Ionosphere-Thermosphere Response to High-Speed Solar Streams Observed during 2018-2019 and Potential Impacts on Mars' Upper Thermosphere

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Session 10

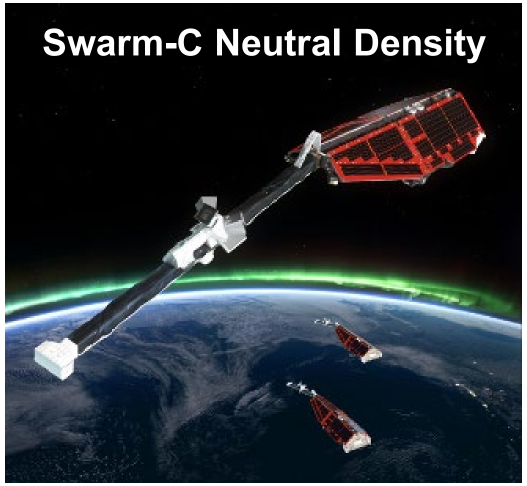
WG2 Focused Topic - Impacts of HSS to Planetary Systems

Thursday, 16 September 2021

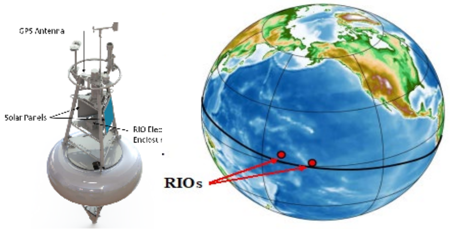
Outline

1. Data and Model
   - Swarm, RIO, MAVEN, and WACCM-X
2. High-Speed Streams during WHPI Campaign
   - Effects on the Terrestrial Ionosphere-Thermosphere
   - Possible Impacts on Mars' Upper Thermosphere
3. Solar Rotation Variation
   - Effects on the Whole Martian Thermosphere

1. Data and Model
Swarm, RIO, MAVEN, and WACCM-X

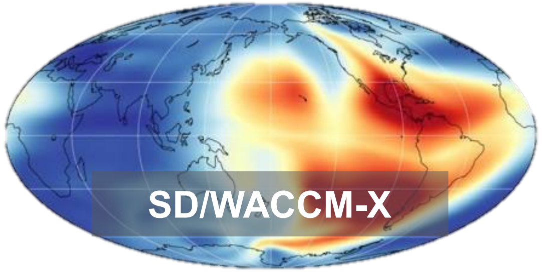


- ❖ Mission launched on 22 November 2013 from the European Space Agency to study the dynamics of the Earth's magnetic field and its interaction with the Earth's system
- ❖ This mission consists of three identical satellites in near-polar low Earth orbits (LEO). The two satellites, Swarm A and C, fly almost side-by-side at an initial altitude of 460 km while the third Swarm satellite B flies in a higher orbit of about 530 km
- ❖ All the three satellites are equipped with a set of six core instruments. Neutral (total mass) densities are inferred by measurements taken by the onboard Accelerometer (ACC) and GPS Receiver (GPSR)



❖Remote Ionospheric Observatory (RIO)-12 and RIO-15 are low-power GPS receivers deployed on NOAA's Tropical Atmosphere Ocean (TAO) buoys in the Pacific Ocean near the geographic equator in Aug. 2018

