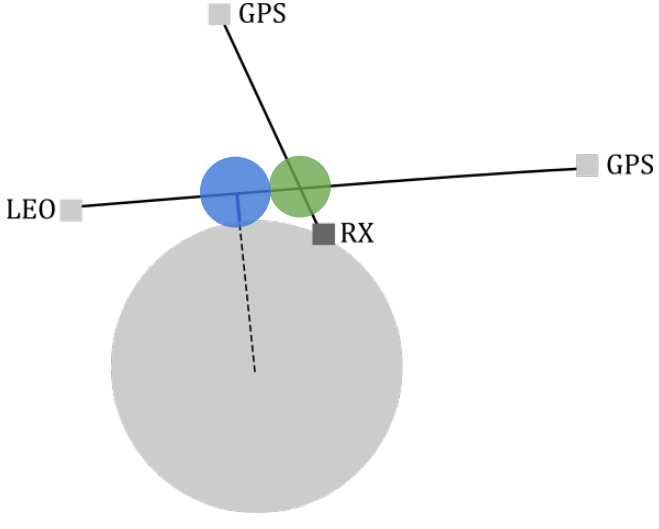
Ionosphere Observability Using GNSS and LEO Platforms



Brian Breitsch

Advisor: Dr. Jade Morton

Colorado State University

- Motivate ionosphere TEC observations
- Past work in ionosphere observability
- Observation volume
  - **Ground receivers**
  - **LEO radio occultations** (RO)
  - Joint ground and LEO overhead/RO
  - LEO beacons
- Data affects in simulated localized imaging

Terrestrial Atmosphere ITM Processes

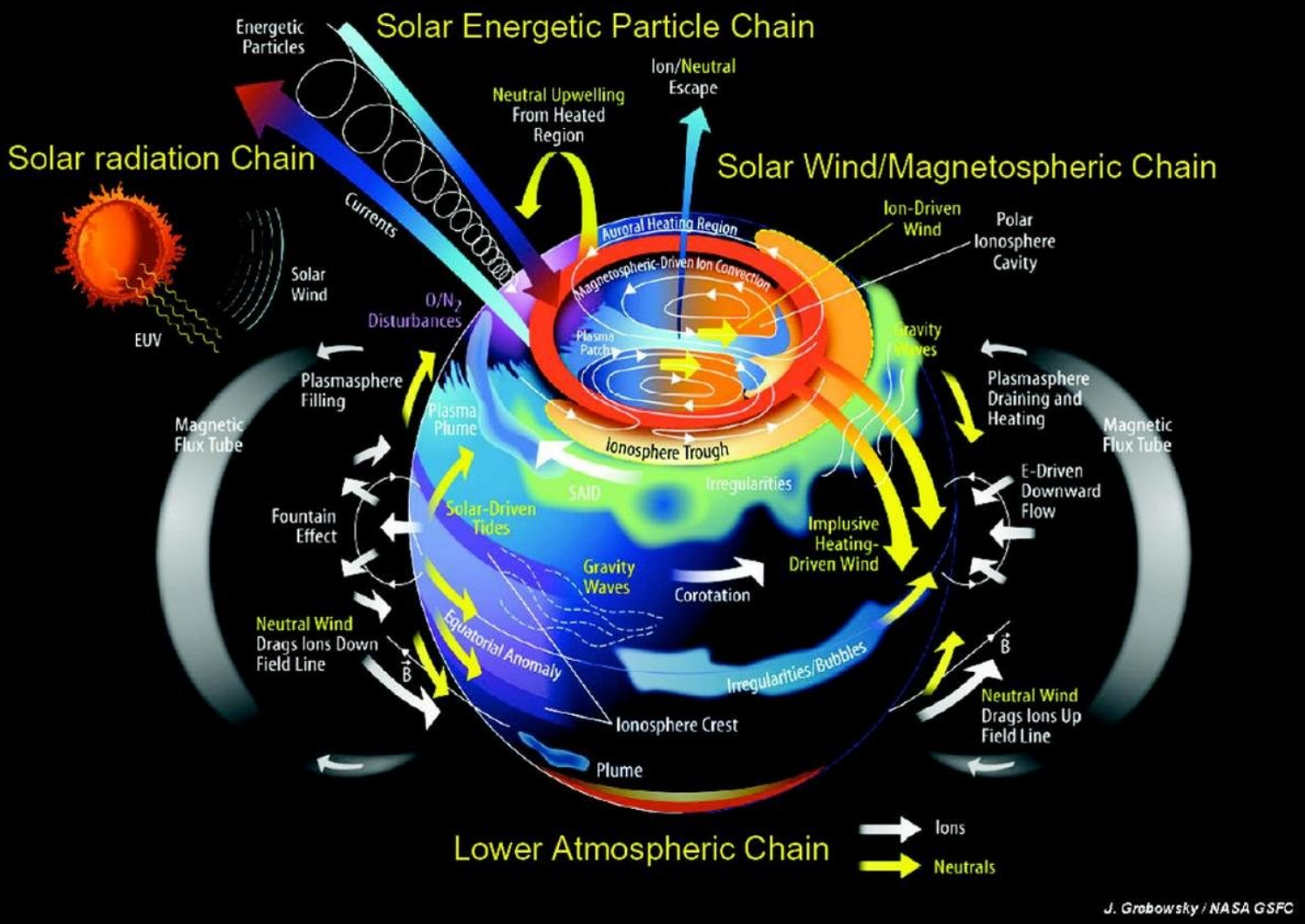


Image credit: NASA/J. Grobowsky 2014

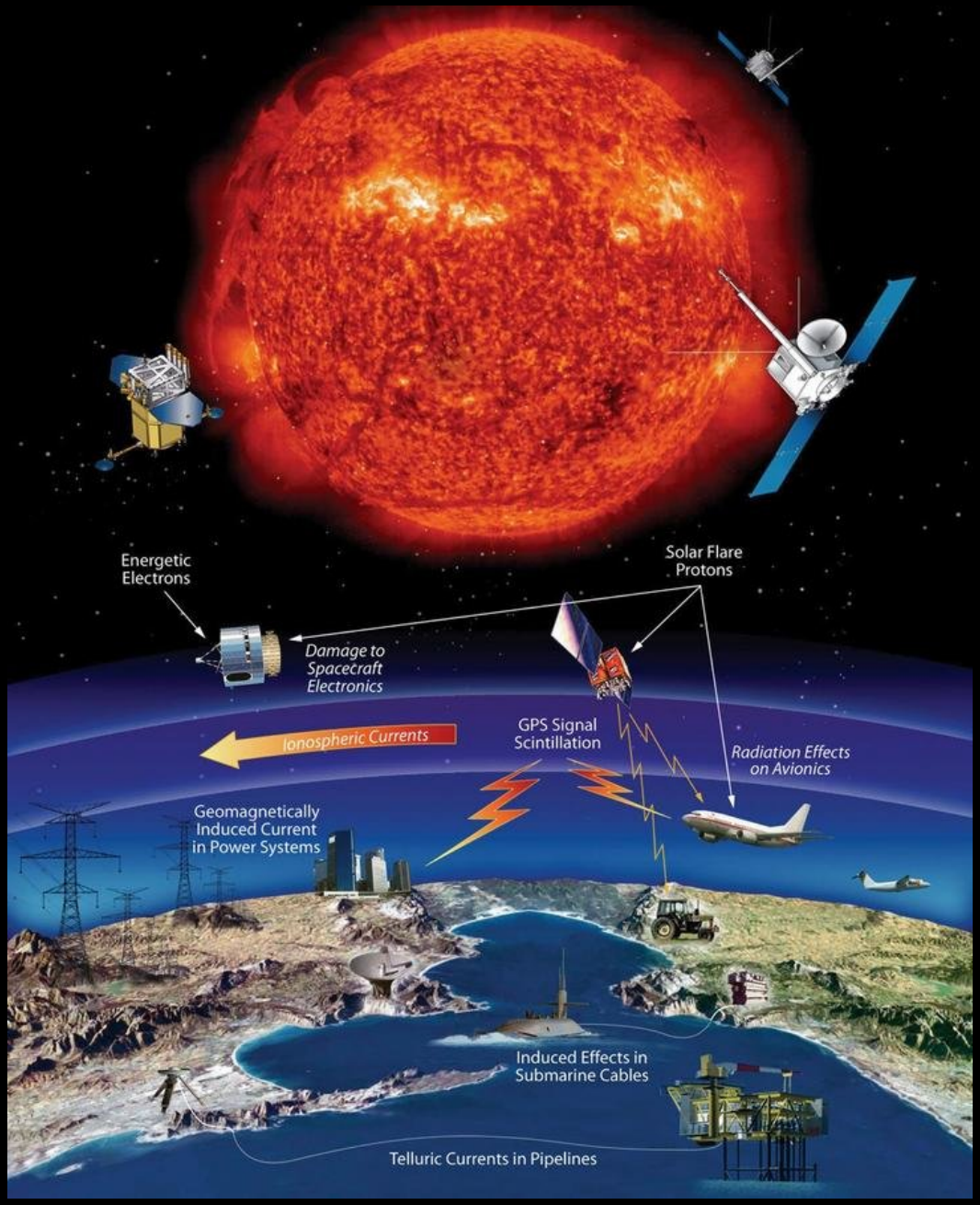


Image credit:

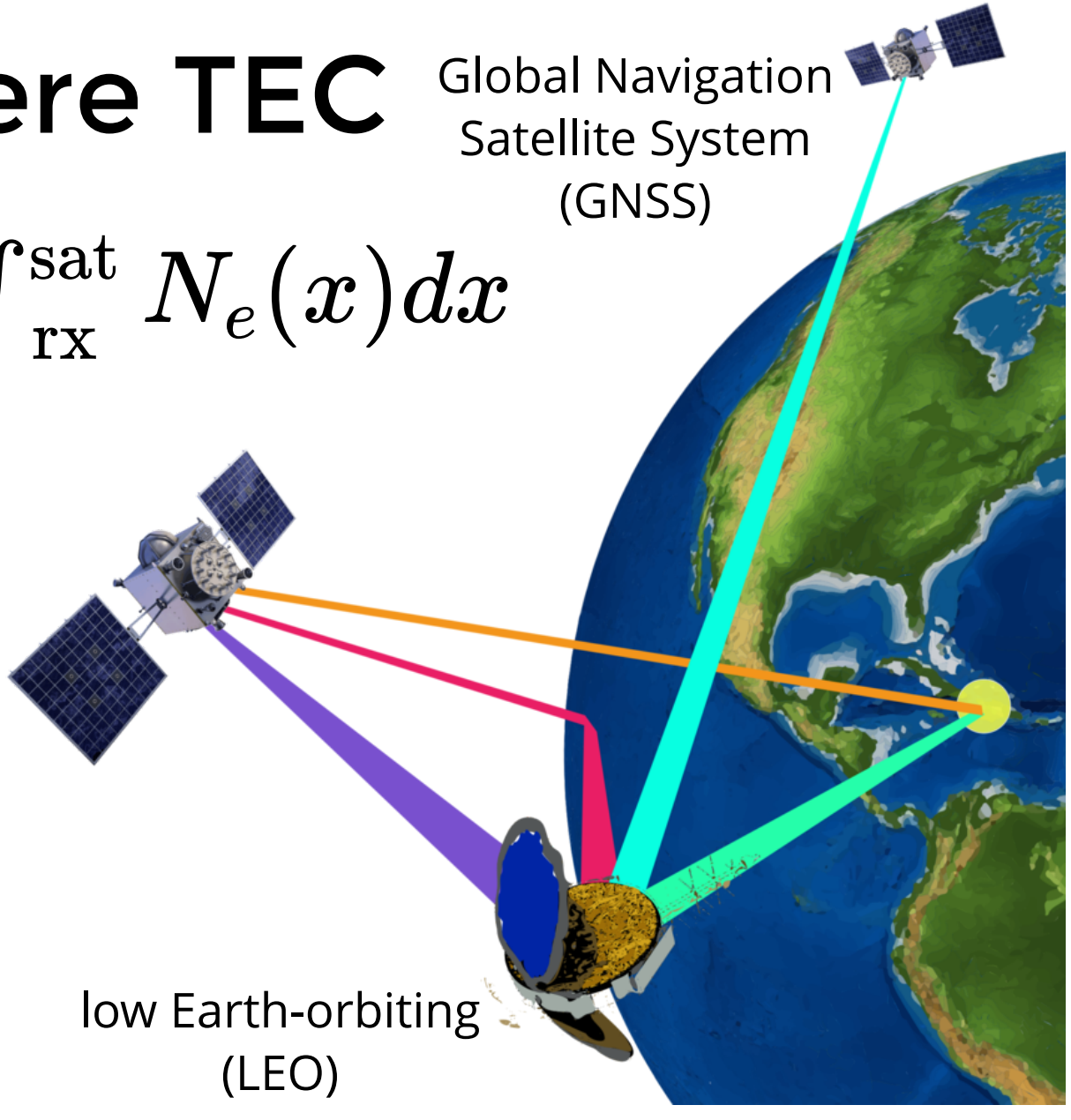
NASA

Ionosphere TEC

$$TEC = \int_{\mathrm{rx}}^{\mathrm{sat}} N_e(x)dx$$

observed by multi-frequency GNSS

- LEO overhead
- LEO reflection
- LEO occultation
- LEO beacon
- ground GNSS



Global Navigation Satellite System (GNSS)

low Earth-orbiting (LEO)

Previous Work

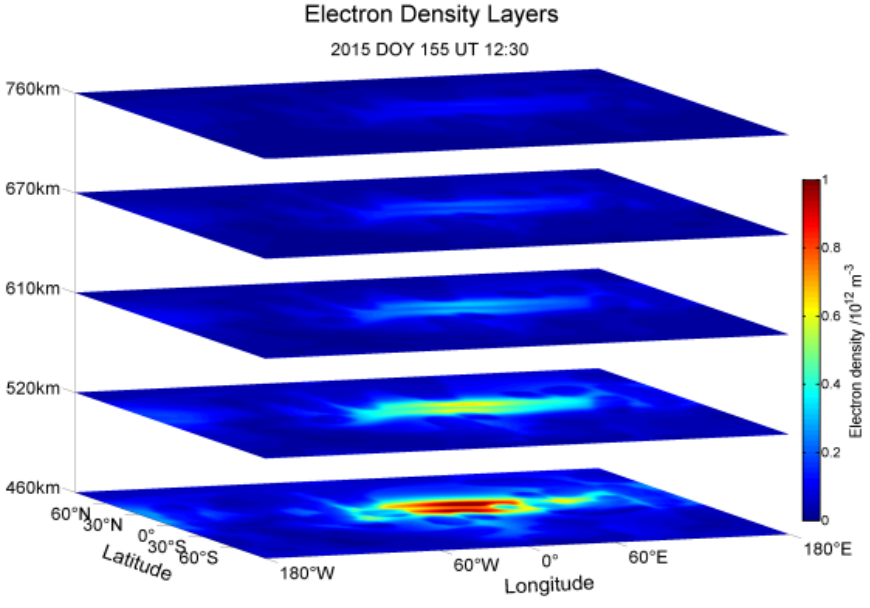
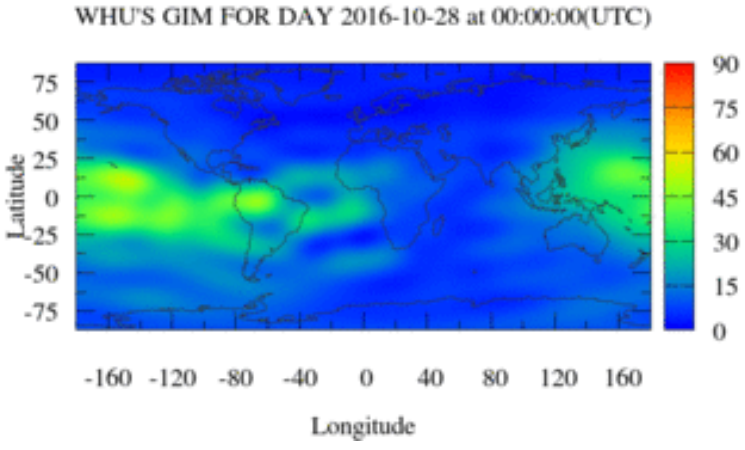


Image Credit: "Multi-satellite ionosphere-plasmasphere electron density reconstruction", GFZ Potsdam



Wang Yang

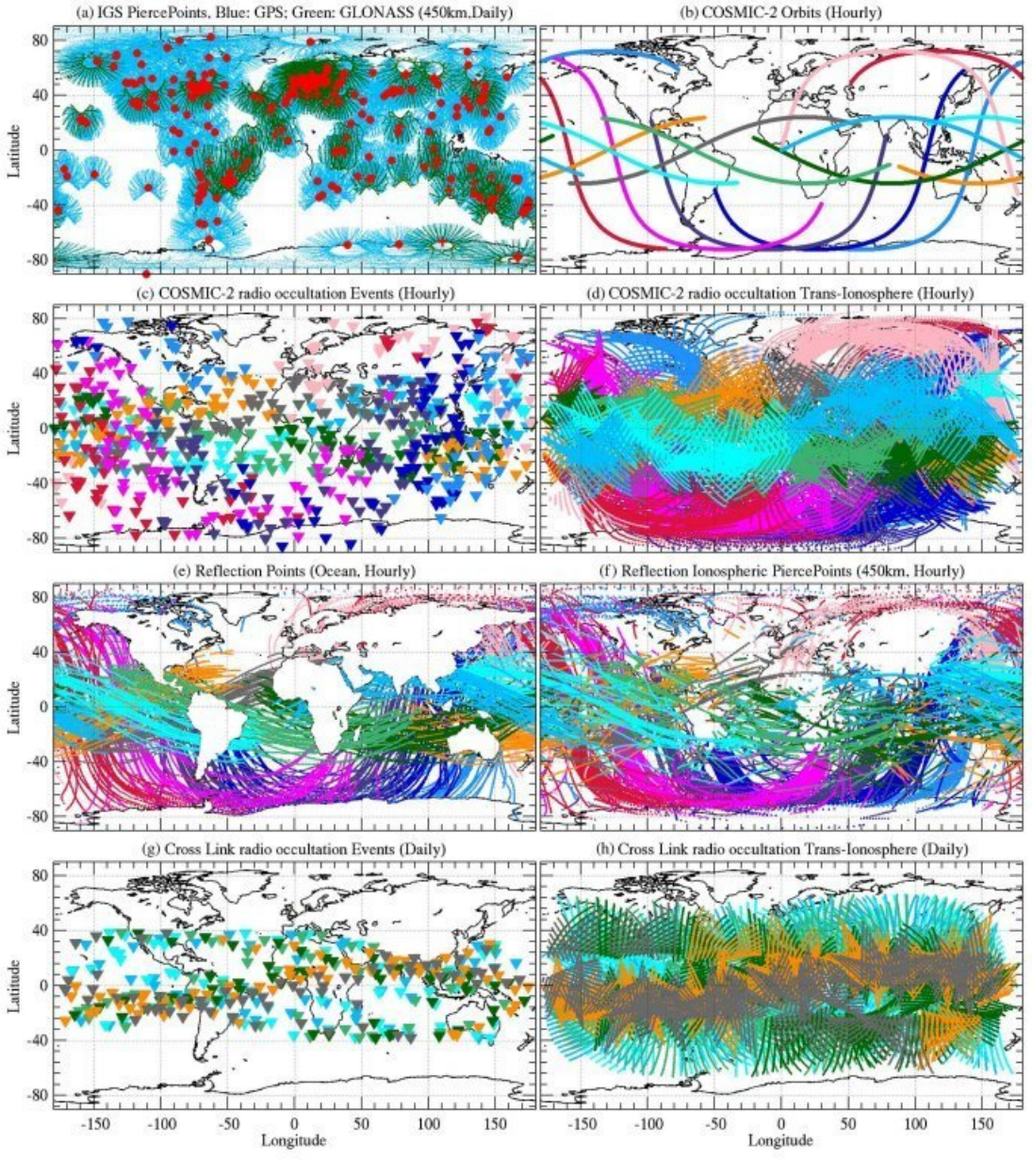
- 2D and 3D ionosphere maps of electron density from TEC measurements
- climatological and large-scale

Previous Work

Xinan Yue et. al. 2013

"Observing System Simulation Experiment Study on Imaging the Ionosphere by Assimilating Observations From Ground GNSS, LEO-Based Radio Occultation and Ocean Reflection, and Cross Link"

