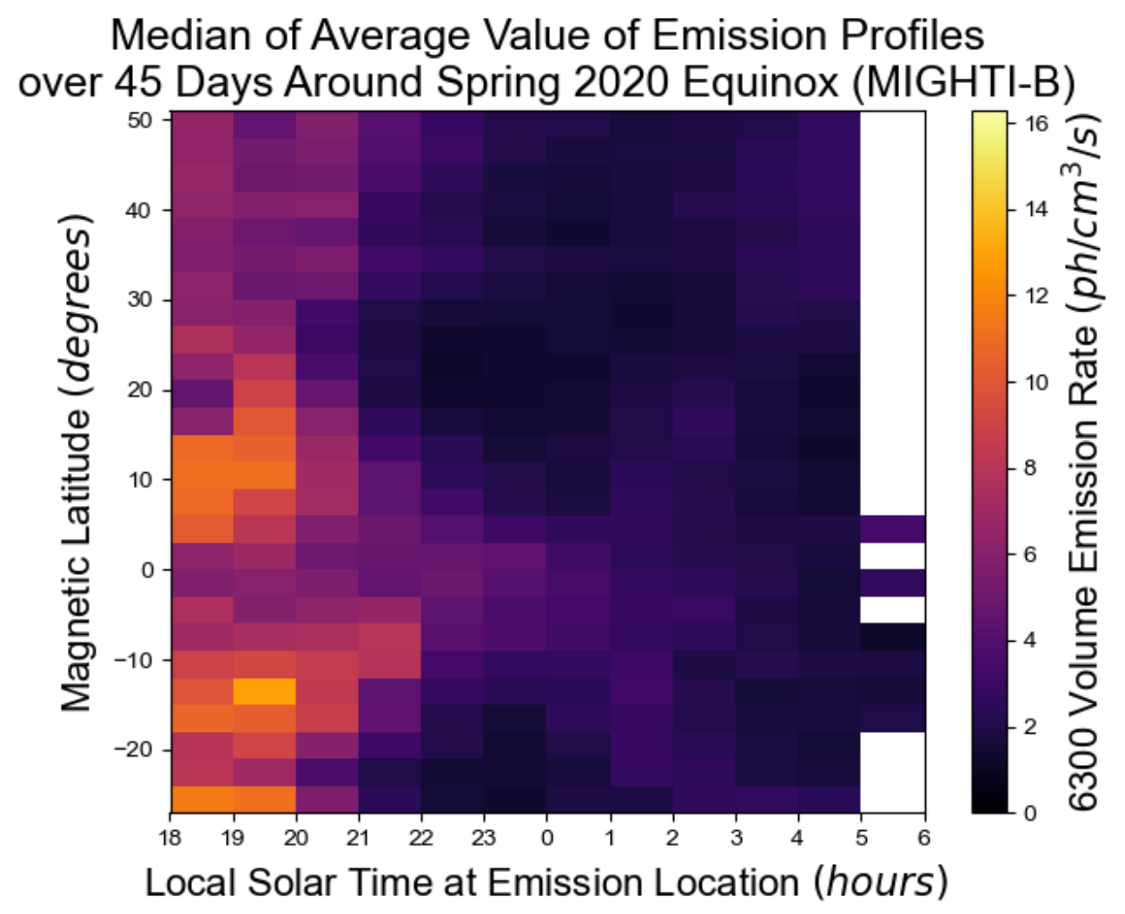


Methodology

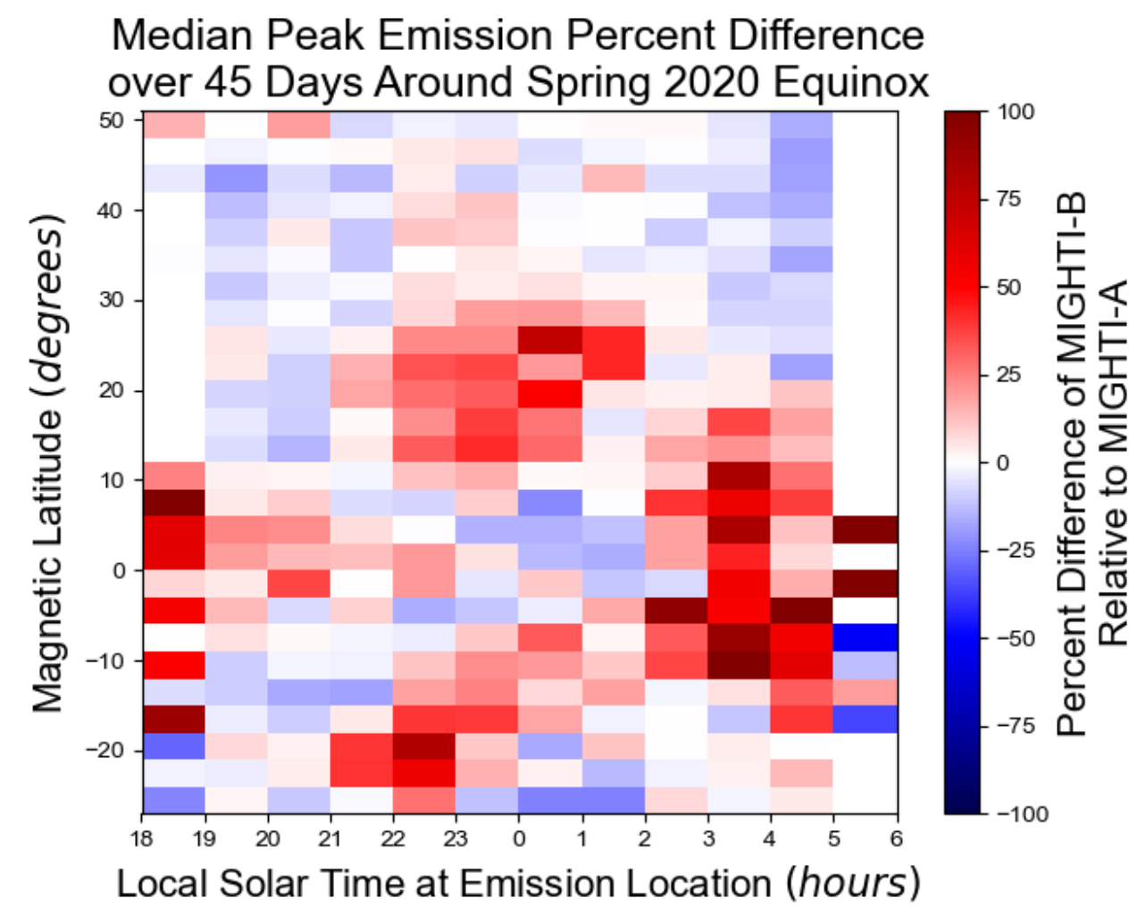


Detecting ionospheric structuring using MIGHTI is possible because the two interferometers, MIGHTI-A and MIGHTI-B, are mounted orthogonal to each other. As ICON orbits, MIGHTI-A measures airglow at a given location, then MIGHTI-B views that same location a short time after from a different angle. Differences in measured brightness between MIGHTI-A and MIGHTI-B can indicate structuring in that area.

