Vertical Variations in O/N2 Using SSULI Tomographic Reconstructions during 2015 St. Patrick's Day Storm

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INTRODUCTION

In this study, we investigate **altitude-dependent variations in thermospheric composition** during the **2015 St. Patrick's Day Storm** using limb observations from the Special Sensor Ultraviolet Limb Imager (SSULI) onboard Defense Meteorological Satellite Program (DMSP) satellites. We utilize **tomographic reconstructions** of SSULI **OI 135.6 nm and N2 Lyman–Birge–Hopfield (LBH)** measurements to construct vertical profiles (100-500 km) of **volume emission rates (VER)**.

Storm-induced **vertical variation** in O/N_2 and its dependence on O and N_2 perturbations are still not fully understood. These vertical variations are important to study because thermospheric circulation can change considerably during storms, resulting in **discrepancies in composition at different altitudes** (Yu et al. 2003).

Science Question:

How do geomagnetic storms modify thermospheric composition as a function of altitude, and what information is missed by traditional column-integrated measurements?

ST PATRICK'S DAY STORM 2015

- Strongest storm of solar cycle 24
- Occurred on March 17, 2015, commencing at around 14:00 UT

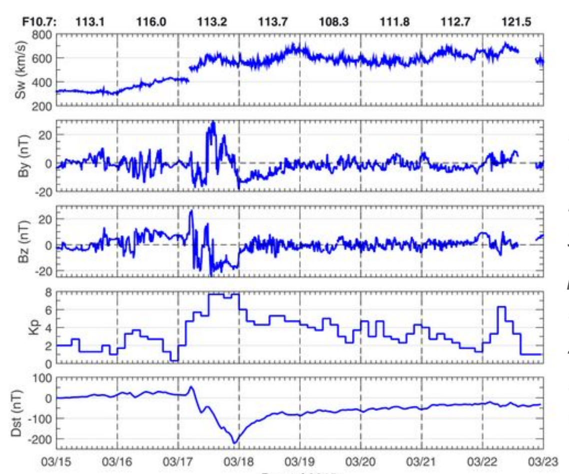


Fig.1: Geophysical indices and solar wind parameters March 15-23, 2015 From Zhong et al. 2016

O/N_2:
In Fig. 2, GUVI (Global UltraViolet Imager) O/N_2 observations show a **depletion in ΣO/N2 at high latitudes** and an **enhancement at low latitudes/equatorial regions** during this storm (Astafyeva et al. 2015).

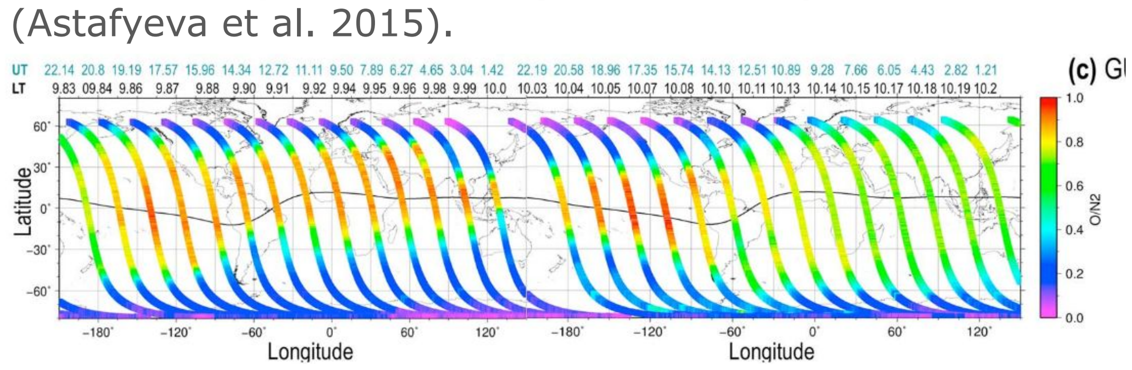


Fig. 2: GUVI O/N2 observed on March 17 and 18, 2015, local morning sector (9.8–10.2 LT), time goes from right to left From Astafyeva et al. 2015

TEC:
GPS TEC measurements indicate that there was **significant ionospheric uplift** or the occurrence of an **additional F3 layer** (Astafyeva et al. 2015). During the storm main phase and at the beginning of the recovery phase, **topside TEC patterns were different** from those seen from lower orbital altitudes (Zhong et al. 2016).

