Toward interpretation of HF propagation data obtained by the HamSCI Community - Ray Tracers and Ionospheric Models

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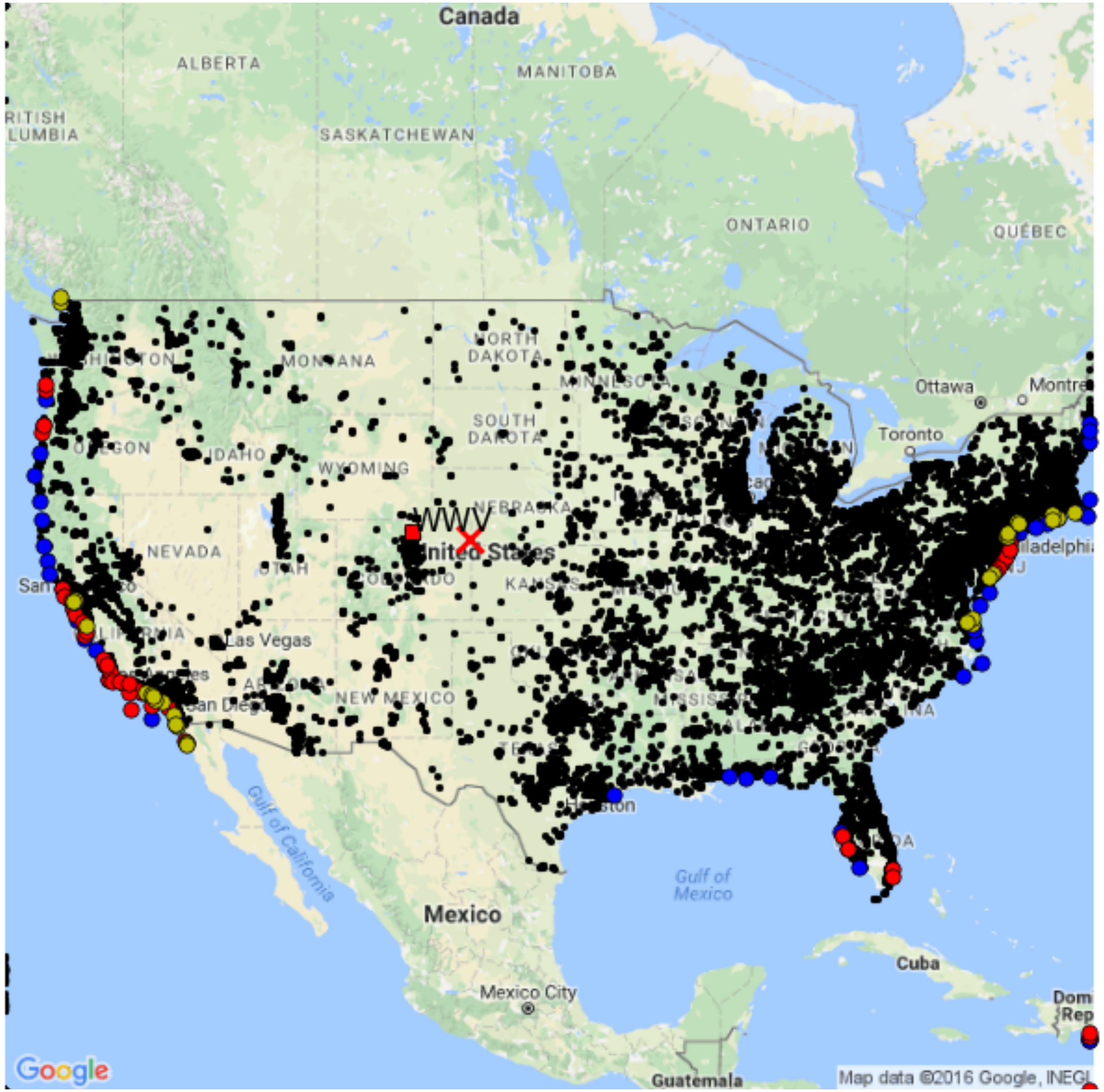
Purpose of this talk

- Thanks to: Phil Erickson, Nathaniel Frissell, Gareth Perry, and Ethan Miller for ongoing conversations on this topic
- This talk is more to present a framework and some thoughts I have on this topic vs. a scientific talk
- My hope is that this talk will generate some ideas and get people thinking more about these problems.

