Use of GNSS Sensors in the Study of Space Weather

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Overview

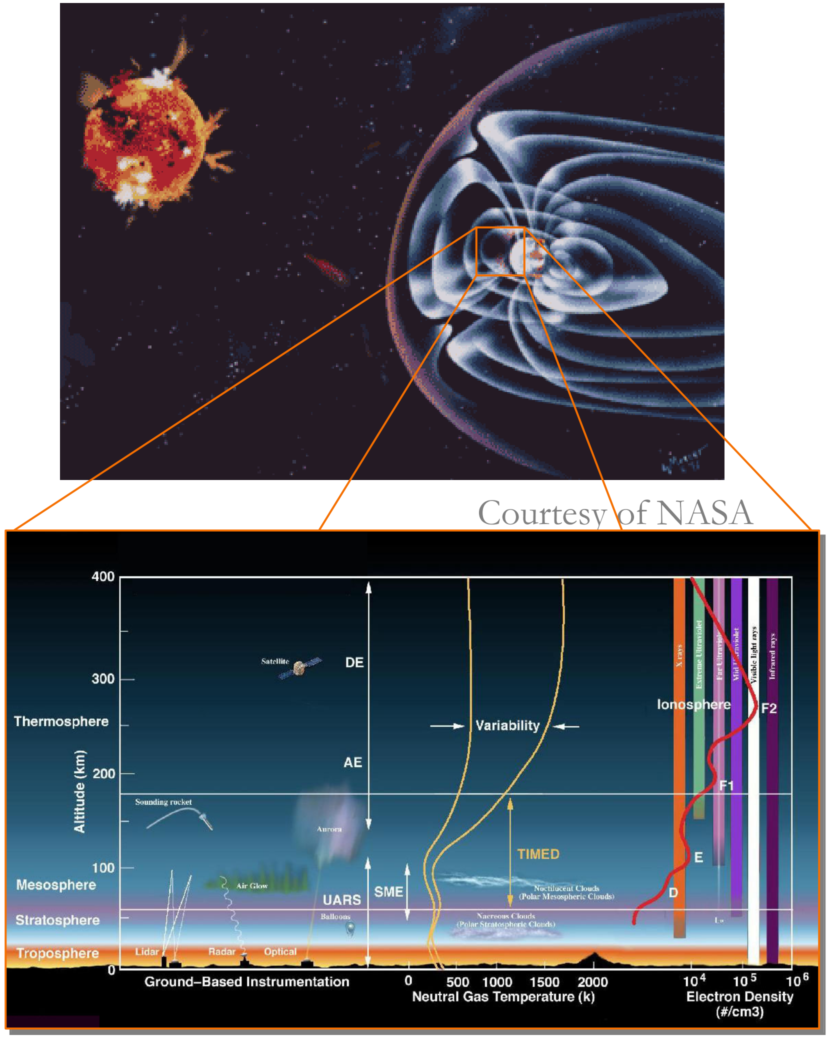
- What is “Space Weather”?
- Space Weather effects on GNSS
- Examples of use of GNSS in studying Space Weather
- The future of GNSS-based studies of Space Weather

Space Weather: A Definition

- The National Space Weather Program defines Space Weather as "the conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere than can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."
  - "As the world moves into the twenty-first century, our civilization is becoming increasingly dependent on technology which is vulnerable to conditions in the space environment."

Space Weather

- A large portion of Space Weather is driven by solar activity
  - Space Weather consists of both “typical” variations (diurnal, seasonal, yearly) and deviations from these conditions (e.g., storms)
- Some effects are internally generated within the Earth’s atmosphere/ ionosphere
- The typical state of the ionosphere is accounted for in GNSS applications using dual-frequency receivers, models, or differential techniques