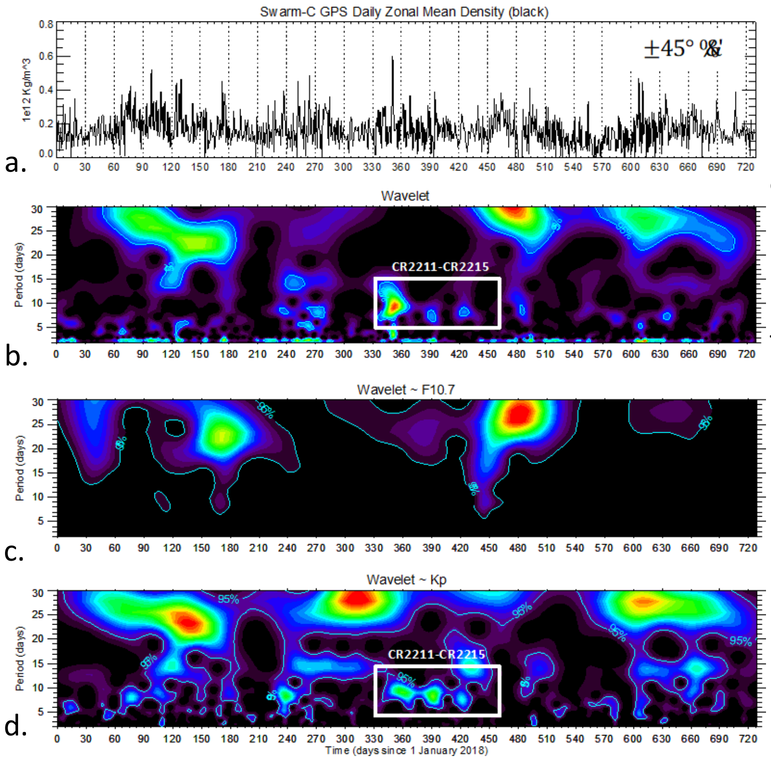
❖Each RIO system consists of a GPS receiver and operates autonomously

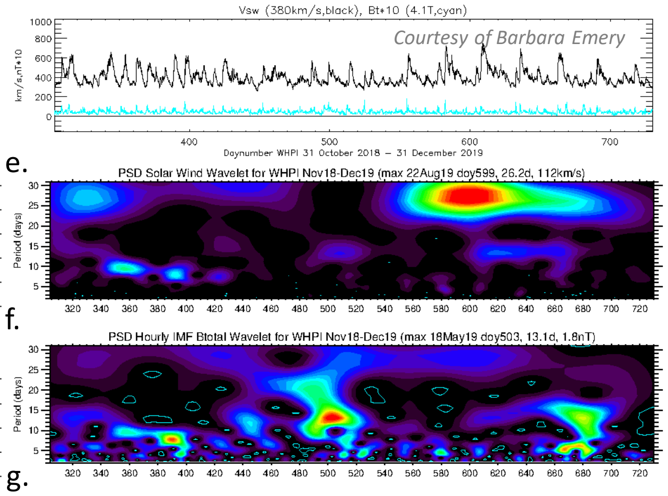


- ❖ The Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) is a comprehensive numerical model
- ❖ We employ Specified Dynamics (FXSD) simulations with solar/magnetic forcing by F10.7/Kp and Heelis forcing

- ❖ Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiting Mars since 22 Sept 2014
- ❖ We utilize EUVM irradiances, SWEA electron counts, NGIMS mass densities

