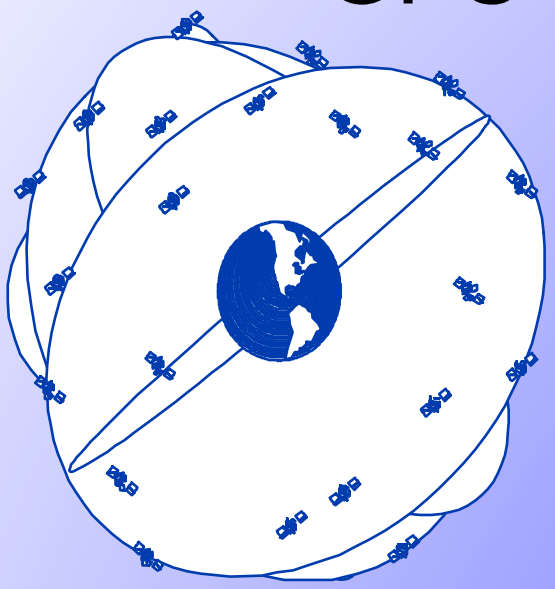
An Analysis and Exploration of TEC & Scintillation Data from the CASES GPS Receiver

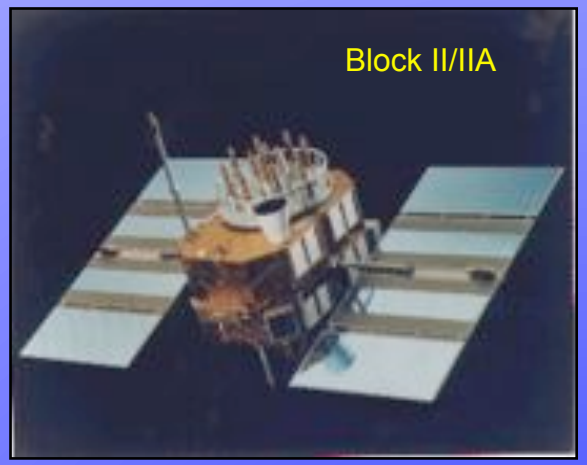
Chana Tilevitz, SUNY Stony Brook
chana.tilevitz@stonybrook.edu
Mentors: Adam Reynolds, Irfan Azeem, Geoffrey Crowley, ASTRA, LLC

Outline

- GPS
  - Overview, uses
- Scintillation
  - What is it, why does it matter?
- CASES
  - What makes this receiver different from all other receivers?
- TEC and biases
- Radio Occultation

GPS Space Segment





- 24-satellite (nominal) constellation
- Six orbital planes, four satellites per plane
  - 55 deg inclination
- Semi-synchronous, circular orbits (~20,000 km altitude)

GPS Uses

- Navigation
  - taxi routes
  - FAA/ATC
  - Tracking cattle, wildlife
- Geodetic
  - Earthquake prediction
  - Iceberg tracking
  - Precise Surveying
- Earth Science
  - Water vapor measurements
  - **Ionospheric Mapping**

GPS

- The true range can be found using the following equation—

$$P = \rho + c(t_u - \delta_t + \delta_{t_D})$$

t_u =receiver clock offset

δ_t =satellite clock offset

ρ =true range

P = pseudorange

$$\delta_{t_D} = \delta_{t_{atm}} + \delta_{t_{noise}} + \delta_{t_{mp}} + \delta_{t_{hw}}$$

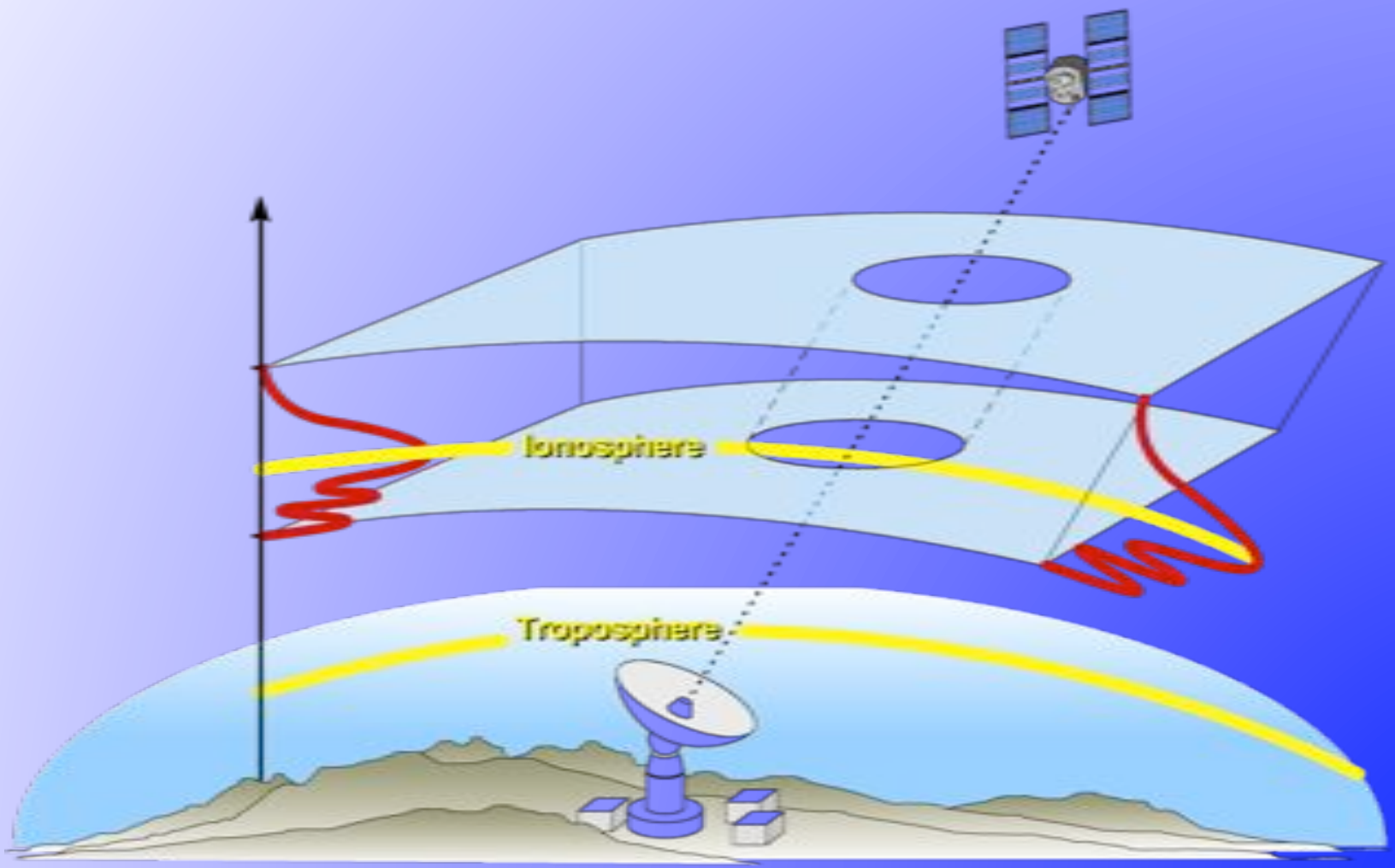
$\delta_{t_{atm}}$ =atmospheric delay (troposphere+ionosphere)