Courtesy of NASA

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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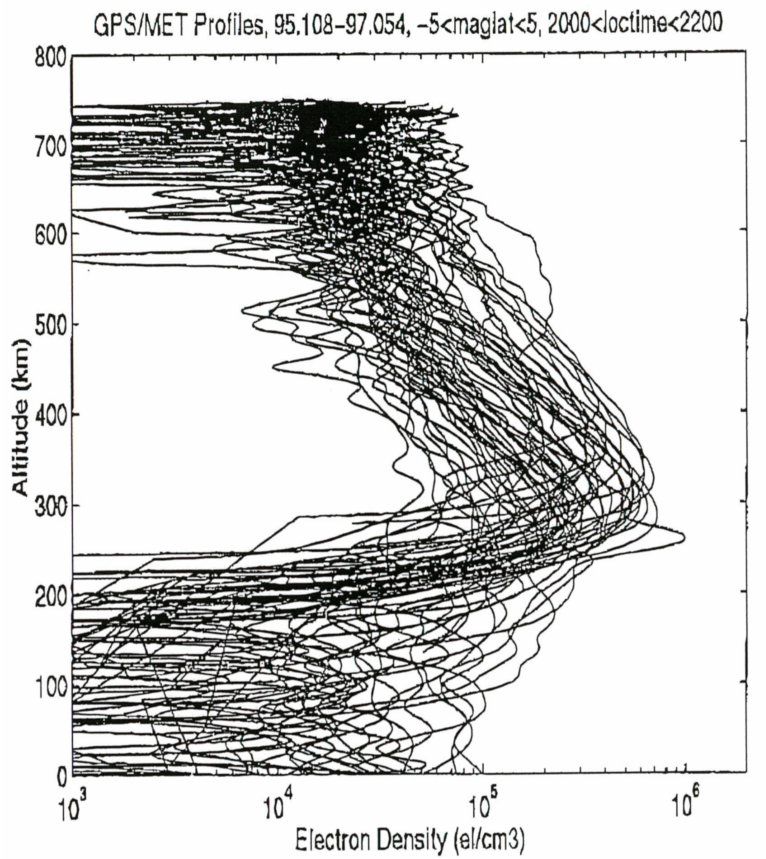
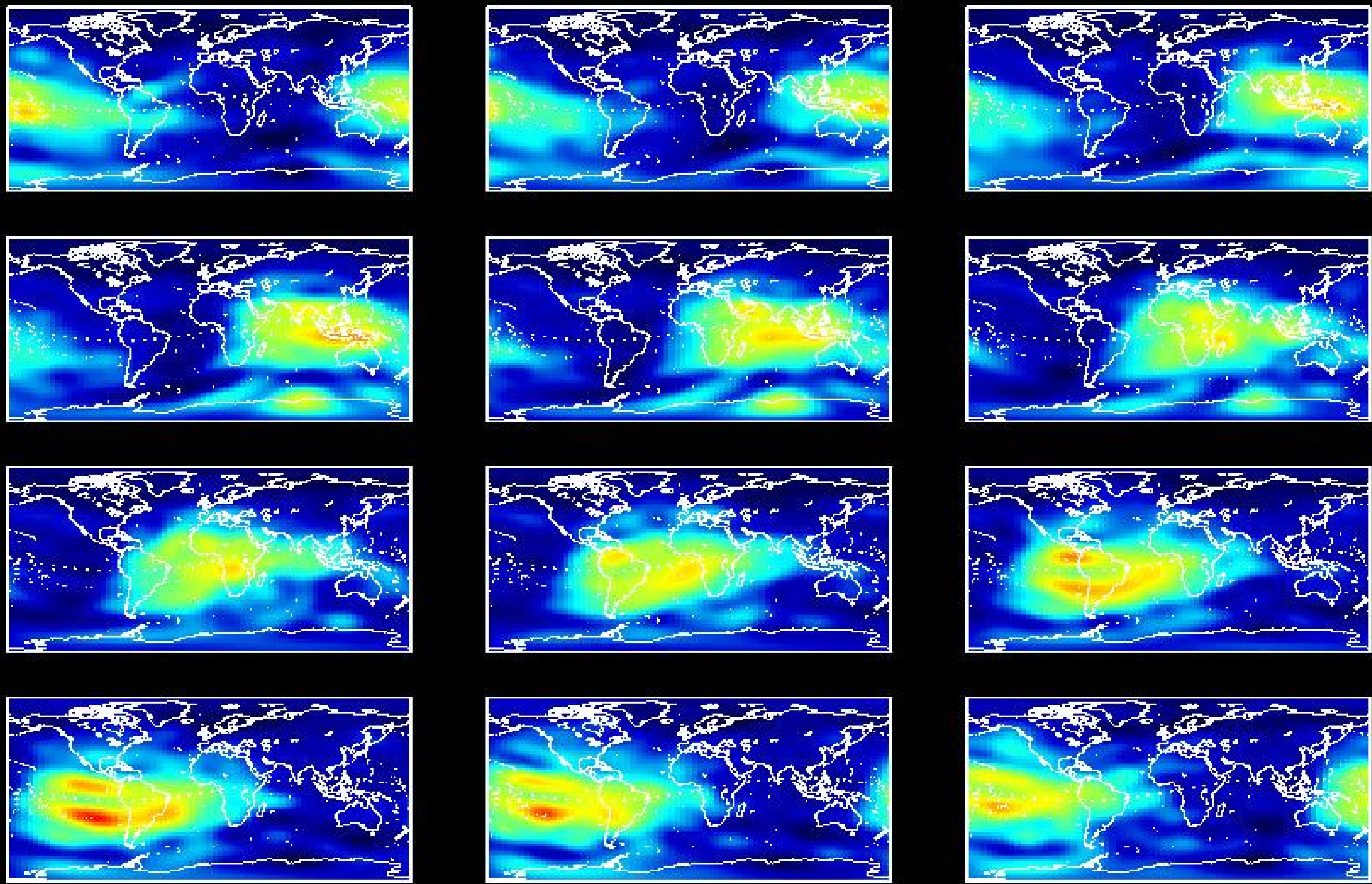


