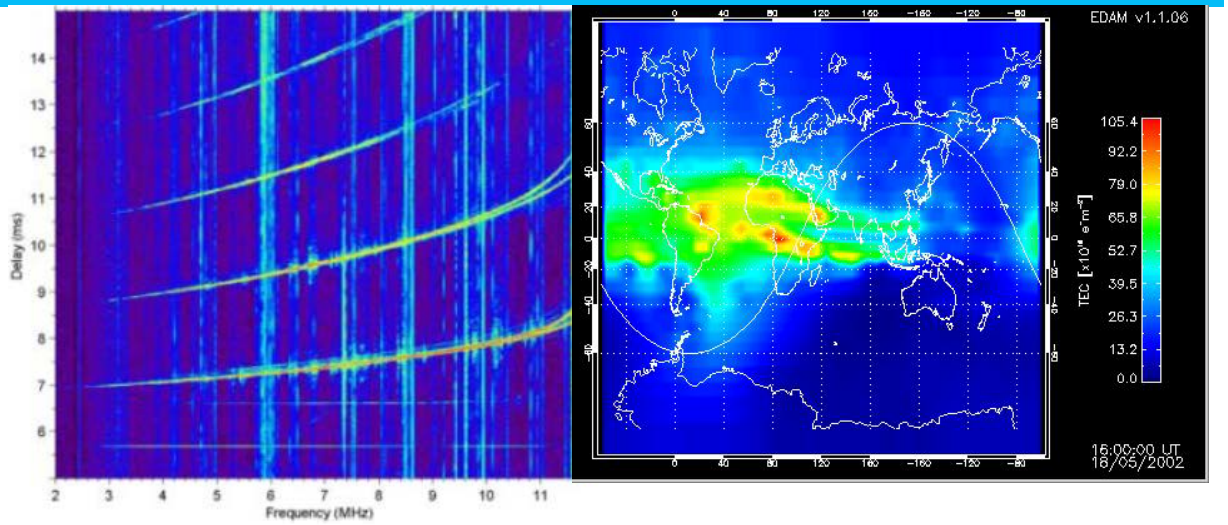
Preliminary results for the assimilation of forward oblique ionosondes into the Electron Density Assimilative Model