$\delta_{t_{noise}}$ =error from receiver noise

$\delta_{t_{mp}}$ =multipath offset

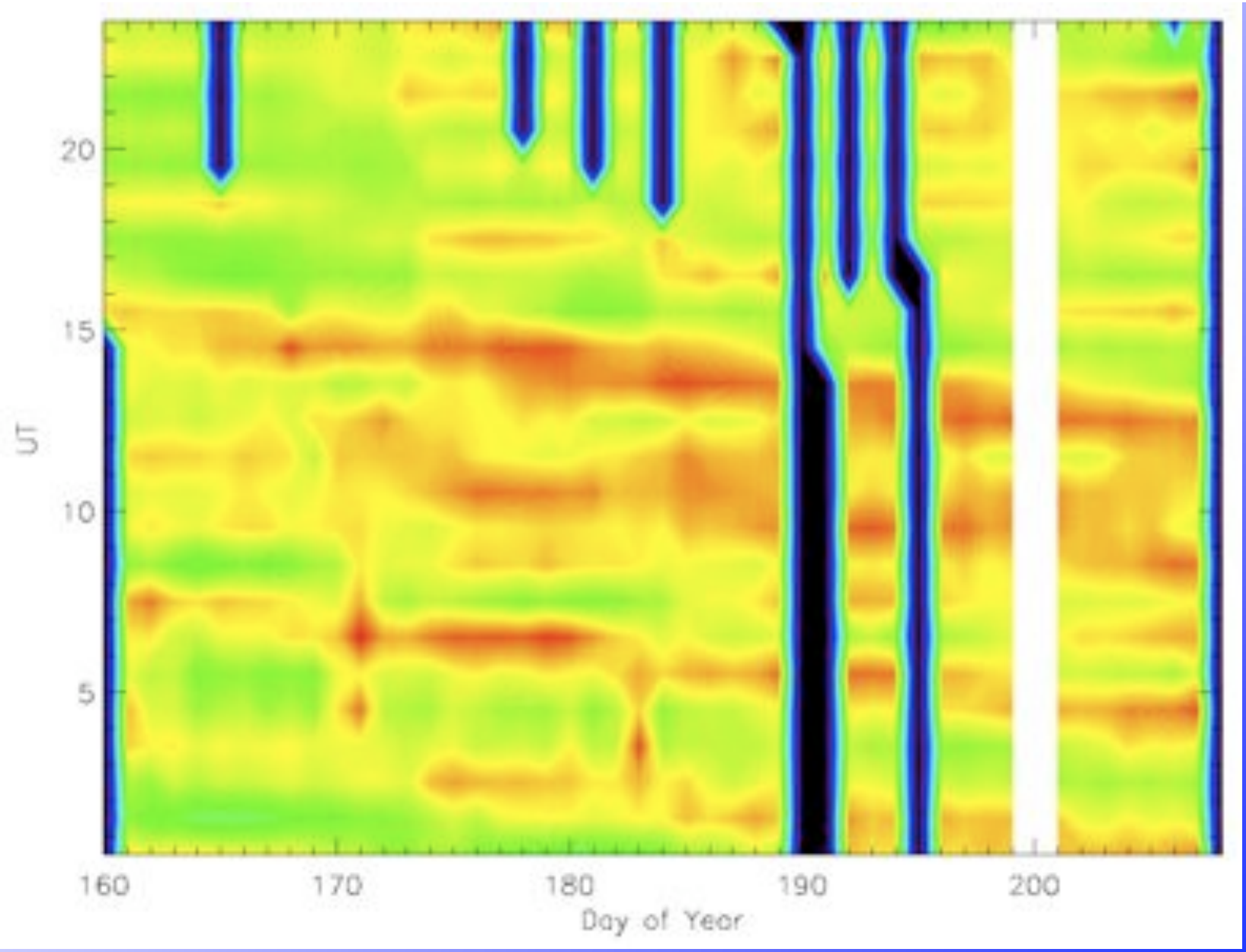
$\delta_{t_{hw}}$ =receiver hardware offset

Atmospheric Propagation



Scintillation

- When concentrations of free electrons in the ionosphere are disturbed, they can scatter and modify radio signals—this is scintillation.
- There are two forms of scintillation that affect GPS
  - Amplitude scintillation occurs mostly at lower latitudes and is characterized by an abrupt, severe fade in signal level, which can drop the level below the GPS receiver's threshold for maintaining lock.
  - Phase scintillation occurs mostly at higher latitudes and is characterized by rapid phase changes in the carrier wave, which make a signal hard to track, and can also cause the receiver to lose lock.



Scintillation map in Boulder, CO (range: 0-.04)