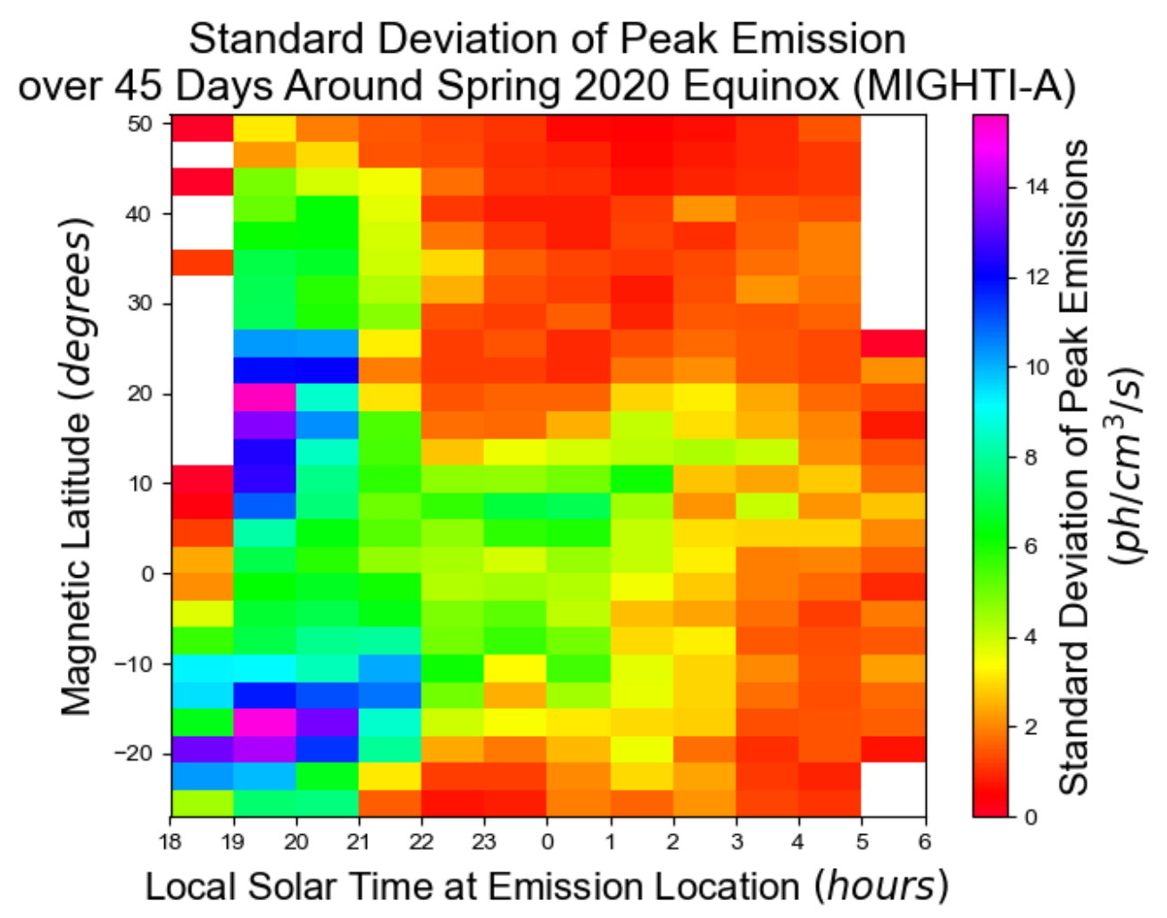


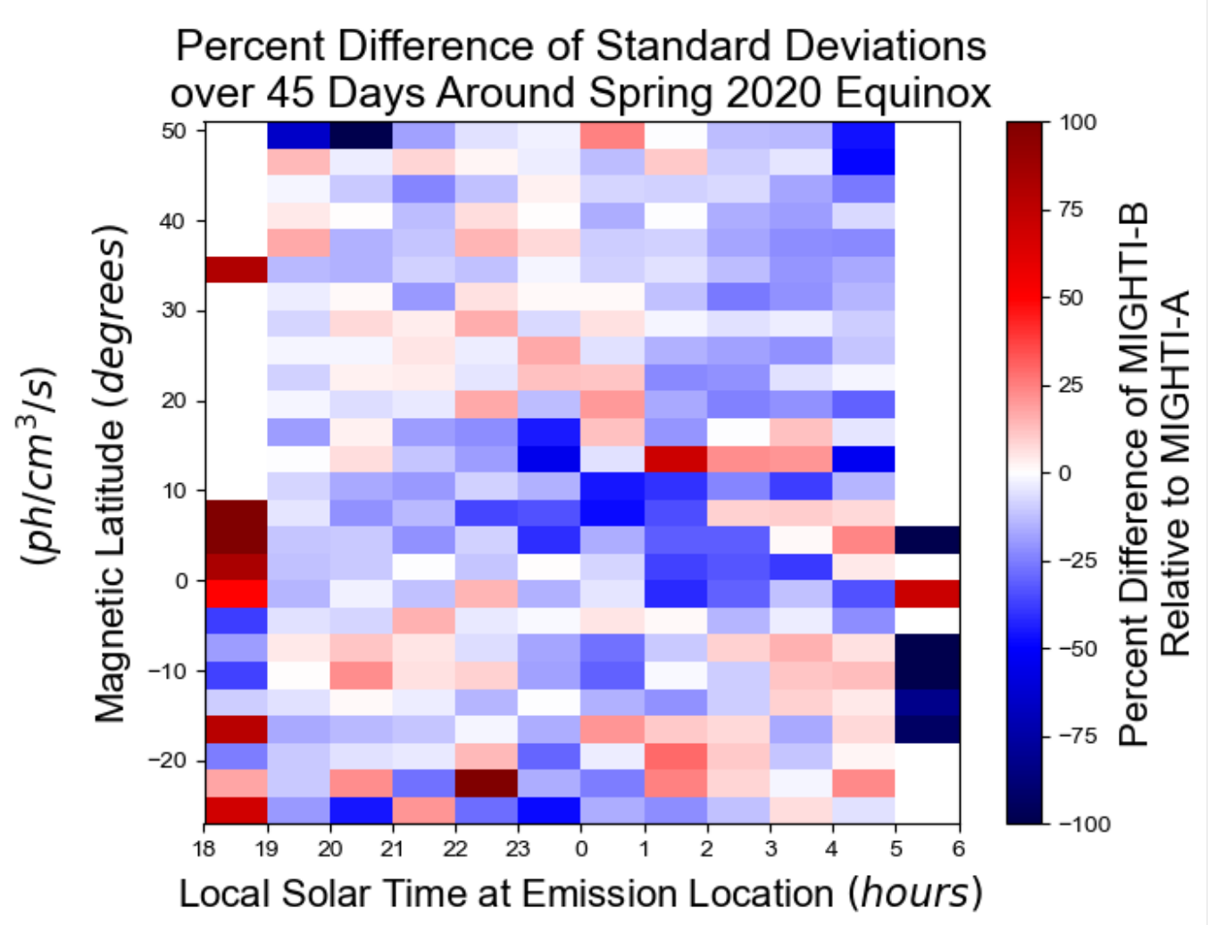


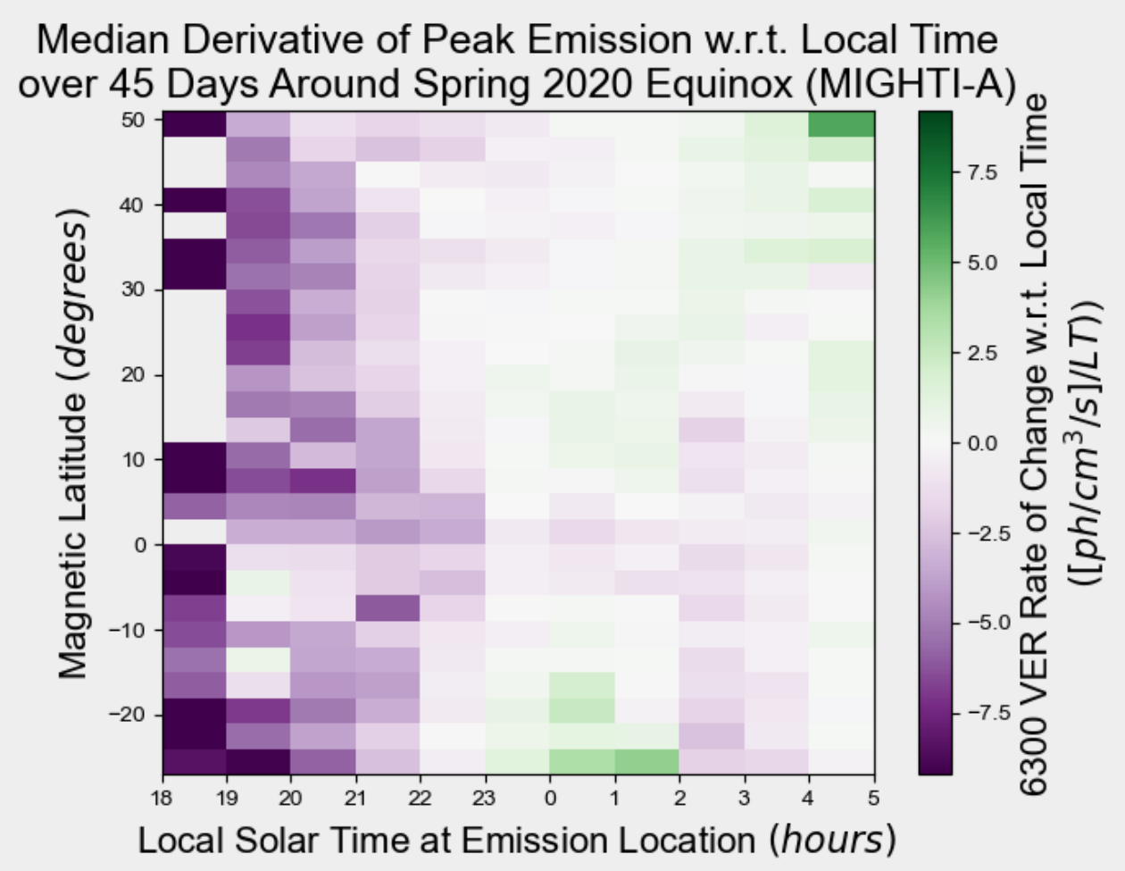
As MIGHTI-A and MIGHTI-B are not cross-calibrated for absolute brightness, systemic differences between them must be characterized before their data can be compared. We do this by studying their observations around the spring 2020 equinox to see how they differ depending on magnetic latitude and local time.