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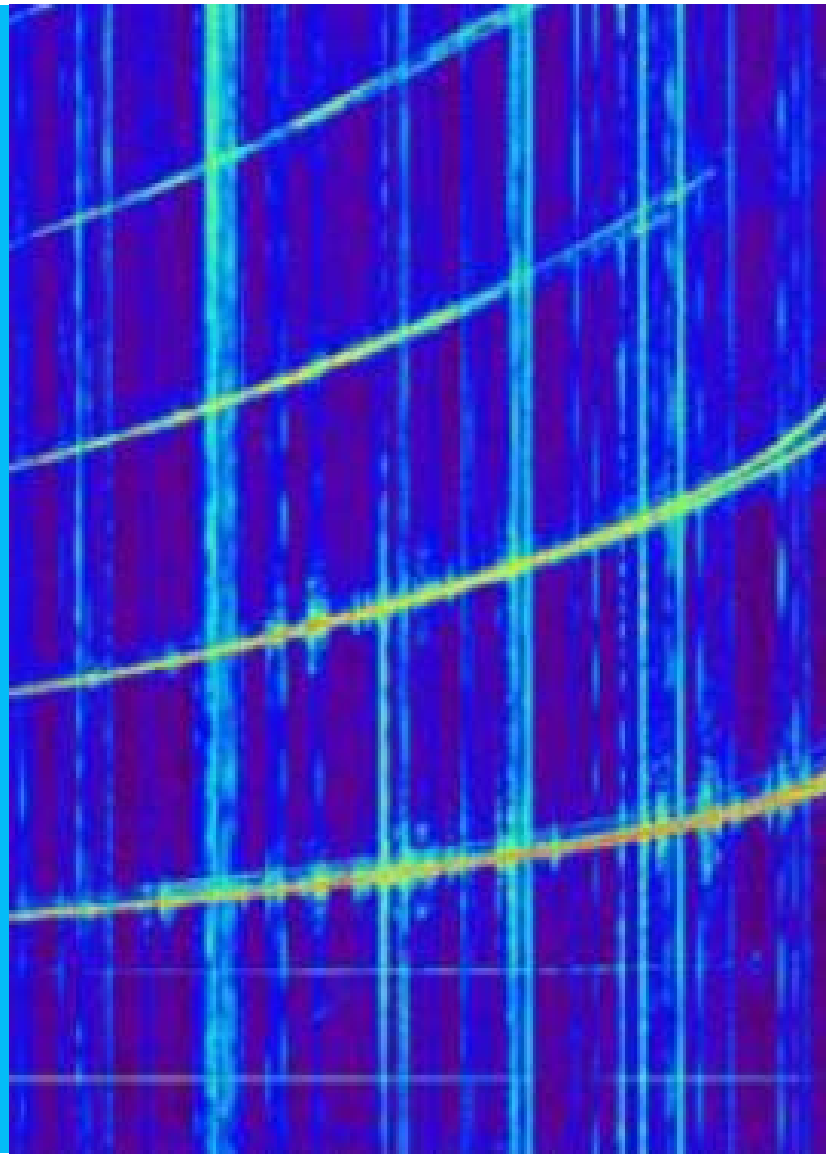
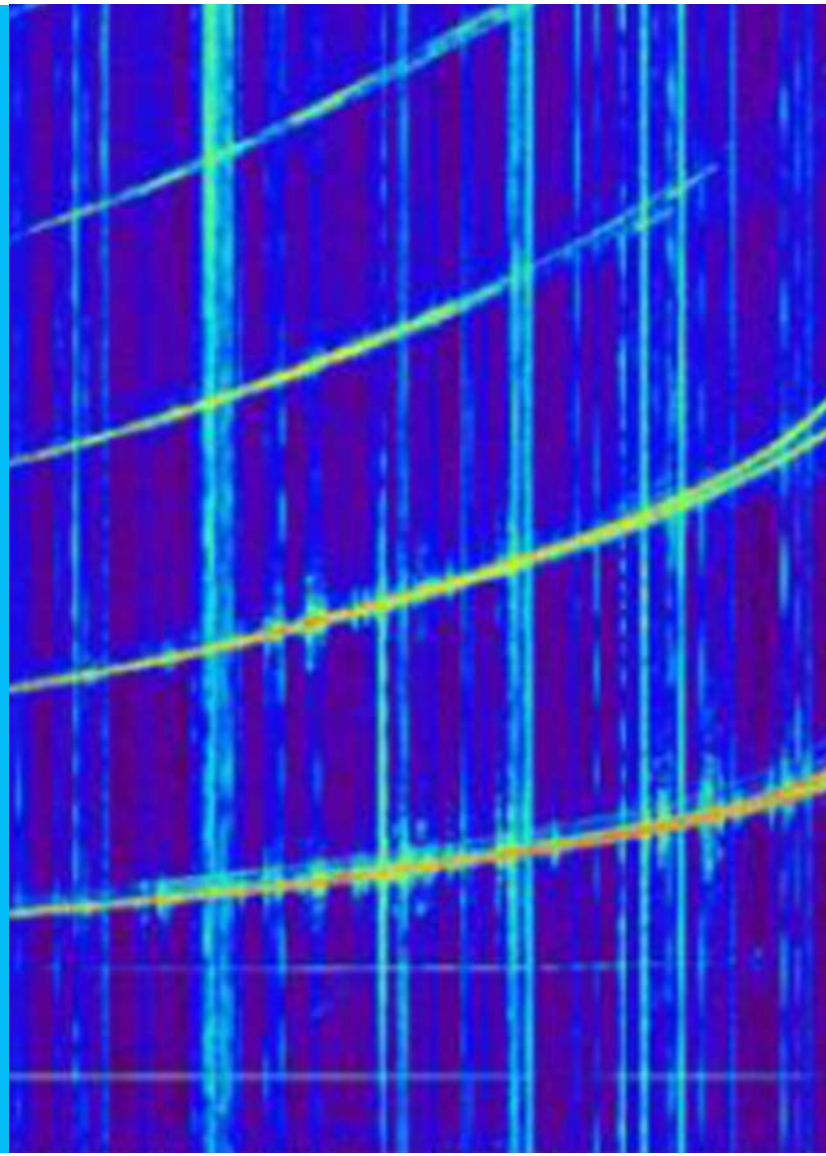