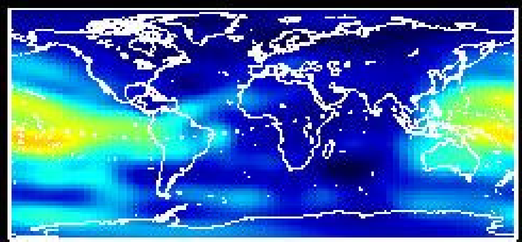
Space Weather Effects on GNSS

- Two primary effects of Space Weather on GNSS are:
  - Propagation delay of signals caused by the presence of the ionosphere
    - Increased errors in pseudorange and navigation solution
  - Loss of signal due to scintillation effects caused by small-scale irregularities in the ionosphere
    - Increased errors due to decreased numbers of useable satellites
    - Possible inability to navigate

GNSS Sensors as a Space Weather Tool

- The delay and scintillation caused by the ionosphere can be turned into a tool to probe the properties of the ionosphere
  - Compared to many other techniques (radar, imaging, satellites) GNSS provides inexpensive and plentiful sensors
  - One of the most-used data sources for current state-of-the-art assimilative models of the ionosphere

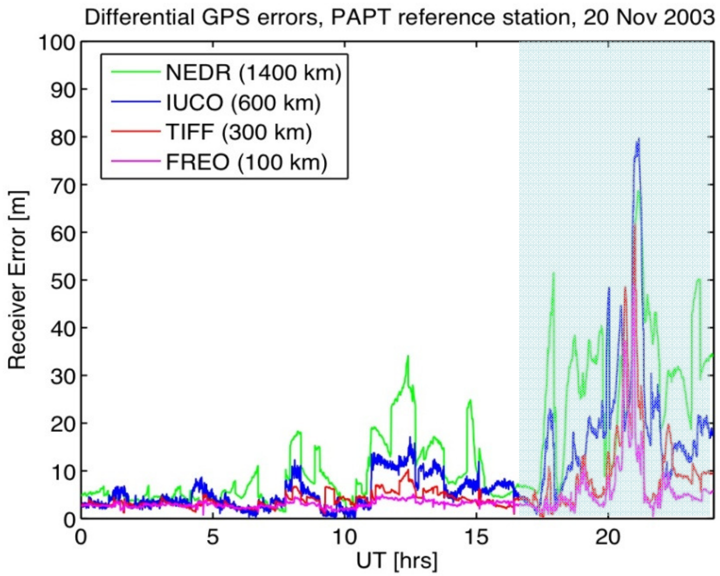


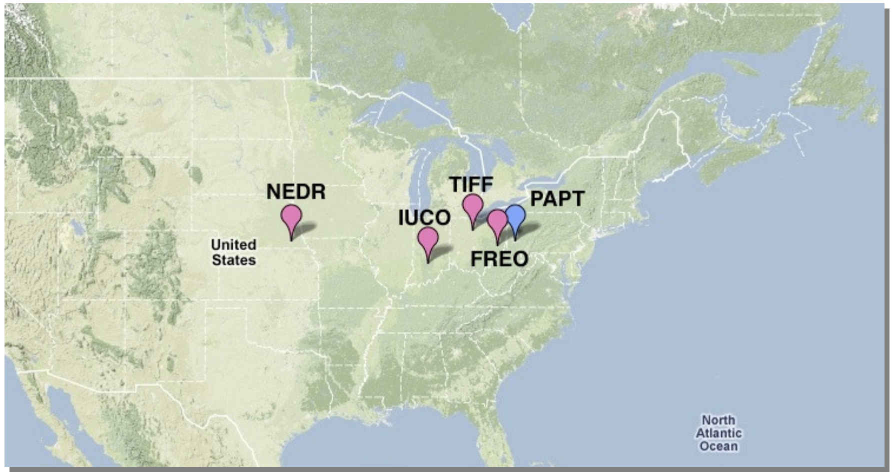


Data from the Atronomisches Institut
Der Universitat Bern

Ionospheric Delay: Ionospheric Gradients

- During large geomagnetic storms, severe gradients in the ionosphere can occur
  - Drastically different ionospheres seen from stations separated by ~100 km (or less!)
  - Differential errors can reach ~50 m over short baselines





