Space Weather Impacts on GPS Navigation Systems

Xing Meng
Attila Komjathy, Xiaoqing Pi, and Anthony J. Mannucci

Jet Propulsion Laboratory, California Institute of Technology

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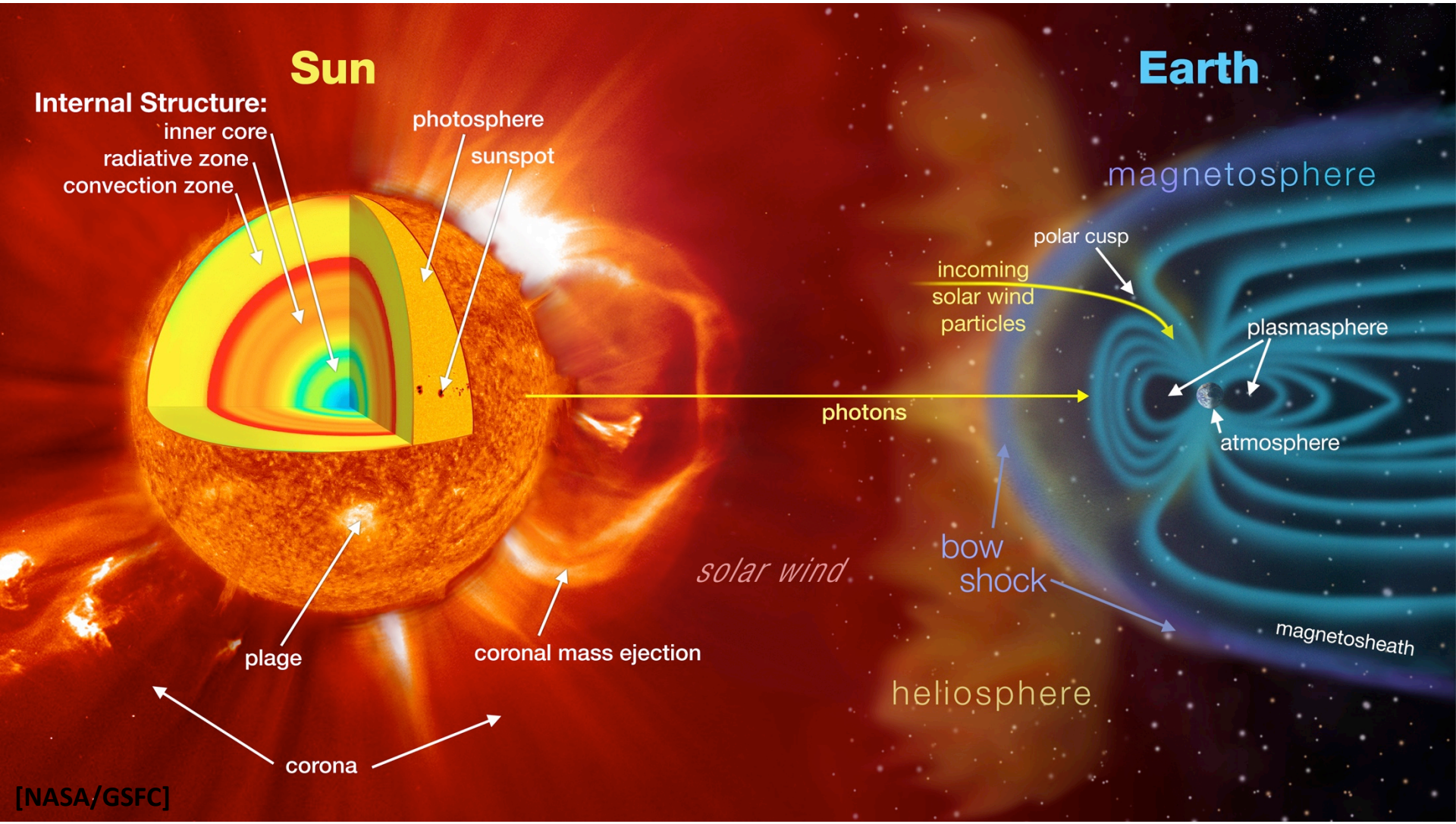
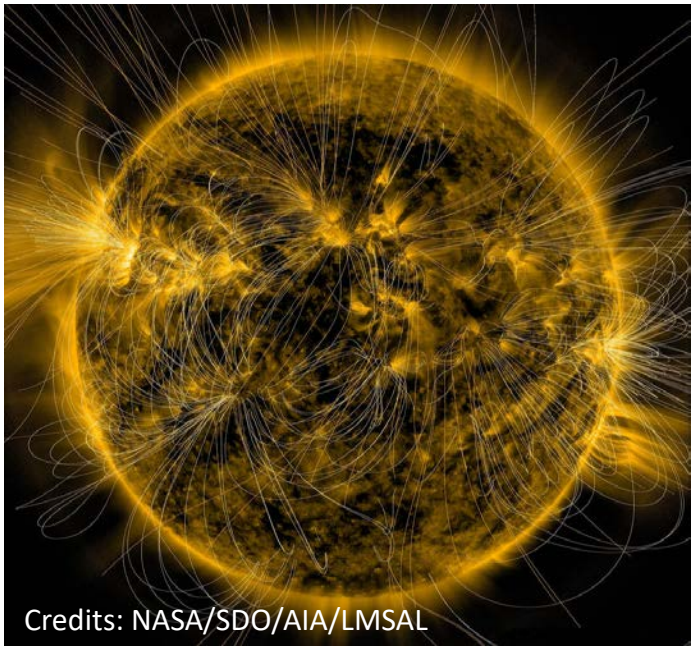
Outline

