New NASA Missions Focus on Terrestrial Forcing of the Space Environment

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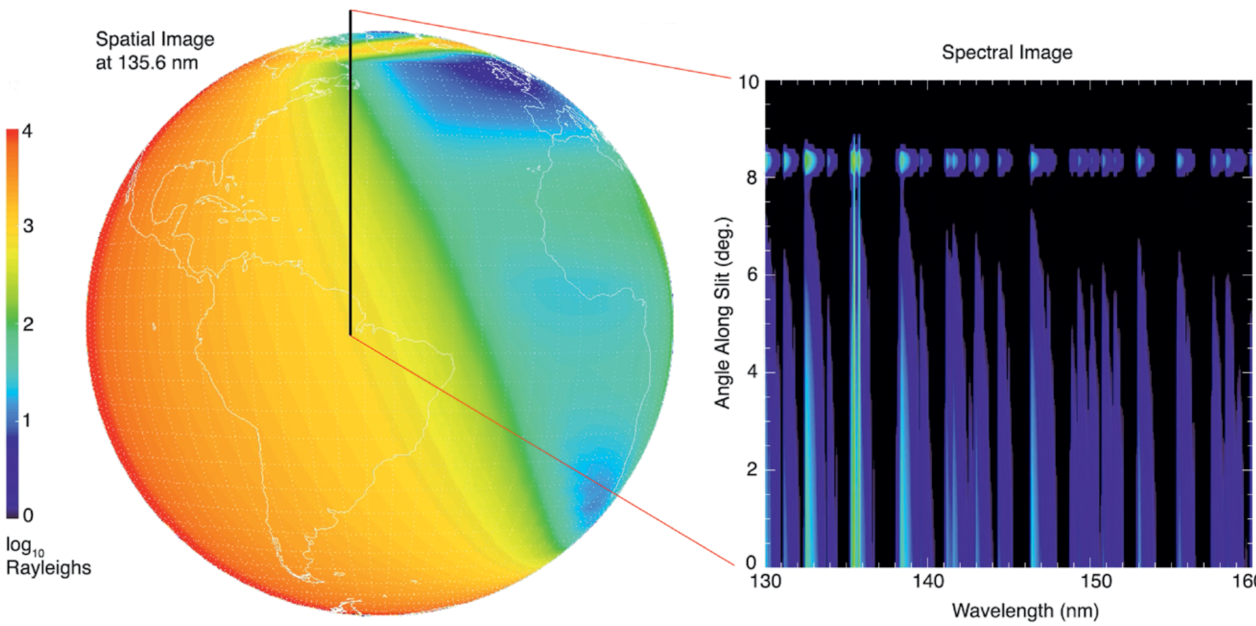

Fig. 1. Simulated airglow emissions as observed by GOLD. (left) Disk image of the 135.6-nm emission, showing dayglow, nightglow, and aurora. Landmass boundaries are shown from geostationary orbit at 47.5°W longitude, where GOLD will be stationed. (right) Spectral image in wavelength and position along the slit (shown as white rectangle on the disk image). (Figure courtesy S. C. Solomon, NCAR/HAO.)

In late 2019, two ground-breaking NASA missions to explore the conditions in near-Earth space environment are expected to both be on orbit and operational. These missions are designed to observe changes in the state of the neutral upper atmosphere and ionosphere (at 100–500-km altitude) in response to forcing from the sun and solar wind, as well as the terrestrial atmosphere below. Together these observatories will provide a comprehensive view of the near-Earth space environment, the conditions of which can be broadly described as space weather, and explore the degree to which the lower and middle atmosphere exert a significant, possibly controlling, influence. These missions provide complementary capabilities for quantifying the drivers of the near-Earth space environment and its responses at low and middle latitudes. The comprehensive view provided by these missions will lead to a much improved understanding of space weather, and inform the international effort to improve prediction of conditions in Earth's space environment, both in terms of its neutral and ionized components.

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TWO NEW SPACE MISSIONS. The Global-Scale Observations of the Limb and Disk Imager (GOLD; Fig. 1) (Eastes et al. 2017) was launched in January 2018. This NASA mission of opportunity is flying a pair of identical, imaging spectrometers on *SES-14*, a communications satellite in geostationary orbit over South America at 47.5°W. GOLD makes spectrally and spatially resolved scans of the far-ultraviolet (FUV) emissions (132–162 nm) from the upper atmosphere and ionosphere. Earth's daytime disk and limb are observed with a 30-min cadence. From these observations the first full-disk images of both the neutral temperatures and composition in the upper atmosphere are retrieved. Simultaneous imaging of both quantities during the dayside observations provide a never-before-seen view of the short-term changes that occur across the American continents and the Atlantic Ocean. At night, GOLD measures the intensity of ultraviolet emissions of atomic oxygen, from which the maximum ionospheric density can be directly retrieved.