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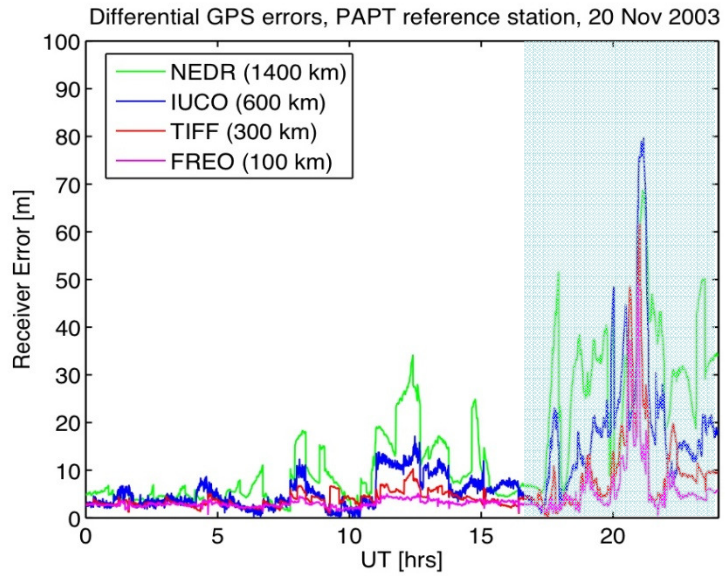
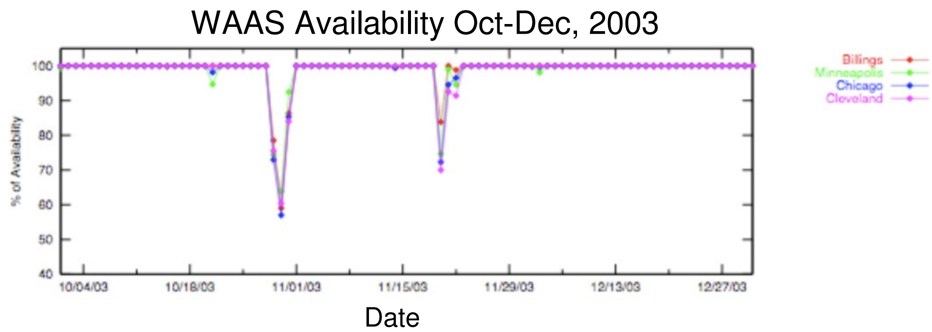
- Affects critical differential systems such as WAAS
  - % availability decreases on days with severe Space Weather