Global Scintillation Map

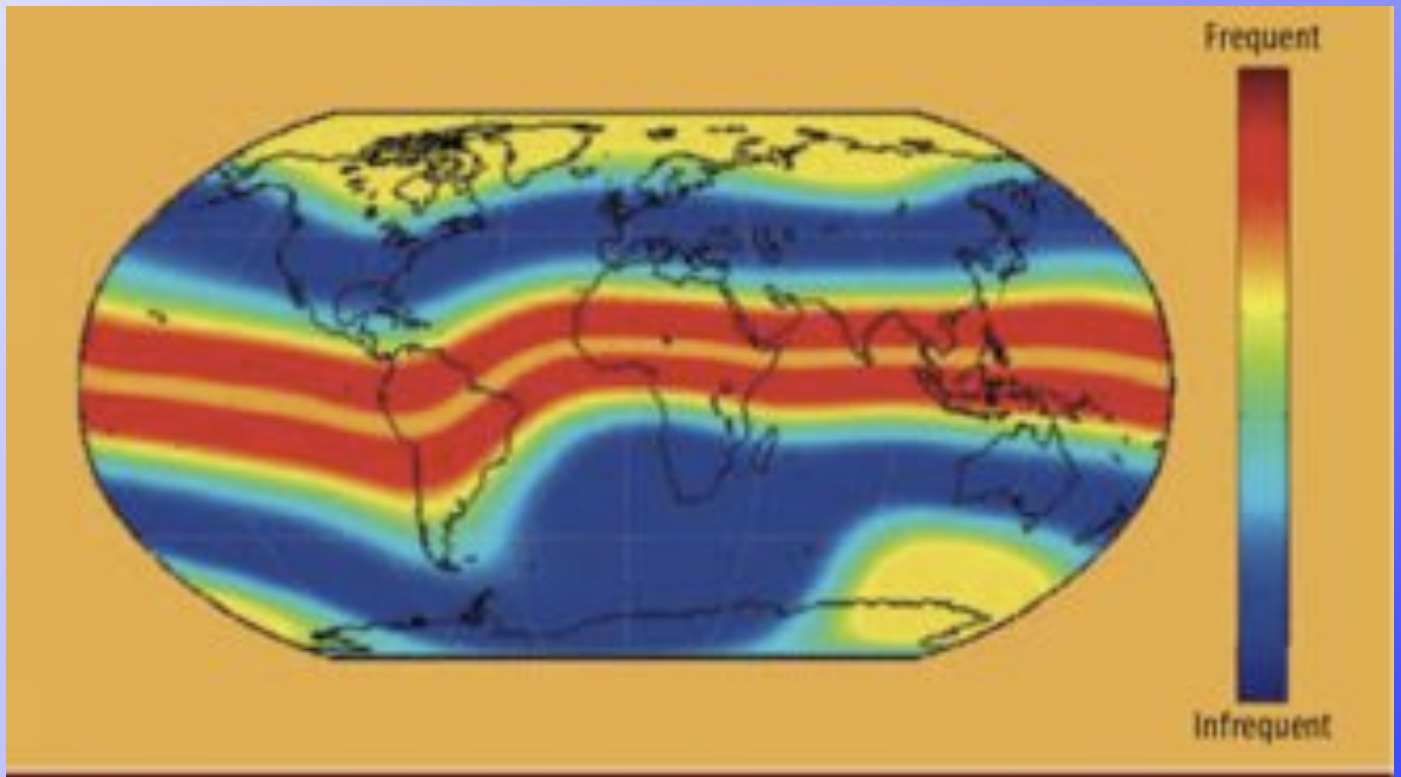


FIGURE 1 Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.

P. Kintner (2009)

CASES

(Connected Autonomous Space Environment Sensor)

- Can maintain satellite lock during atmospheric scintillation, rather than losing lock like most receivers
- Software-based, which makes it inexpensive to produce and very easy to modify
- Limited to L1 and L2C frequencies, because of software constraints

GPS & TEC

- TEC refers to the path-integrated number of electrons located between the GPS satellite and receiver
- A dual-frequency GPS receiver can be used to keep track of the TEC

$$\delta t_{L1} - \delta t_{L2} = \frac{40.3 * TEC}{c} \frac{f_{L1}^2 - f_{L2}^2}{f_{L1} f_{L2}}$$

$\delta t_{L1}, \delta t_{L2}$ =the clock-offsets of the individual signal frequencies

Biases in GPS

- All satellites and receivers have inherent biases that have an effect on relative L1-L2 delay

$$\delta t_{L1} - \delta t_{L2} = \frac{40.3 * TEC}{c} \frac{f_{L1}^2 - f_{L2}^2}{f_{L1} f_{L2}}$$

$\delta t_{L1} - \delta t_{L2}$ becomes $(\delta t_{L1} - \delta t_{L2}) + bias$

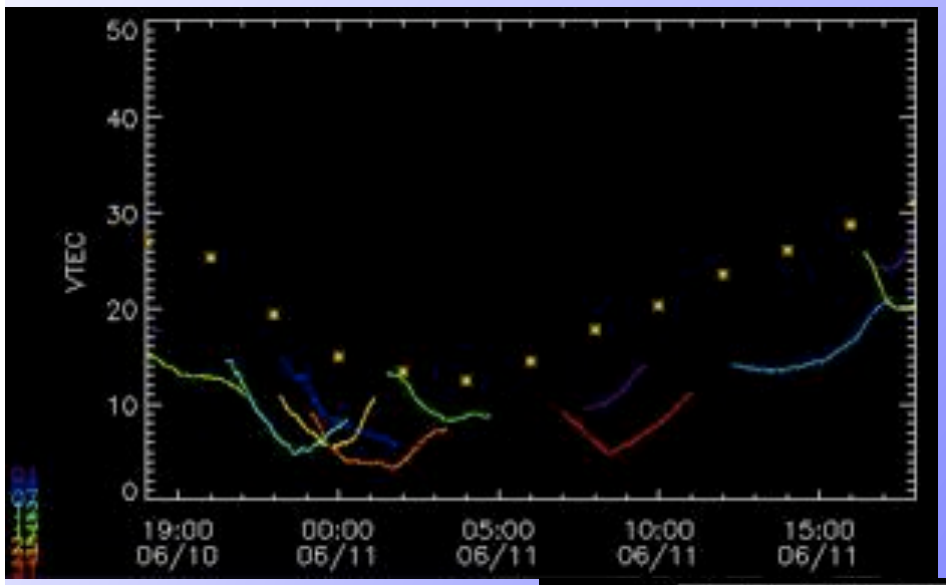
- Some of these biases are known and accounted for, but the L2C bias is not published, so it must be found another way.
- Why is debiasing necessary?

$$VTEC = (STEC + bias) * \sqrt{(1 - (\cos(elevation * \frac{\pi}{180}) / (1 + \max hgt / R_e))^2)}$$