The Ionospheric Connection Explorer (ICON; Fig. 2) mission (Immel et al. 2018) is prepared for a 2019 launch and will retrieve a comprehensive set of characteristics of the neutral upper atmosphere and ionosphere. Implementing an innovative heterodyne imaging technique (Harlander et al. 2017), ICON retrieves wind profiles in the upper atmosphere using a Michelson interferometer. In daytime, these wind profiles extend from the edge of space at 95 km to the ionospheric peak above 300 km. Simultaneously, ICON makes in situ plasma density and 3D velocity measurements (at 575 km, the satellite's target altitude) using an ion velocity meter. By the design of the mission, these measurements are often connected by Earth's magnetic field, where near the magnetic equator a magnetic field line at the spacecraft can be followed directly down to the region of the remote measurement. Given the high electrical conductivity in this region, the electric potential that is, in part, generated by the dynamo action of the

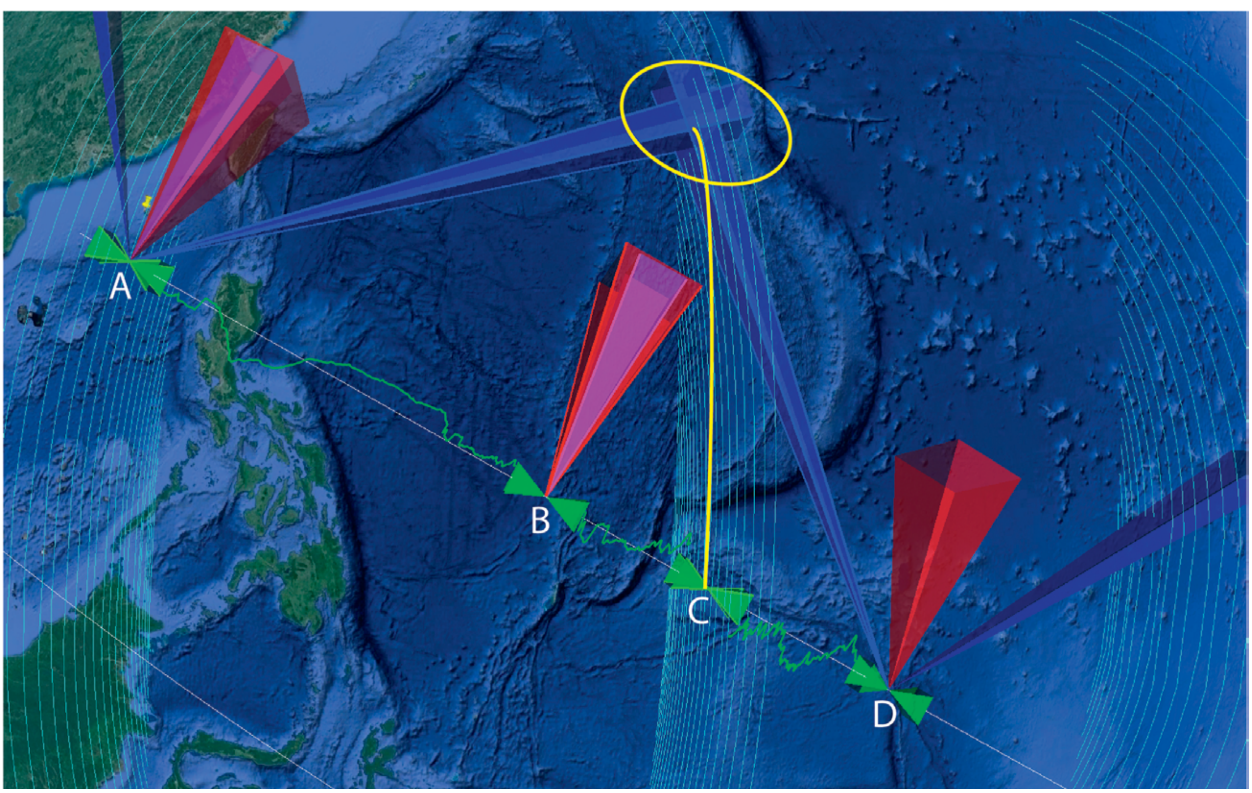

Fig. 2. Key observations during a pass of ICON over the Pacific. Products are provided from the same physical region within a 7-min window. The cardinal wind and temperature profiles come from interferometric observations from positions A and D. The neutral and ion composition profiles are provided at position B. Electric fields that originate from the region of interest are measured continuously (green line) and specifically measured at position C. Earth's magnetic field is described by arched blue lines, illustrating the connection between the in situ and remote measurements.