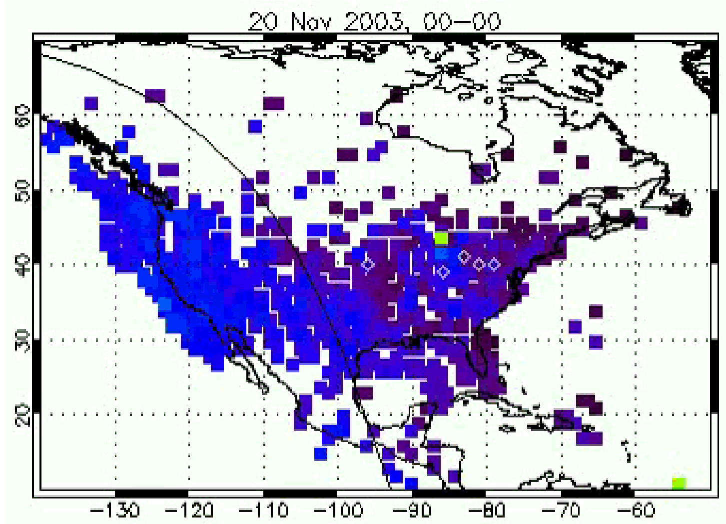


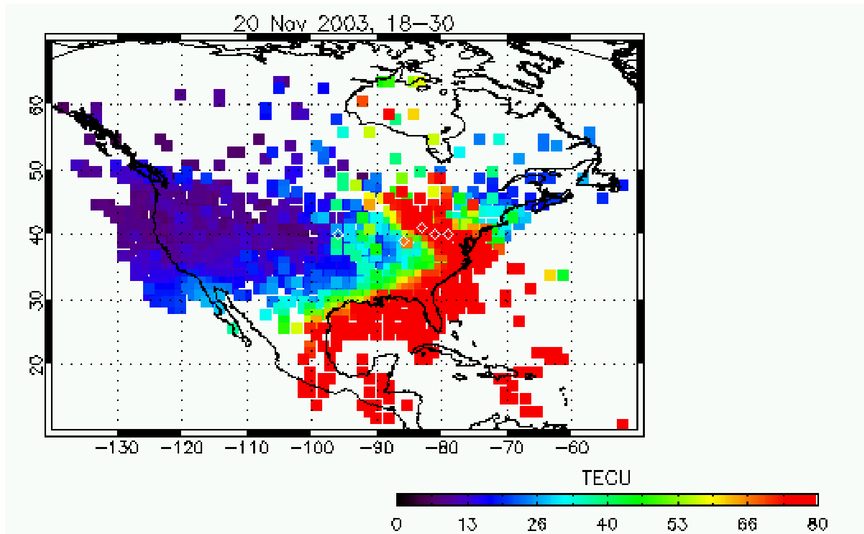


http://www.nstb.tc.faa.gov/DisplayArchive.htm

Ionospheric TEC maps

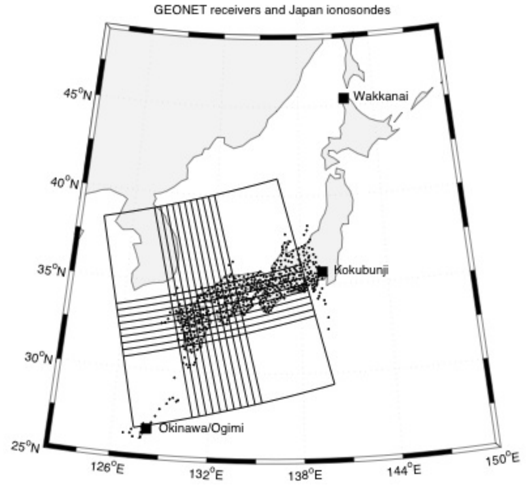
- Combining data from local, regional, and national networks of GNSS receivers large-scale ionospheric phenomena have been studied in detail
  - These networks have provided the first “continent-scale” ionospheric monitoring tool that is continuously operational
- As more receivers come on-line, the spatial resolution of these maps increases
  - Leads to a better understanding of the physics

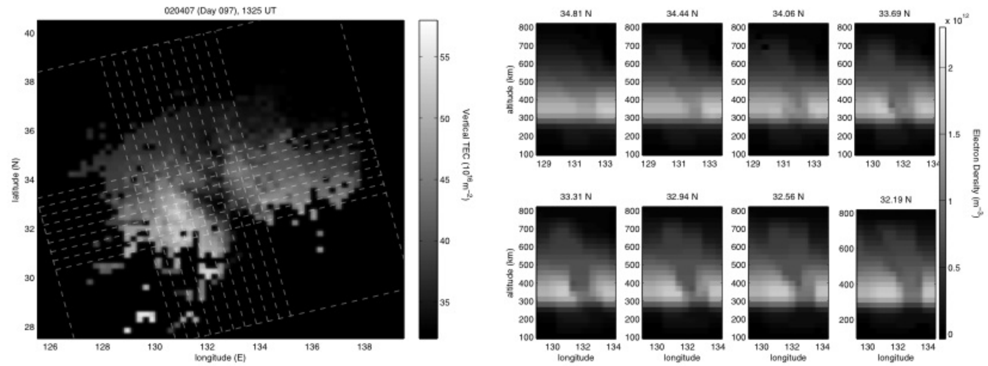




Ionospheric Tomography

- In regions of dense receiver coverage, GNSS data can be used to perform ionospheric tomography
  - recover four-dimensional ionospheric structure
- Improvements will come from:
  - increasing the diversity of available look directions from a given receiver (more satellites)