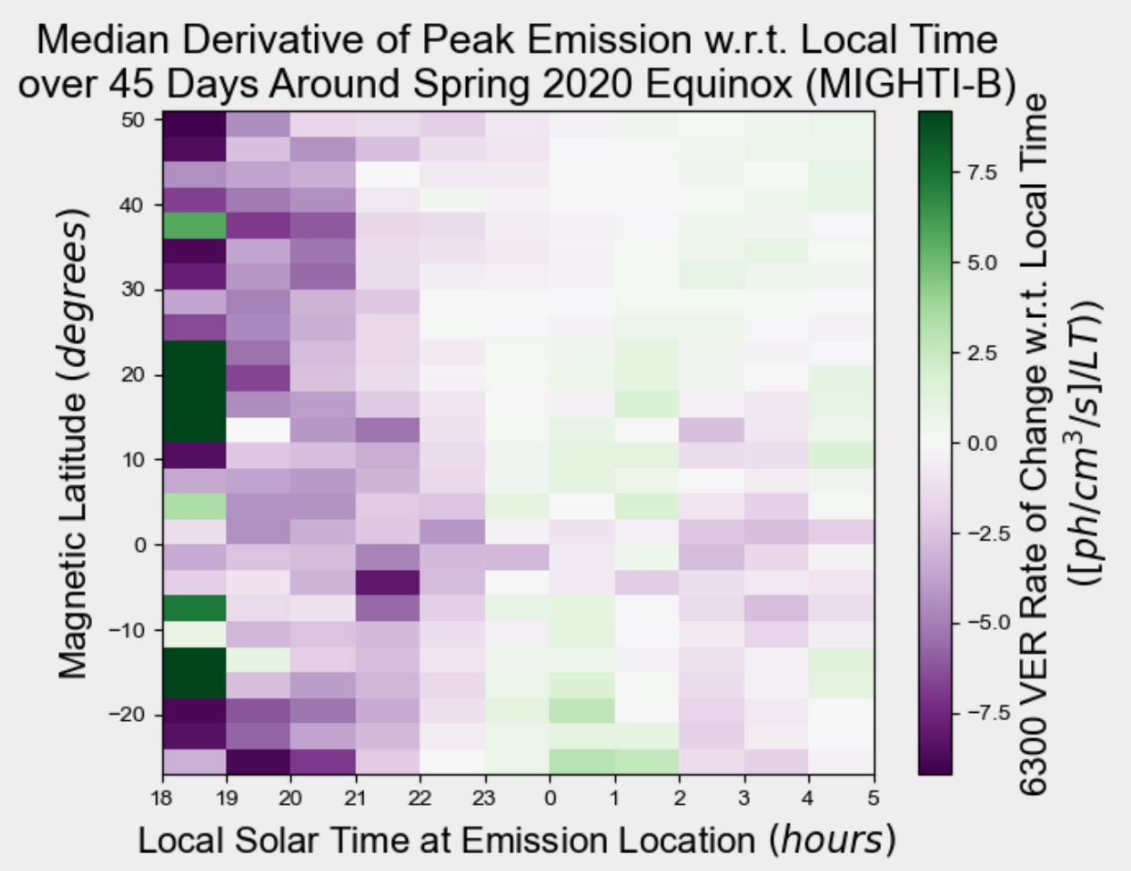


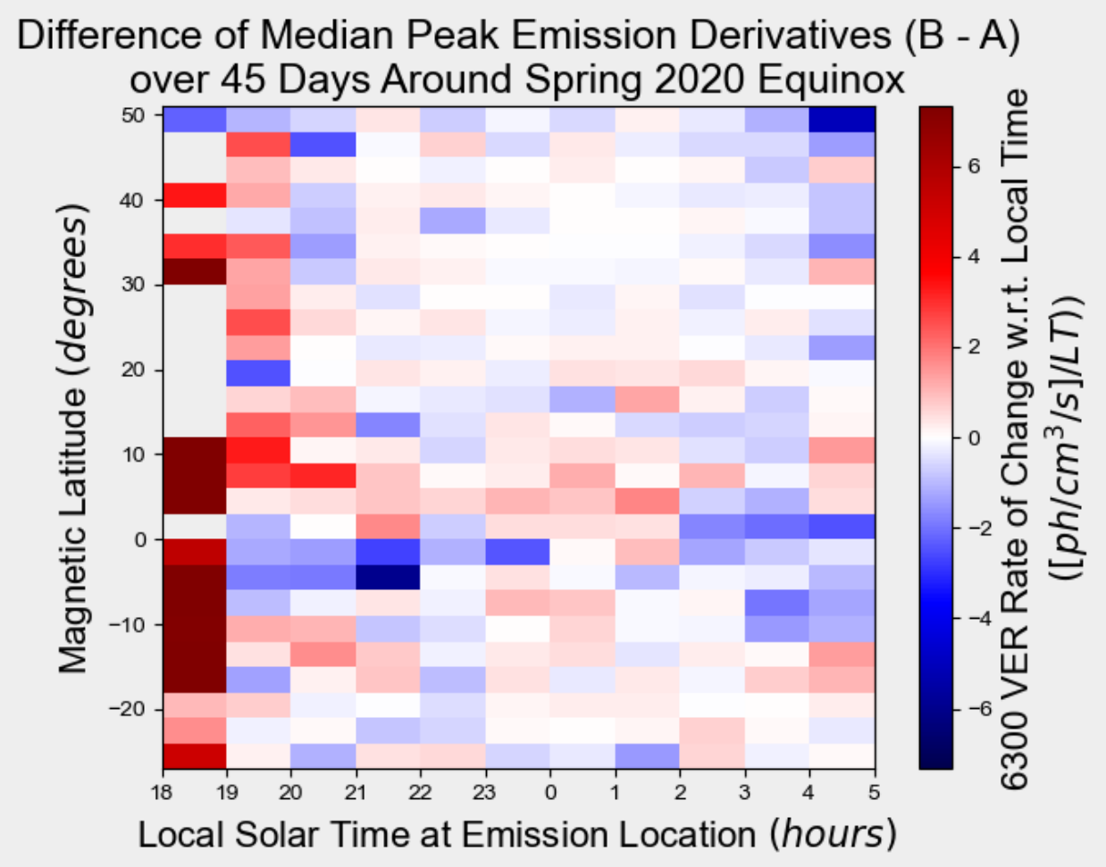
At local times in early evening and near the magnetic equator later in the night, observations from MIGHTI-B are around or less than 25% below A measurements. However, B tends to observe more 6300 emission relative to A between the bands of the EIA and at locations with very little to no emission. Interestingly, observations of peak emission from B consistently have smaller variations in brightness than does A.