- Principles behind “space weather”
  - the solar-terrestrial environment
  - Eruptions on the Sun
  - Geomagnetic storms
- GPS signals and the ionosphere
- Space weather impacts on GPS system performance

It all starts from the Sun …

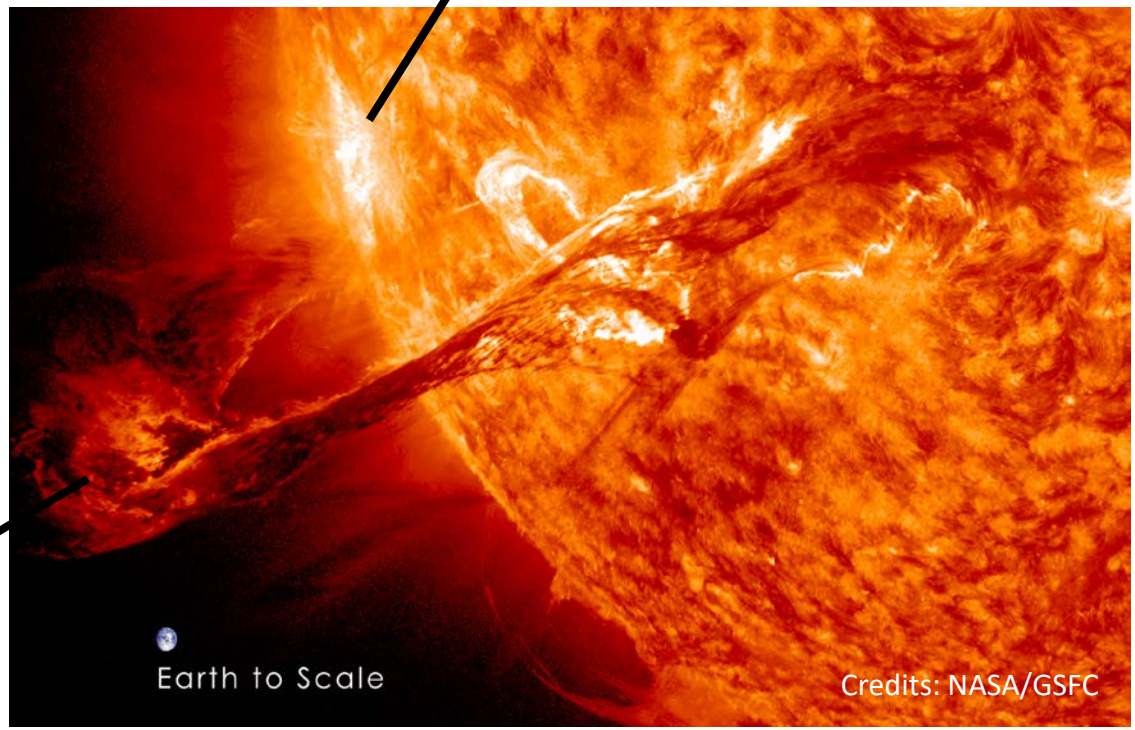


The Restless Sun



Solar magnetic field

Solar flare



Coronal Mass Ejection (CME)