Storm time behavior of the topside ionosphere is impacted by altitude-dependent physical processes.

DATASETS

DMSP-F19 Orbit: polar dawn-dusk sun-synchronous (6 AM/6 PM), 840 km altitude

SSULI:
- Measures vertical profiles of airglow through scans of the Earth's limb from ~100-750 km
- Wavelength range: 80 nm to 170 nm, 1.8 nm resolution
- Scans forward into the orbit path

SSUSI (Special Sensor Ultraviolet Spectrograph Imager):
- Collects subsatellite airglow measurements through cross-track scans of Earth's disk
- 160 spectral channels

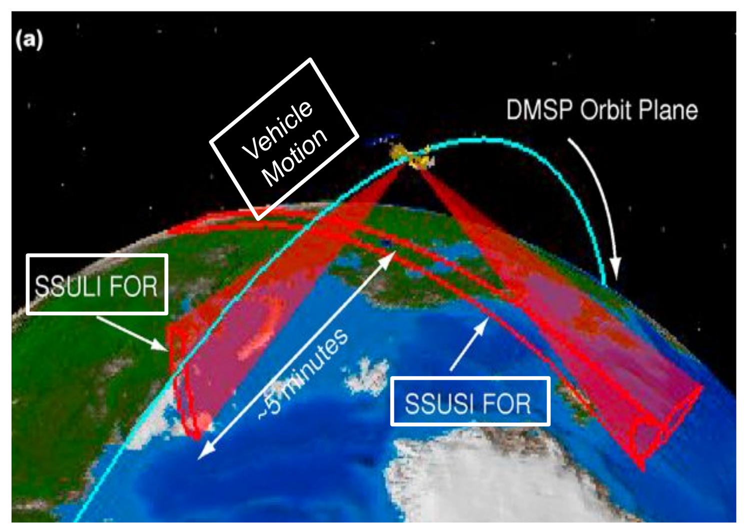


Fig. 3: DMSP viewing geometry and Field of Regard (FOR) for both SSUSI and SSULI Modified from Hei et al. 2017

TOMOGRAPHY

Tomography: technique to construct a 3D or a 2D-slice of a 3D object using multiple measurements at different viewing angles.

Dymond et al. 2017 and Hei et al. 2017 used SSULI tomography to reconstruct Volume Emission Rate (VER) along SSULI's orbit path.

- Good agreement with incoherent scatter radar data
- Robust enough to capture day to day variability of the ionosphere as well as auroral structure

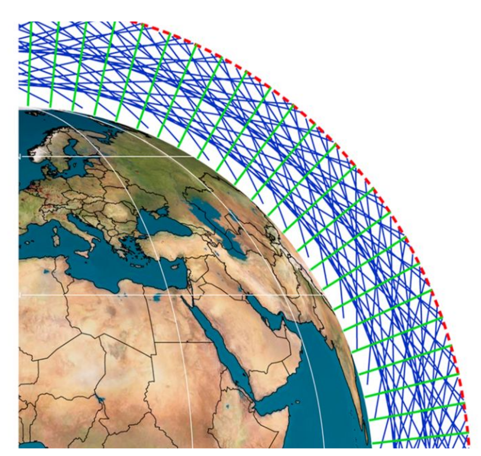


Fig. 4: SSULI lines of sight are called out in blue, SSUSI lines of sight are indicated in green From Hei et al. 2017

