GNSS applications to ionospheric disturbance studies

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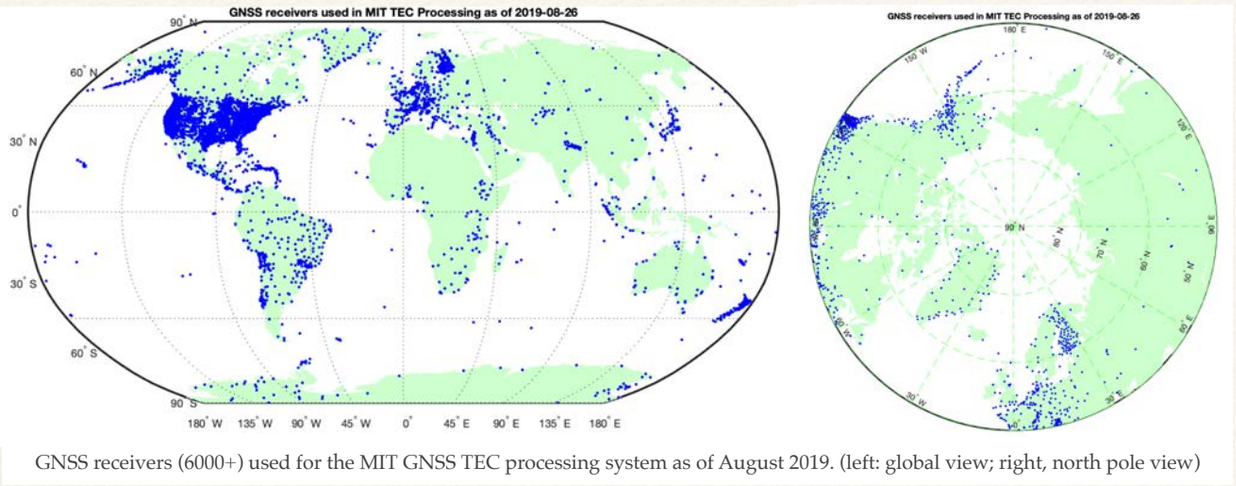
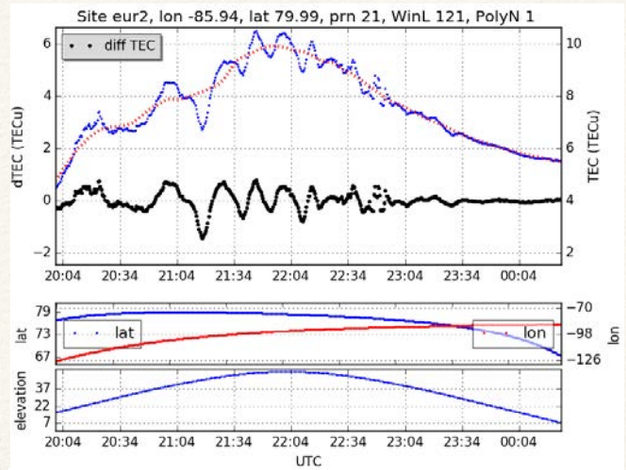
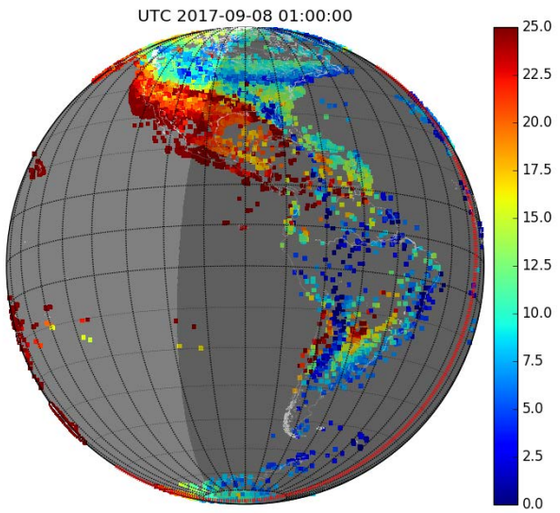


GNSS receivers (6000+) used for the MIT GNSS TEC processing system as of August 2019. (left: global view; right, north pole view)