“And then what happened”

- The next (or one of the next) phase(s) of the hamsci will be to extract usable scientific data from sensors placed in the field
  - This is already happening, i.e., Steve Cerwin and Kristina Collins
- The TangerineSDR will be designed to obtain estimates of ionospheric time delay and Doppler (this is going to be a really nice sensor!).

Imagine if we had a network of tangerineSDRs like this – what could we do???

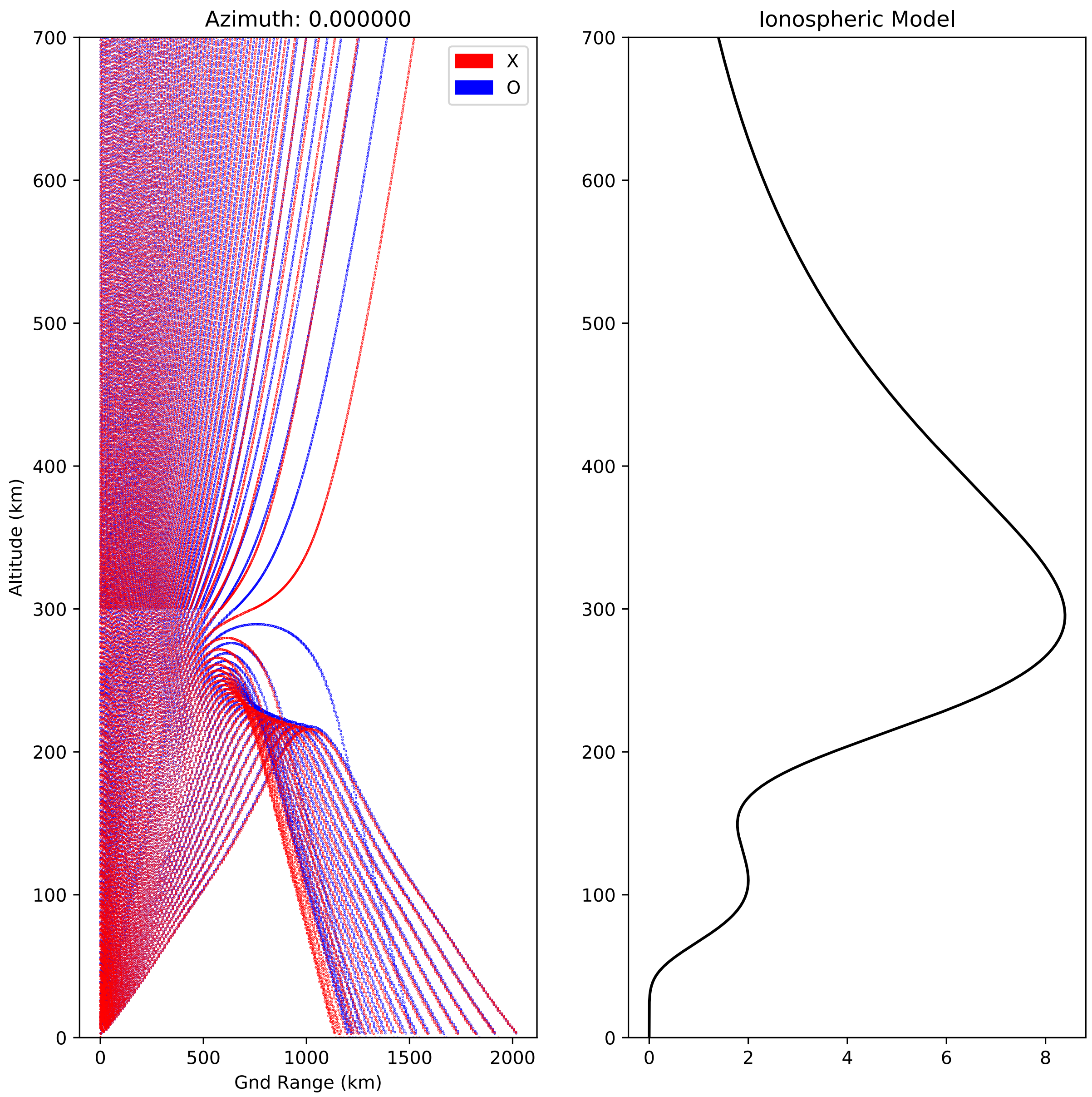


Black dots are RBN data from 2014.

