Real-Time Operational Measurements of the Thermospheric State: Recent Advances and Future Possibilities

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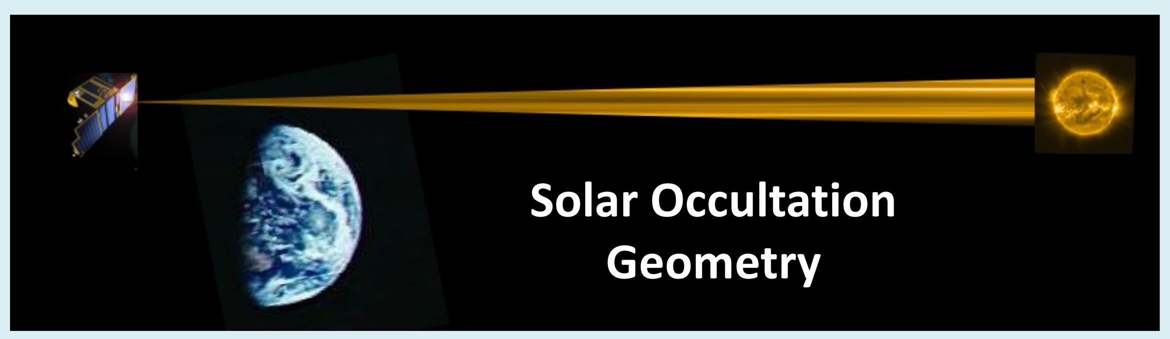
Summary

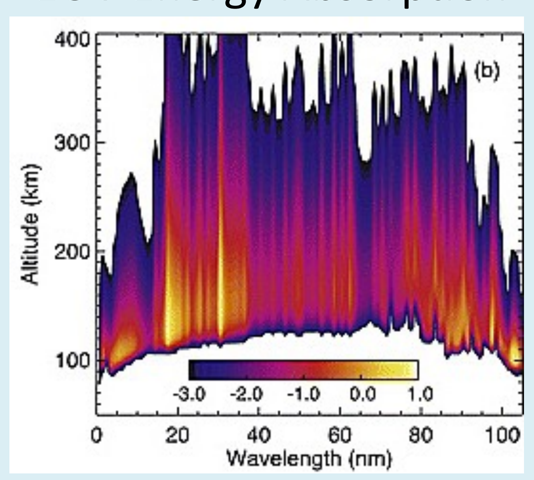
The Earth's thermosphere is the neutral region of the upper atmosphere and plays a critical role in the Earth's response to space weather, including creating satellite drag, and influencing ion lifetimes and ionospheric density. Despite its crucial role in space weather, there are presently no direct measurements of the thermospheric state for space weather operations. Today, the thermospheric state can only be estimated by driving numerical models with known space weather drivers, or by assimilating spatiotemporally averaged satellite drag data into upper atmosphere models.

This is soon to change with the arrival of real-time operational measurements of thermospheric density between 150 and 350 km from solar occultations measured by the SUVI solar telescope on-board the latest-generation GOES-R series satellites. These thermospheric data are currently undergoing validation, with an anticipated public release time-frame of mid-2023. The question then becomes: ***What will the space weather community do with these data and how will their availability change fore- and now-casting of space weather in the ionosphere and thermosphere?***