remotely observed wind is measured at the spacecraft by measuring the plasma velocity field. In this way, the relationship between the neutral and plasma velocity fields can be evaluated for the first time. In addition, height profiles of plasma density in the daytime are retrieved from daytime measurements by an extreme ultraviolet spectrometer. ICON also carries an FUV imager for retrieval of atmospheric composition and ionospheric density profiles in day and night, respectively, providing a high-resolution local compliment to the large-scale imaging by GOLD.

The combination of local and global observations from these two missions provides data that can enable new assimilative and physics-based approaches for predictions of the conditions in Earth's "space weather." Together the two missions represent a corollary to that used by the meteorological community, combining global-scale contextual observations from geosynchronous orbit with critical, focused in situ observations at smaller scales.

Improvement in the reliability and accuracy of space weather forecasts is enabled by increasing the number and breadth of key state variables measured and made available for analysis and assimilation. Space weather conditions are known to respond strongly to variability in solar UV irradiance, solar energetic particle flux, and bulk plasma emanating from the sun; the last of these reaching Earth in a magnetized solar wind. Knowledge of the solar radiation and solar wind output is a national interest that if currently fulfilled by NOAA's space assets including Deep Space Climate Observatory (DSCOVR; Burt and Smith 2012) with planned continuation follow-on missions. However, it is now clear that the transfer of energy and momentum from the troposphere and stratosphere upward into Earth's upper atmosphere is likely a defining process in space weather (Immel et al. 2006; Hagan et al. 2007; Liu et al. 2013). Together, ICON and GOLD provide more than a dozen related products to help resolve the mystery of day to day variations in space weather that are apparently not related to the currently measured solar wind key parameters and therefore not predictable at this time.

TERRESTRIAL ATMOSPHERIC DRIVERS OF SPACE WEATHER. There are several atmospheric phenomena that are now thought to be of key importance when considering the connection of the terrestrial atmosphere to space weather. Examples include atmospheric tides energized in the lower atmosphere that propagate to much higher altitudes. Several upward-propagating atmospheric tides with origins in the troposphere grow to their largest amplitudes in the 90–120-km range before breaking or dissipating (Hagan and Forbes 2002). Tropospheric forcing, therefore, extends to and well above the boundary of space and into the plasma of the lower ionosphere. The largest of these tides is energized by absorption of solar infrared radiation by water vapor and latent heat released by cloud formation. These tides can therefore vary over short time periods as weather patterns change, varying more rapidly than does the relatively steady diurnal tide generated in the thermosphere by the absorption of solar extreme UV radiation. In addition, gravity and acoustic waves originating from tropospheric sources also propagate into the region, with some reaching the ionospheric peak near 300–400 km. Perhaps most spectacular are global-scale disruptions of the ionosphere that have been attributed to large changes in the planetary wave spectrum in the polar stratosphere [see Goncharenko et al. (2010) for an excellent example]. The changes in the ionosphere observed during major stratospheric warming events, with both enhancements and reductions of plasma density as large as a factor of 2, over locations at low or middle latitudes, are of a magnitude comparable to extreme space weather events driven by the solar wind.

CONCLUSIONS. Although measurements and models of the space environment have advanced significantly in recent decades, the needs for prediction still exceed current capabilities. The ICON and GOLD missions will provide unprecedented measurements that will advance our understanding of the behavior of the near-Earth space environment and open avenues for improvement in scientific capability in space weather prediction. As each mission seeks to discern the influence of terrestrial drivers on Earth's upper atmosphere, combining these new observations with those from other NASA missions, U.S. agencies, and international partners holds promise for even more comprehensive views of the system. The ICON and GOLD missions were designed separately, but carry naturally synergistic capabilities that are soon to be realized.

FOR FURTHER READING

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