Tropospherically Induced Signatures observed in Earth's Ionosphere

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Paper: Control of equatorial ionospheric morphology by atmospheric tides

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The upper portion of Earth's atmosphere, the thermosphere, extends from approximately 90 to 1000 km, depending upon solar cycle. Embedded within the thermosphere is Earth's ionosphere, which is a weakly ionized plasma containing free electrons and ions. The ionosphere-thermosphere (IT) system represents the transition region from Earth's atmosphere to space. Due to the location of the IT in Earth's atmosphere it is subject to energy inputs from both above (e.g., solar radiation, solar wind, and magnetosphere) and below (e.g., waves from troposphere, stratosphere, and mesosphere). Despite the many different energy inputs that drive dynamics and structure of the IT, there are still many features in the IT system that are of unknown origin. Specifically, one outstanding question that has yet to be resolved is: Are the longitudinal variations observed in the upper portion of the IT system related to tropical rainstorms in troposphere via vertical wave coupling?

Atmospheric Tides 101

Figure 1 shows an illustration of the meteorological influences that affect the IT system. A spectrum of different wave components, originating throughout the atmosphere, dissipate and deposit momentum and energy into the IT system. Dissipation and deposition have roles in driving what is commonly referred to as "space weather." One such momentum and energy input from the lower atmosphere, depicted in Figure 1,is the spectrum of atmospheric tides. Atmospheric tides are global scale perturbations in pressure, wind, temperature, and density that result from the periodic absorption of solar radiation by Earth's atmosphere. Tidal perturbations generated in the troposphere and stratosphere through the absorption of solar radiation by water vapor (H_2O) and ozone (O_3) can propagate to higher altitudes, grow exponentially with height (due to the conservation of energy along with an exponential decrease in density with altitude) and dominate the "weather" in the mesosphere and lower thermosphere (MLT), as well as the IT.

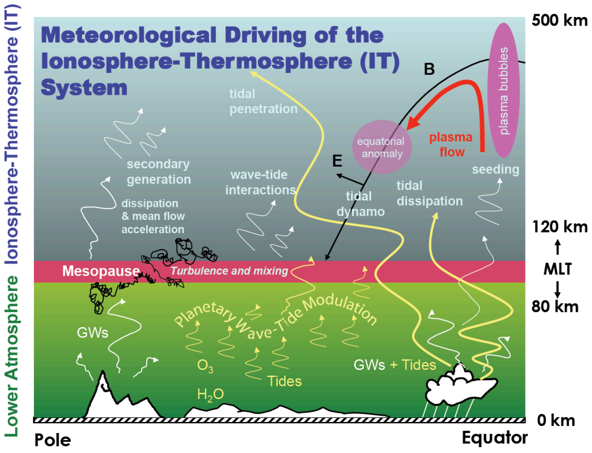

Figure 1. Schematic of the Meteorological Forcing of the IT System. Figure from the Committee on a Decadal Strategy for Solar, Space Physics (Heliophysics); Space Studies Board; Aeronautics, Space Engineering Board, Division of Earth, and Physical Sciences; National Council.

Observations and Modeling Results

The dissipation of atmospheric tides in the MLT and lower IT can drive "space weather" at high altitudes through the ionospheric wind dynamo. *Immel et al*. provide a nice diagram showing how the ionospheric wind dynamo works in Figure 2.