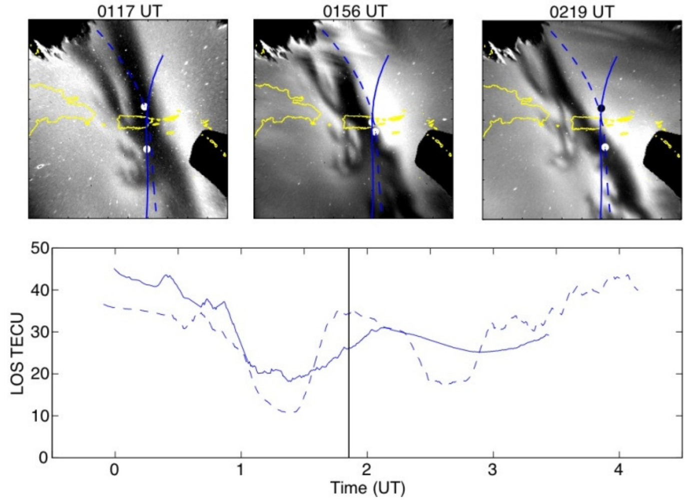




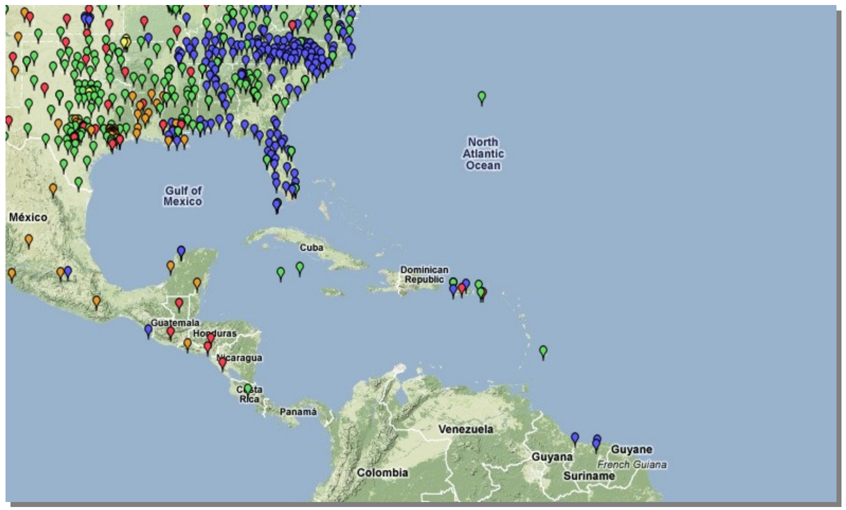
Lee et al., *Radio Sci.*, 2008

Current Limits of GNSS Technologies

- In regions of the world with sparse land masses, it is difficult to create dense networks of receivers
  - Limits obtainable spatial resolution and achievable coverage
- In many locations of interest, power is difficult to come by
  - Limits where receivers can be deployed
- Improvements will come from (inexpensive) receivers that:
  - can track signals from multiple GNSS platforms
  - consume minimal power