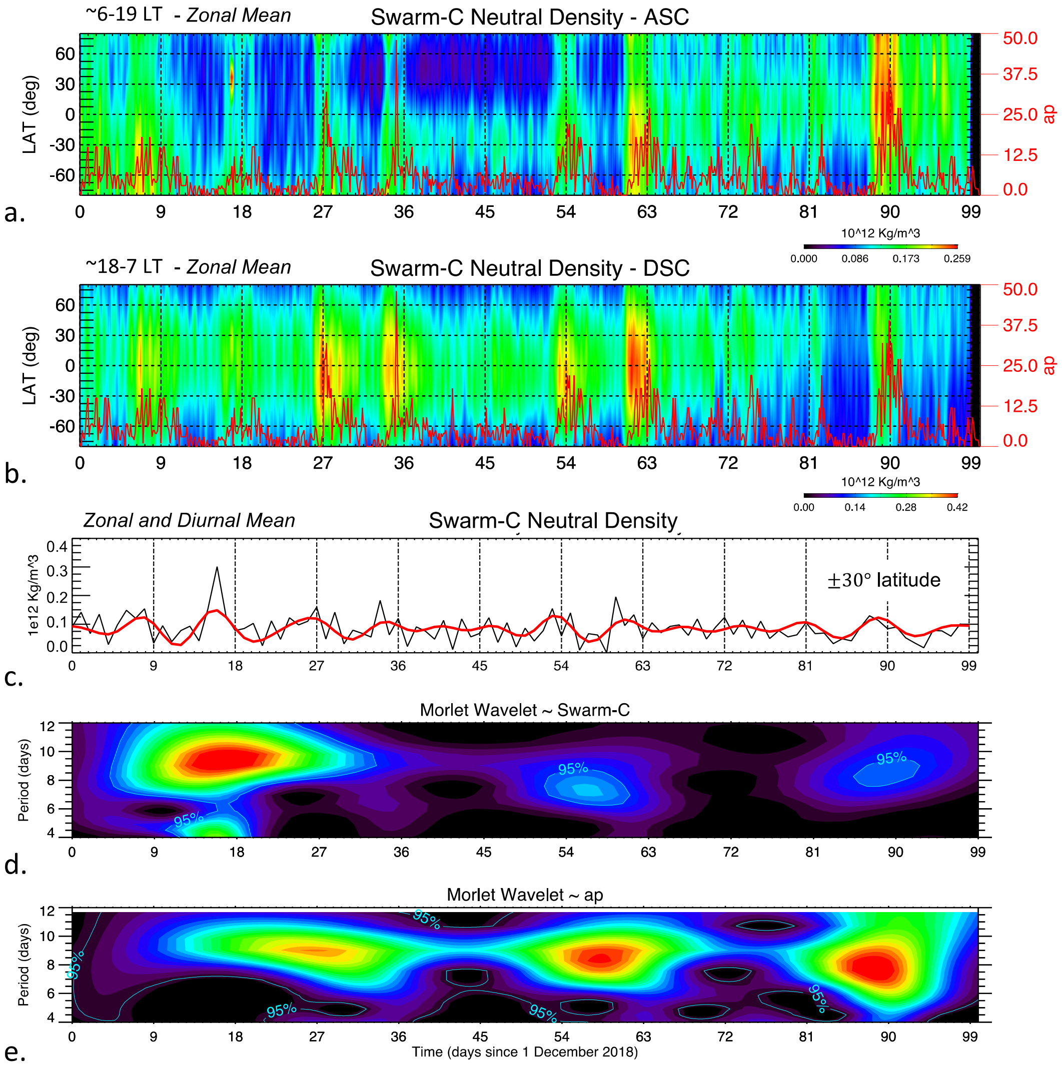
2a. High Speed Stream during 2018-2019
Swarm-C total mass density analyses