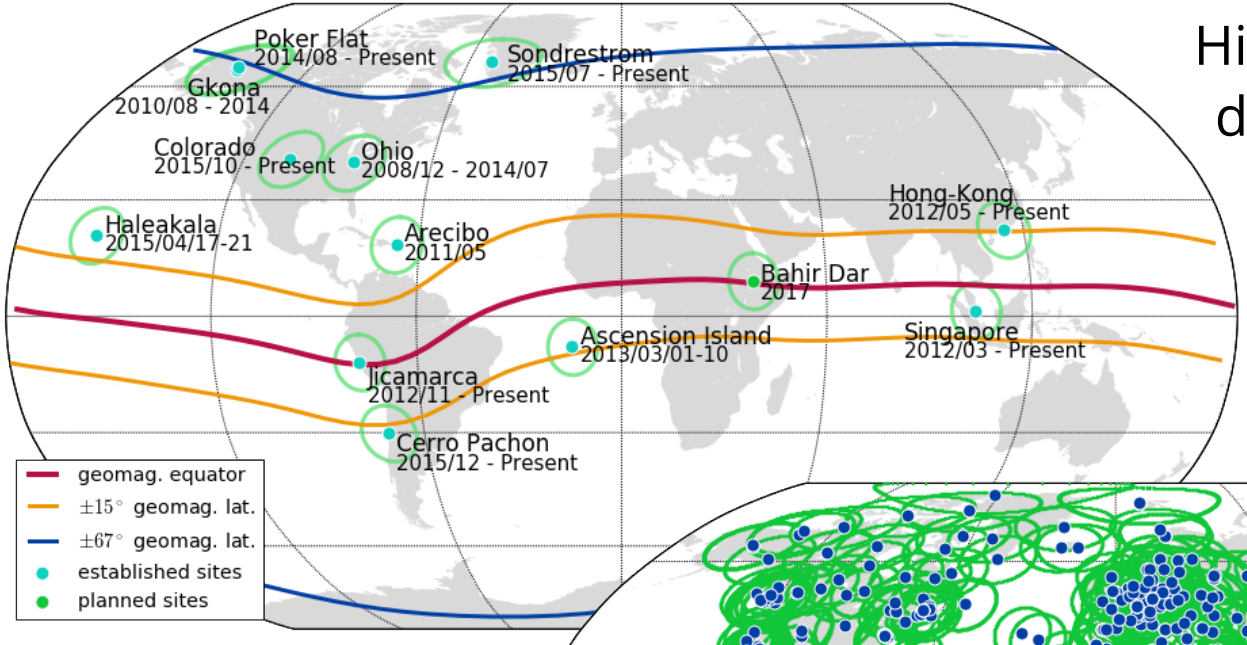
- LEO occultations largely contribute to global-scale models due to lack of ground RX over oceans



GNSS Ground Receivers

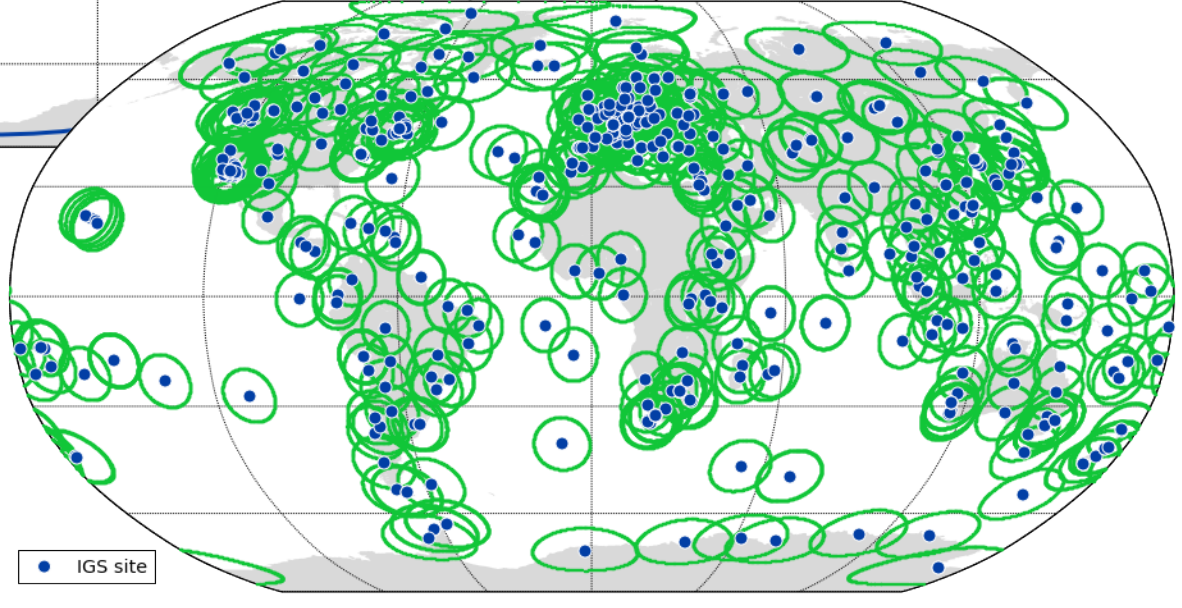
GPS Lab

High-rate GNSS data collection network



IGS

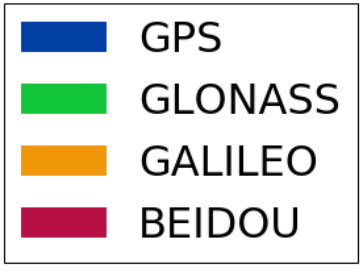
Station Map

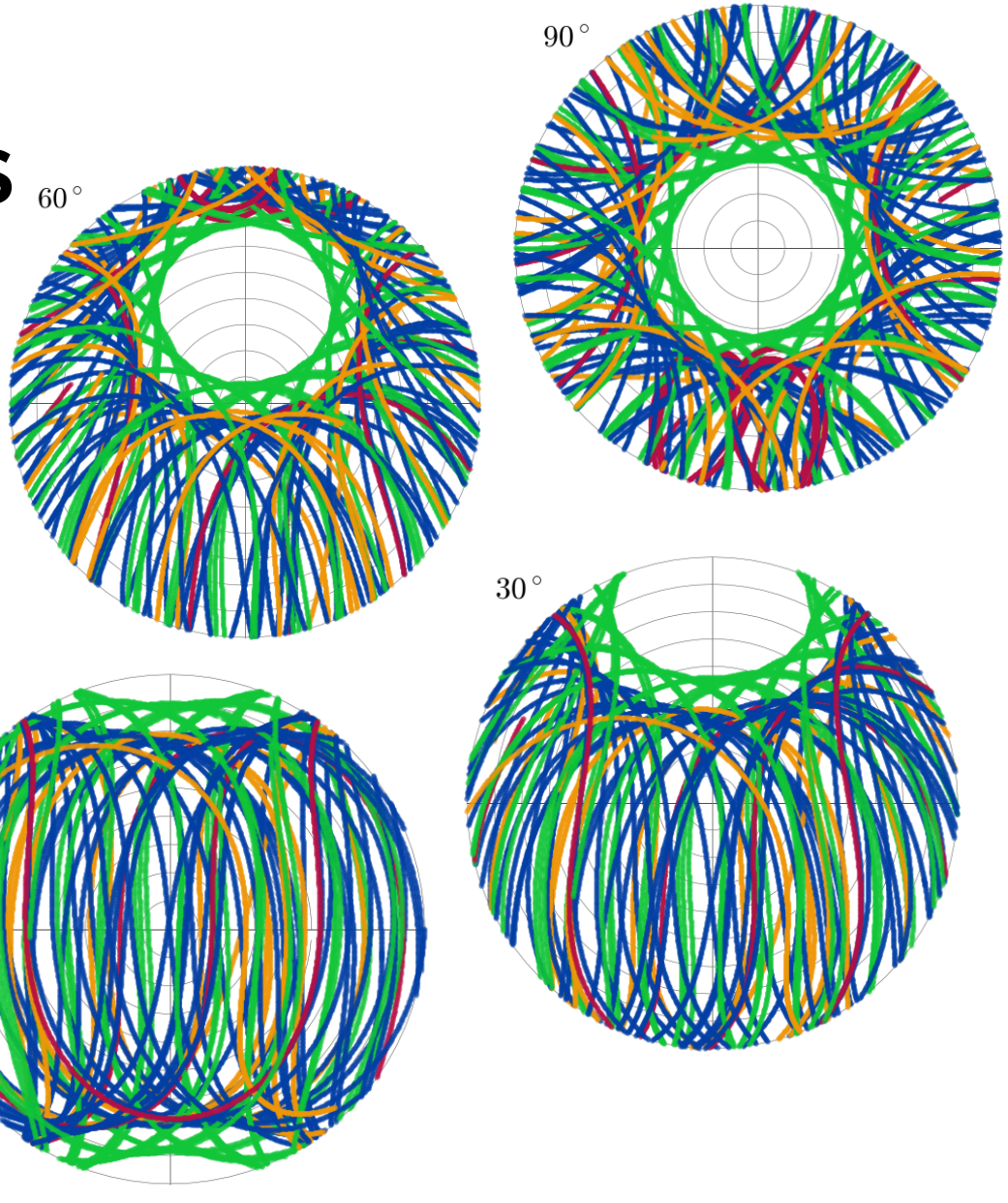


GNSS network data available from many sources: IGS, CORS, ARGN, etc.