CME on August 31, 2012

Credits: NASA/GSFC

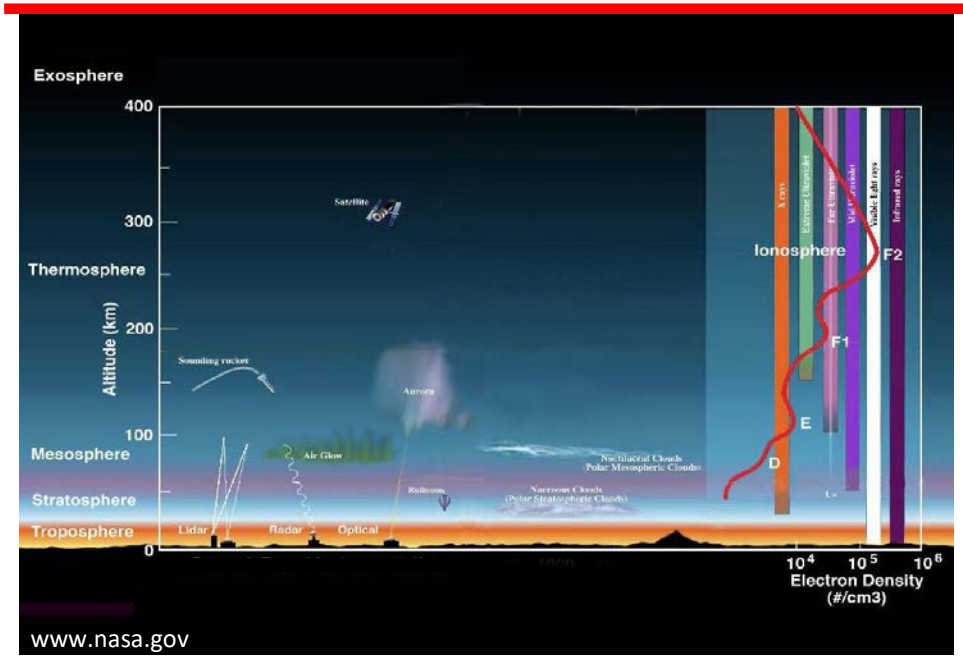
CME Propagating Toward the Earth

Credits: NASA/GSFC

Geomagnetic Storms and Auroras

Credits: NASA/GSFC

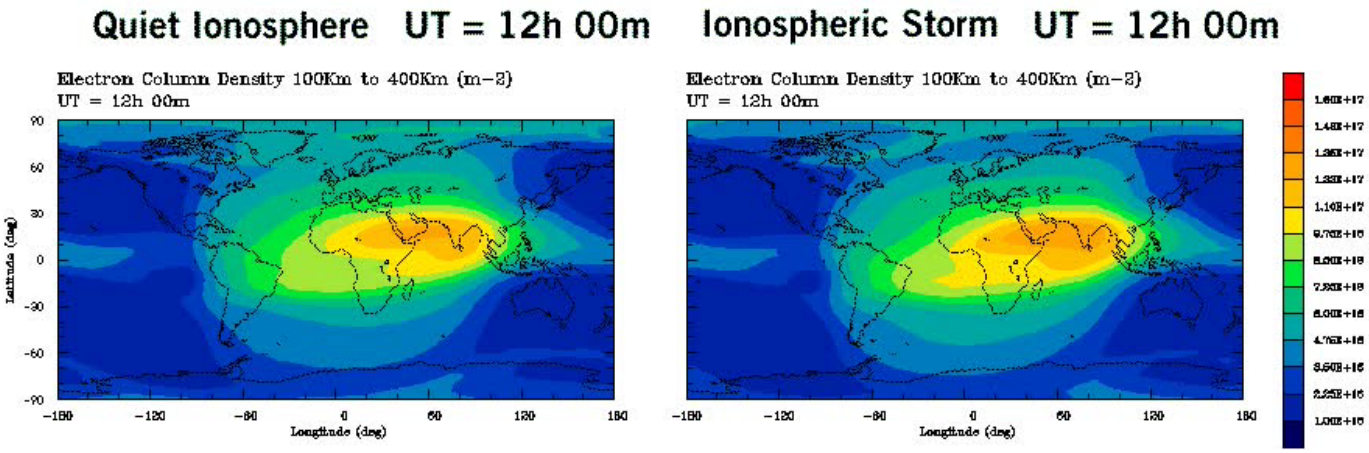
Ionospheric Storms



www.nasa.gov

The ionosphere is where charged particles are important in determining the chemical and physical properties of the atmosphere.

Total electron content (TEC) is the electron column number density (1 TECU = 10^{16} m^{-2}). TEC is a direct indicator of the ionospheric state.



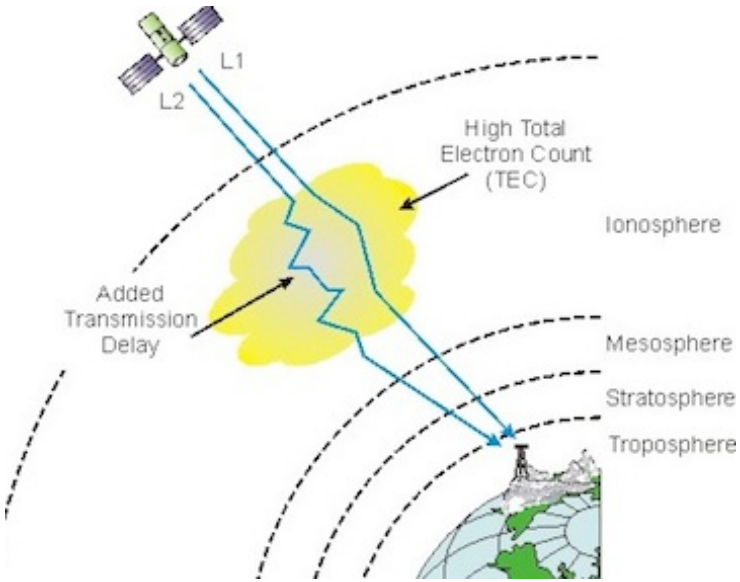
Source: http://radiojove.gsfc.nasa.gov/education/educ/radio/tran-rec/exerc/iono.htm

GPS Signals Through the Ionosphere

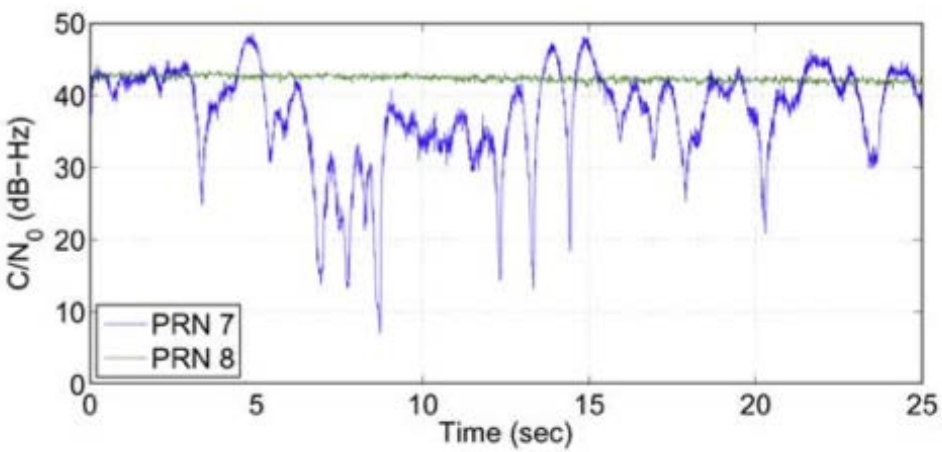
Scintillations: rapid amplitude and phase fluctuations in a received electromagnetic wave.