Question:

- Given that we have many sensors capable of measuring delay and Doppler: how will we be able to scientifically useful information from many distributed sensors? What analysis techniques need to be developed? How can we use the data provided optimally to obtain new ionospheric information?
- Possible Solution: develop a modeling framework and approach which could be used to provide interpretation of data collected by distributed network of SDRs
  - One way to approach this is to develop simulations or a simulator capable of producing the data you might collect.
    - Can control the physics and generate ensembles of ionospheric states
    - Even for a few simplistic examples, may give us some insight into what we might expect the data will look like

Ray Tracer is an important tool.



Modeling framework

$$\mathbf{y} = f(\mathbf{x}; Iono, Bfield)$$ *f* is the ray tracer in this equation

For one ray:

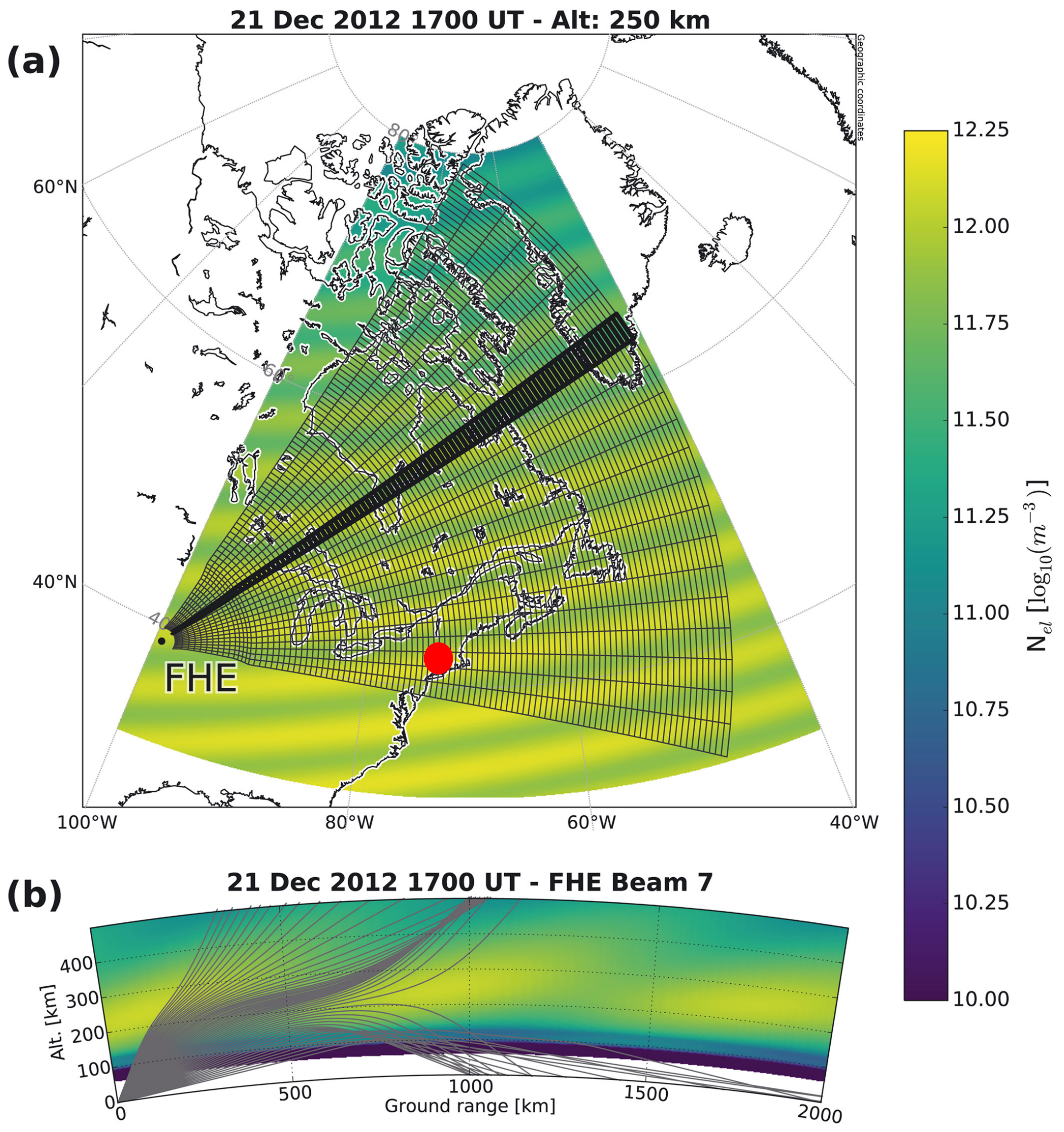
$$\mathbf{x} = [f_{TX}, az, el, XO, n_{hops}, r_{TX}, \theta_{TX}, \phi_{TX}]^T$$

$$\mathbf{y} = [f_{TX}, r_{gnd}, \theta_{gnd}, \phi_{gnd}, GP, PP, \Delta f]^T$$

We can generalize this for M rays and N transmitters. Iono is the ionospheric model used and B-field is the magnetic field model used.