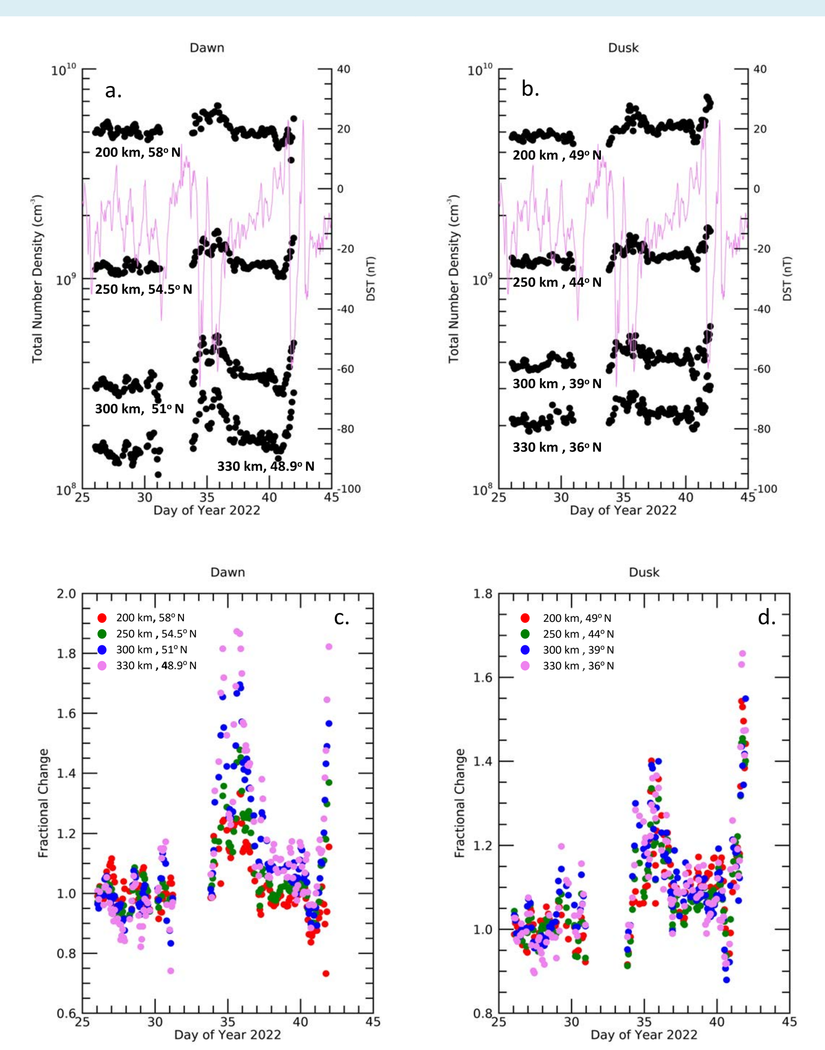
EUV Solar Occultations



EUV Energy Absorption



Breaking Ground with LYRA

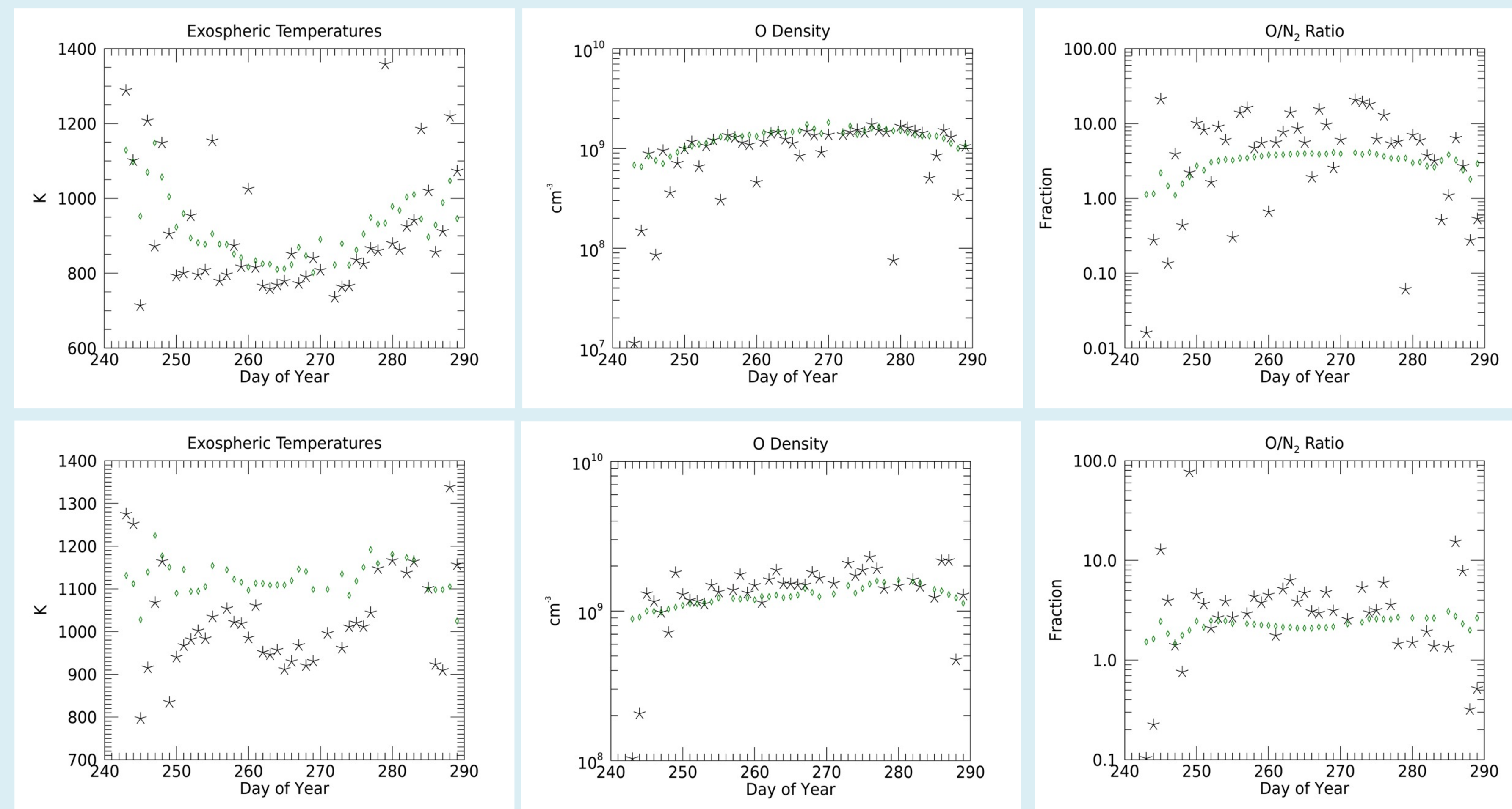


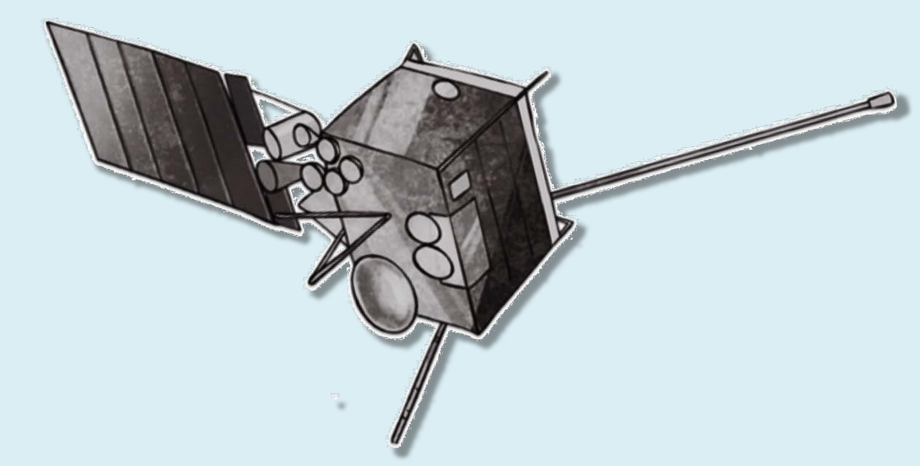
- Large Yield Radiometer (LYRA)
- Onboard ESA PROBA2 Satellite
- 2010 through present
- Primary science: Irradiance
- Secondary science: Neutral Density (150-350 km)
- Measures total number density ($O+N_2$) using Zr (10-20 nm) channel
    - November- Late February
    - mid/high latitudes
- 30 Measurements/Day
    - 15 dawn, 15 dusk
- Irradiance downlinked < 4 hours
- No operational density processing

Left: LYRA density measurements during a geomagnetic storm in February 2022 that resulted in the loss of dozens of Starlink satellites.

Realtime Data from SUVI

Below: Measurements from Fall 2022, @ 250 km. Top row is Dawn, bottom row is Dusk. MSIS values shown with green diamonds showing agreement with SUVI data but real thermosphere much more variable than MSIS climatology.





- Solar Ultraviolet Imager (SUVI)
- Onboard GOES 15, 16, 17, 18 (not yet launched)
- 2016 through at least 2035
- Primary Science: Solar corona imagery
- Secondary Science: Neutral density, composition, temperature (200-350 km)
- Uses 17.1, 19.5, 28.4, 30.4 nm channels as available
- 2 Measurements/day
    - 1 dawn, 1 dusk
- Downlinked in real time
- Operational pipeline (NCEI) under-test Spring 2023

New Prospects for Space Weather Modeling

The most accurate predictive upper atmospheric models rely on data assimilation. For the neutral atmosphere, this is currently done using measured trajectory information of a set of target satellites.