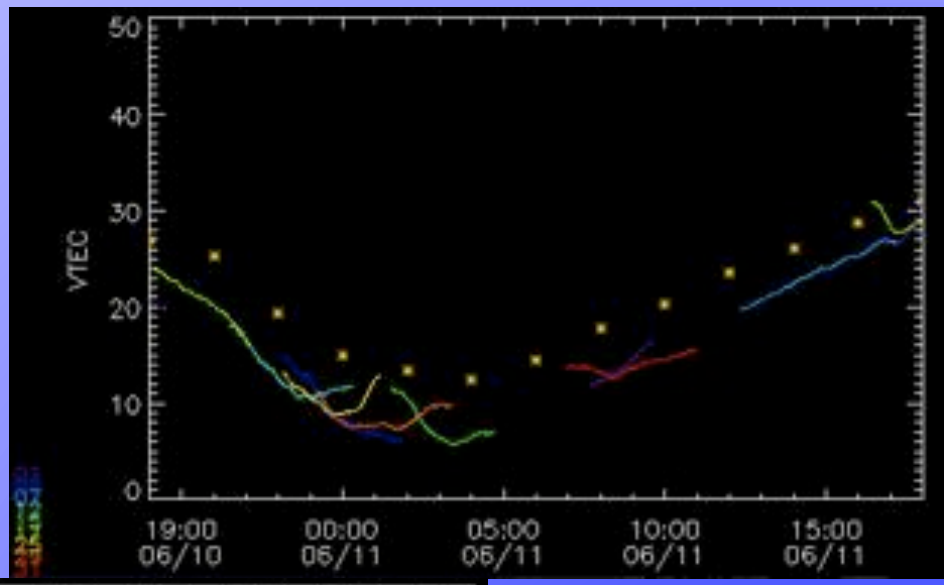
Objectives: Debiasing

- Manually manipulate biases, use trial-and-error to fit the VTEC to a curve
- Automate the process using IGS data as a reference point
- Integrate debiasing algorithm into real-time processing software