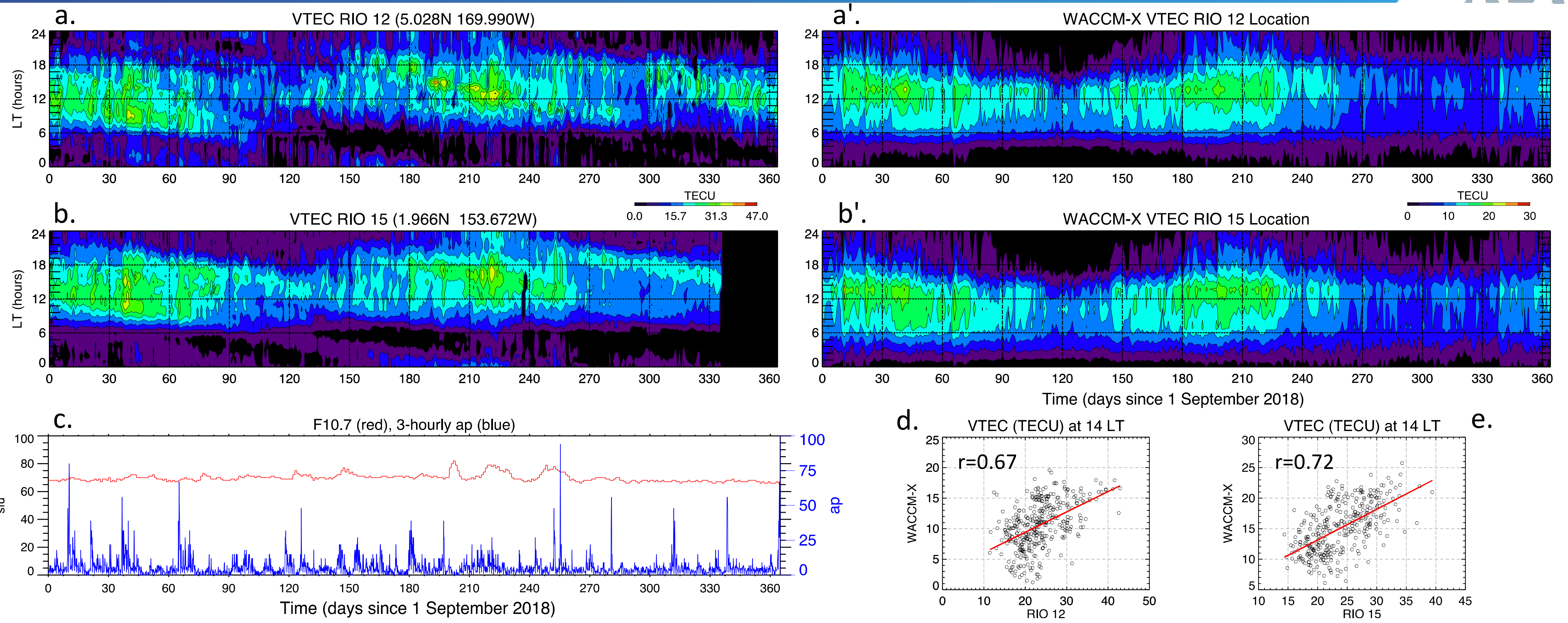


LEFT: *(a) Time series of Swarm-C zonal/diurnal mean mass density av. ±45° latitude during 2018-2019; (b) Morlet wavelet of (a); (c)-(d) wavelets of F10.7 and Kp. (e) Time series of solar wind speed and B_{tot}, and (f)-(g) their wavelets.*

RIGHT: *Latitude-time contours of Swarm-C neutral density from the ascending (a) and descending (b) nodes. Red line in (a) and (b) is ap. (c) Time series of daily zonal mean density near ±30° lat. before (black line) and after (red line) applying an 8 to 10-day band-pass-filter. (d) Morlet wavelet of the daily zonal mean density in (c), and (e) of ap.*