Ground RX Observations

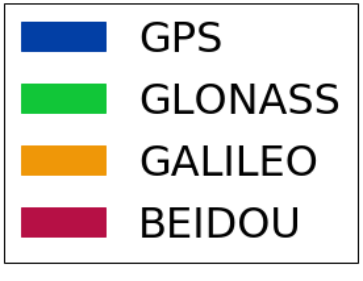
GNSS sky plots

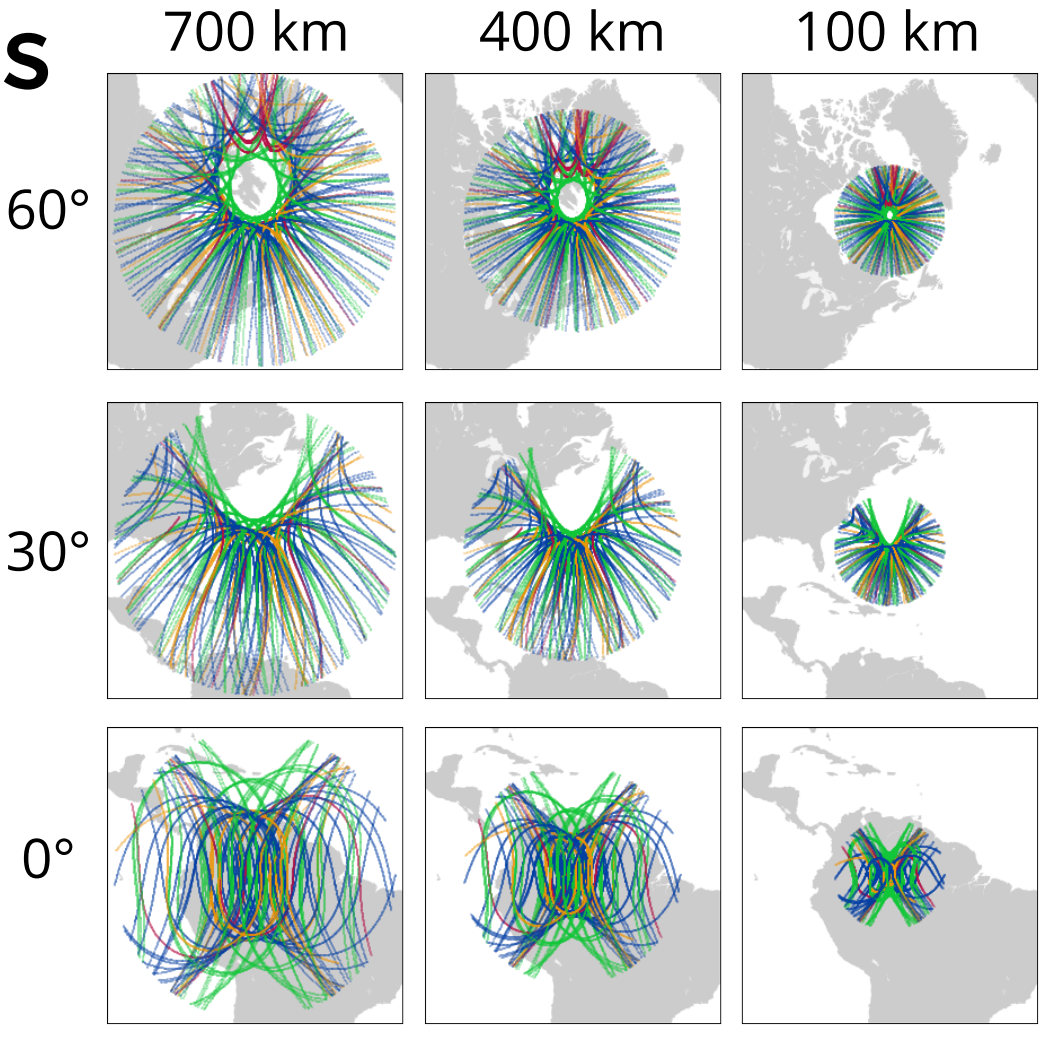




Ground RX Observations

GNSS signal ionosphere piercing points for ground receiver at low/mid/high latitude
5° elevation mask





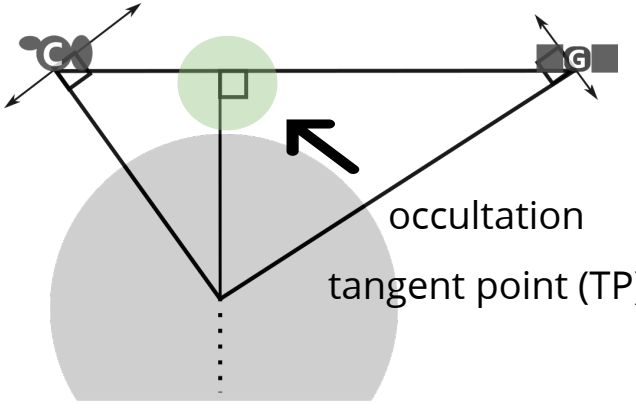
LEO Receiver Observations

e.g. COSMIC/COSMIC-2

orbital altitude: between 500-800 km

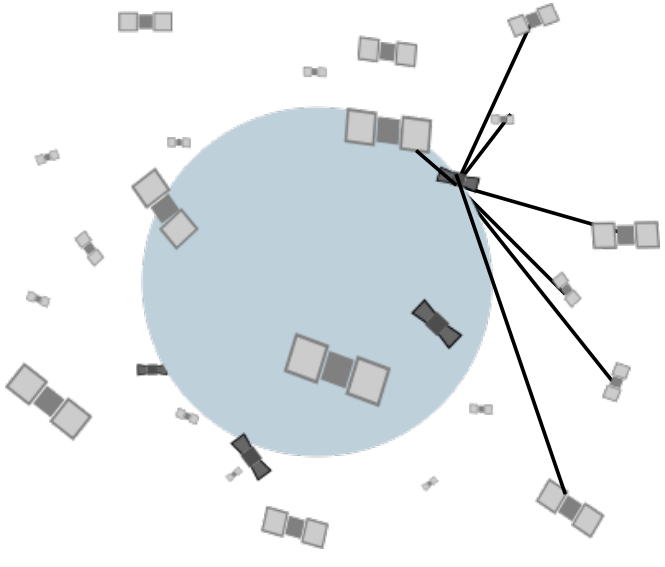
orbital inclination: 24° or 72°

Radio Occultations (RO)



- use occultation antennas
- traverse large ionosphere volume

Overhead Obs.

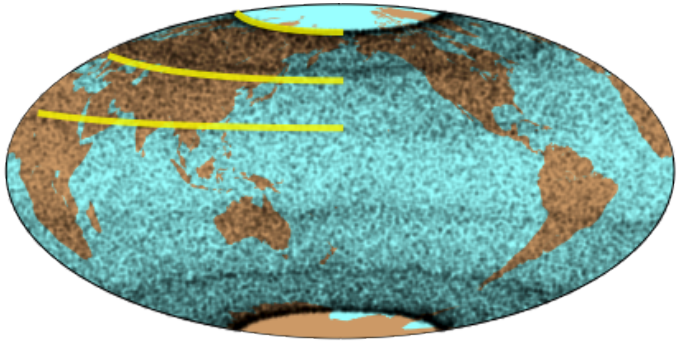


- use POD antenna
- highly localized to LEO satellite

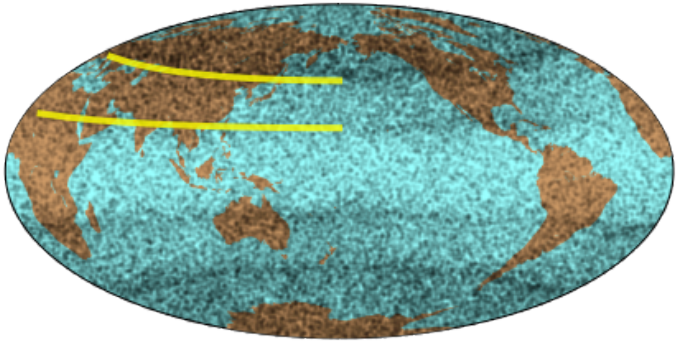
LEO Occultations

90-day scatter of COSMIC-GPS occultation tangent points

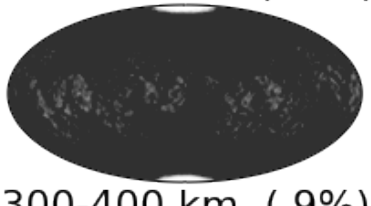
top coords.



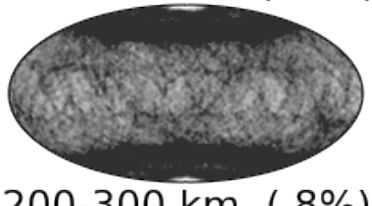
bottom coords.



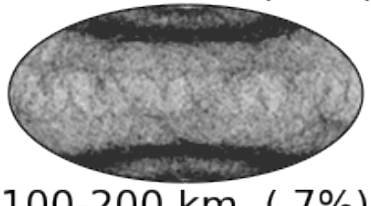
700-800 km (30%)



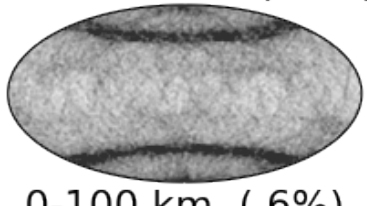
600-700 km (17%)



500-600 km (13%)

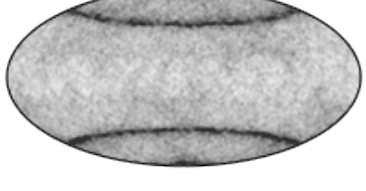


400-500 km (10%)



300-400 km (9%)

200-300 km (8%)



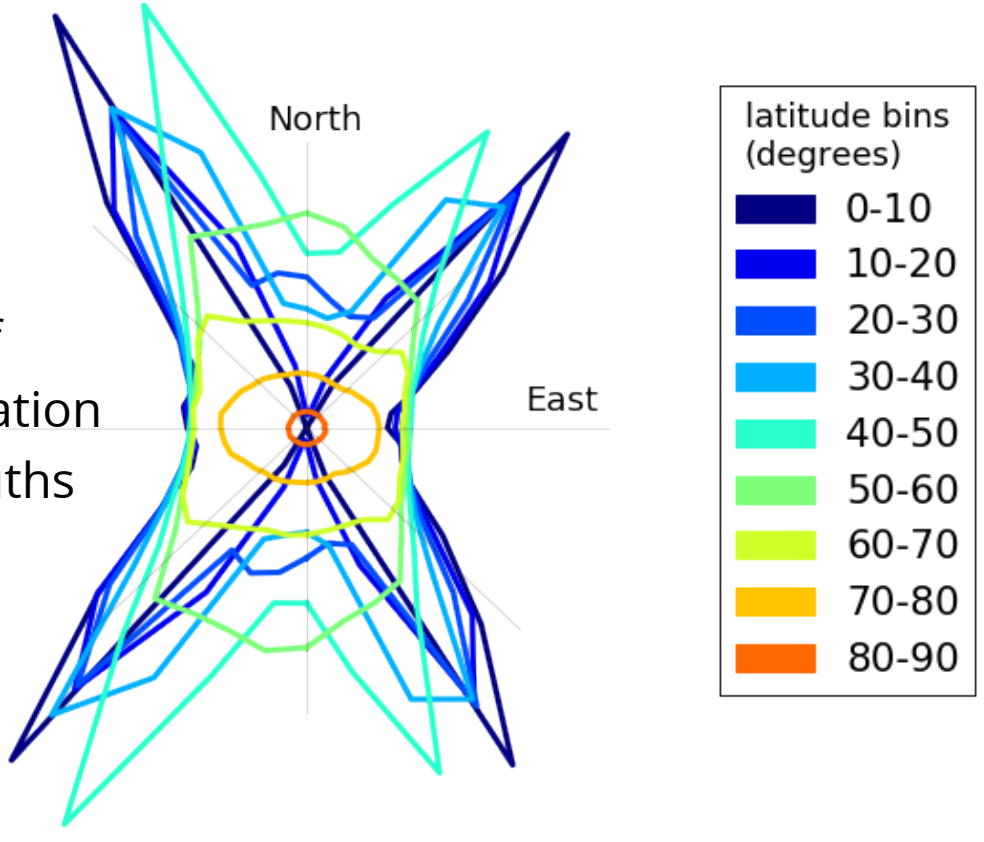
100-200 km (7%)