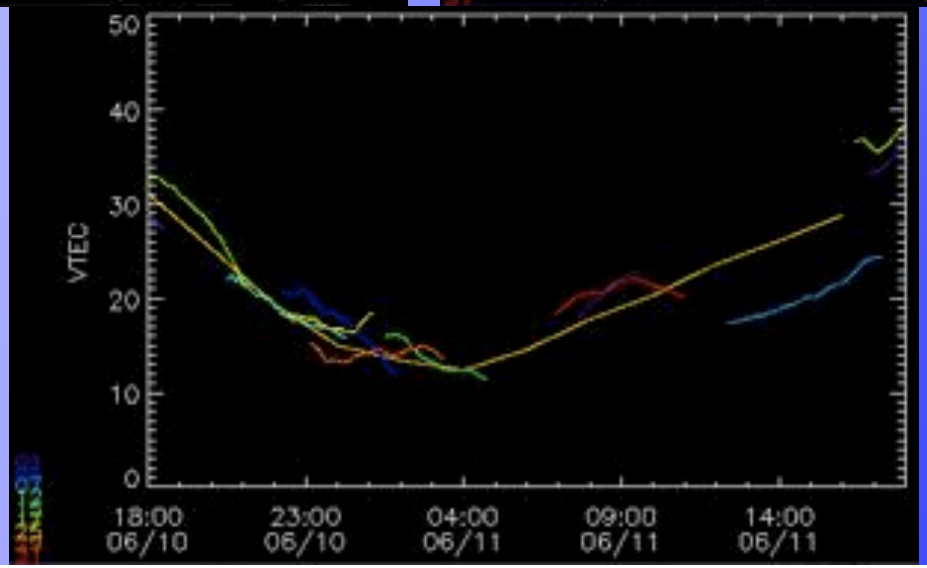
Results: Debiasing I



Biased VTEC



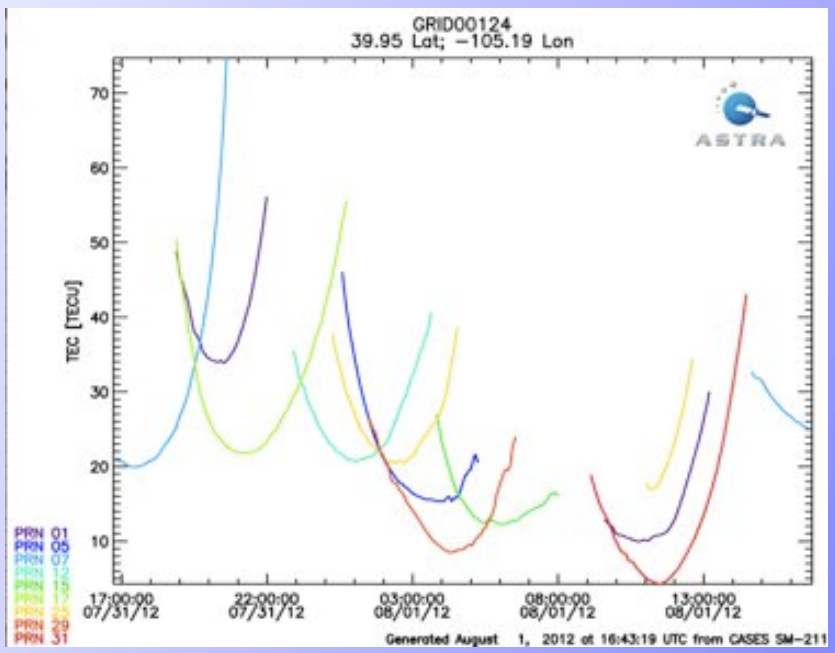
Manually debiased VTEC



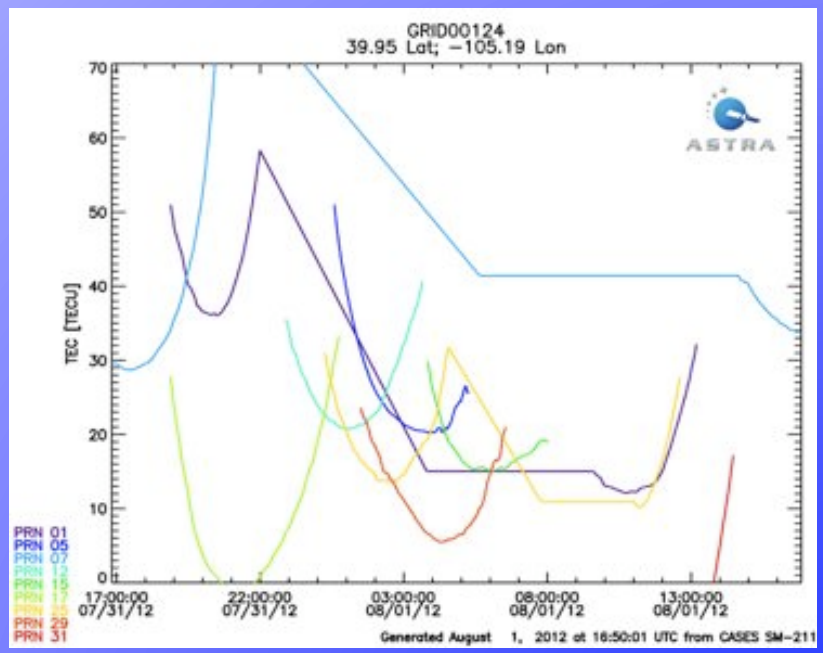
Automatically debiased VTEC

Results: Debiasing II

- Integrated into the real-time system—



Biased real-time TEC



Debiased real-time TEC

- Some improvement, more work still required

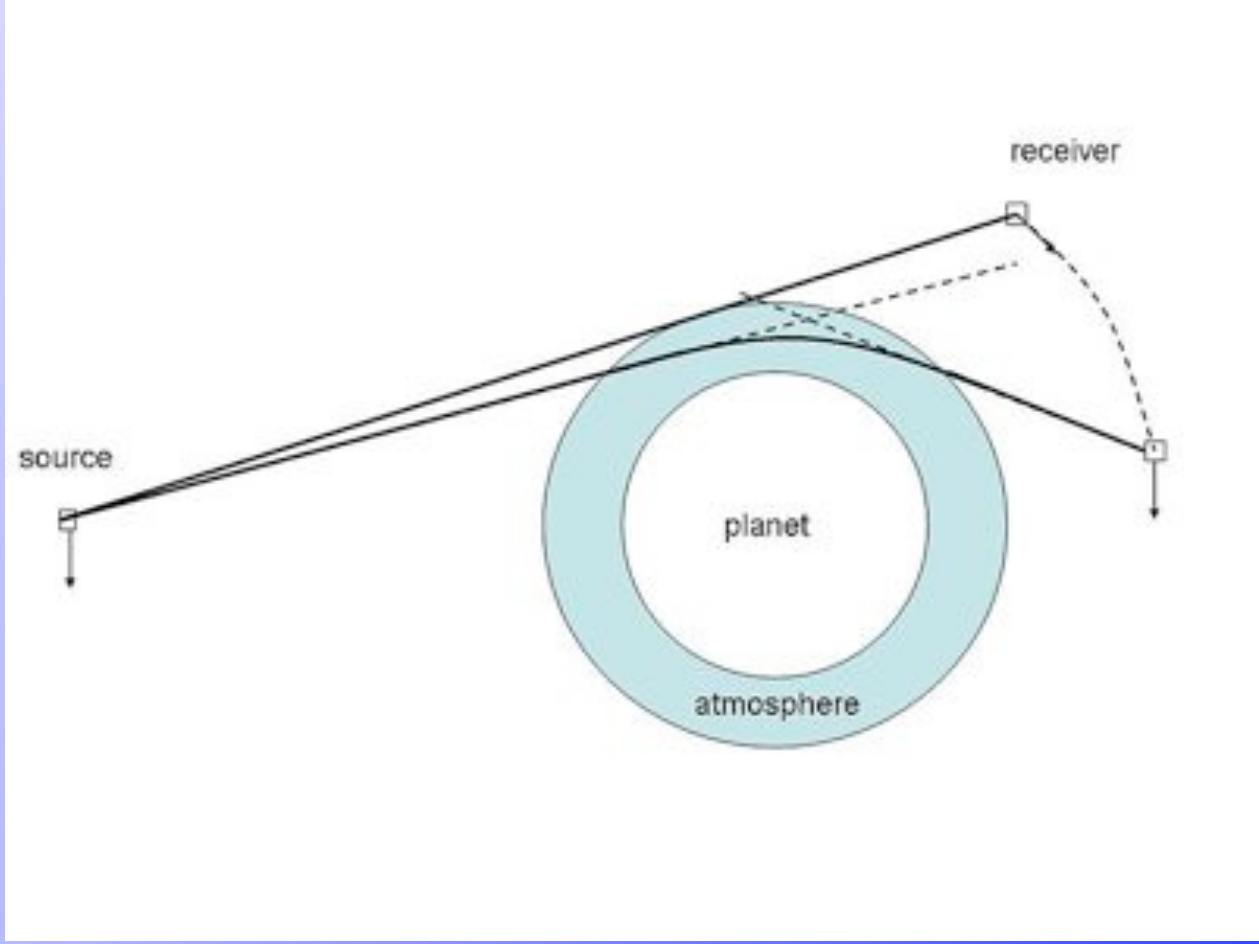
Conclusion/Further Work: Debiasing

- Automation provides a significant improvement in the accuracy of VTEC measurements
- Adaptation for real-time still needs work
- Is there any way to make the automated debiasing independent of the IGS data?

Radio Occultation

- Uses the refraction of the satellite signal in the atmosphere to measure atmospheric properties such as temperature and water vapor content
- Normally done between GPS satellites and receivers on satellites in low-Earth orbit
- CASES will be put on a high-altitude balloon to test the quality of radio occultation measurements that can be made from within the atmosphere

Radio Occultation



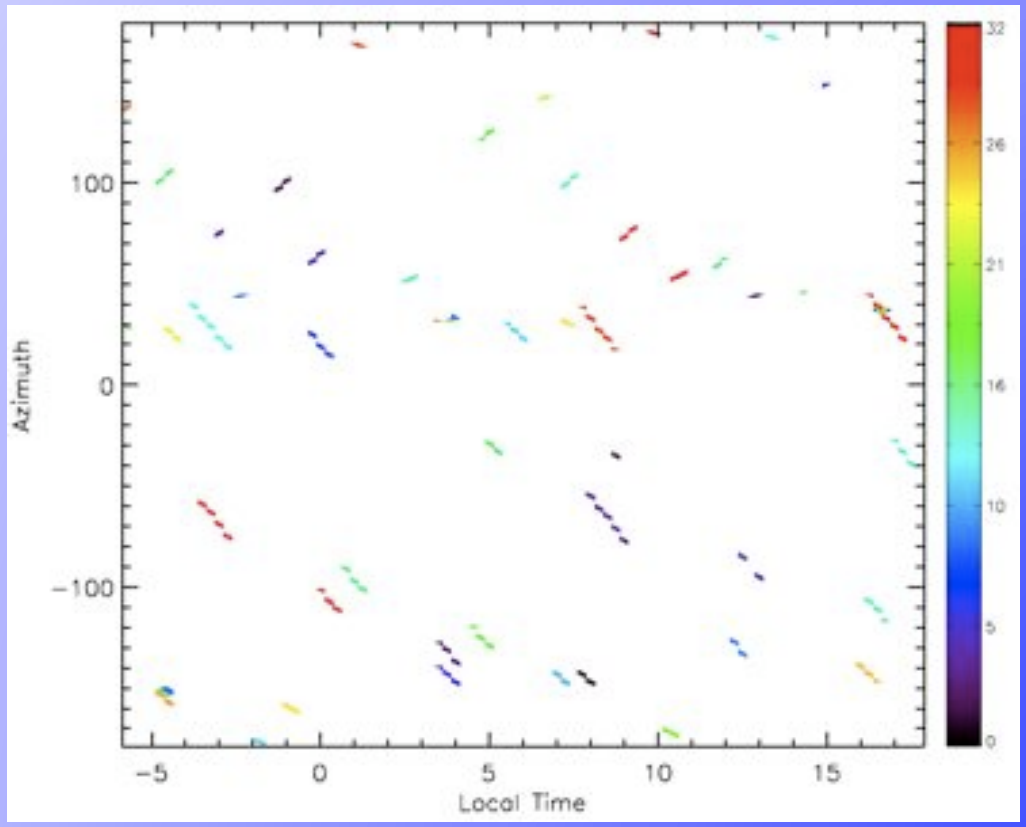
Schematic of RO using a space-based receiver (Wikipedia)