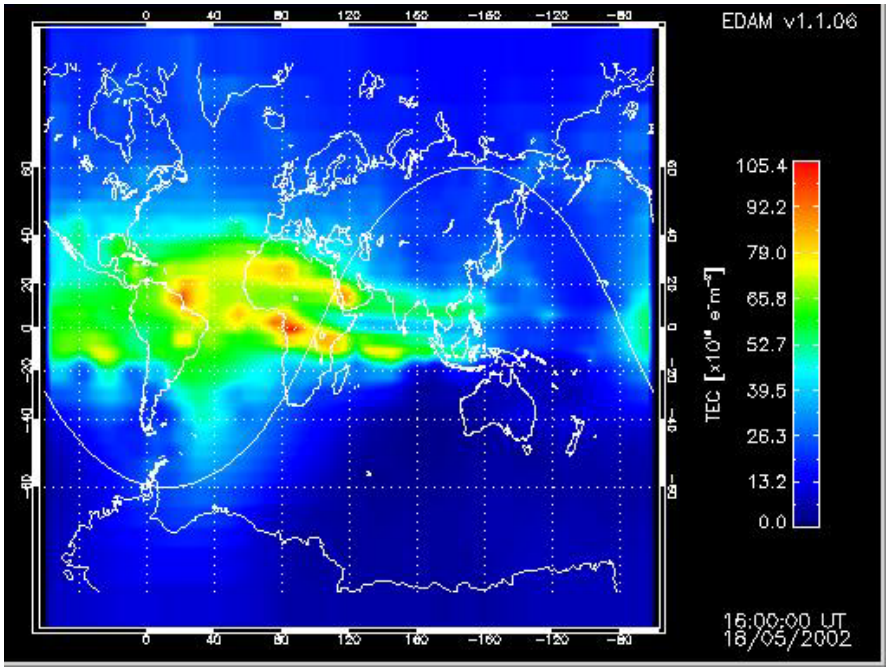
Assimilation of FOIs into the Electron Density Assimilative Model (EDAM)