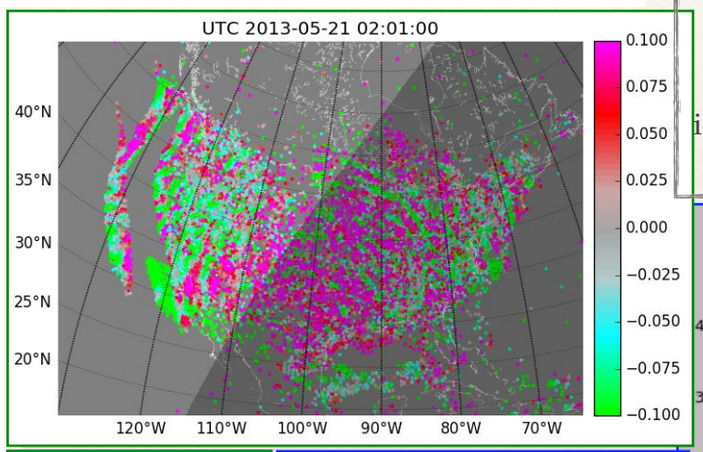
We demonstrate a range of ionospheric disturbances detected with the GNSS receiver network of total electron content (TEC) measurements. These disturbances are originated from geospace storms and substorms, man-made space perturbations, terrestrial weather, and the energy release from the solid earth. The GNSS radio sounding provides a sensitive and versatile means for characterizing the correlation between ionospheric variations and their relevant drivers within the broad heliosphere-earth systems.



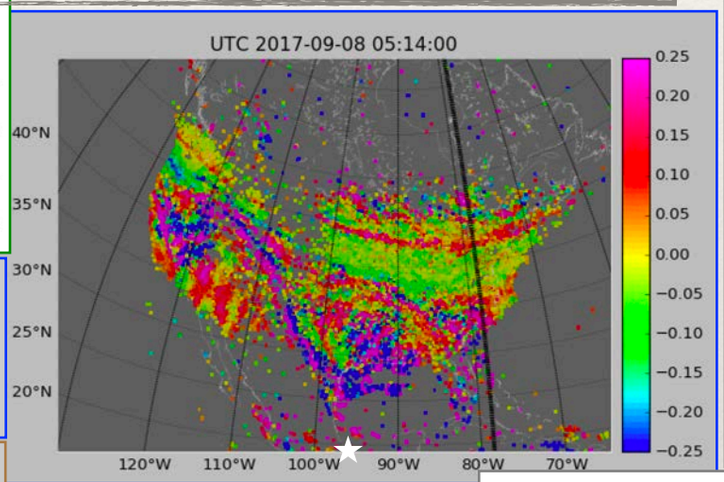
Differential TEC (top, black) calculations based on de-trending a smooth copy of the background variation (red), which results from SG low pass filtering, from the original TEC data (blue) measured from a receiver-satellite pair.



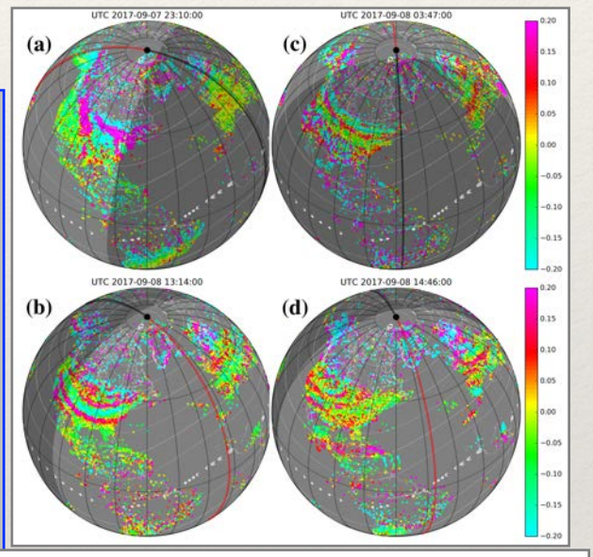
Plasma density depletion seen typically as **plasma bubble** at low latitudes exhibited dramatic extension into mid-latitudes in both hemispheres during the Sept 8, 2017 storm.



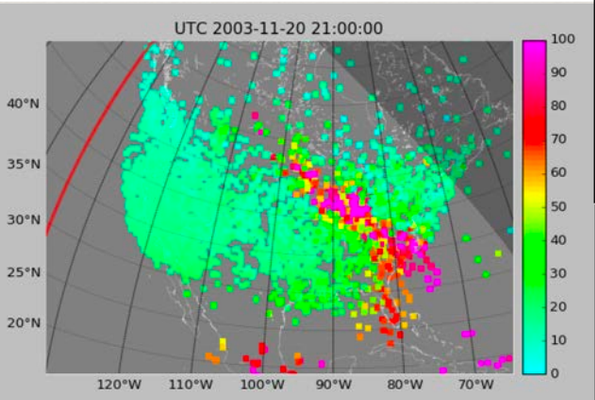
Concentric ionospheric waves induced during the **tornado** landing over the southern US on May 21, 2013.