Objectives: Radio Occultation

- Demonstrate radio occultation from the top of a mountain
  - Discover direction of setting satellites
  - Find test-location with view down to ground level in that direction
  - Assemble receiver and other required test equipment

Results: Radio Occultation I

- In what direction do we look?



Map of setting satellite azimuths and times

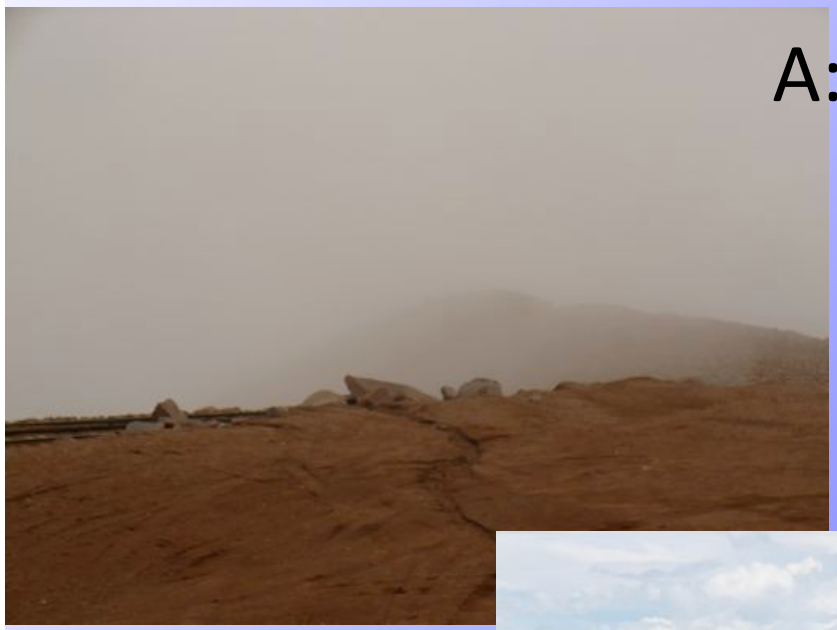
Results: Radio Occultation II

- Where do we look?

Location, Location, LOCATION!