- We can consider the ray tracer to be the forward model, which maps ionospheric state parameters to observables.
  - Homing algorithm can connect ray between the transmitter and receiver – this is a “shooting” method to find the solution

Modeling Framework



Frissell et al., 2016

Imagine you are at the location of that red dot with a receiver.

If this were the ionospheric structure moving southward – what sort of time series of delay and doppler would this produce?

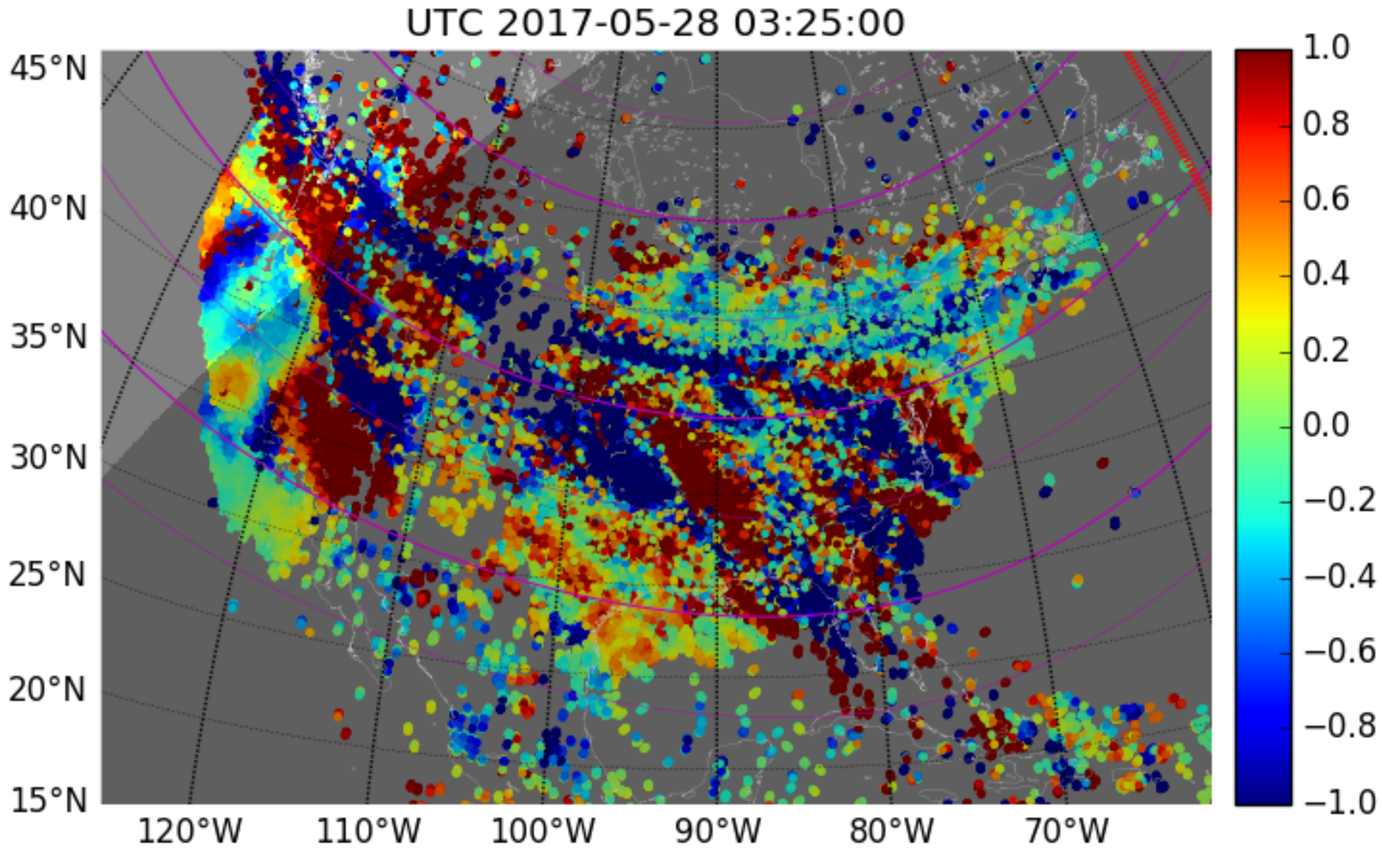
Now imagine that we changed the angle of propagation of these TIDs – how would it change the observed signatures?