Ionospheric scintillations are caused by plasma density irregularities in the ionosphere.

Sufficiently intense signal fluctuations degrade the signal quality, reduce its information content, or cause GPS receivers to stop tracking the signals from GPS satellites ("loss of lock"). This may increase navigation errors or, in some cases, cause navigation failure. [Kintner et al., *Space Weather*, 2007].



[http://xenon.colorado.edu/spotlight/index.php?action=kb&page=61]

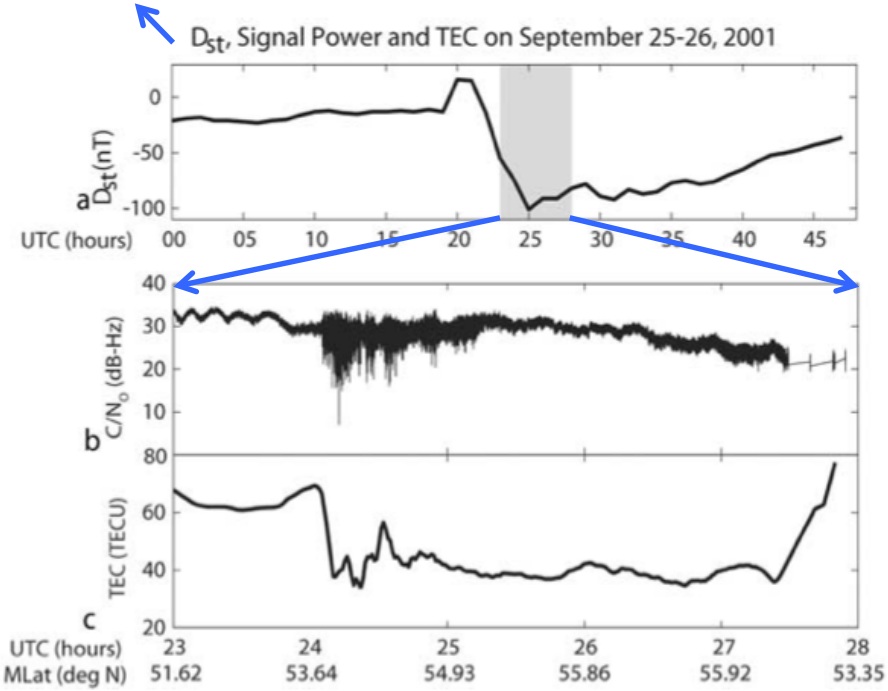


Comparison of scintillating and nonscintillating GPS signals
[Kintner et al., 2007]