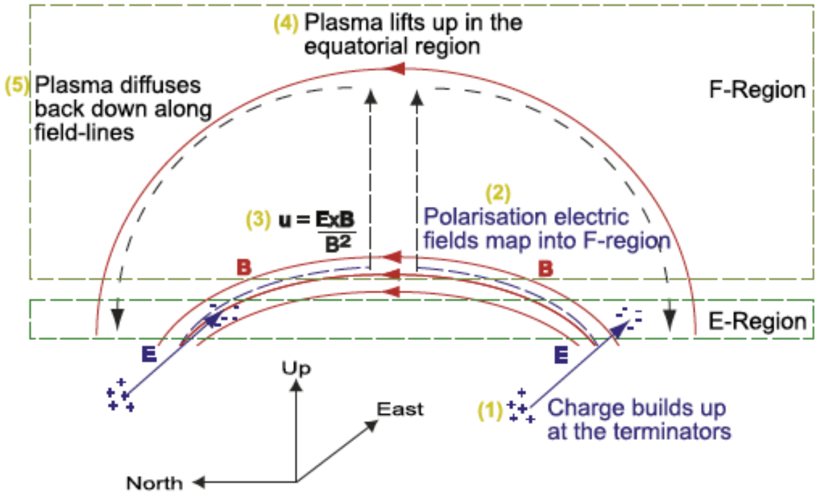

Figure 2. Diagram describing the development of the equatorial ionospheric anomaly, the magnetic and electric fields that combine to produce it. (1) The E-region dynamo, driven by neutral wind-E-layer interaction, produces an eastward electric field across the dayside. (2) These fields are transmitted upward along magnetic field lines into the F-region, causing the plasma to E x B drift upward (3, 4) at the magnetic equator. (5) Through diffusion and gravitational sedimentation, the upward lifted plasma settles along the magnetic field to locations north and south of the equator. Caption from Immel et al.

Any phenomenon that can interfere with the process described above in Figure 2, specifically by changing the daytime electric field described in step 1, can affect the structure of the IT system .The dissipation of vertically-propagating atmospheric tides in the E-region (ca. 100 -150 km in altitude) modulates the polarization electric field that is described in first step of Figure 2. This modulation maps along magnetic field lines into the overlaying F-region (ca. 200 – 500 km) and can be observed as longitude variations in many ionospheric measurements.

For example, Figure 3 shows average nighttime emissions of atomic oxygen ions at F-region peak density altitudes (ca. 350 – 400 km) measured by the far-ultraviolet (FUV) imager onboard the IMAGE satellite in blue overlaid with the diurnal temperature variation at 115 km due to vertically-propagating atmospheric tides from the Global Scale Wave Model (GSWM). Figure 3 clearly shows a four-peaked longitude structure in the diurnal tide amplitude, which corresponds with the brightest nighttime emissions measured from the IMAGE satellite. Also, the strength of the brightness peaks vary with the strength of diurnal tide amplitude that are, in turn, driven by deep convection in the tropics at tropospheric altitudes. Remarkably, *Immel et al*. clearly demonstrate that even though vertically-propagating atmospheric tides are significantly damped in the E-region, they can modulate the electric fields in this altitude regime and map along magnetic fields lines into the F-region with observable results.

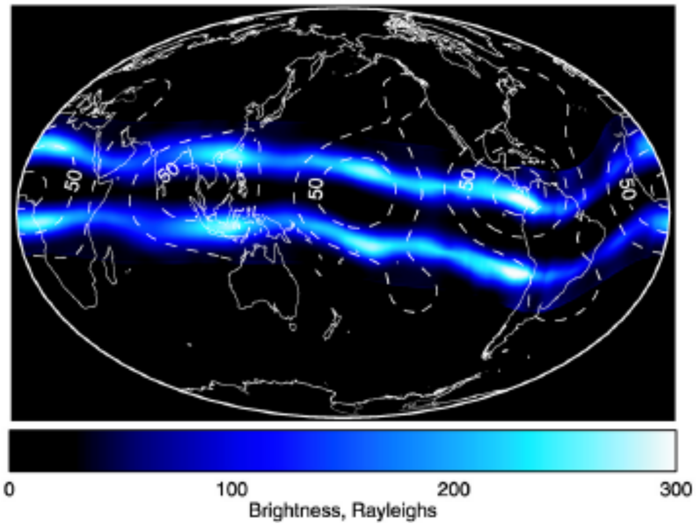

Figure 3. Reconstruction of nighttime ionospheric emissions from 30 days (March 20–April 20) of observations with the IMAGE-far ultraviolet (FUV) imager. The average location and brightness of the equatorial ionospheric anomaly stand out in this presentation. Due to the poor sampling of emissions from the southern anomaly, it is represented here with a mirror image of the northern anomaly across the magnetic equator. This image is representative of the local ionospheric properties at 20:00 LT. Overlaid on this figure with white dashed contours is the amplitude of the diurnal temperature variation at 115 km due to upward-propagating lower atmospheric tides, as reported by the Global Scale Wave Model. Caption from Immel et al.

Broader Impacts to Satellite Missions

Furthering our understanding of the effects vertically-propagating tides have on IT dynamics, electrodynamics, and chemistry is essential to the increased need for more accurate space weather forecasts in support of tracking and monitoring near Earth orbiting satellites and space debris, as well as predicting ionospheric conditions relevant to communications and navigation systems. Additionally, a better understanding of the underlying physics responsible for changes in the IT, specifically the longitudinal and seasonal variability, will prove useful when preparing for upcoming near-Earth space-based missions that are focused on studying the IT (e.g. Ionospheric Connection Explorer (ICON)).