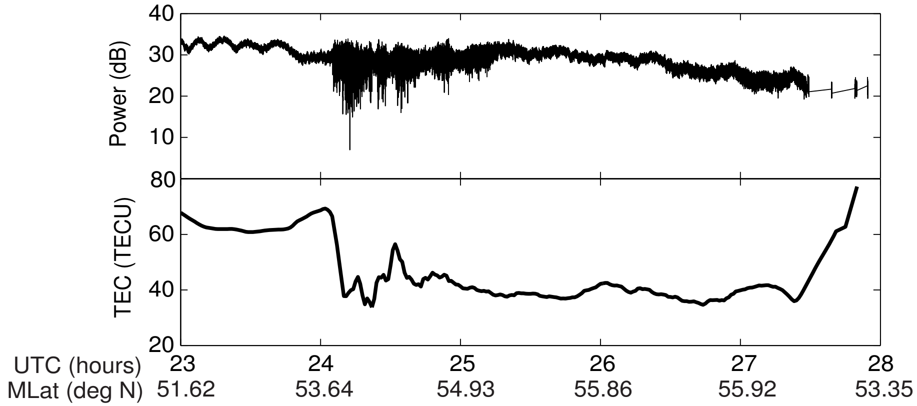


Makela et al., *Radio Sci.*, 2001

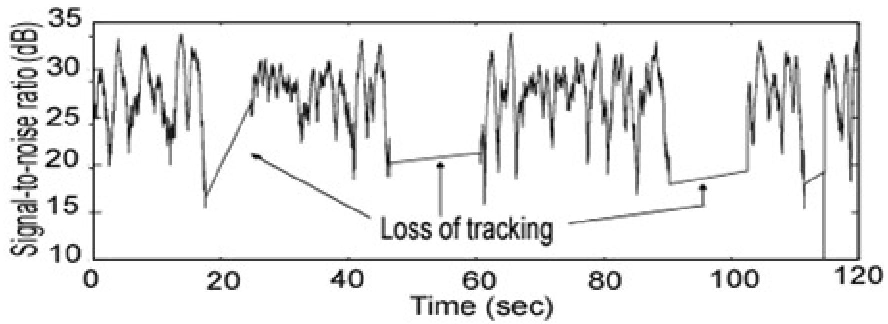


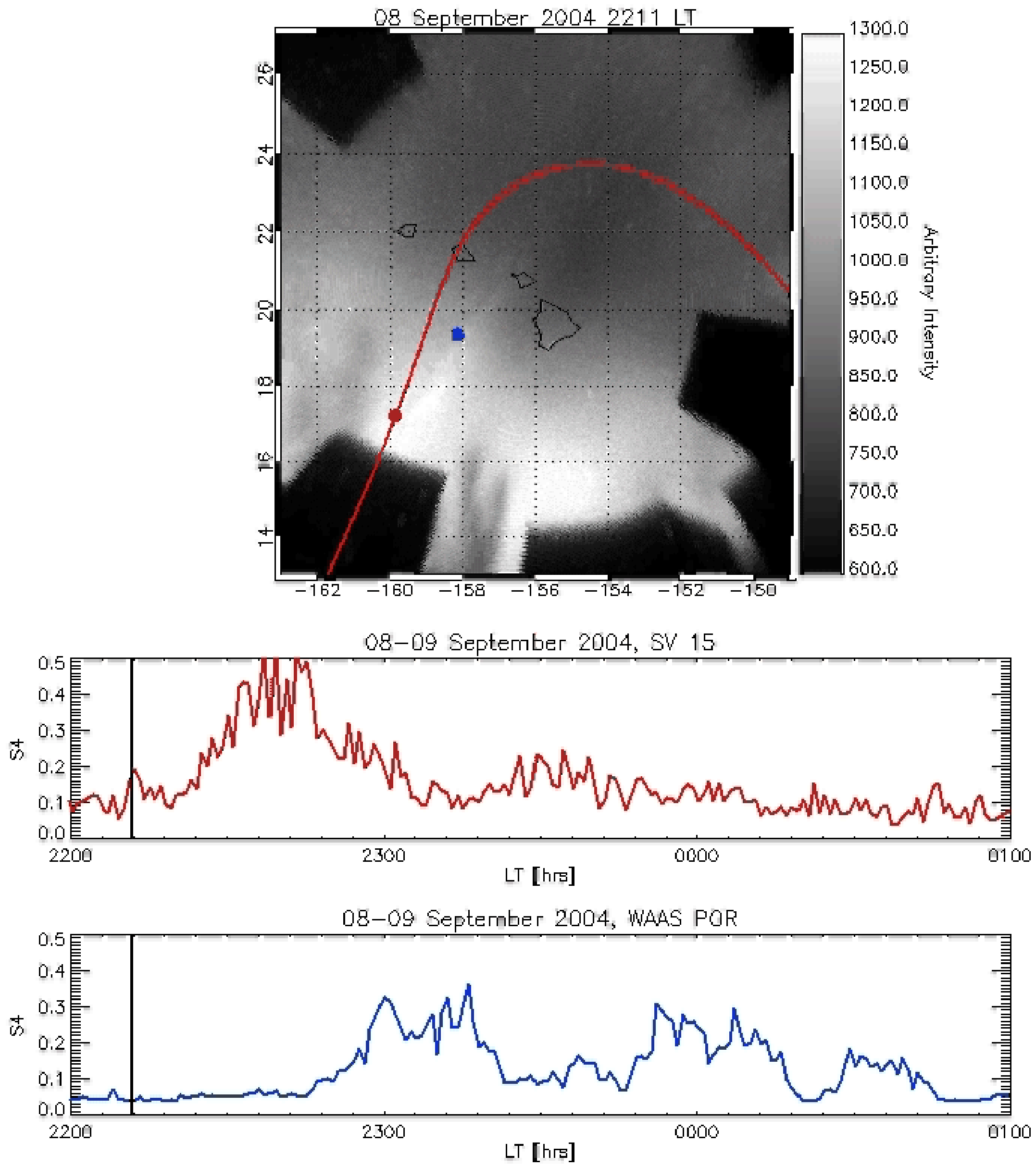
Ionospheric Scintillation

- Electron density fluctuations ordered on the scale of the Fresnel length diffract radio waves
  - cause large fluctuations in received power which can cause tracking loop failure
  - for GPS L1, structures on the order of ~250 m are pertinent