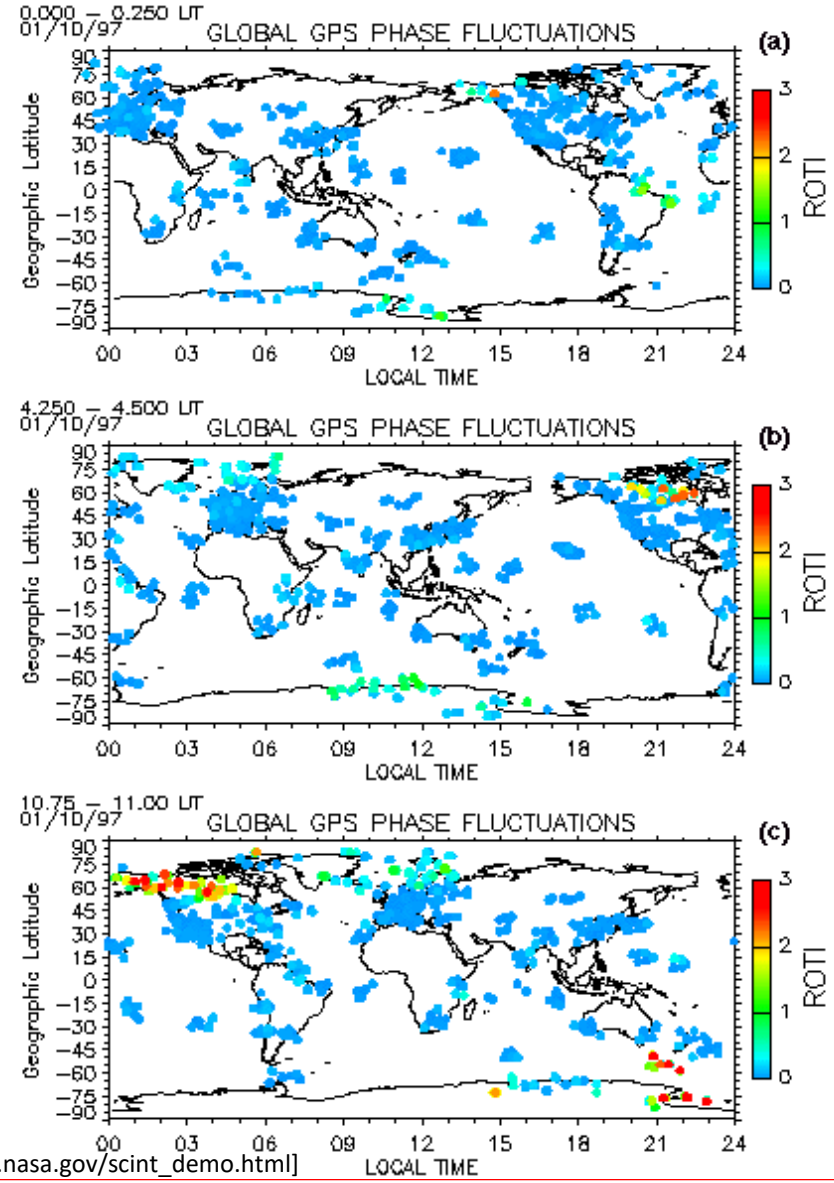
Scintillation Examples

During geomagnetic storms

Dst index indicates the strength of a geomagnetic storm



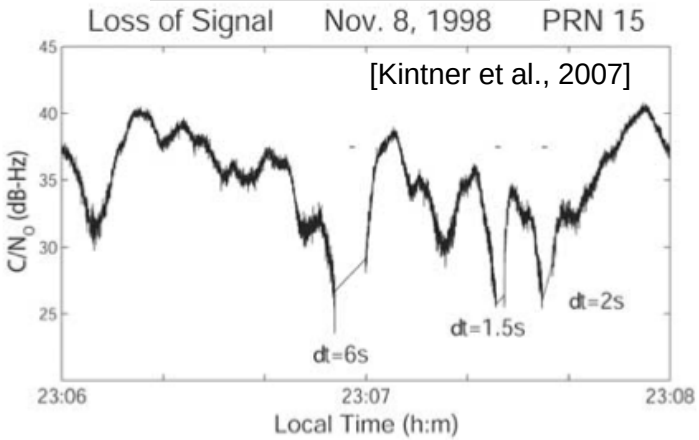
[Kintner et al., 2007]



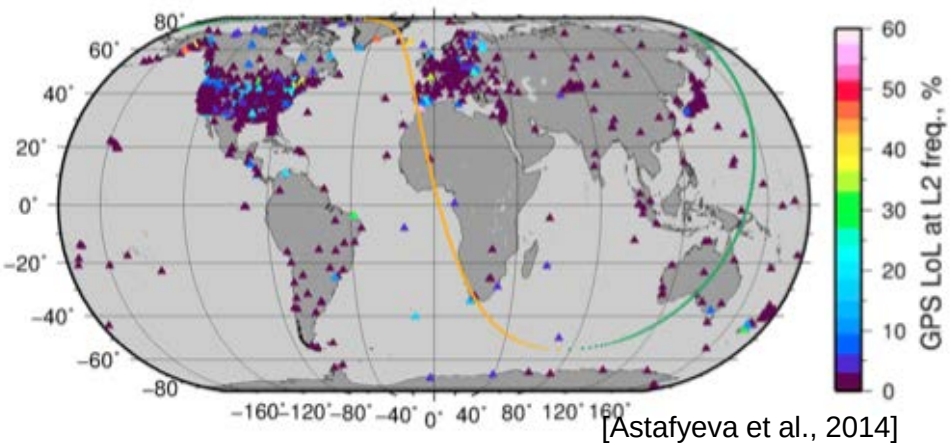
[http://iono.jpl.nasa.gov/scint_demo.html]

Loss of Lock

Loss of lock example

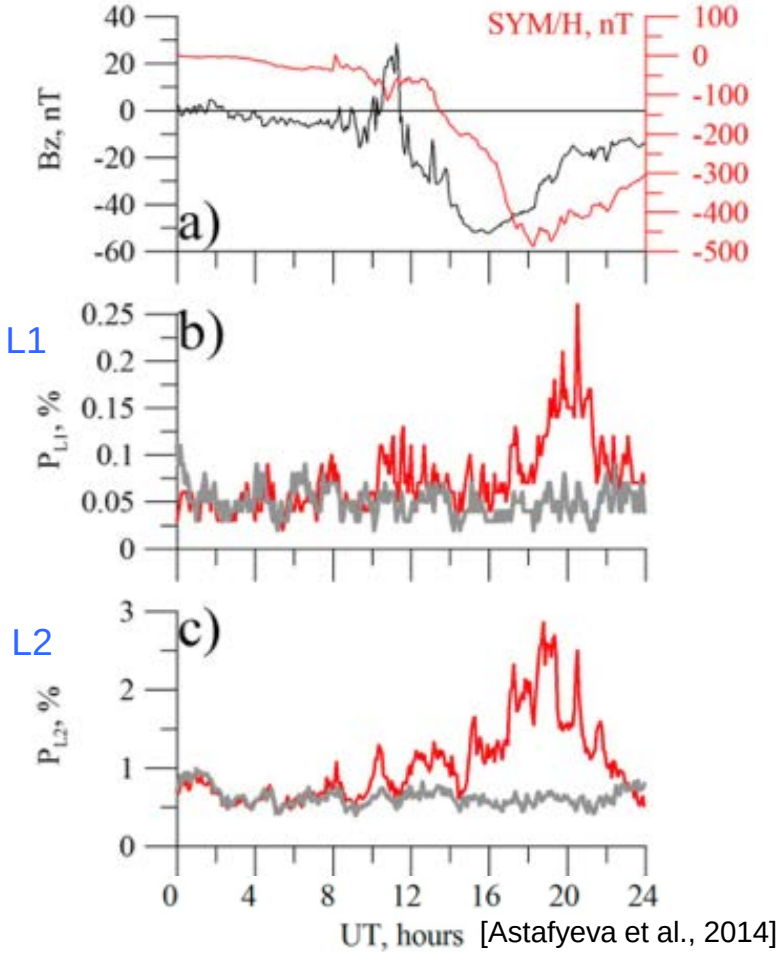


Global loss-of-lock distribution
19 UT, 20 November 2003



[Astafyeva et al., 2014]