EDAM – the Electron Density Assimilative Model

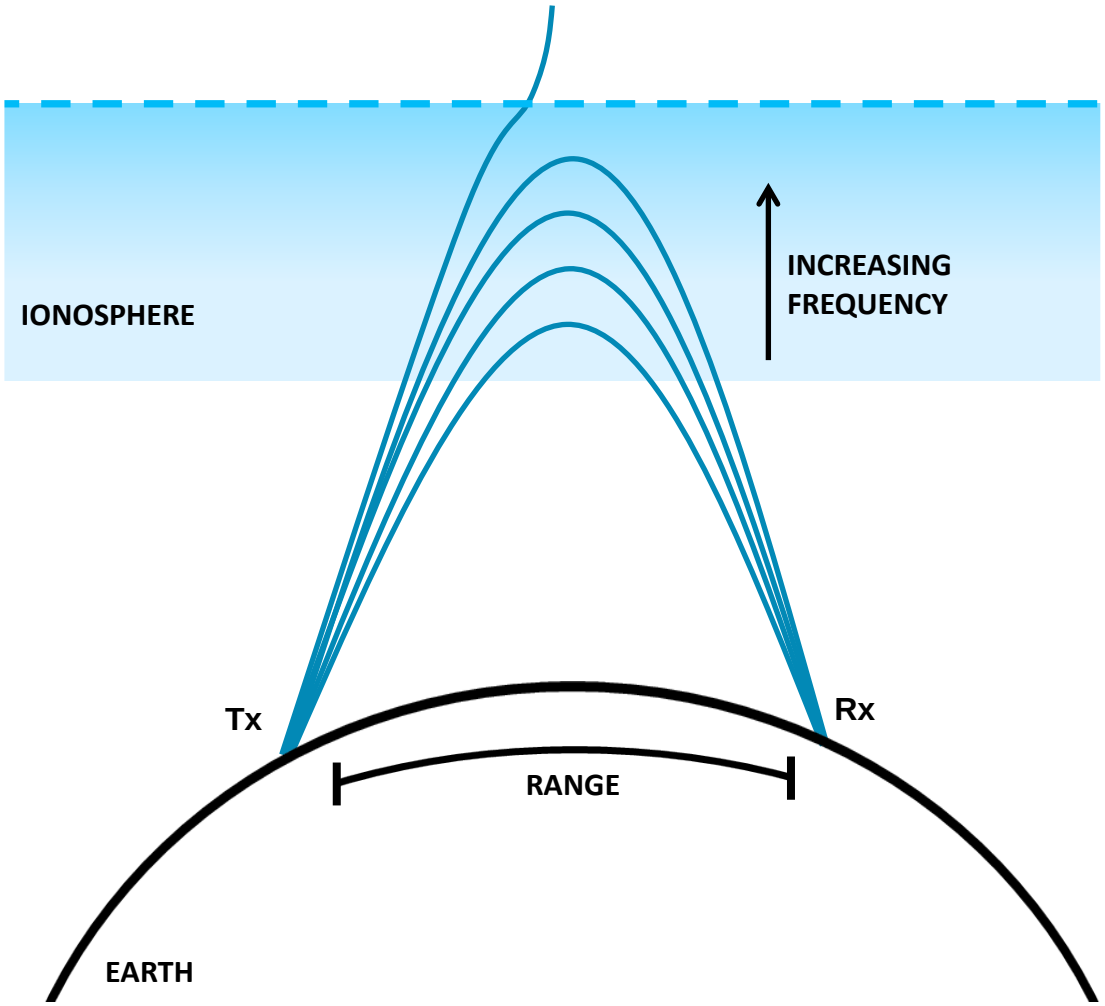
- **Assimilates data from a variety of sources into a background ionospheric model.**
  - TEC measurements derived from GNSS (Global Navigation Satellite Systems).
  - Radio occultation data.
  - Vertical ionosonde data.

- **Uses IRI-2007 as the background model and the previous time step as the initial estimate of the state. EDAM then uses minimum variance optimal estimation to update the initial estimate to match the measured data.**



- **Data from forward oblique ionograms are not currently assimilated into EDAM.**

Forward Oblique Ionograms



- **A forward oblique ionogram provides information about the time delay between a transmitter and a receiver.**
- **The measured time delay is made up of two components,**
  - The physical path taken by the ray.
  - The electron density along the path of the ray.
- **This technique has the potential to provide information about underobserved regions of the ionosphere, where it is prohibitively difficult to place GNSS receiver stations or vertical ionosondes (for example, oceans).**

Need for FOI assimilation

- **Recent trials such as MOSC (in the Marshall Islands) showed that IRI is not capable of tracking the ionosphere during active times**
- **When the ionosphere is under observed models are unable to capture an accurate representation of the ionosphere**
- **During MOSC we captured hundreds of FOIs that could be used to improve EDAM**

Assimilation of the Forward Oblique Ionogram

- A group delay for a specific frequency is found by ray tracing through the background electron density grid – the 'synthesised' delay.