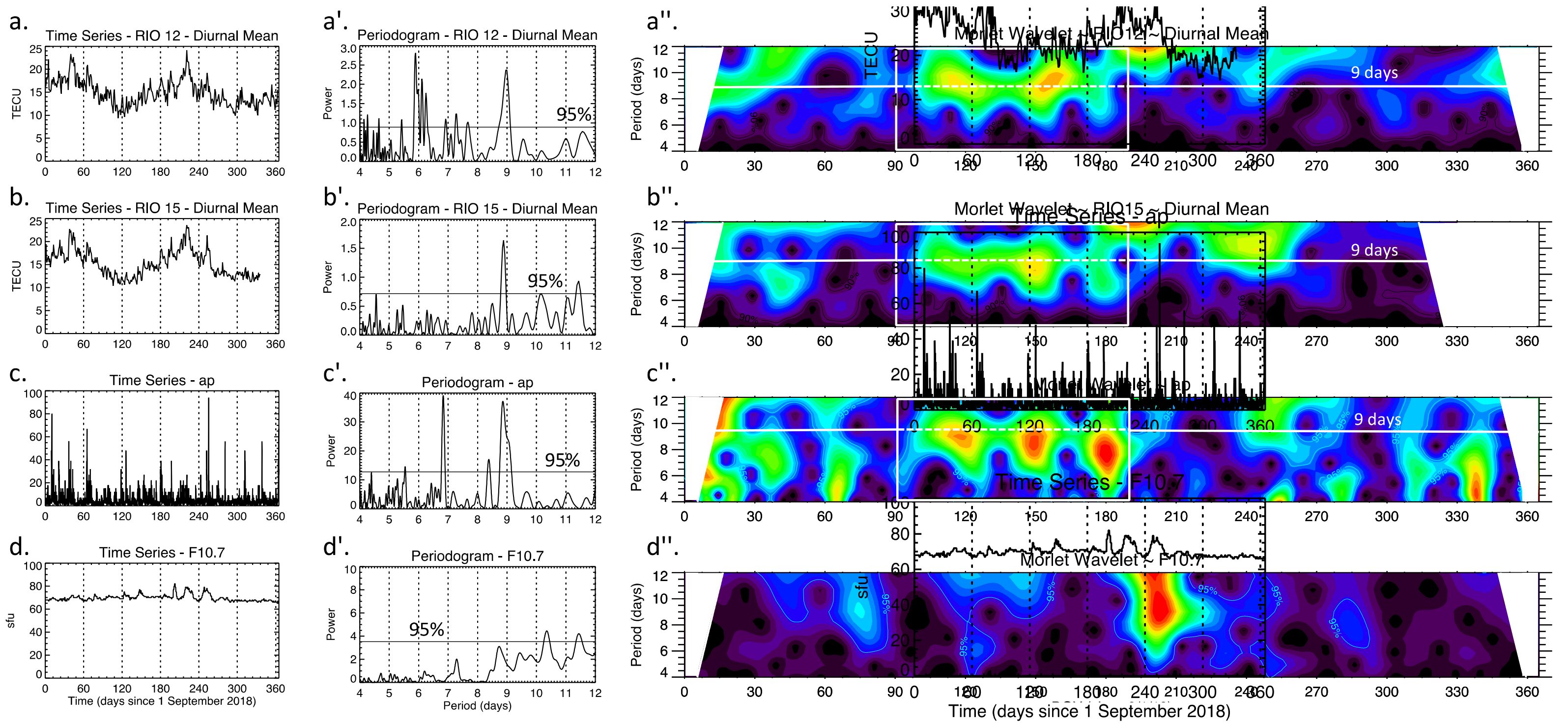


2b. High Speed Stream during 2018-2019
RIO TEC analyses (1 of 2)

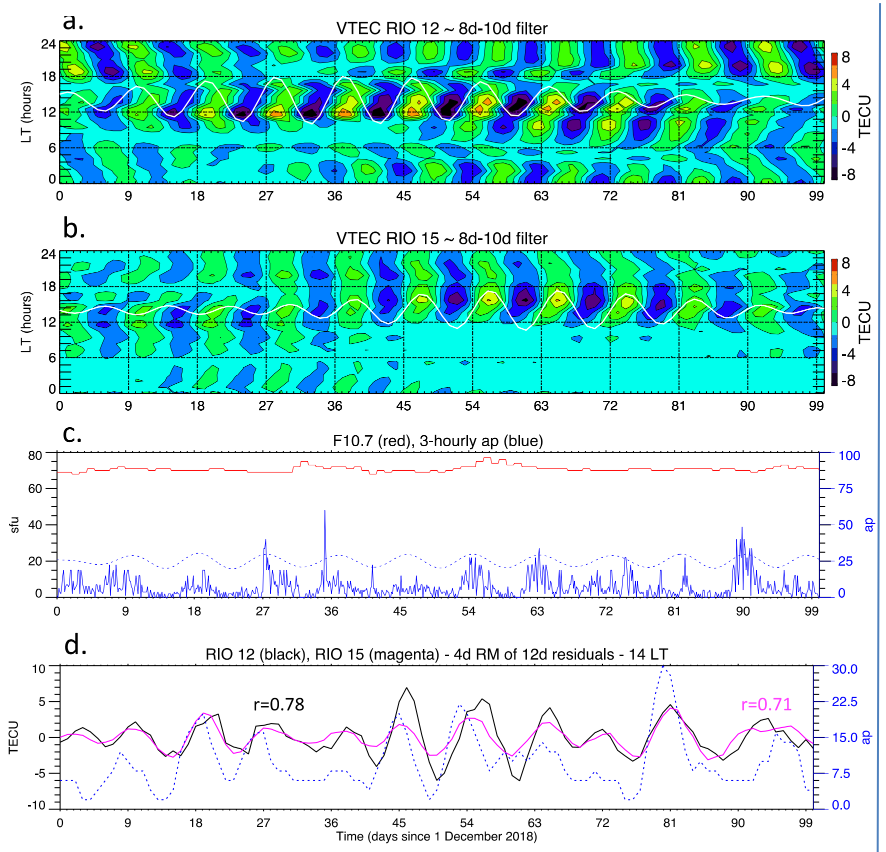


LT-time contours of vertical TEC (VTEC) measured during 1 September 2018 - 31 August 2019 by RIO-12 and RIO-15. (a')-(b') Same as (a)-(b), but for WACCM-X near the RIO locations. (c) Daily solar radio flux F10.7 (red line) and 3-hourly ap (blue line). (d) Scatter plot of WACCM-X versus RIO-12 VTEC (left) and RIO-15 VTEC (right) and their correlation coefficients (r=0.67 for RIO-12 and r=0.72 for RIO-15). Prominent HSS-induced ~9-day periodicities are present during November 2018 – March 2019.