Ledvina et al., *Geophys. Res. Lett.*, 2002

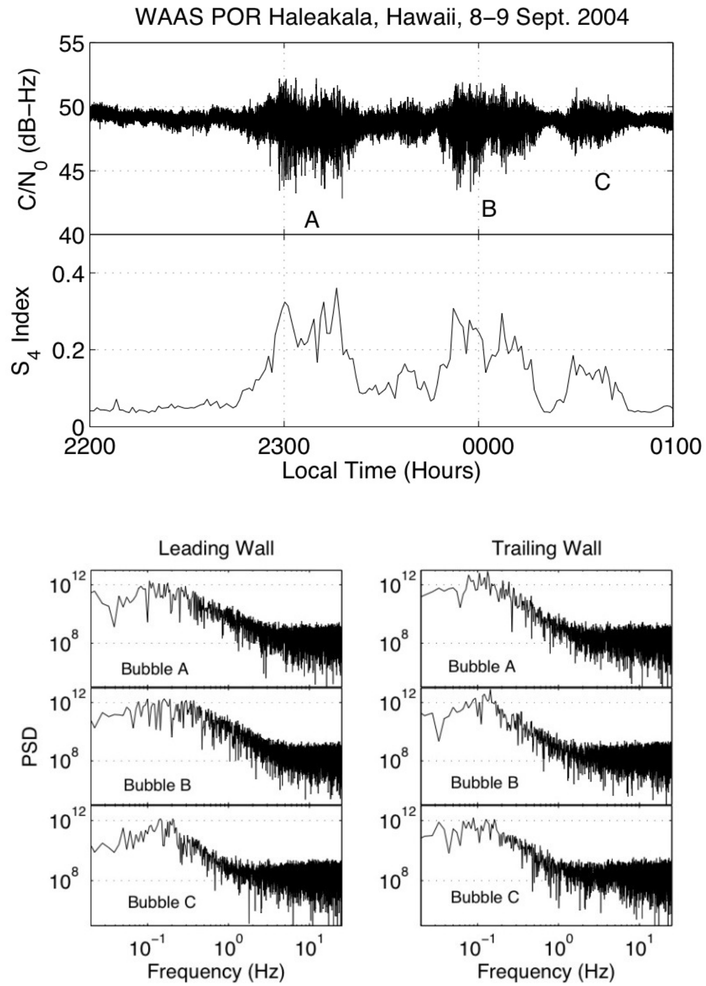




Ledvina and Makela, *Geophys. Res. Lett.*, 2005

Ionospheric Scintillation

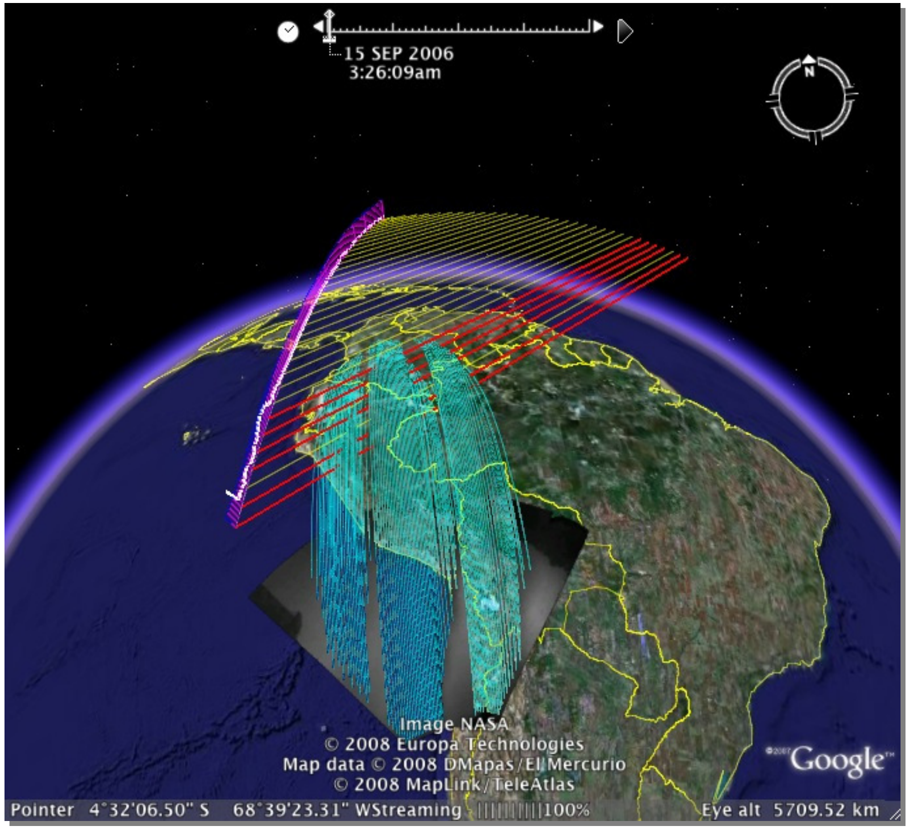
- Spectral characteristics of received signal power fluctuations reveal insights into physical processes
  - requires rapid sampling of received signal power during periods of scintillations
- Improvements will come from:
  - (inexpensive) receivers that track open signals at frequencies other than L1
  - more satellites at GEO transmitting GNSS signals



Ledvina and Makela, *Geophys. Res. Lett.*, 2005

Occultation Sounding of Ionosphere

- Imaging sensors can detect regions of scintillation-causing irregularities through their optical signature
- Combining with COSMIC occultation data, can estimate the scattering-layer altitude of field-aligned regions



Miller and Makela, *J. Geophys. Res.*, in press

Future Needs

- The expected growth in GNSS signals in the coming decade represents a potential boon for ionospheric research, as long as signals are open and interoperable
  - increased number and diversity of look angles provide higher resolution tomographic reconstructions
  - increased data points useful for TEC measurement coverage on islands for more complete ionospheric maps
  - increased number of frequencies useful for studying spectral characteristics of irregularity regions
- Requires inexpensive, low-power, dual- (or tri-) frequency GNSS receivers providing access to low-level data
  - aid in deploying to remote areas
  - aid in deploying dense networks
- Long-term data sets are required, integrating data from multiple networks

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