0-100 km (6%)

tangent point altitude histogram

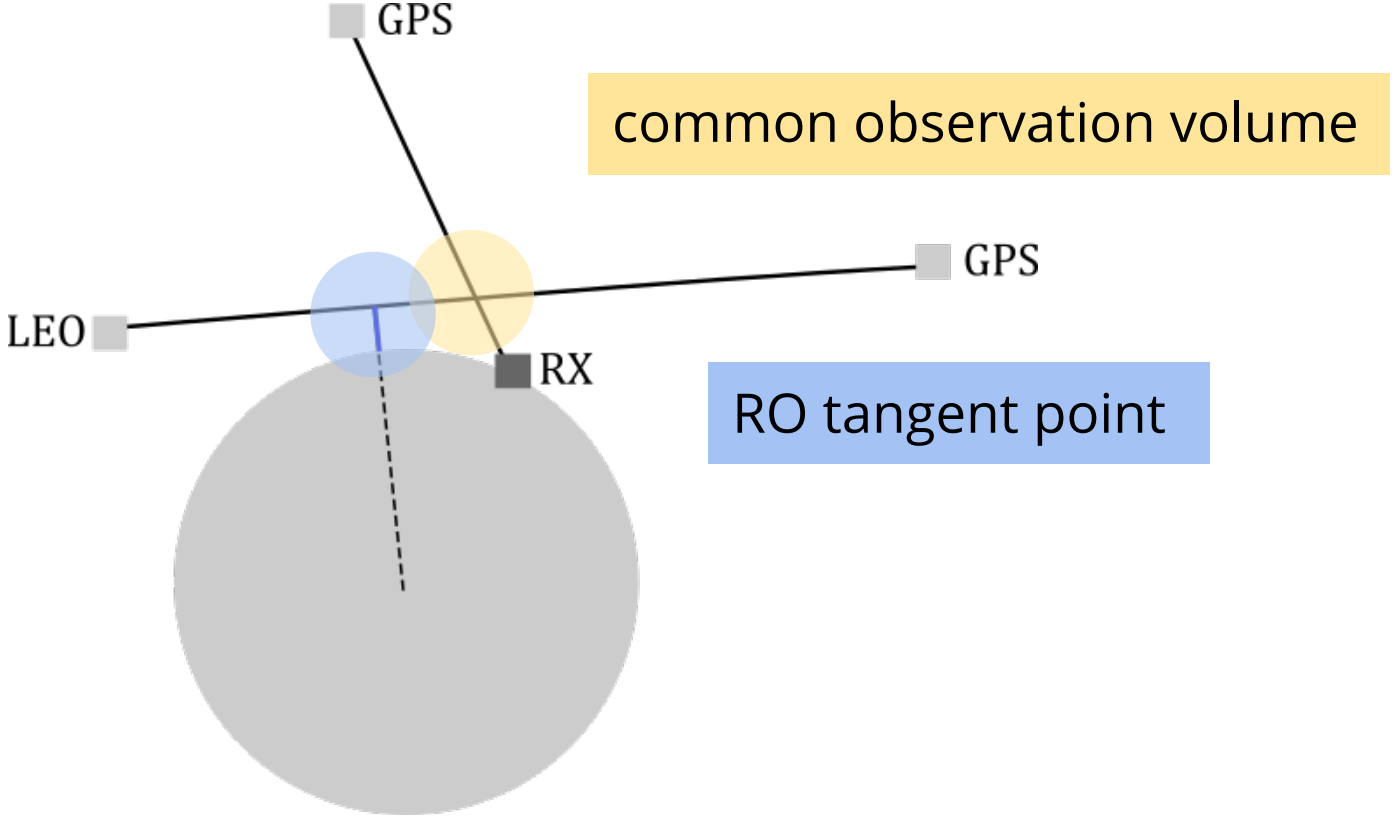
LEO Occultations

90-day histogram of COSMIC-GPS occultation tangent point azimuths



Ground/LEO Common Volume

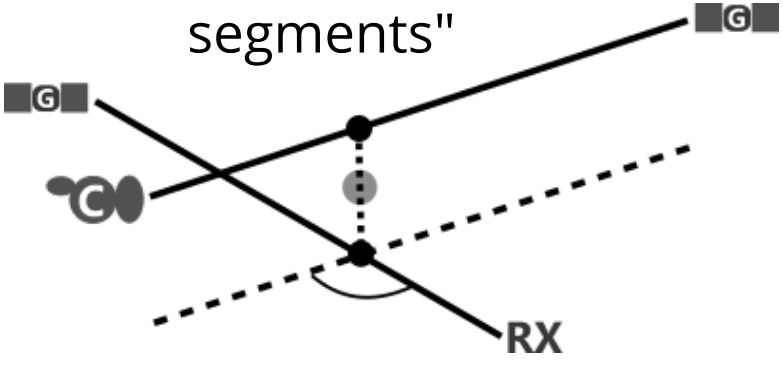
Geometry



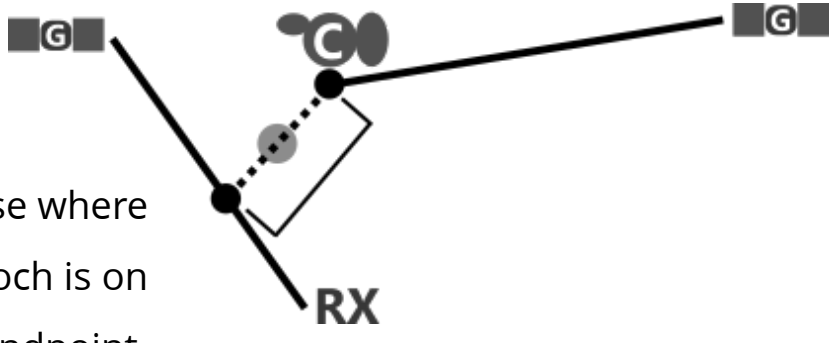
Ground/LEO Common Volume

3D Line-Segment Intersection

"the points of closest approach between two line segments"



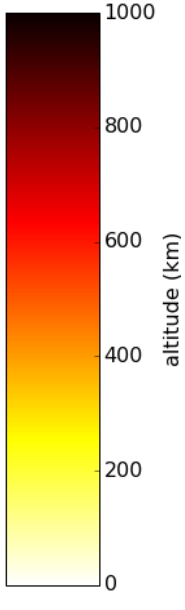
- **common-volume point-of-interest**
  - midpoint b/w points of closest approach
  - GNSS rays <100 km apart

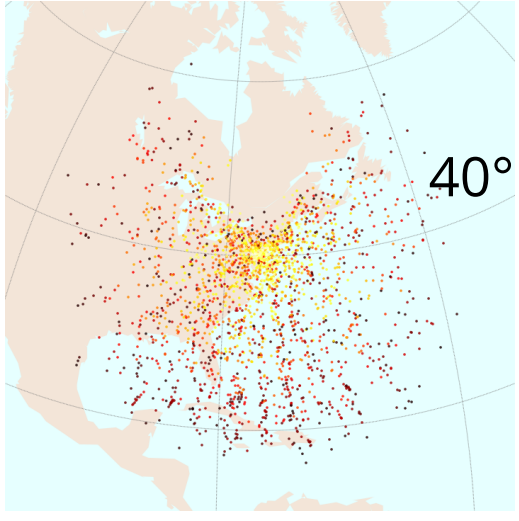


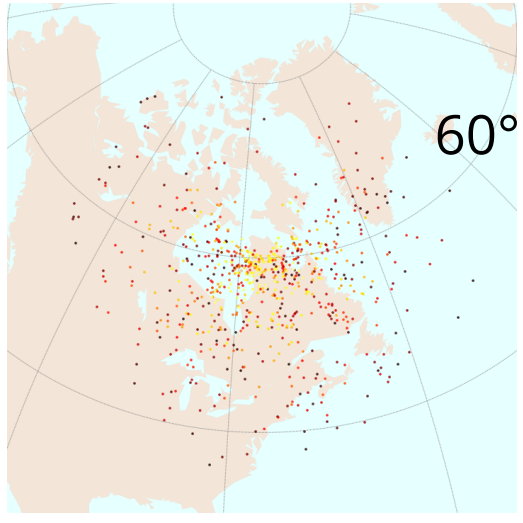
*must handle special case where point of closest approch is on segment endpoint.

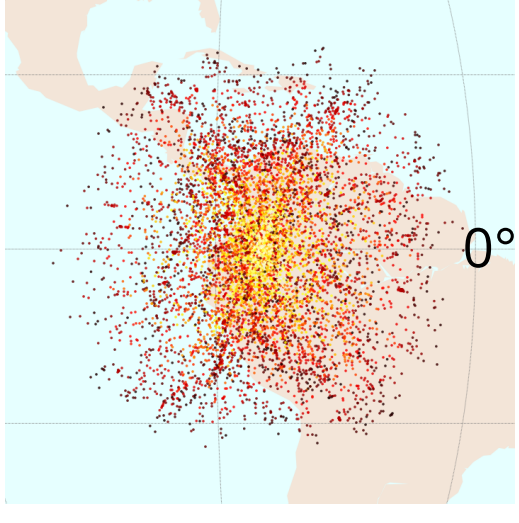
Ground/LEO Common Volume

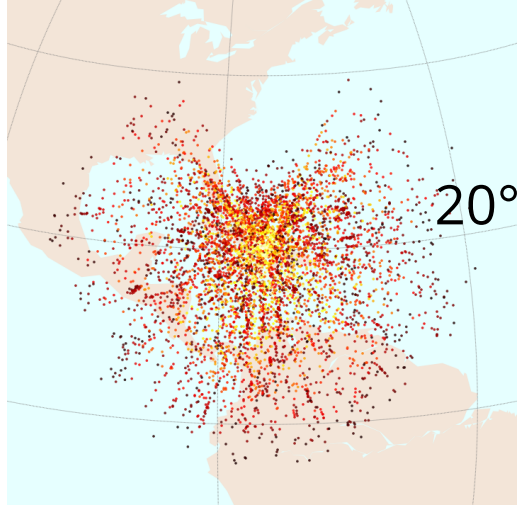
- 6-satellite constellation
- 750 km altitude
- **24° inclination**