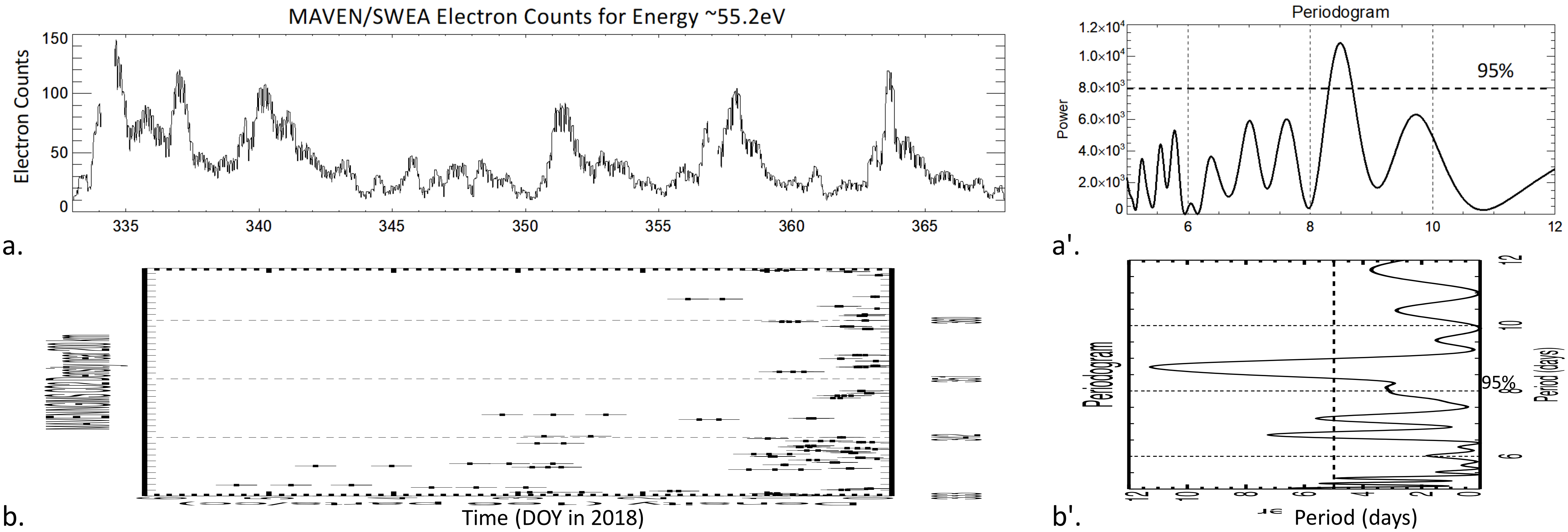
2b. High Speed Stream during 2018-2019
RIO TEC analyses (2 of 2)



LEFT: *(a) Diurnal mean TEC from RIO-12, (a') periodogram of (a), (a'') Morlet wavelet of the time series in (a). (b)-(b'') Same as (a)-(a''), but for RIO-15. (c)-(c'') Same as (a)-(a''), but for ap. (d)-(d'') Same as (a)-(a''), but for F10.7. The horizontal black lines in (a')-(d') show 95% confidence levels. The white box in (a'')-(c'') highlights the 100-day period of strongest ~9-day periodicity, marked with the horizontal white line.*