- The synthesised delay is then compared with the measured delay and used to calculate a fractional difference which is used to increase or decrease the total number of electrons along the ray path.

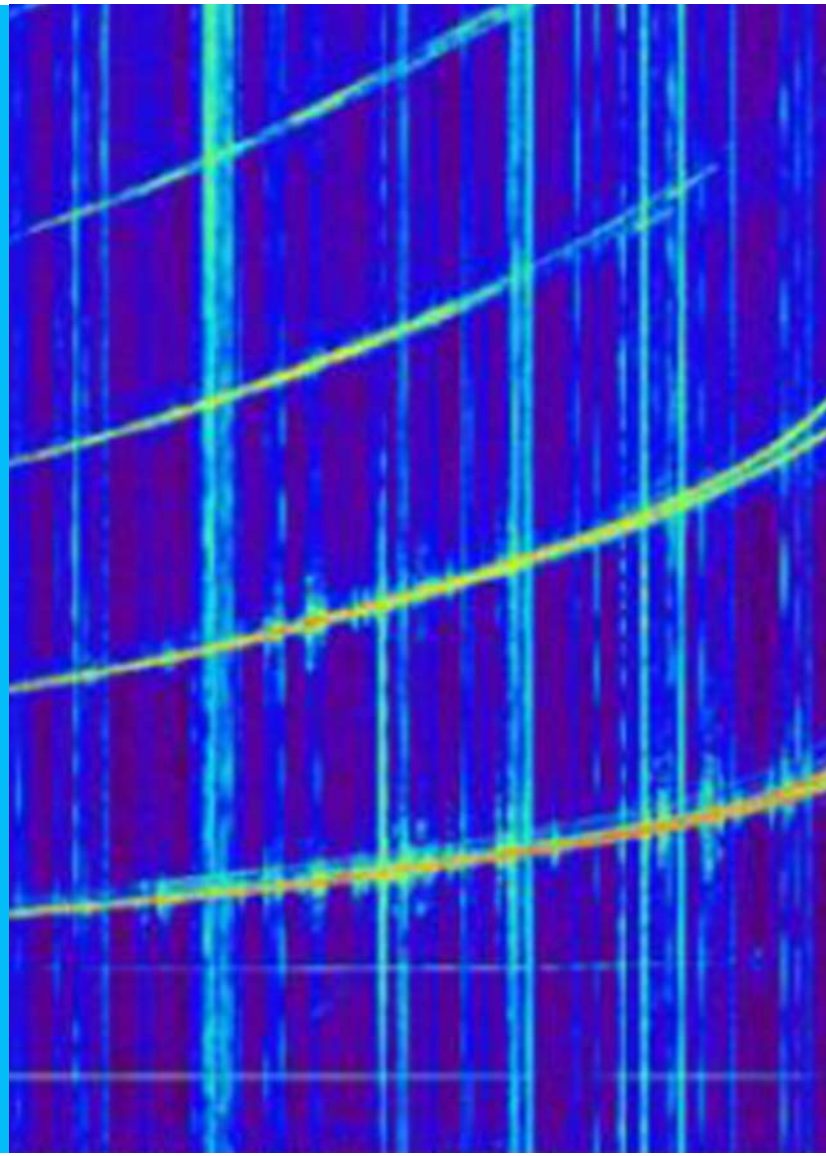
- This new value is then assimilated into the model using a Gauss Markov Kalman filter,

$$x_a = x_b + \mathrm{K}\left(y - H(x_b)\right)$$

where $\mathrm{K}=\mathrm{BH}^{\mathrm{T}}(\mathrm{HBH}^{\mathrm{T}} + \mathrm{R})^{-1}$