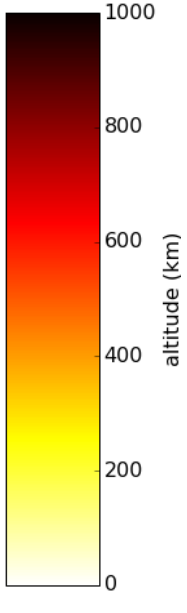


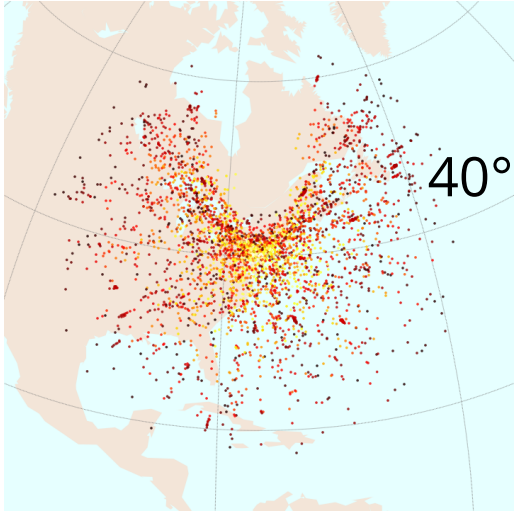


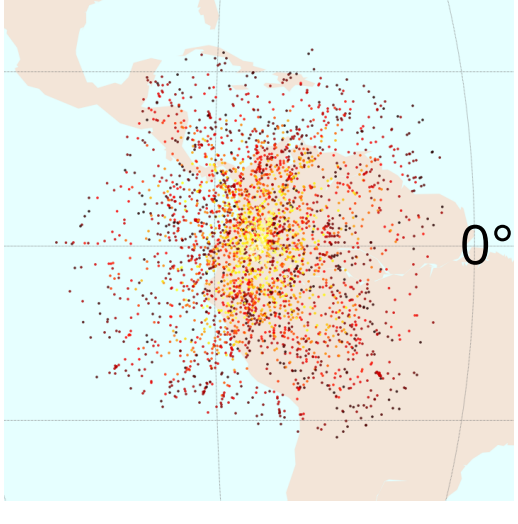


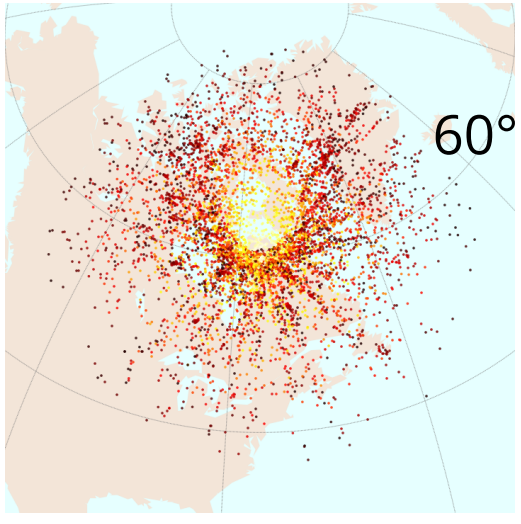
Ground/LEO Common Volume

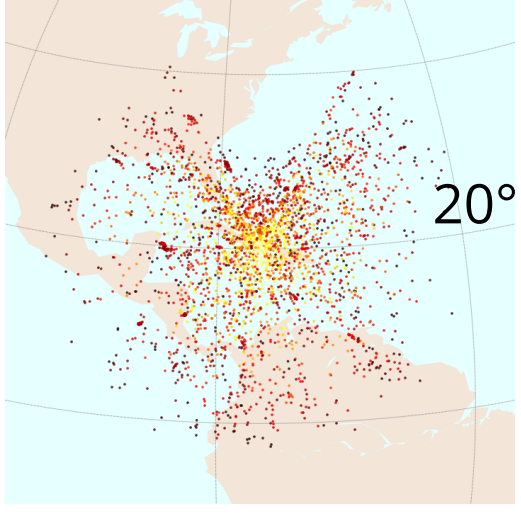
- 6-satellite constellation
- 750 km altitude
- **72° inclination**





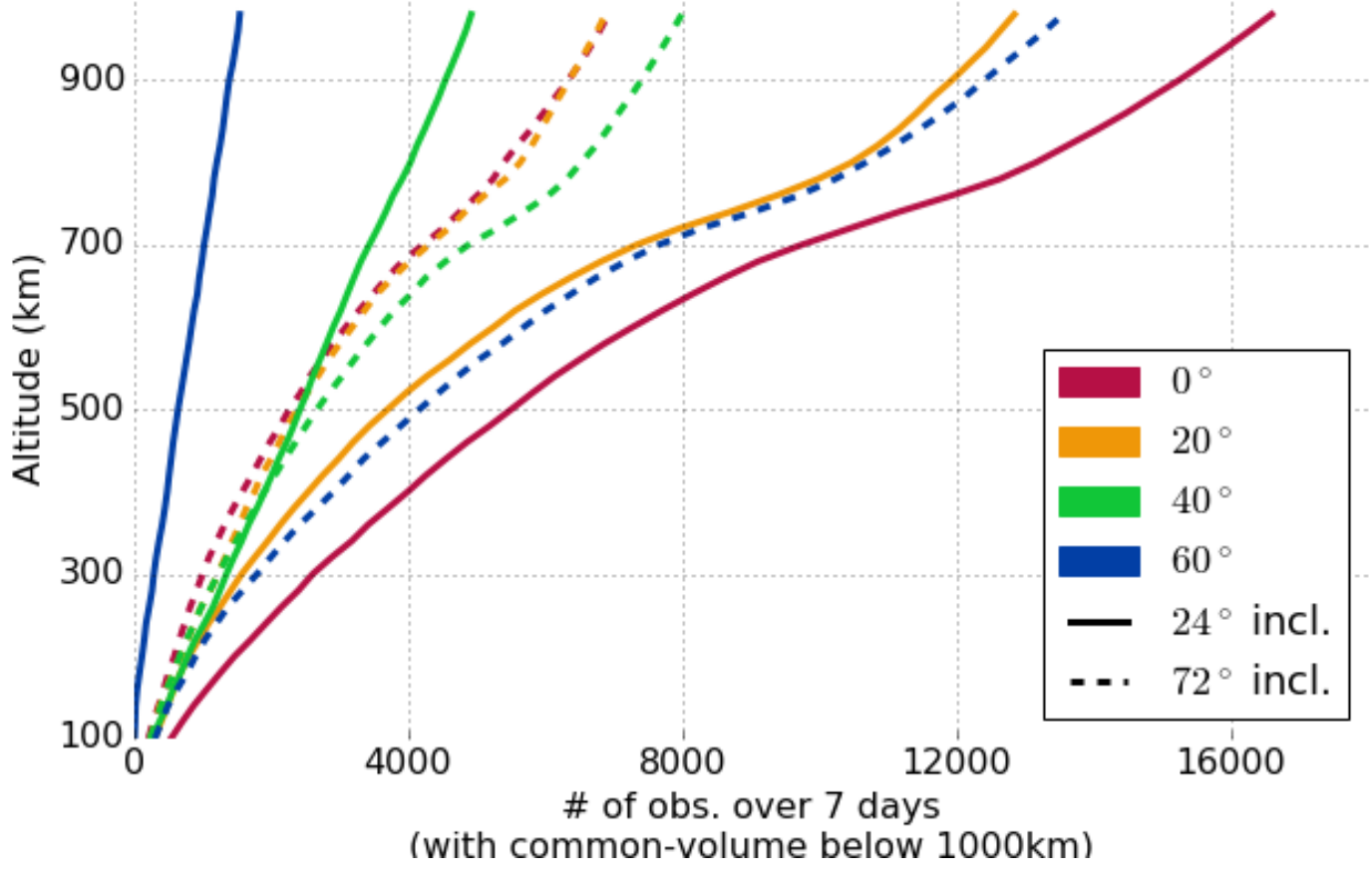




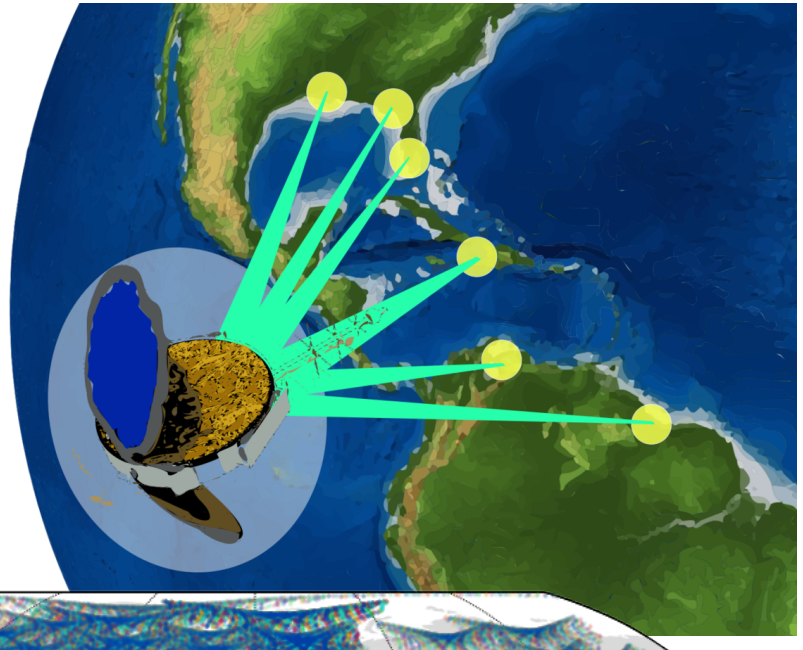


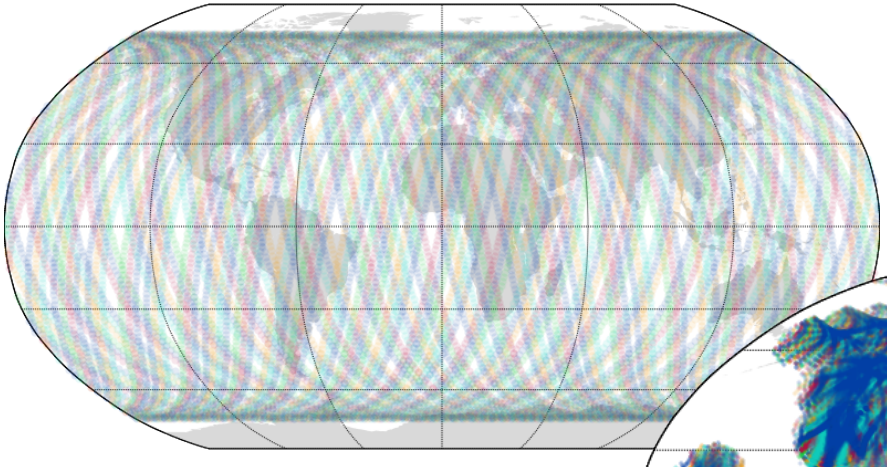
Ground/LEO Common Volume

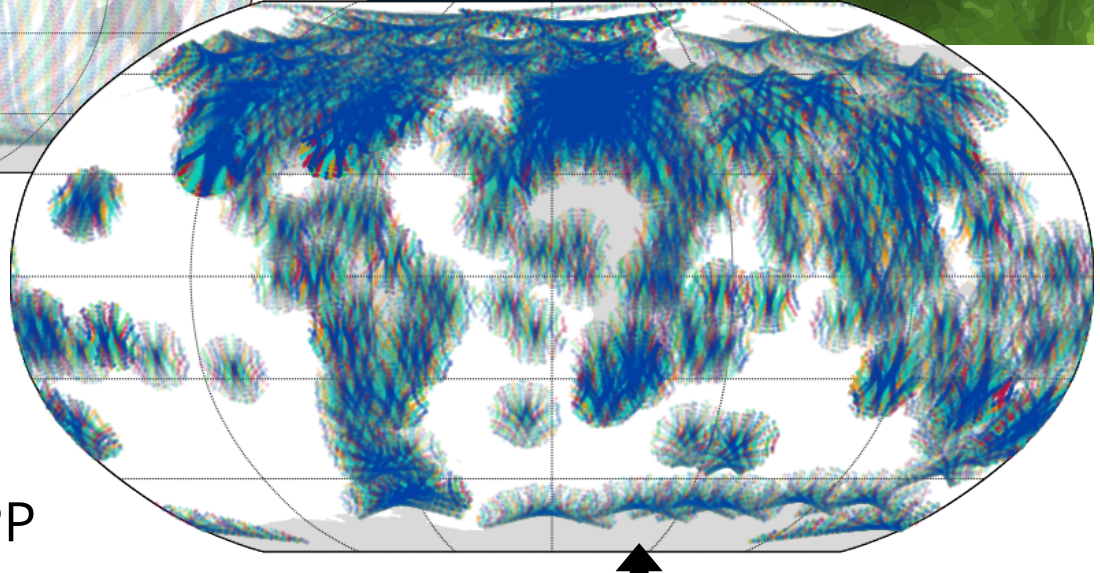
- 6-satellite constellation
- 750 km altitude
- **24° and 72° inclination**



LEO Beacon Observations







LEO constellation ground track coverage

72° incl.