Modeling Framework

- Given the forward model framework – we could generate synthetic time series (including noise) which could then be compared directly with observations (once we have them)
- Useful for testing how well any of our analysis/inversion algorithms work
  - For example, we can see how well we can reproduce or estimate some sort of propagating structure we may specify.

One Example: TIDs

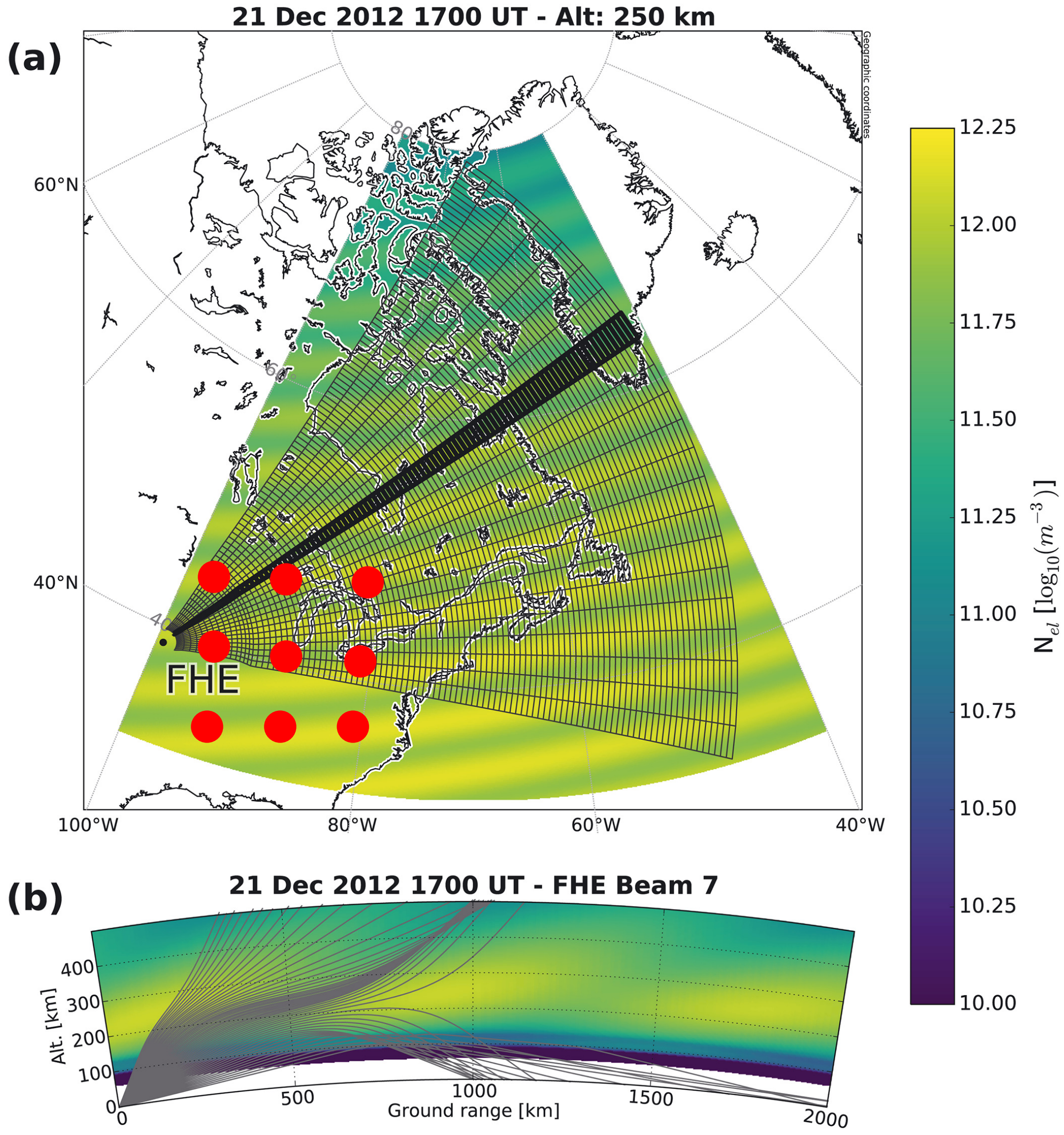
- How many RX stations do we need to be able to resolve TIDs (for example) properties and/or image TIDs?
  - Know 3 is the minimum number. What about if you had 10 stations or 100 stations or 1000 stations?