Loss of lock during
November 2003 storm



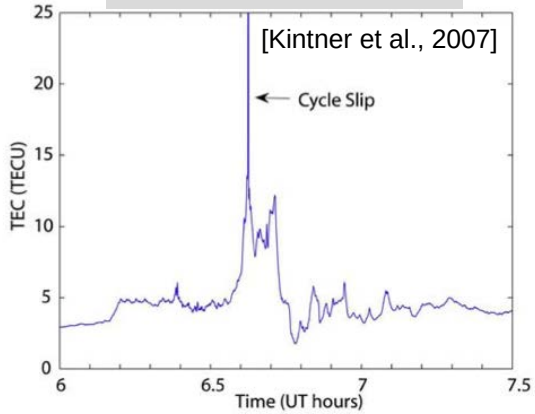
[Astafyeva et al., 2014]

TEC Slip

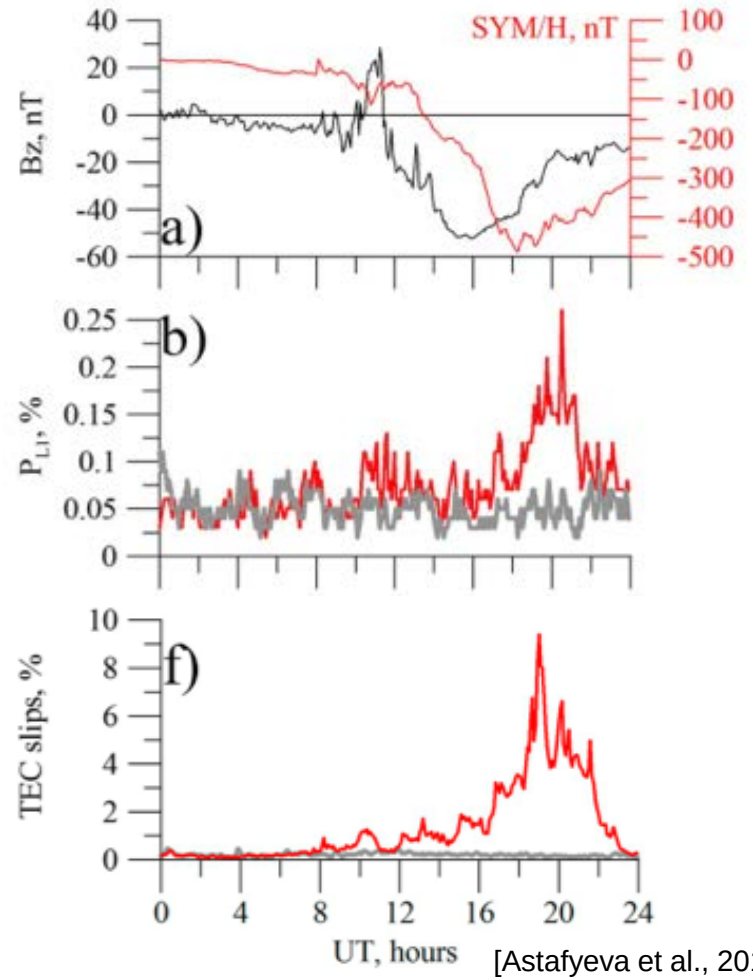
TEC is derived based on the time delay of the GPS radio signals through the ionosphere:

$$TEC = \int_{receiver}^{satellite} N_e(l)dl$$

TEC slip example



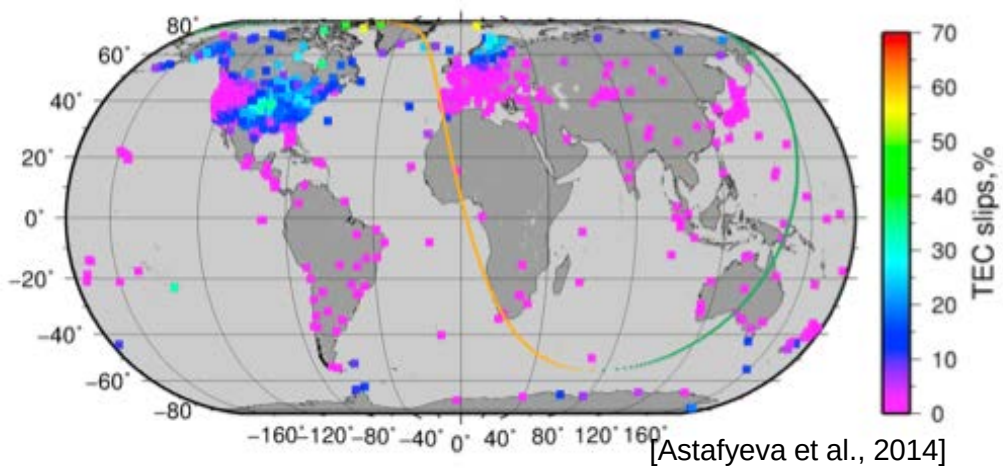
TEC slip during November 2003 storm



[Astafyeva et al., 2014]