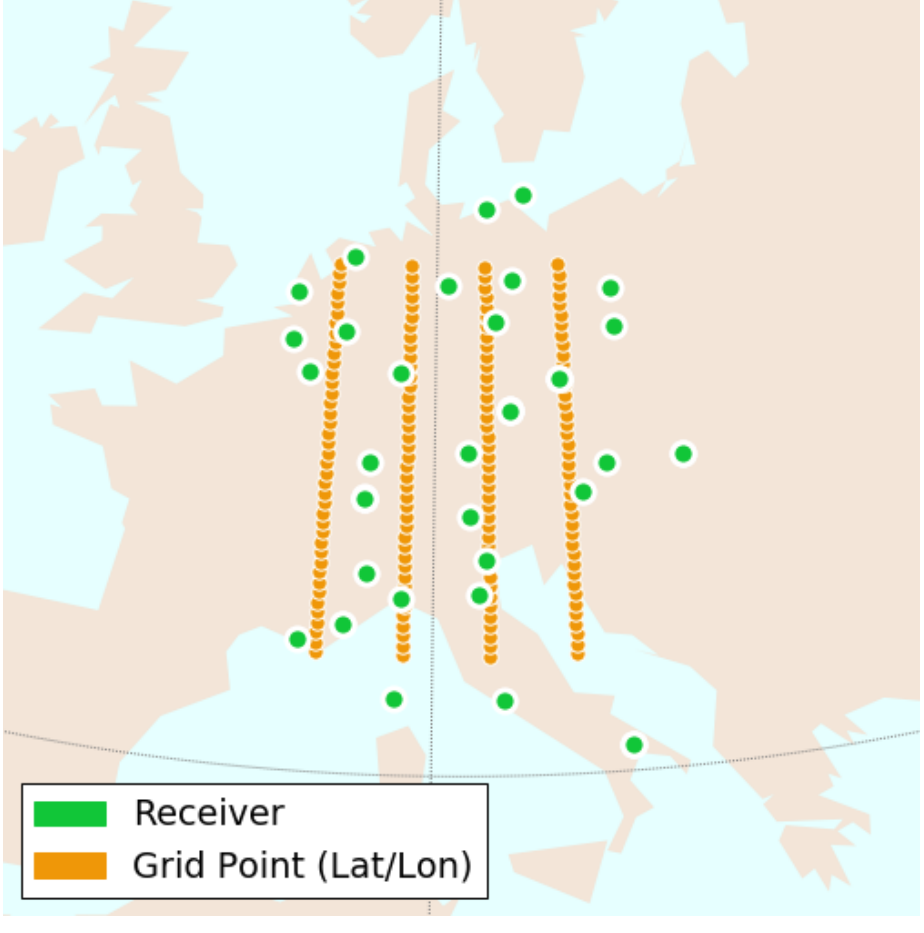
LEO beacon IPP

@ 150 km and 20° elev.

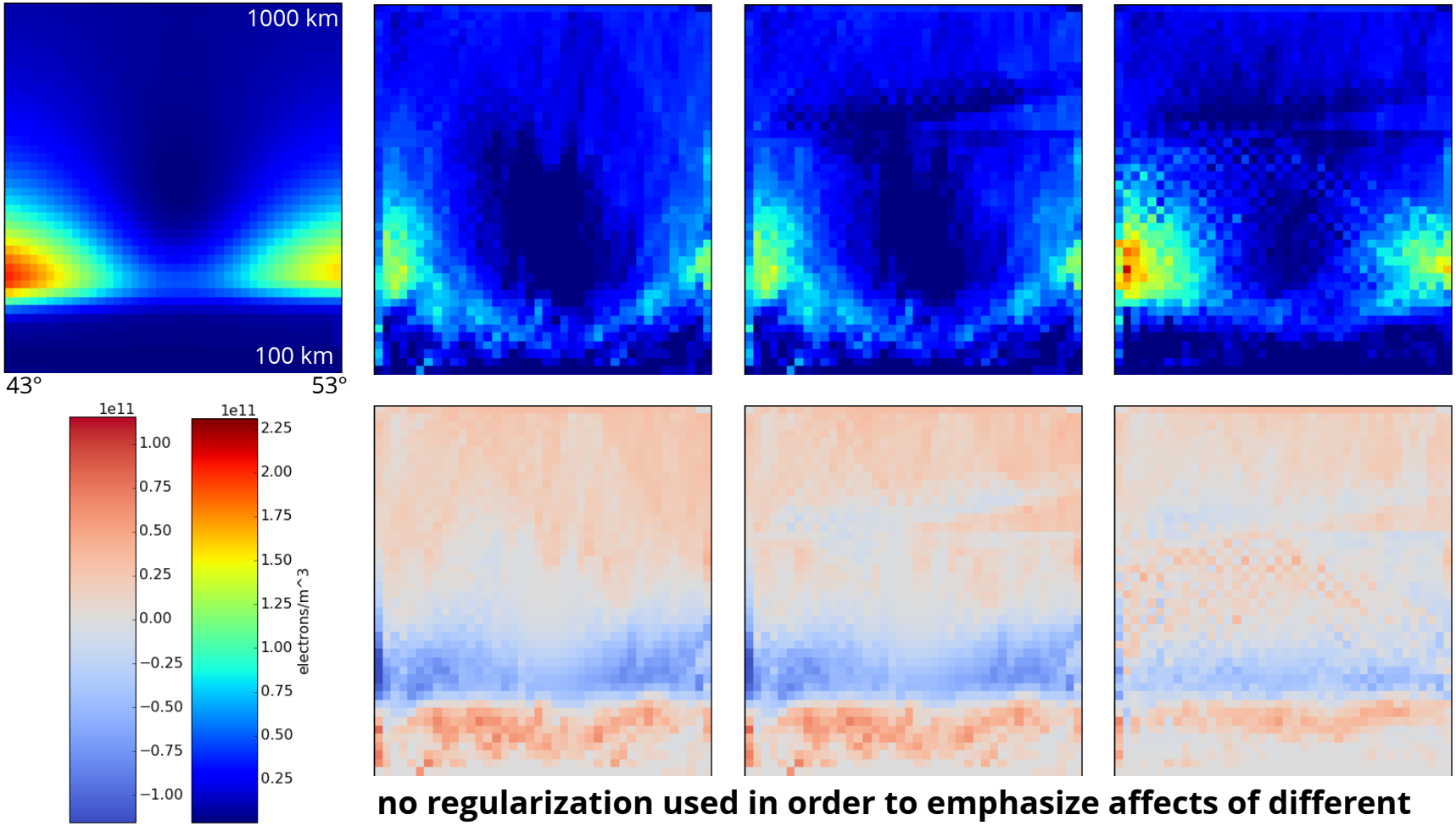
if we had beacon RX at every IGS station

Simulated Effects on Localized Imaging

- regional IGS network in Europe
- latitudes
  - 43°-53° @ 0.25° sep.
- longitudes
  - 6°-15° @ 3° sep.
- altitudes
  - 100-980 km @ 20 km
- attempt to reconstruct IRI image with depletion feature from uniform density starting image



