Ionosphere Observability Using GNSS and LEO Platforms

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• 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
Ionosphere TEC

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

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

- 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

- Blue: GPS
- Green: GLONASS
- Orange: GALILEO
- Red: BEIDOU
Ground RX Observations

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

- 60° IPP
- 30° IPP
- 0° IPP
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.

tangent point altitude histogram
LEO Occultations

90-day histogram of COSMIC-GPS occultation tangent point azimuths
Ground/LEO Common Volume

Geometry

common observation volume

RO tangent point
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 approach 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 especially important at low altitude
- Use 3-frequency GNSS measurements to address low-elevation TEC estimation
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

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References

• TS Kelso et al. Validation of sgp4 and is-gps-200d against gps precision ephemerides. 2007
• 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.
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)