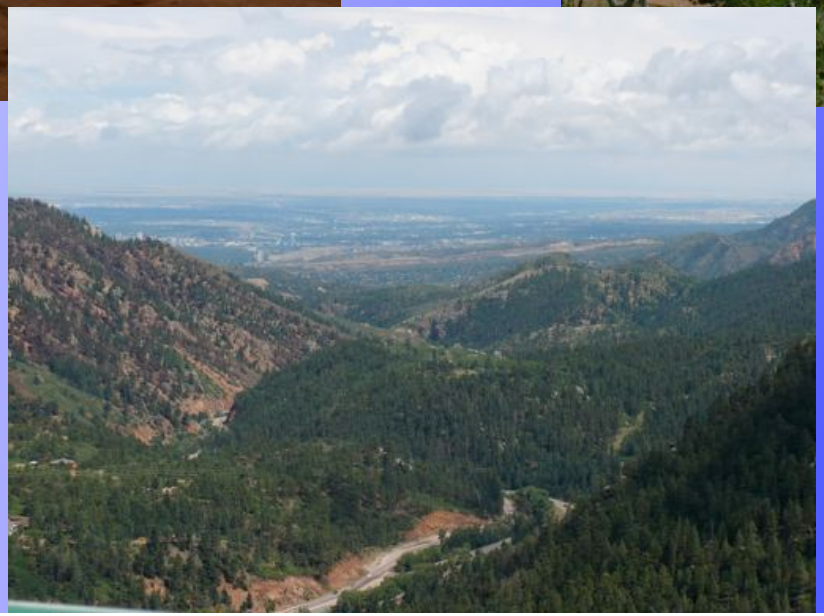
Results: Radio Occultation II

A: Pike's Peak



Bad day to go

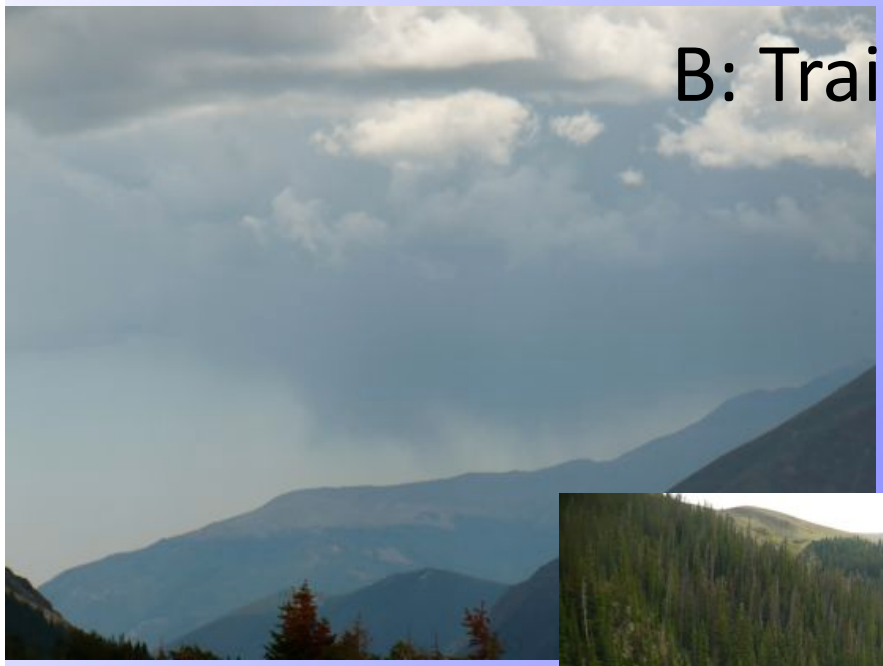
Mountains everywhere

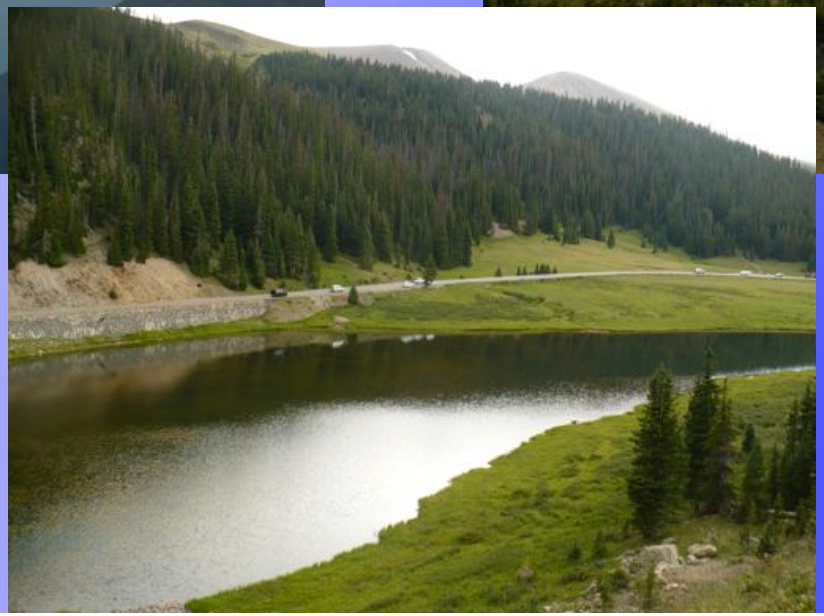


Field of view too narrow

Results: Radio Occultation II

B: Trail Ridge Road





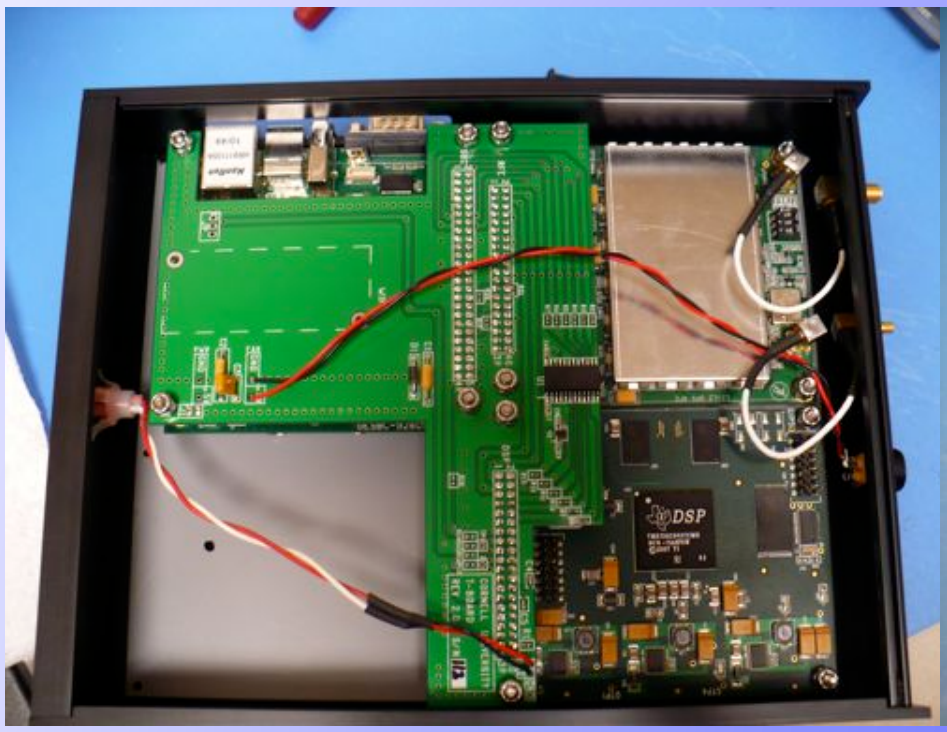
Mountains,
mountains,
everywhere

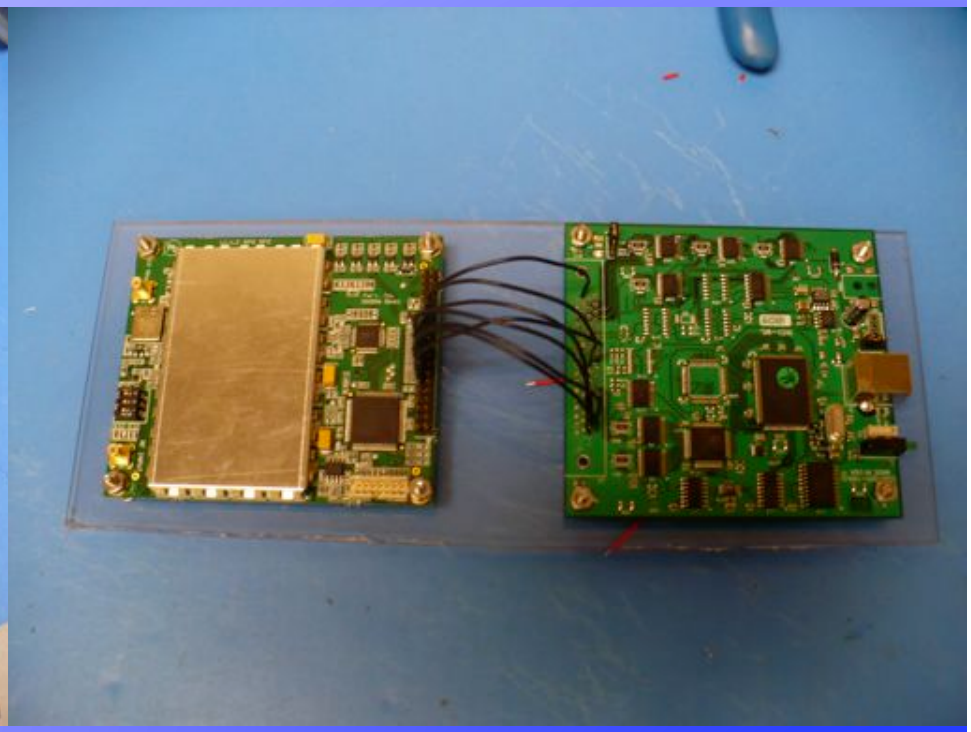
Results: Radio Occultation II

Juuuuuuuuuust right!

