Fv Ionospheric Disturbances - CEDAR Notes:

Go ahead and make comments here!

1) What are the goals of predicting ionospheric disturbances?

Rob Steenburgh - NOAA

- SWPC has origins in radio propagation
- Not much forecaster in the loop for ionospheric disturbances (yet)
- Routine, Watch (days forecast), warning (minutes to hours), Alert (happening now!). Mostly global alerts. Would like to shift to regional.
- Can we do better than D-RAP for HF impacts? Can we produce actionable forecast products for GNSS and HF?
- Has defined
    - Can provide what observing requirements are needed for TEC / scintillation
    - Doing user surveys right now for Space weather action plan - final report delivery planned 30 August 2018 then committee review/approval/release

Jade Morton - CU Boulder

- Spatial Decorrelation vs Scintillation
- Worst case scenario on order of 0.5 m/km due to TEC gradients one 40-100 km
- Accuracy Requirements:
    - 16m horizontal, 4m vertical
    - Ground vehicle: 0.5m
    - Agriculture: 10 cm
    - Unsure what TEC gradients models should be accurate to

Comment: 1TECU translates to 0.163m for L1 and to 0.267m for L2. So for a single frequency receiver, 1m uncertainty corresponds to 4-6TECU, approximately.

-
    - A requirement for time errors needs to be added.
- Scintillation:
    - Loss of signal
- How well do we need to predict scintillation?
    - Don’t really need accurate prediction of scintillation, but need to know that it may happen in some area and give users warning that this could be possible
    - Need to know when there is a bunch of dynamics
        - When the TEC is small-scale and changing rapidly, then you get signal loss.
        - When there are large TEC enhancements or depletions, but over a larger area and relatively steady, you are ok
        - Very dependent on location
    - Need to separate what the ionosphere is doing vs what the satellites are doing.

        - Need some sort of an index based on the model results
        - Need in situ data (cubesats) but would be nice to have a 3D in-situ data -- from scintillation/ propagation modeller's perspective

Need to separate the ionospheric structures/forecast from the impact on receivers which is an engineering issue. Need to determine a forecast or description of ionospheric structure parameter that is easily translated by the user community into PNT impacts.

Comment: One-to-one correlations between GPS signal loss and magnitude of local plasma density gradients were presented by Xiong et al., Space Weather, 2016 and Xiong et al., AnnGeo, 2018 using *Swarm* satellite data of GPS and in situ electron density; for both low and high latitudes. A clear relation between probability of signal loss and magnitude of density variation was derived. Seasonal, longitudinal, and local time variations are described. As discussed during the session, this technically holds for the GPS receivers used in the study (in this case the Austrian receivers mounted on *Swarm*) and also for the receiver settings at the time of correlation. It also should be noted that this study was made with an GPS receiver in orbit, e.g., eventually crossing the ionospheric irregularity. The relation between signal loss and ionospheric structure can be different for other or for ground receivers.

2) What gaps in understanding must be filled to enable predictive simulations?

Dave Hysell

- Boy, we wish that there were neutral wind measurements! Those clouds!!!
- Attempted to model a spread-f night and non-spread-f night to see if the model could do it:
    - Wow - the model actually worked! Forecasted spread-f!
    - Problem: didn't really forecast, used neutral winds and electric fields
- What if you had electron number densities everywhere all of the time? Could you predict other things, like drifts and winds and then spread-f?
    - Could possibly work?
    - Mid-latitudes could be harder because there is more stuff going on with the winds
- Putting in gravity wave in neutral winds can cause all sorts of instabilities at mid-latitudes
- It would be really nice to have neutral winds!!!
    - We seem to understand the physics, but the drivers are not well understood at all!
- If we had electron densities everywhere, what are the scales that are important?
    - 10 km in longitude

Hyunju Connor

- IT models need auroral precipitation and electric fields
    - Typically use empirical models (aurora has like 7 maps and that is it!)
    - Using a global MHD code as a driver can help with some of the dynamics
        - MHD codes are not perfect!!!

- Need auroral measurements!

3) What modeling advances are needed for prediction and specification?