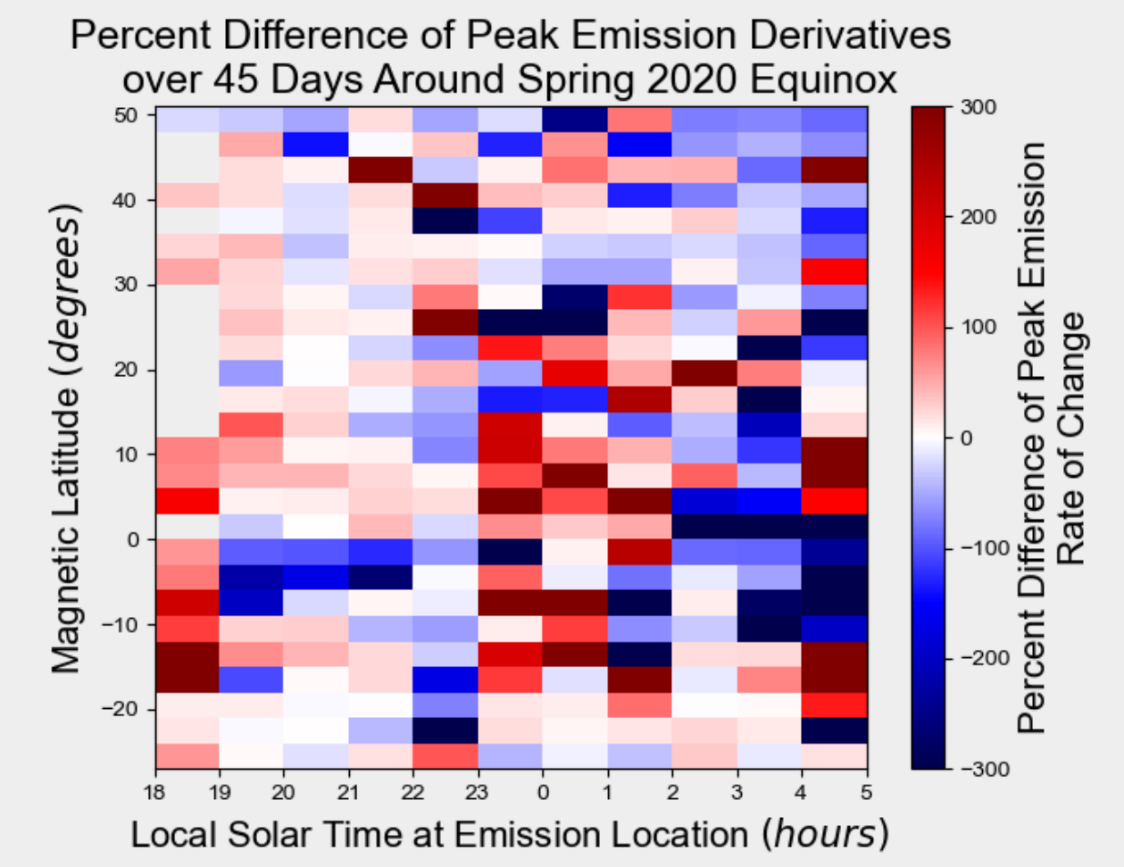












How the peak emission brightness varies with local time between A and B as ICON orbits can also be a useful indicator of how closely A and B align. In areas of low emission and little change in emission with local time, B varies relative to A in small amounts seemingly randomly. However, in brighter areas around the EIA away from the magnetic equator, B often appears to dim between 0% to 50% slower than A.

These observations suggest MIGHTI-B may be slightly less sensitive than MIGHTI-A when observing brighter airglow and more sensitive to noise in dark conditions, as MIGHTI-B has lower variance and dims slower in areas of brighter airglow.

Future Work

Future work will include implementing a correction for these differences to account for the systemic differences between MIGHTI-A and MIGHTI-B and bring MIGHTI-B closer into alignment with MIGHTI-A. This correction can then be used on a per-orbit basis to identify areas where MIGHTI-A and MIGHTI-B continue to significantly disagree, which may point to ionospheric structuring in that area. Alongside estimates of the thermosphere, a relative difference in observed electron density between the two measurement orientations can be determined.

References

Englert C. R., et. al., "Michelson Interferometer for Global High-Resolution Thermospheric Imaging (MIGHTI): Instrument Design and Calibration," https://doi.org/10.1007/s11214-017-0358-4.

Link R., Cogger L. L., "A Reexamination of the O I 6300-Å Nightglow," https://doi.org/10.1029/JA093iA09p09883.