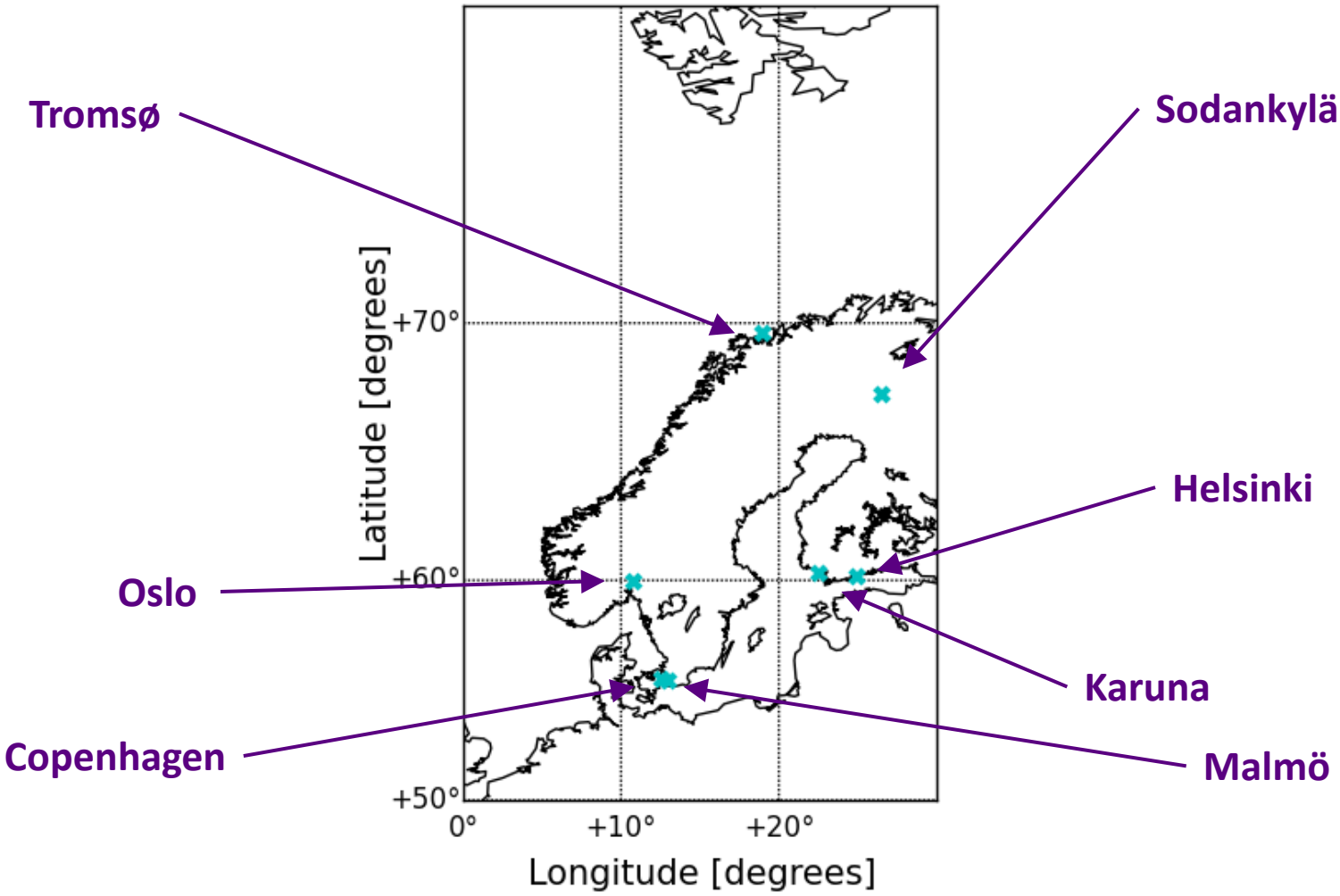
- The assimilation proceeds stepwise through each frequency in the measurement.