Simulated Effects on Localized Imaging

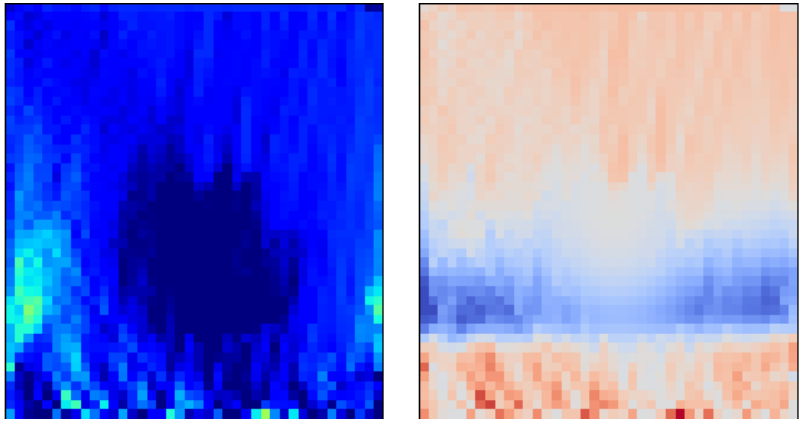


no regularization used in order to emphasize affects of different data

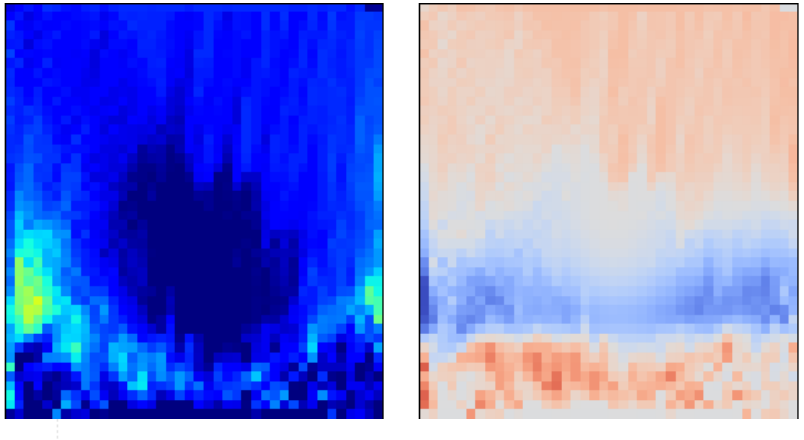
Future Work

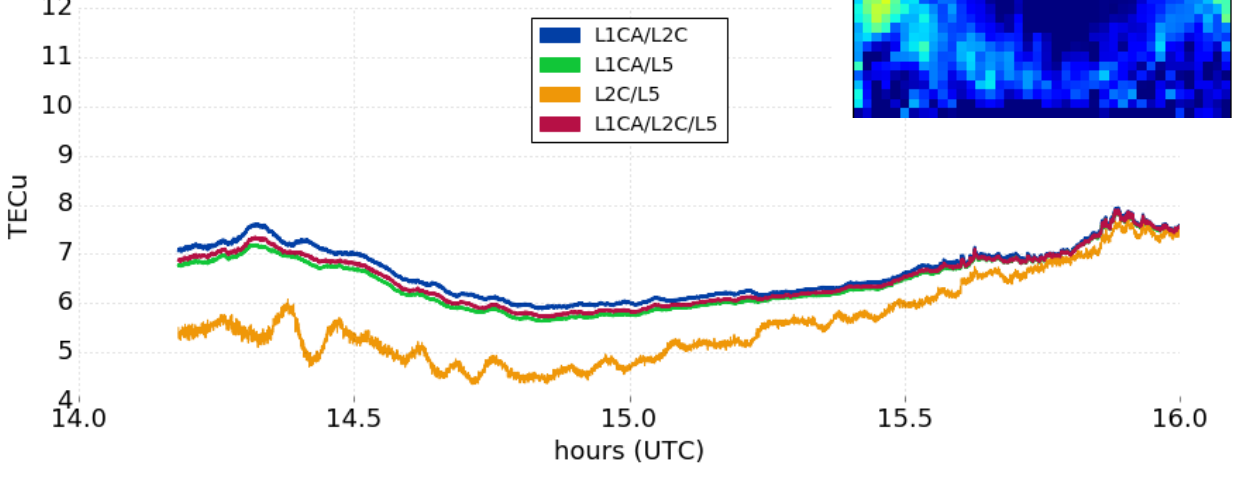
- Low elevation ground GNSS esspecially important at low altitude
- use 3-frequency GNSS measurements to address low-elevation TEC estimation

20° el. mask



5° el. mask



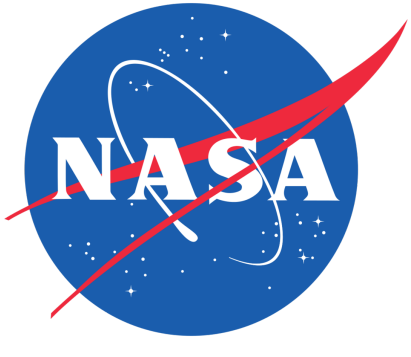


Conclusions

- Poleward deficit of GNSS satellites causes gap in information from ground receivers
- Occurrence of ground and LEO GNSS observations in common volume heavily depends upon LEO constellation orbital inclination
- Overhead and RO LEO observations aid in topside ionosphere imaging
- LEO beacons have good potential to improve 3D imaging over ground and LEO GNSS observations
- Accurate low-elevation GNSS measurements will allow improved imaging

Acknowledgements

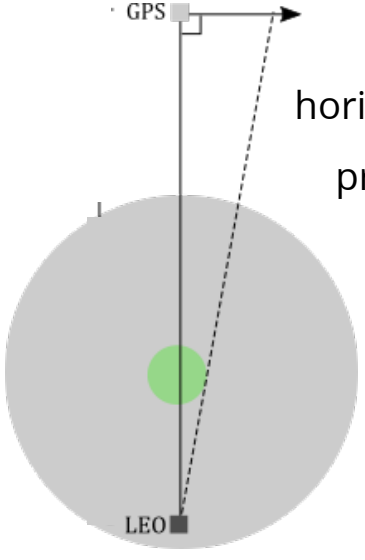
This research was supported by the Air Force Research Laboratory and NASA.



References

- TS Kelso et al. Validation of sgp4 and is-gps-200d against gps precision ephemerides. 2007
- "COSMIC-2." *COSMIC 2*. UCAR, n.d. http://www.cosmic.ucar.edu/cosmic2. 02 Jan. 2016.
- Yue, Xinan, et al. "Observing system simulation experiment study on imaging the ionosphere by assimilating observations from ground GNSS, LEO-based radio occultation and ocean reflection, and cross link." *IEEE Transactions on Geoscience and Remote Sensing* 52.7 (2014): 3759-3773.
- Yue, Xinan, et al. "Global 3-D ionospheric electron density reanalysis based on multisource data assimilation." *Journal of Geophysical Research: Space Physics* 117.A9 (2012).

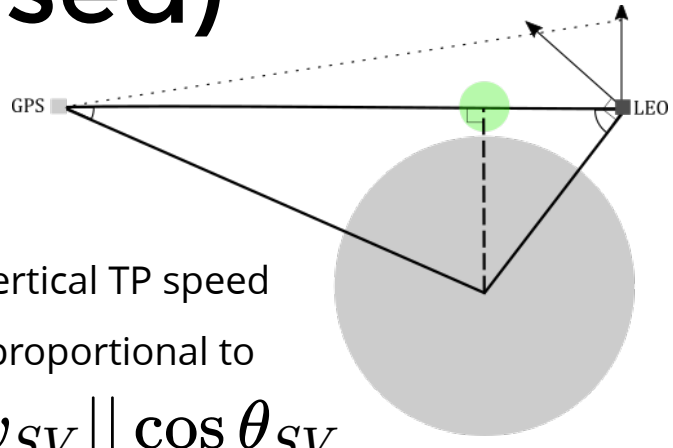
COSMIC (LEO-based)



horizontal TP speed

proportional to

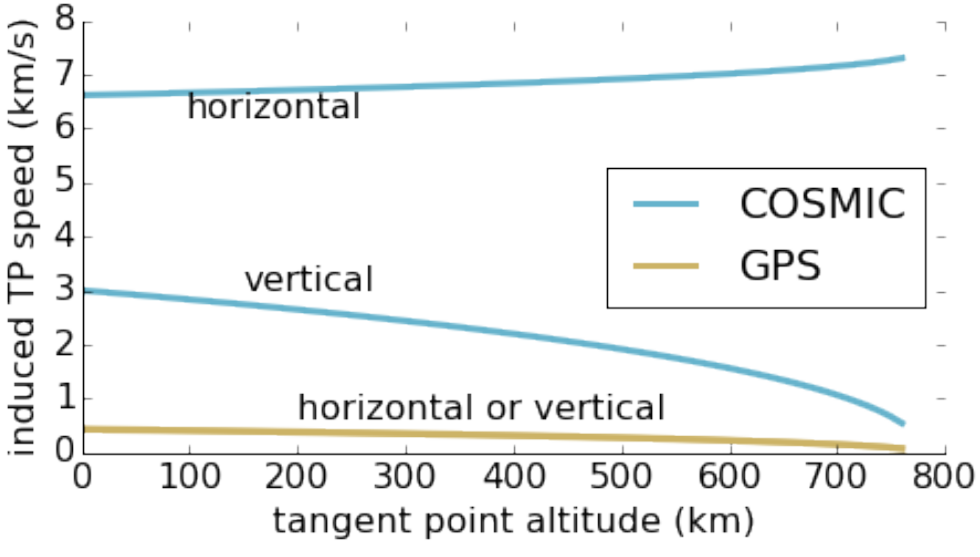
$$||v_{SV}||$$



vertical TP speed

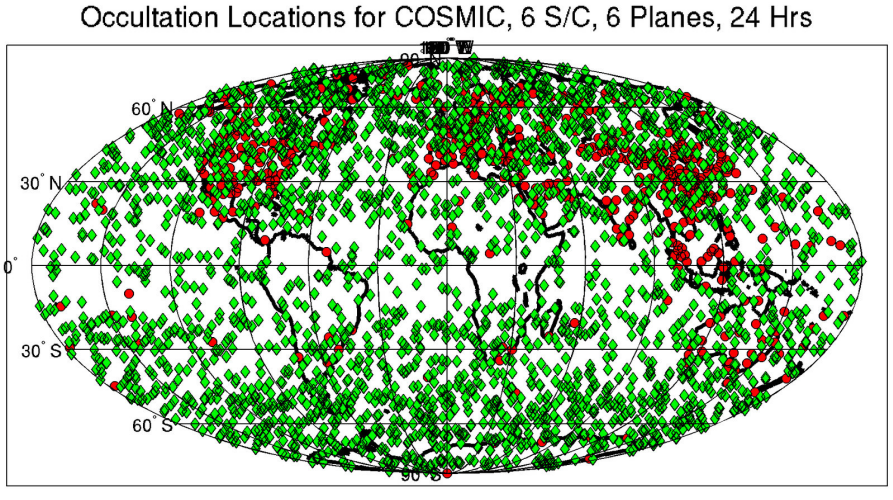
proportional to

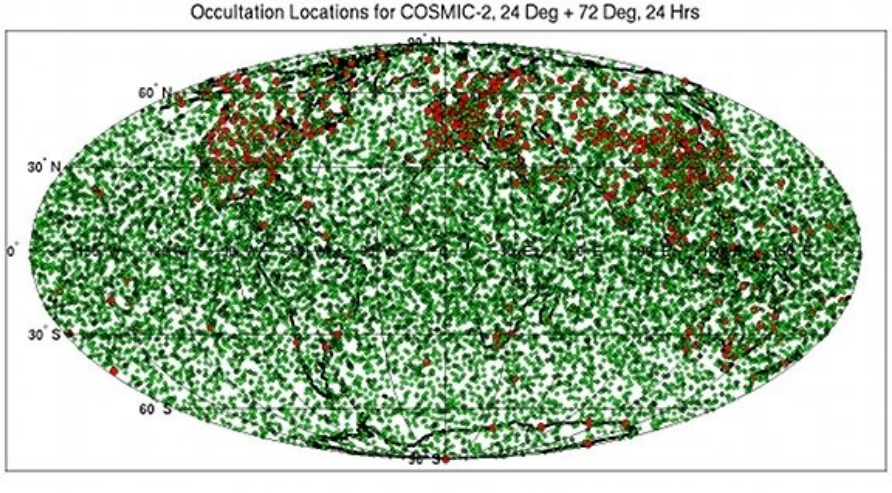
$$||v_{SV}|| \cos\theta_{SV}$$



COSMIC 2

Occultation occurrences over 24 hours for COSMIC and COSMIC-2





images originally published at www.cosmic.ucar.edu

Mask/Filters

Ray paths through Earth

- GPS 1 (for RX) elevation > threshold (5 degrees)
- closest approach of LEO ray-path to Earth surface > 2 km altitude

Volumes way out in space

- proximity < threshold (100 km)
- common-volume altitude < threshold (1500 km)