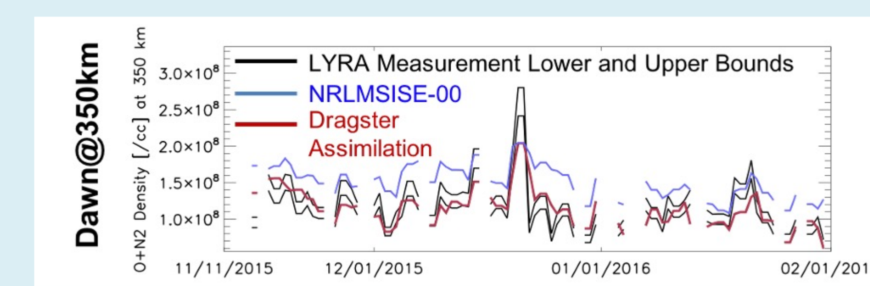
Drawbacks of current approach include:

- Latency--Days of data need to be fitted for density estimates.
- Altitude coverage—Few targets below 250-300 km.
- No composition—critical for forecasting the ionosphere.

How should new real time thermospheric data be used?

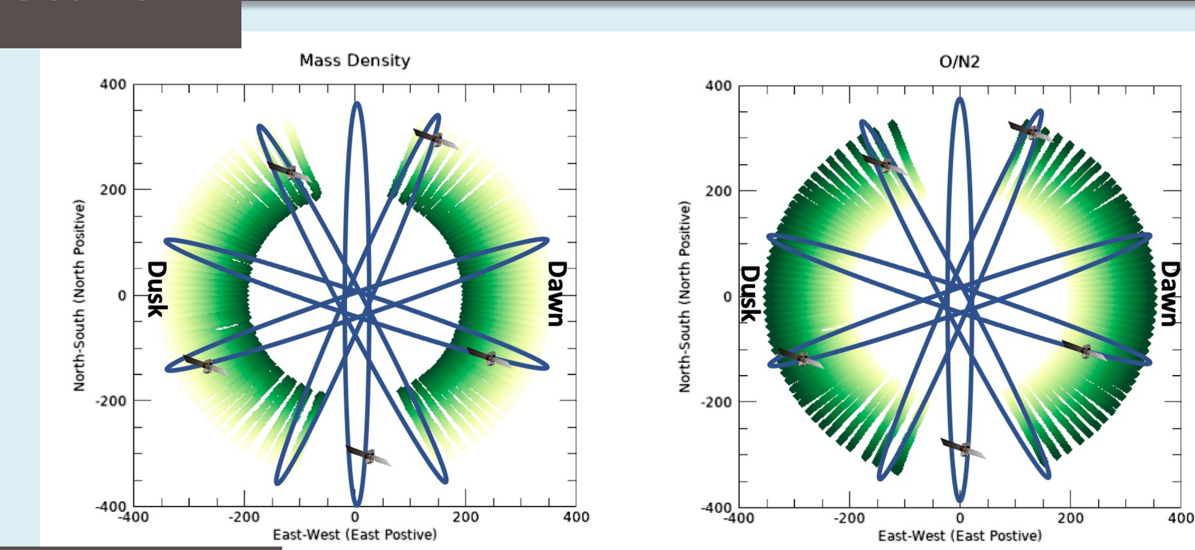
- SUVI occultations will provide real-time knowledge of ongoing space weather events.
- Composition and temperature should improve physics-based model assimilation improving both neutral and ionosphere forecasting.

Right: Dragster trajectory-based assimilative model agrees better with LYRA than MSIS climatology. Next step and current work is to assimilate occultation data itself into Dragster.