A Typical SSULI Tomographic Orbit Reconstruction

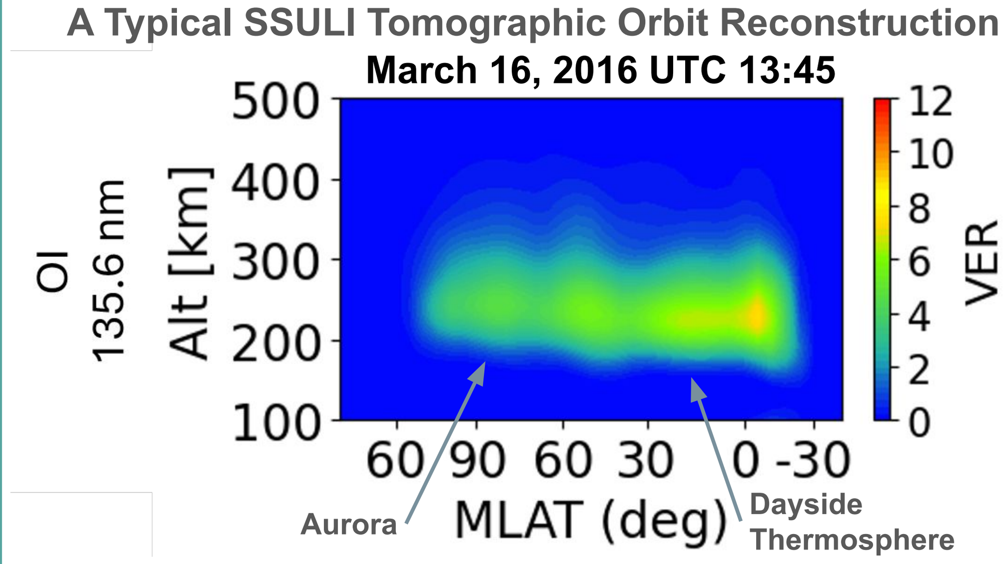


Fig. 5: A typical single SSULI orbit tomographic reconstruction in 135.6 nm VER. 5 degree bins (360 degrees along entire orbit) and 10 km bins from 100-500 km altitude were used as gridding. Southern hemisphere data is not available.