Tomoko Matsuo

- Drivers (neutral winds on coarse scales) can be estimated by combining global thermosphere-ionosphere models with existing GPS (RO + ground) data via data assimilation
- Areas of data assimilation method challenges: Characterize representative errors, Restore balance in analysis increments among dynamic states (e.g., winds, conductivity, dynamo-electric fields)

Tzu Wei Fang

- Model resolution is limited by current computing resource and is not able to capture small-scale structures.
- Forecast products might not meet the need of customers.
- Modeler needs to work much closely with forecasters

Joe Huba

- Need to do ensemble forecasts?
- Primary data that we use is TEC and electron density - no drivers of the system
- In order to forecast well, we need to know:
  - Pressure (ion, electron)
  - Electric fields
  - Neutral winds (this seems to be most important!)
- Spatial and temporal scales -- enough for intermediate scale irregularities? --need better resolution than <10km, 0.1 deg
- Numerics is important for models also.
- Resolution is important. This is probably one of the most important things.

Neutral winds are critical, but are almost impossible to actually measure all the time and all over the place. How can we supplement the data with models? Can we replace measurements of the neutrals with models?

Tomoko: Variables not available today but need for better assimialtion - would liike to know conductance for closure in assimilation, winds too; with data we have today, we can give decent inputs to disturbance model. New observations are needed but we are not using existing observations optimally yet.

Tzu-Wei: Global models cannot capture small-scale variability, in low,mid-latitude region. Computational capabilities is a major limitation.

4) What observations are necessary to provide the basis for understanding and modeling?

Farzad Kamalabadi

- Understanding can follow predictive capability (e.g., neural nets) even if the capability doesn't initially have an underlying physical approach
- OSSE: could be binary or global or regional distribution of error
- OSSE: May be able to transfer specification of sensor distribution in space to a more abstract distribution to optimize model performance (eigenvalues?)

5) What instrumentation is necessary to provide those observations?

Bill Bristow

Joe Malins

- Radio astronomy needs information about ionospheric plasma density to correct measurements; area of cross-directorate collaboration
- LWA provides a very sensitive TEC measurement (better than GPS)

Comment: A user that has not been mentioned and perhaps not considered: Radio Telescope Users. In last 10 years explosion in low frequency radio telescopes (Long Wavelength Array, 4, P, and C band Very Large Array, Low Frequancy Array, Murchison Widefield Array). Ionosphere acts as a dynamic shifting lens that bends and refracts cosmological radio signals as they pass through it. Radio Telescope Community needs predictive products that can show exactly what was discussed in GPS in order to screen observations (can't observe if bad "weather") or better yet more accurate products that allow for at least first order corrections of phase and amplitude to allow for observations to continue.

Example IDEAL products:

· Size and direction of TIDs over telescope hours in advance

· Prediction of scintillation, both phase and amplitude, and depth of scintillation to degree scale above instrument (translates to ~5 km scale over instrument) several hours in advance

Obviously difficult, but these would be very useful predictive products. Instead, if the following was available it would allow for observation screening

· Presence of TIDs over telescope area hours to days in advance

· Presence and severity of scintillation in region of telescope hours to days in advance

Consider asking radio telescope for requirements for ionospheric models (Joe Malins)

Asti Bhatt

- Clouds are a problem, but it's not cloudy everywhere all the time. The same ionosphere can be viewed from multiple vantage points, not all of which will be cloudy.

Seebany Datta-Barua

- UNAVCO proposal to NSF (EAR?) to upgrade some of their GNSS geodetic networks to Septentrio PolaRx5. Option/opportunity for SWON to tie in to upgrade to scintillation receivers PolaRx5S.
- Support enthusiastically vocalized from at least one person.
- Scintillation receivers for borrowing from UNAVCO on a campaign basis.
- Reminder that, in considering astronomy or Earth science networks, not to forget MAG networks, Class II facilities.
- Canada has multiple arrays, and note that scintillation receivers don't have to be commercial off-the-shelf units. They may be, and only require firmware upgrades. Or they may be antennas+front-end portions of the GNSS receiver, where all the data stored can subsequently be used for computing e.g., scintillation indices on the user's own.

Diana Loucks

- 25 scintillation receivers to be deployed in Alaska (Anthea C) may be useful to this project

Discussion topics: Enabling technologies (Ground and Sats and synergies)