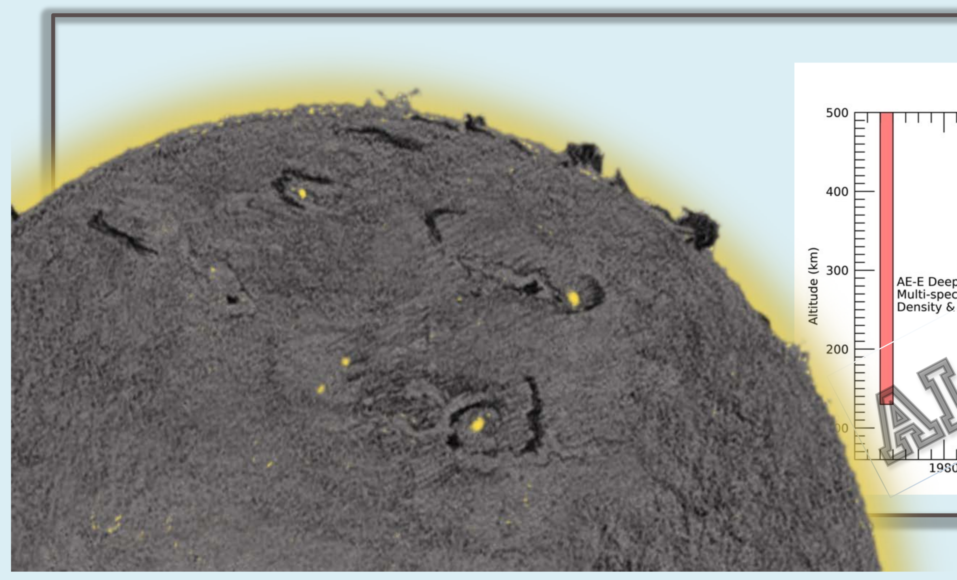


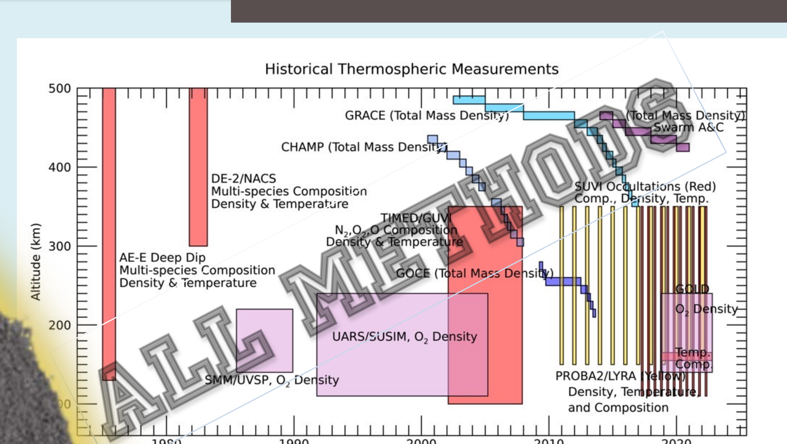
A Future Constellation for Operations and Research

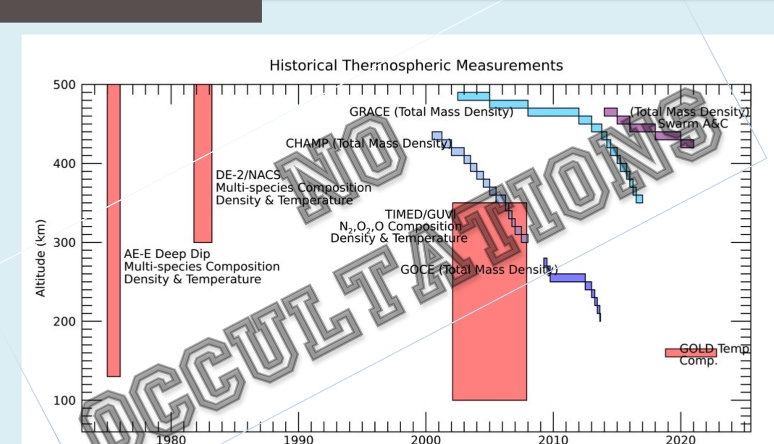
- SUVI was chosen for operational solar occultations primarily because its images are already used for space weather operations. Its primary drawbacks are observing cadence (2 measurements/day available for ~14 weeks/year)
- SUVI data at right requires 6 weeks to scan all latitudes.
- A constellation of 5 satellites in LEO (indicated with ellipses) could measure indicated latitudes every ~100 minutes.
- LYRA technology scalable to ~1/4 U size making it suitable for smaller CubeSats



Why Occultations?







Measurement methods:

- In-situ
- Airglow (remote)
- Occultations (remote)
- Much of the data record from occultations (mostly solar) due to platform longevity, high SNR and self-calibrating nature.

Acknowledgements

- This work is funded by NASA Space Weather Operations to Research (SWO2R) Grant 80NSSC21K0028
- Pilinski, M et al. (2019, September). Dragster: An Assimilative Tool for Satellite Drag Specification. In Advanced Maui Optical and Space Surveillance Technologies Conference (p. 70).
- Thiemann, E. M. B., et al. "Vertical thermospheric density profiles from EUV solar Occultations made by PROBA2 LYRA for solar cycle 24." Space Weather 15.12 (2017): 1649-1660.
- Solomon, Stanley C., and Liying Qian. "Solar extreme-ultraviolet irradiance for general circulation models." Journal of Geophysical Research: Space Physics 110.A10 (2005).