Ionospheric disturbances excited by multiple sources, including a geomagnetic storm and the Mexico M8.2 **earthquake** at 04:49 UT Sept 8, 2017 (white star: epic center; black line: midnight)

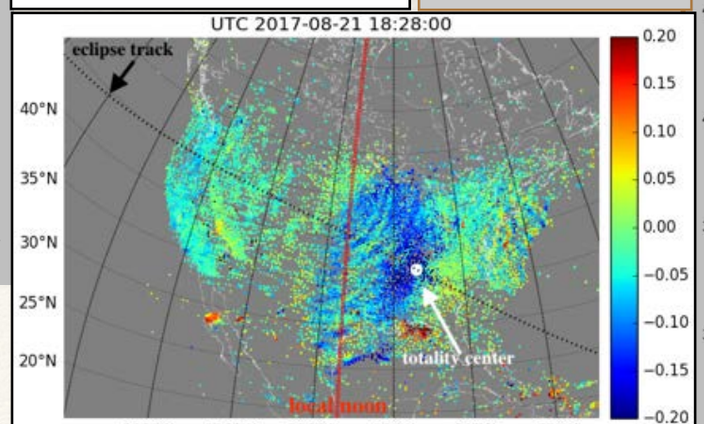


Typical wave front patterns of traveling ionospheric disturbances excited near the auroral zone during the **geospace storm** in Sept 7-8, 2017. These different wave fronts suggest variations in excitation sources and thermospheric conditions for the wave propagation.

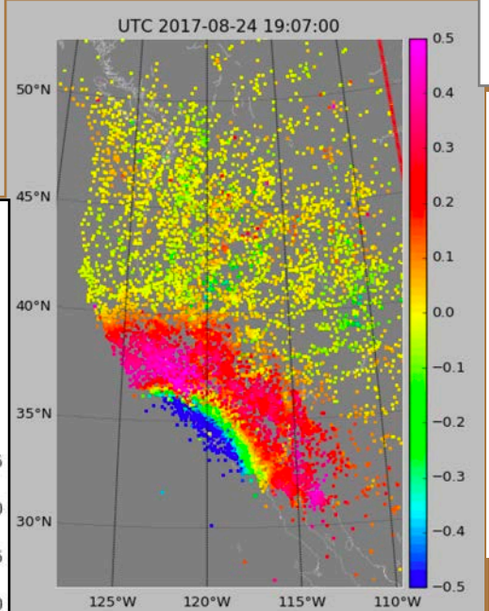


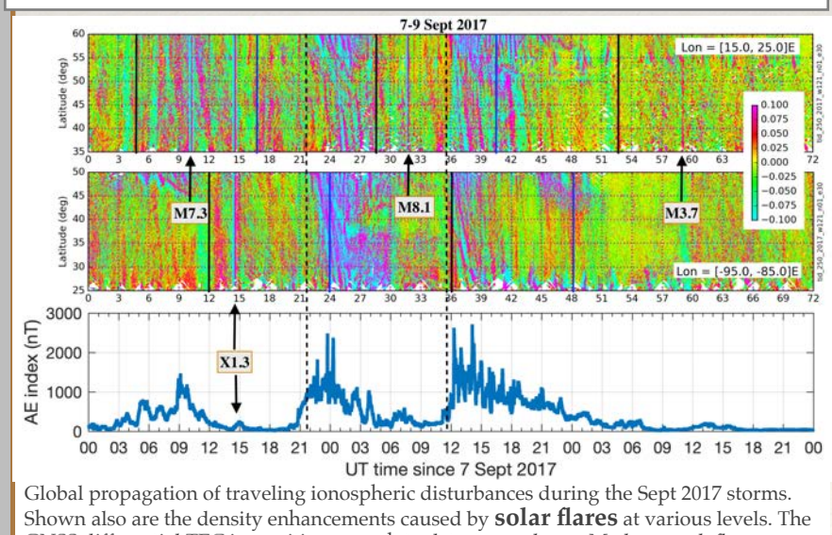
Storm enhanced density (SED) plume structure observed during the Nov 20, 2003 super solar storm

Bow-shaped wave fronts of medium scale traveling ionospheric disturbances excited by the total **solar eclipse** on August 21, 2017. Unprecedented spatial coverage for the eclipse observation with GNSS receivers made it possible to detect the wave propagation along the totality path (dotted).(red line: noon)



Significant ionospheric density disturbances following the SpaceX Falcon 9 rocket launch with the Taiwan satellite Formosat-5 on Aug 24, 2017 from the Vandenberg Air Force Base in CA





Global propagation of traveling ionospheric disturbances during the Sept 2017 storms. Shown also are the density enhancements caused by **solar flares** at various levels. The GNSS differential TEC is sensitive enough to detect even lower M-class weak flares.

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