Test scenarios



Comparison to simulated truth data

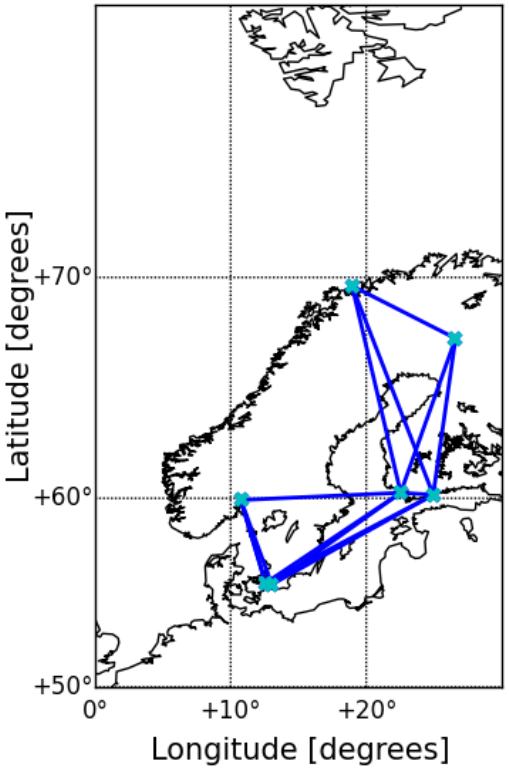
- We select a range of transmitter and receiver sites distributed over a large area.