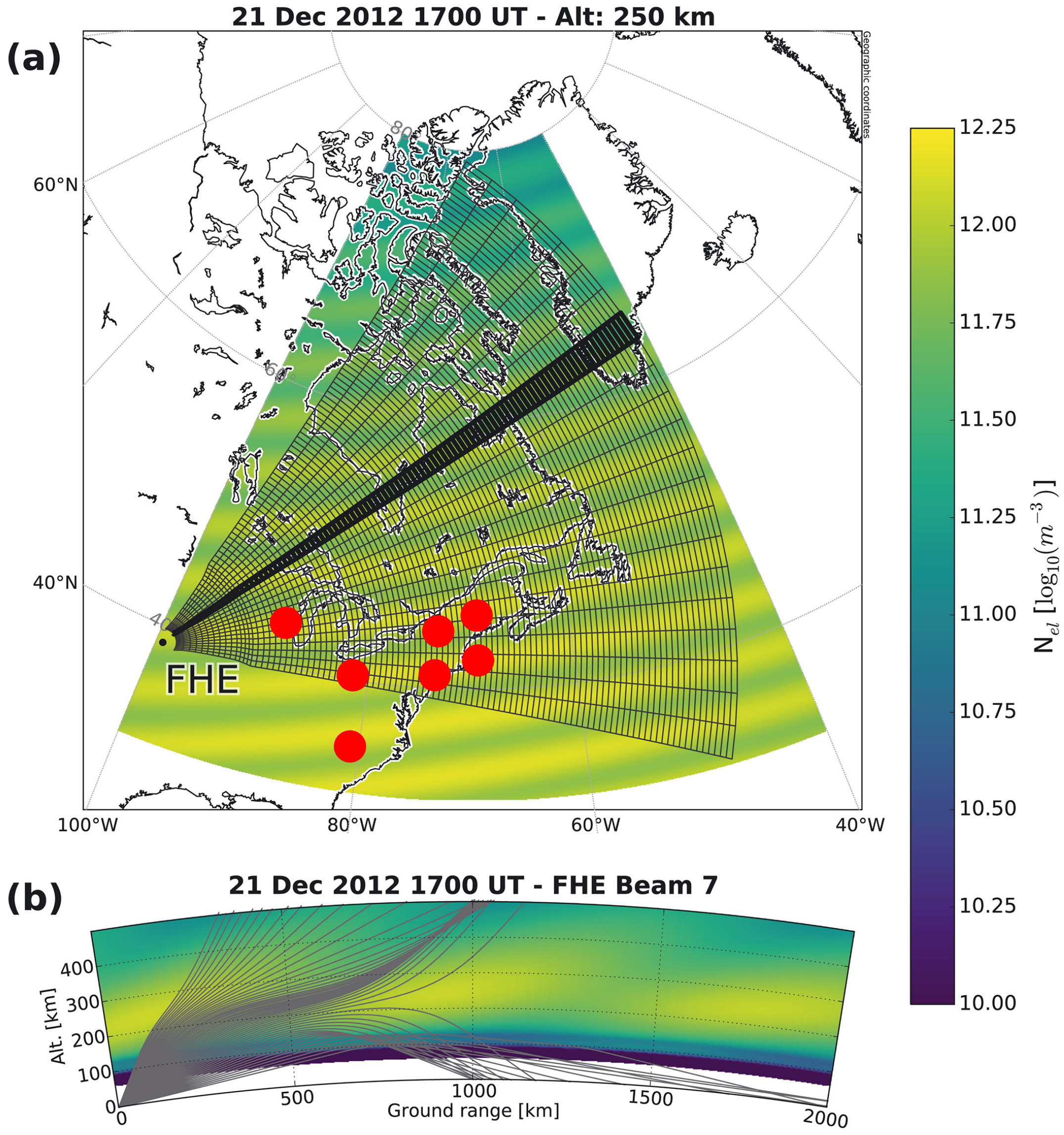


https://www.haystack.mit.edu/wp-content/uploads/2020/07/project_GNSS-TEC_001-e1594949014814.png

One Example: TIDs

- What spatial distribution of receive stations is optimal for reconstruction?





Advanced Ray tracing modes – improve speed?

- Shooting method may be quite slow – are there other methods?
  - Increase speed of ray tracer using GPU processing?
- Point to point ray tracing using direct variational method (Coleman 2011)

Scott Driggers Poster: Point to Point Ray Tracing