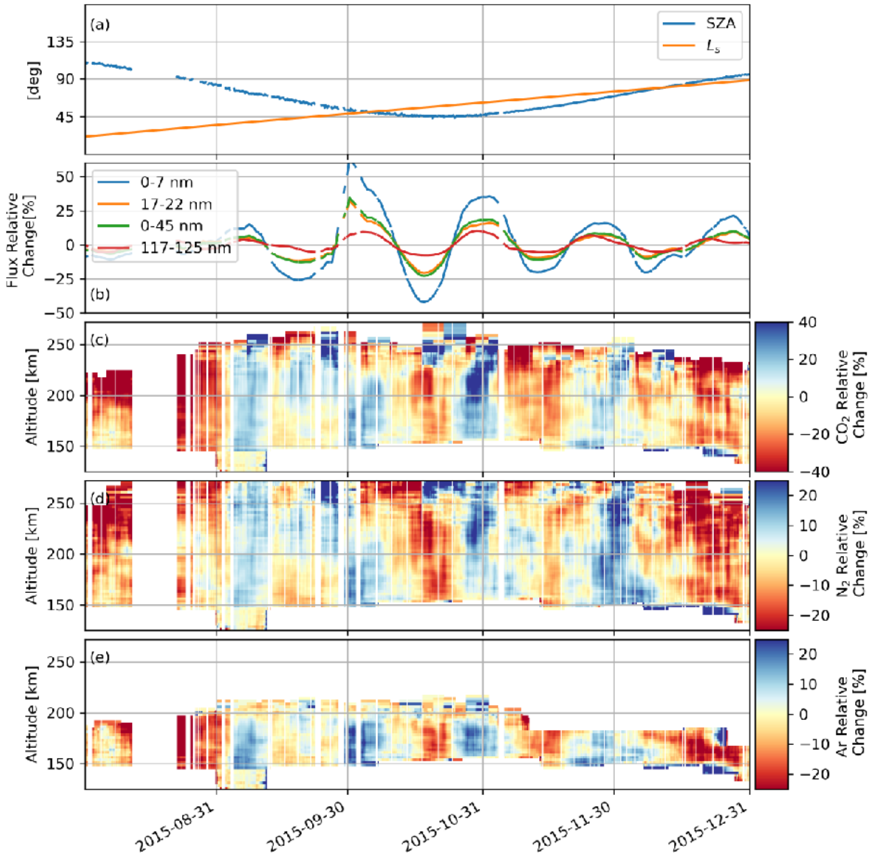


RIGHT: *LT-time contours of 8- to 10-day band-pass-filtered VTEC from RIO-12 (a) and RIO-15 (b) for the 100-day period. The white line in (a) and (b) shows the time series of the 8-10 day filtered TEC at 14 LT. (c) Time series of F10.7 (red line) and ap (blue line). The dotted blue line in (c) shows 8- to 10-day band-pass-filtered time series of ap. (d) Time series of 4-day running means of 12-day residuals of RIO-12 (black line) and RIO-15 (magenta line) TEC, and ap (dotted blue line). Correlation coefficients between RIO-12 (RIO-15) and ap of r=0.71 (r=0.78) are noted in (d).*

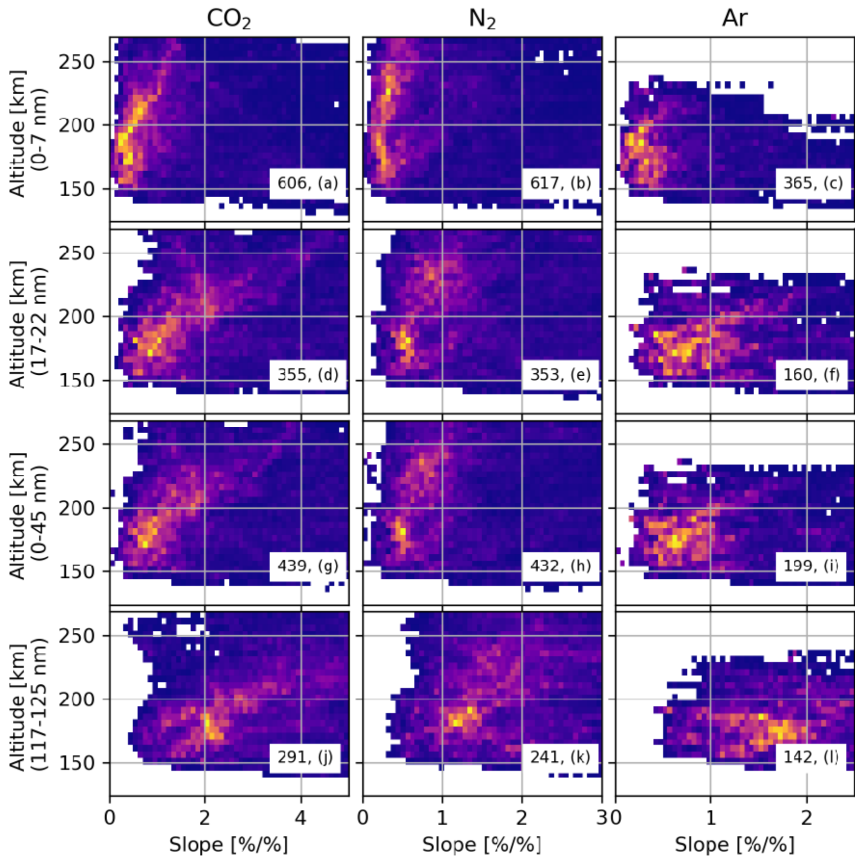


(a) Time series of MAVEN SWEA ~55eV electron counts during December 2018, (a') periodogram of time series in (a). (b) same as (a) but for MAVEN NGIMS CO_2 density near 200 km and (b') its periodogram. Prominent ~9-day variability is observed in both electron counts at Mars and NGIMS upper thermosphere density. Are these the effects of the HSS observed at Earth?