Indicates regions of intense ionospheric irregularities

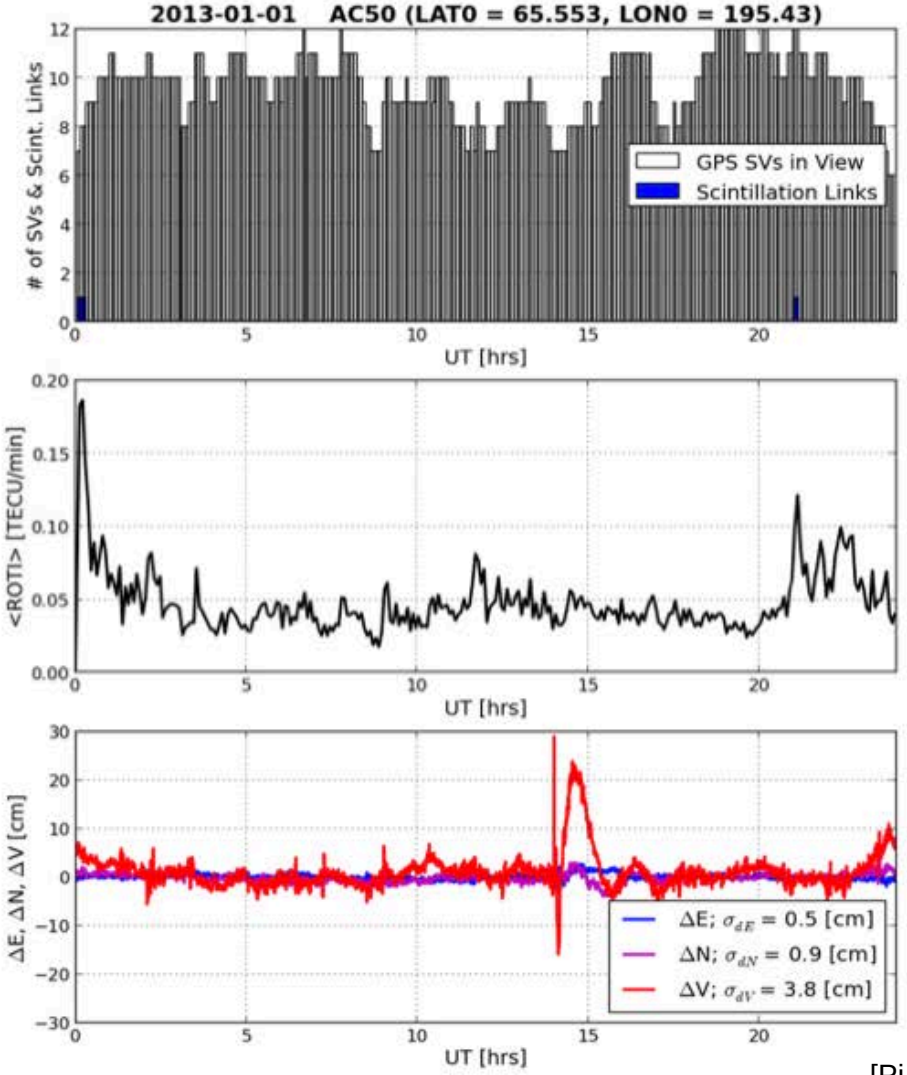
Global TEC slip distribution
19 UT, 20 November 2003



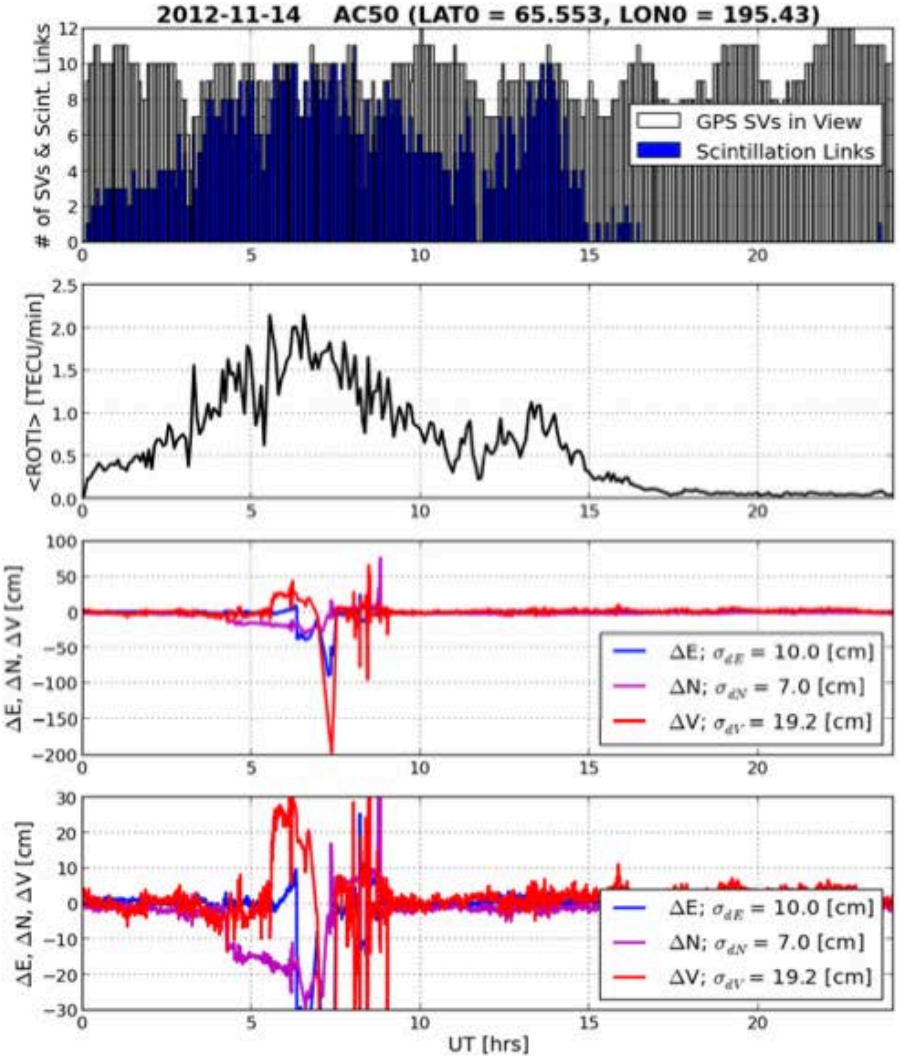
[Astafyeva et al., 2014]