RESULTS/DISCUSSION

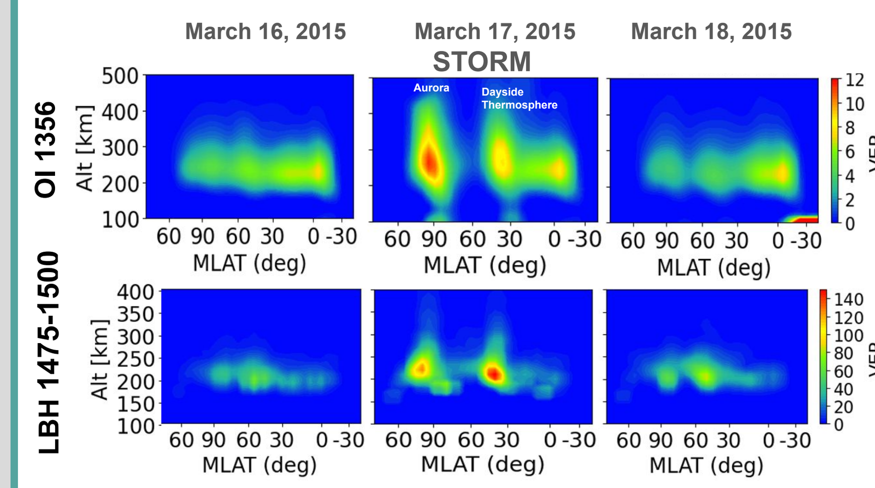


Fig. 6: 135.6 nm and LBH VER SSULI orbit reconstructions March 16-18, 2015

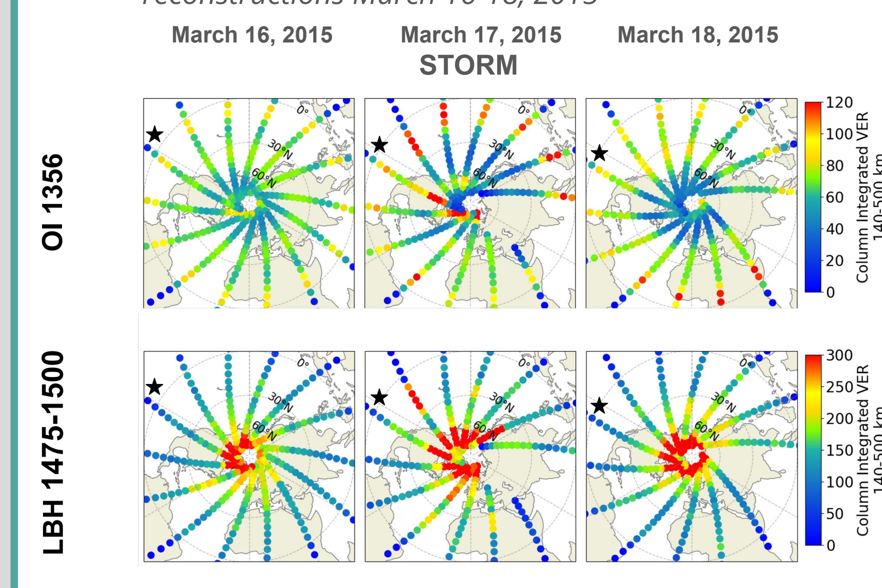


Fig. 7: Multiple SSULI orbit reconstructions for March 16-18, 2015, 6 AM side of orbit. The black star corresponds to the orbits shown in Fig. 6

Fig. 6:
- 135.6 nm VER extends into higher altitudes (~500 km) as well as into lower altitudes (100 km)
- LBH VER also extends to higher altitudes (~350 km)

Fig. 8 shows the evolution of the 135.6 and LBH VER on the day of the storm. We can see the orbit-to-orbit change in vertical structure.

Fig. 7:
- Overall depletion in 135.6 VER at the polar regions
- Enhanced LBH signal at the pole on the day of the storm

Fig. 9:
- Depletion in 135.6 VER persists for many days after the storm
- LBH VER recovers quickly