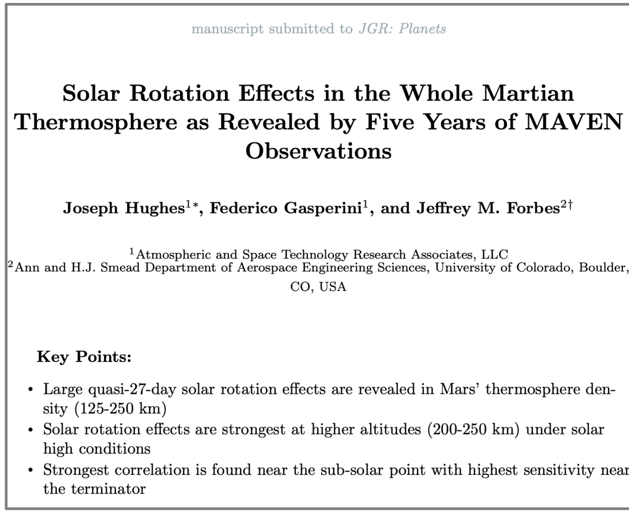
3. Solar Rotation Variation in Mars' Thermosphere
MAVEN NGIMS and EUVM analyses



Relative change in flux and density. Panel (a) shows the season and SZA. Panel (b) shows the flux relative change for all flux bands. Panels (c) through (e) show the density relative change for all species as a function of altitude for CO2 (c), N2 (d), and Ar (e).



Two dimensional histogram of slopes as a function of altitude for all species-flux band pairs. The number preceding the panel letter indicates the number of counts in the brightest cell while the dimmest pixel corresponds to 1 count.



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Solar Rotation Effects in the Whole Martian Thermosphere as Revealed by Five Years of MAVEN Observations

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Key Points:

- Large quasi-27-day solar rotation effects are revealed in Mars' thermosphere density (125-250 km)
- Solar rotation effects are strongest at higher altitudes (200-250 km) under solar high conditions
- Strongest correlation is found near the sub-solar point with highest sensitivity near the terminator

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Summary and Conclusions

- Thermospheric density near 460 km from the Swarm-C spacecraft, vertical TEC from RIO GPS receivers, and SD/WACCM-X reveal a significant global ionosphere-thermosphere (IT) response to HSS events occurring during Nov. 2018-Mar. 2019.
  - SD/WACCM-X output shows general agreement with observations, with some daily variability not well reproduced.
  - Model and observations demonstrate that the maximum response to the HSS events in thermospheric density and ionospheric TEC persists for several days after the onset of activity and has a global impact - even at low latitudes.
  - Analyses of MAVEN SWEA and NGIMS data reveals significant 9-day variability in measured electron counts and upper thermospheric density during December 2018 at Mars, likely connected to the HSS events observed at Earth.
- Further, solar rotation effects on the whole Martian thermosphere is studied by applying correlation analysis techniques to over five years of coincident MAVEN NGIMS and EUVM observations. Least squares methods are used to estimate the response of CO_2, Ar, and N_2 densities to the quasi-27-day solar rotation variability over the 0-7 nm, 17-22 nm, 0-45 nm, and 117-125 nm spectral bands.
  - Results reveal the presence of prominent solar rotation effects in the Martian thermosphere density for all species, irradiance bands, and altitudes. These effects are strongest at higher altitudes (200-250 km) and under high solar flux conditions. The best agreement between solar rotation variability in flux and density is found close to the sub-solar point, but the highest sensitivity to solar flux is found near the solar terminator.
- Future work will (a) verify the the connection to the HSS for the ~9-day thermospheric variability observed at Mars, (b) compare the response with that at Earth, (c) extend the comparative analysis to the solar rotation variation in EUV irradiance.

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