Impact on GPS Positioning

Quiet



Geomagnetic storm



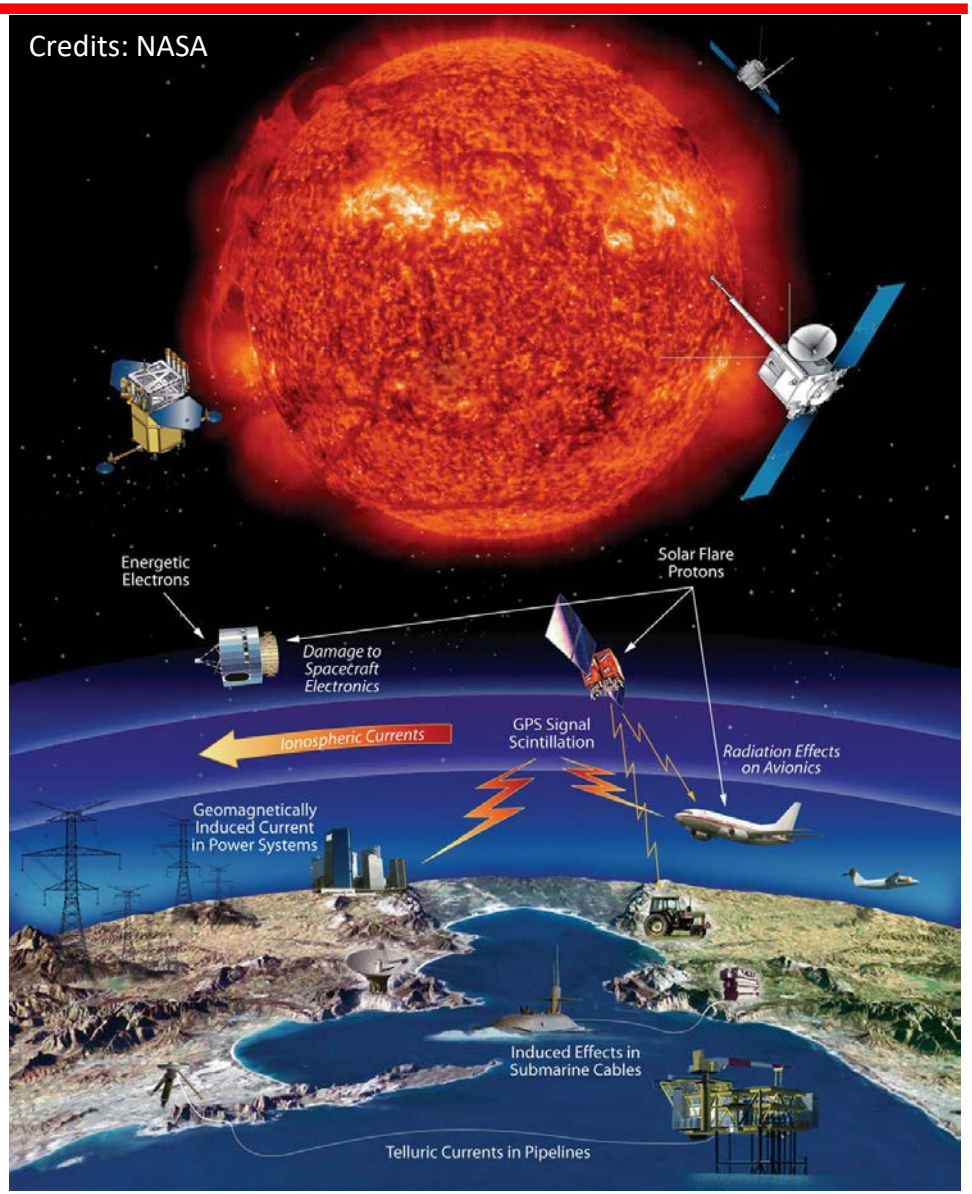
[Pi et al., 2013]

Summary

1. **Space weather events are can cause electron density disturbances in the ionosphere.**

2. **GPS signals travelling through the ionosphere are affected by these disturbances.**

3. **GPS positioning error greatly increases, or even lose the capability.**



References

- Astafyeva, E., Y. Yasyukevich, A. Maksikov, and I. Zhivetiev (2014), Geomagnetic storms, super-storms, and their impacts on GPS-based navigation systems, Space Weather, 12, 508–525, doi:10.1002/ 2014SW001072.
- Kintner, P. M., B. M. Ledvina, and E. R. de Paula (2007), GPS and ionospheric scintillations, Space Weather, 5, S09003, doi:10.1029/2006SW000260.
- Xiaoqing Pi, Anthony J. Mannucci, Bonnie Valant-Spaight, Yoaz Bar-Sever, Larry J. Romans, Susan Skone, Lawrence Sparks, and G. Martin Hall, Observations of Global and Regional Ionospheric Irregularities and Scintillation Using GNSS Tracking Networks, ION Pacific PNT, pp.752-761, 2013.