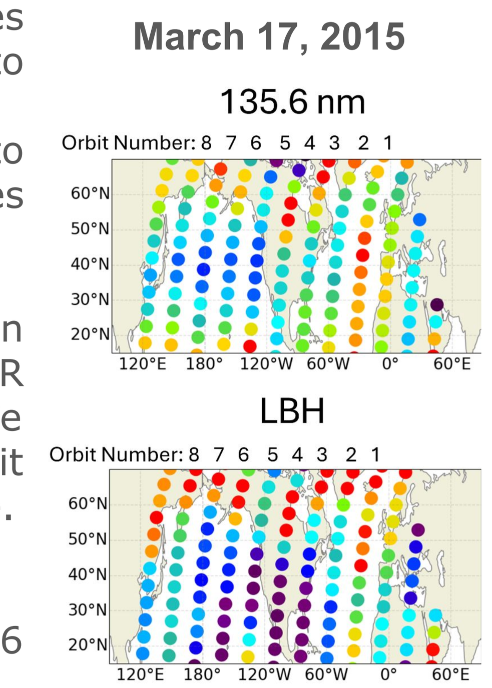
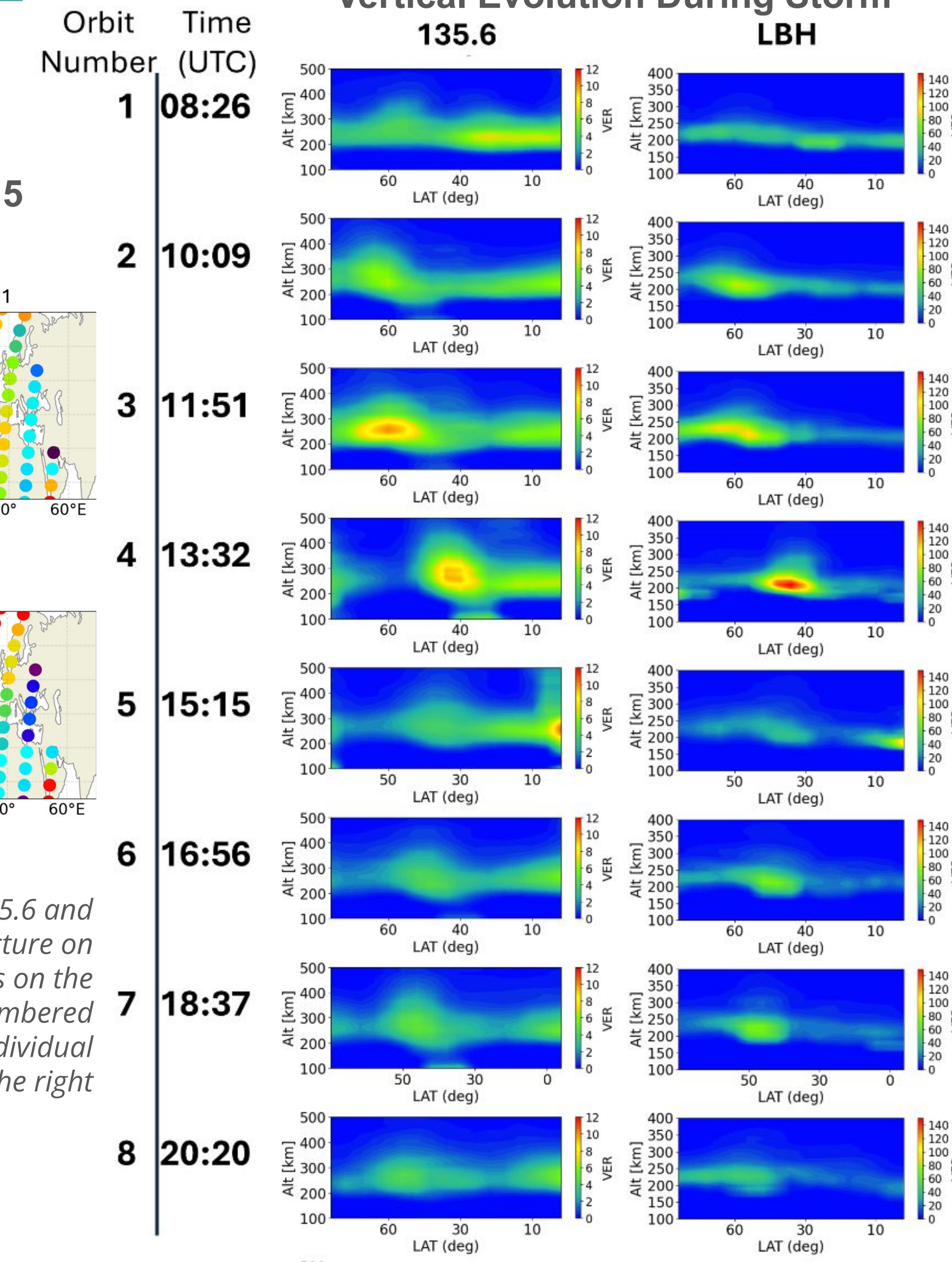


Fig. 8: Evolution of 135.6 and LBH vertical structure on March 17, 2015. Orbits on the left are numbered corresponding to individual altitude plots on the right

Vertical Evolution During Storm



In Fig. 10, we compare our SSULI tomographic reconstructions to radiance measurements from SSUSI. SSUSI reproduces the large-scale horizontal depletion patterns observed by SSULI, but cannot resolve the strong altitude-dependent changes evident in the vertical profiles. We use the ratio of OI 135.6 nm to LBH emissions as a proxy for thermospheric O/N_2 composition. Both SSUSI and SSULI 135.6/LBH plots agree well with GUVI ΣO/N observations of a high latitude depletion (Fig. 2). Generally, storm-time depletions in ΣO/N2 are attributed to upwelling of N_2-rich air to higher altitudes. However, the simultaneous changes in both OI and LBH vertical structure at different altitudes, latitudes, and time scales indicate that there are likely additional processes occurring as well. Future work will focus on understanding the contribution of competing production/loss mechanisms for 135.6 and LBH emissions during geomagnetic storms.