Results: Radio Occultation III

- Assembling the test receiver



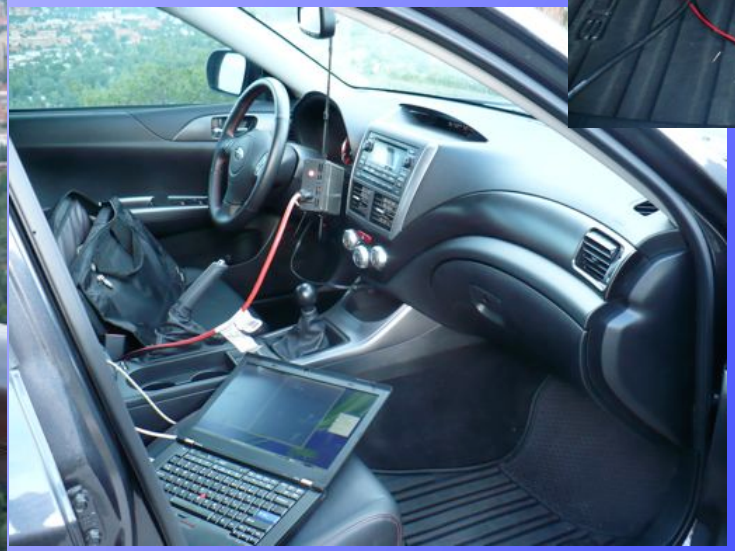


Before

After

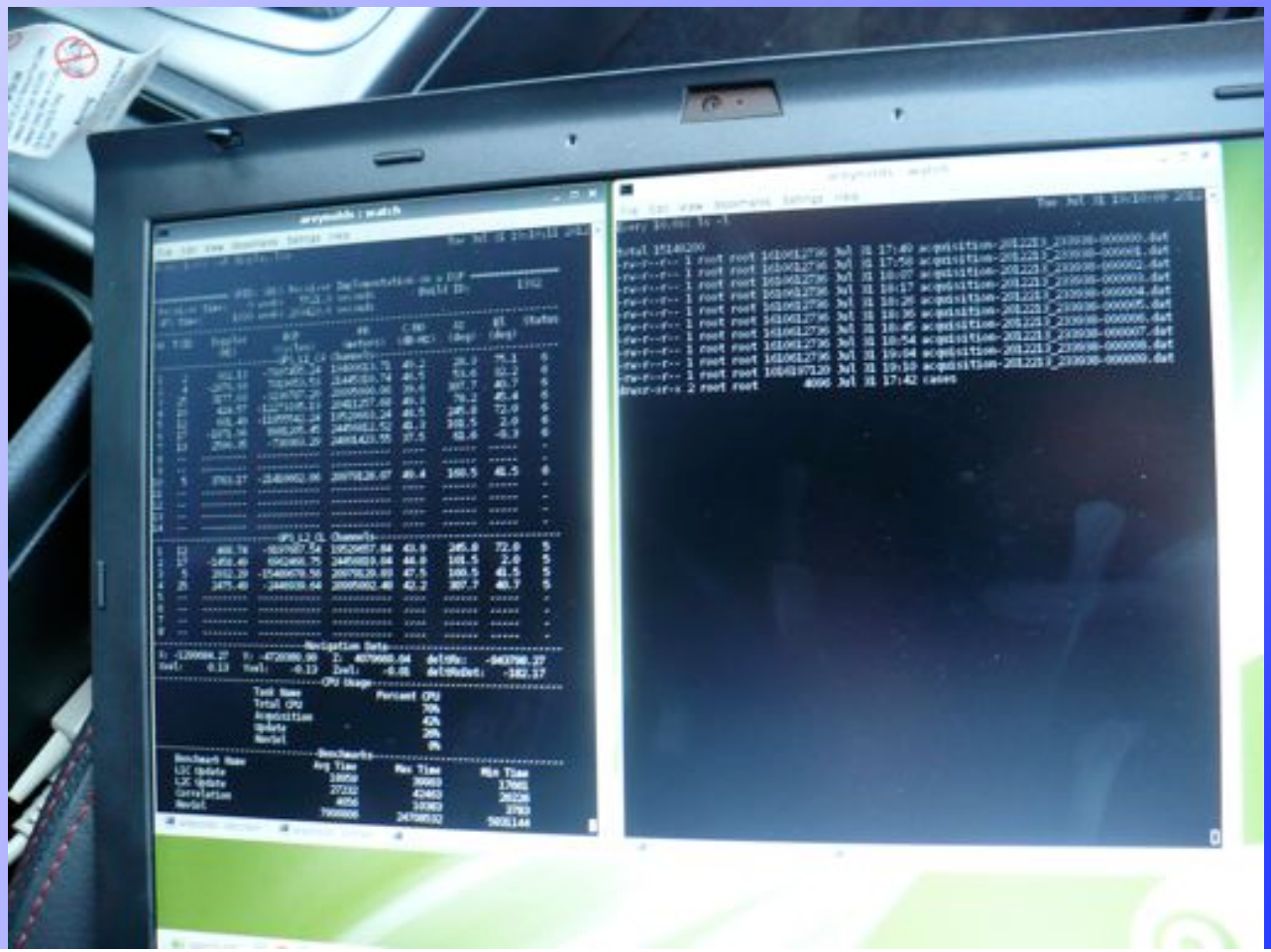
Results: Radio Occultation III

- The setup—



Results: Radio Occultation III

- SUCCESS!



Conclusion/Further Work: Radio Occultation

- Mountaintop test was a success, to a point—data analysis still required
- Additional mountaintop test probably to be performed on a higher mountain before CASES actually goes up in the high-altitude balloon
- The balloon will go up sometime this September

References

- International GNSS (Global Navigation Satellite System) Service, http://igscb.jpl.nasa.gov/ (reference data)
- "Effect of Ionospheric Scintillations on GNSS—A White Paper", SBAS Ionospheric Working Group, November 2010

Acknowledgements

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