SSUSI vs SSULI Comparisons

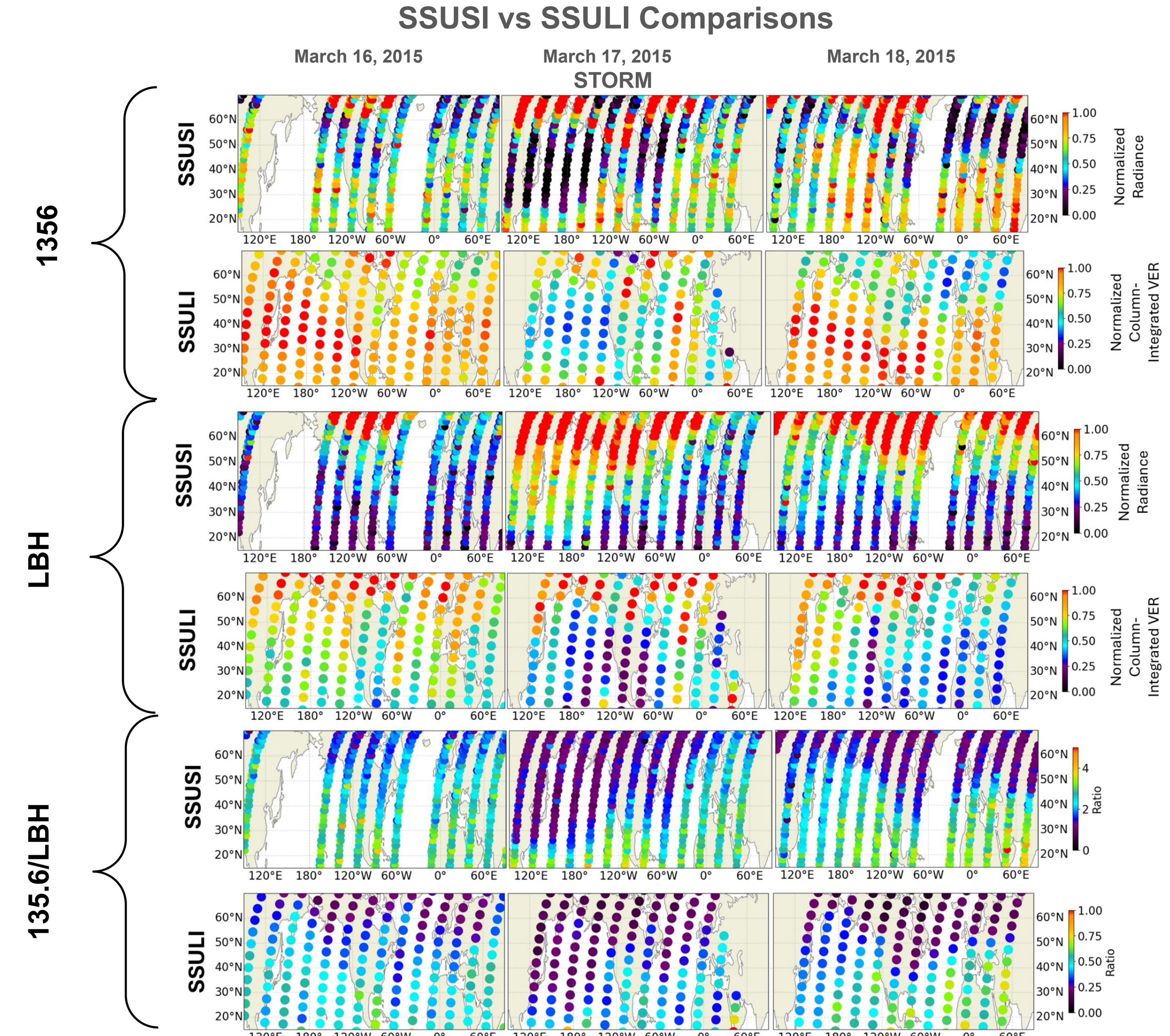


Fig. 10: Comparisons of SSUSI radiance measurements and SSULI column-integrated tomographically reconstructed VER (140-500 km)

Time Series of Average VER

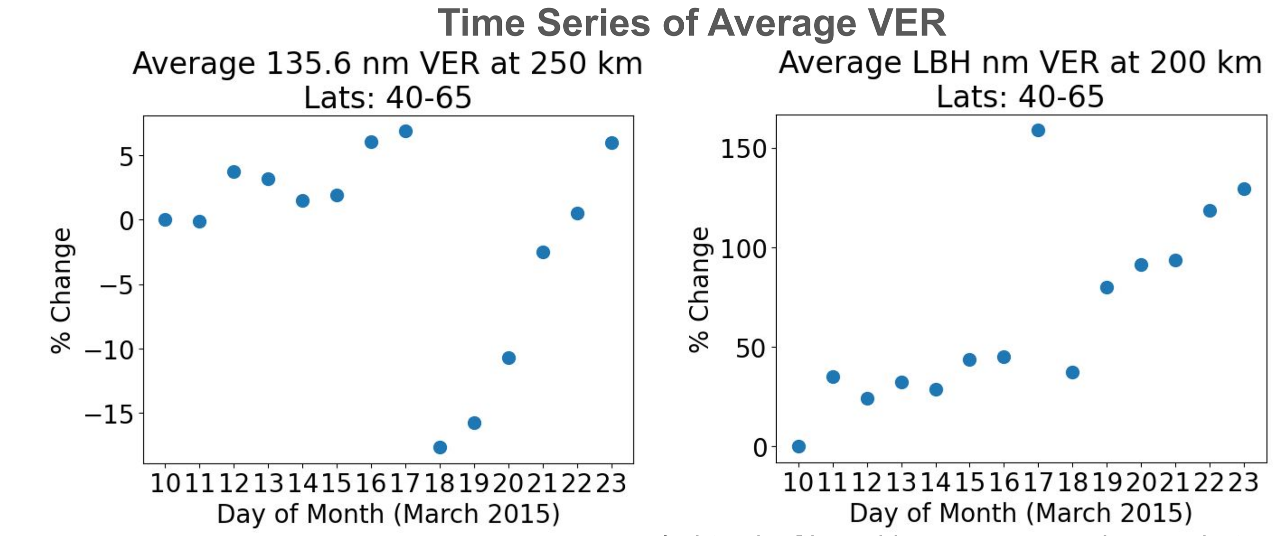


Fig. 9: Average VER values taken for a specified altitude, filtered between 40-65 degrees latitude

Conclusions:

- SSULI tomographic reconstructions reveal **significant altitude-dependent changes** in thermospheric composition during the 2015 St. Patrick's Day storm that are not apparent in traditional column-integrated observations.
- The response of storm-time 135.6 nm and LBH emissions differs in both **altitude and latitude** and occur on **different timescales**. This substantial restructuring of thermosphere composition is likely caused by competing factors such as wind or electric field driven changes in vertical transport, enhanced auroral zone temperature driven upwelling, etc.
- Comparisons with SSUSI and GUVI demonstrate that SSULI provides consistent large-scale storm signatures while adding **unique vertical information**.
- These results demonstrate that **geomagnetic storm impacts cannot be fully characterized using column-integrated measurements alone**.

Acknowledgement:
This research was supported by NASA's Heliophysics H-FORT program (award 80NSSC22M0105).

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References