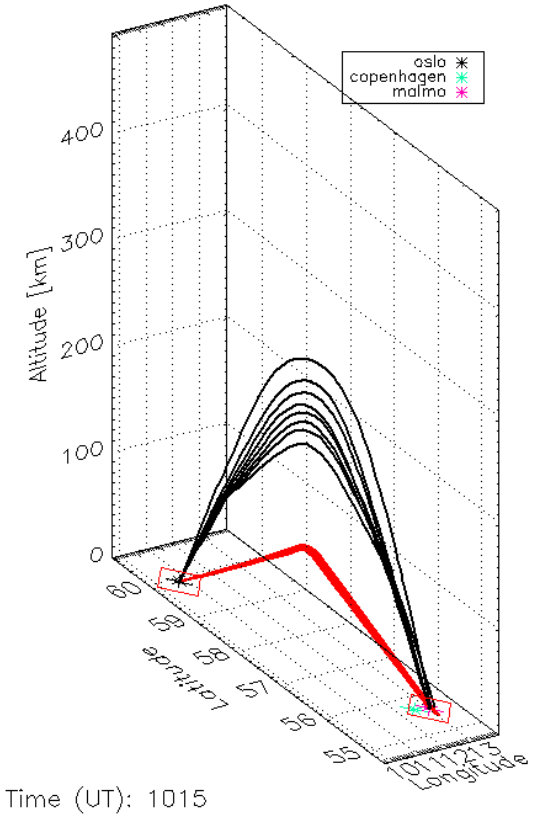


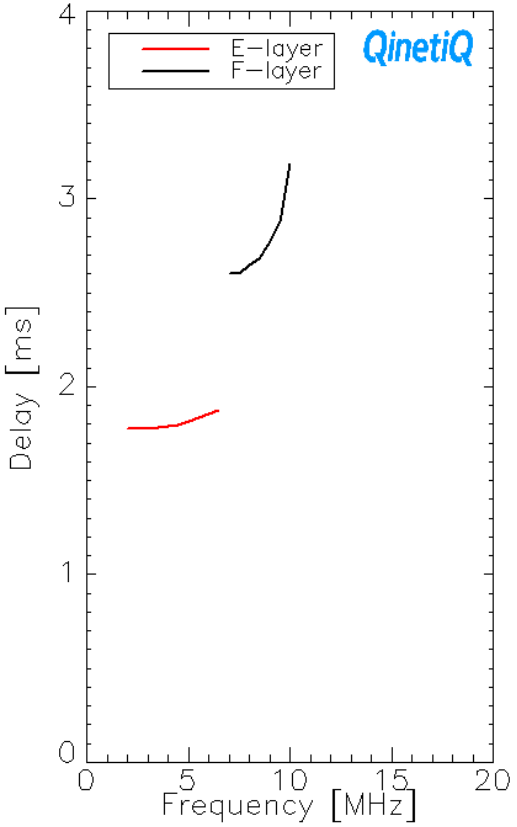
Comparison to simulated truth data

- **We synthesise ionograms between these receivers and transmitters through a simulated electron density grid. We use these as our 'measured' delay.**

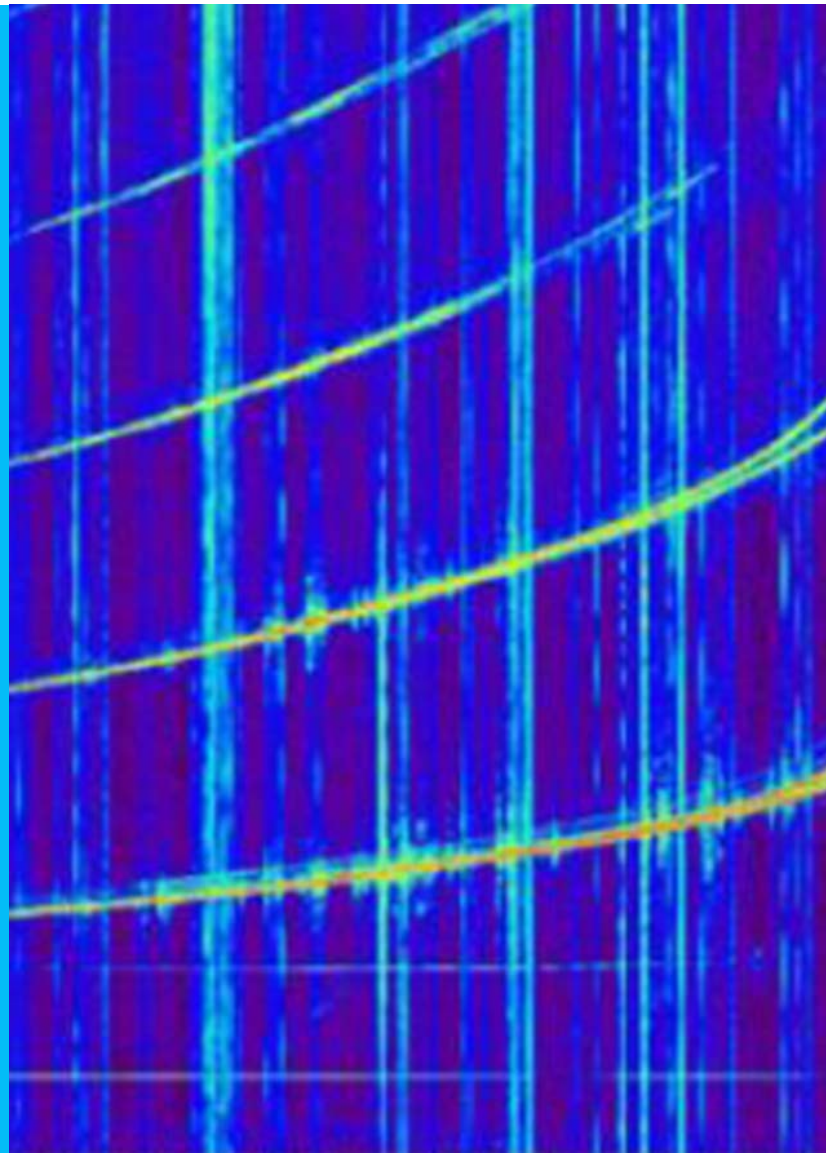
- **These data are then assimilated into a background model (IRI-2007) using the FOI assimilation technique.**







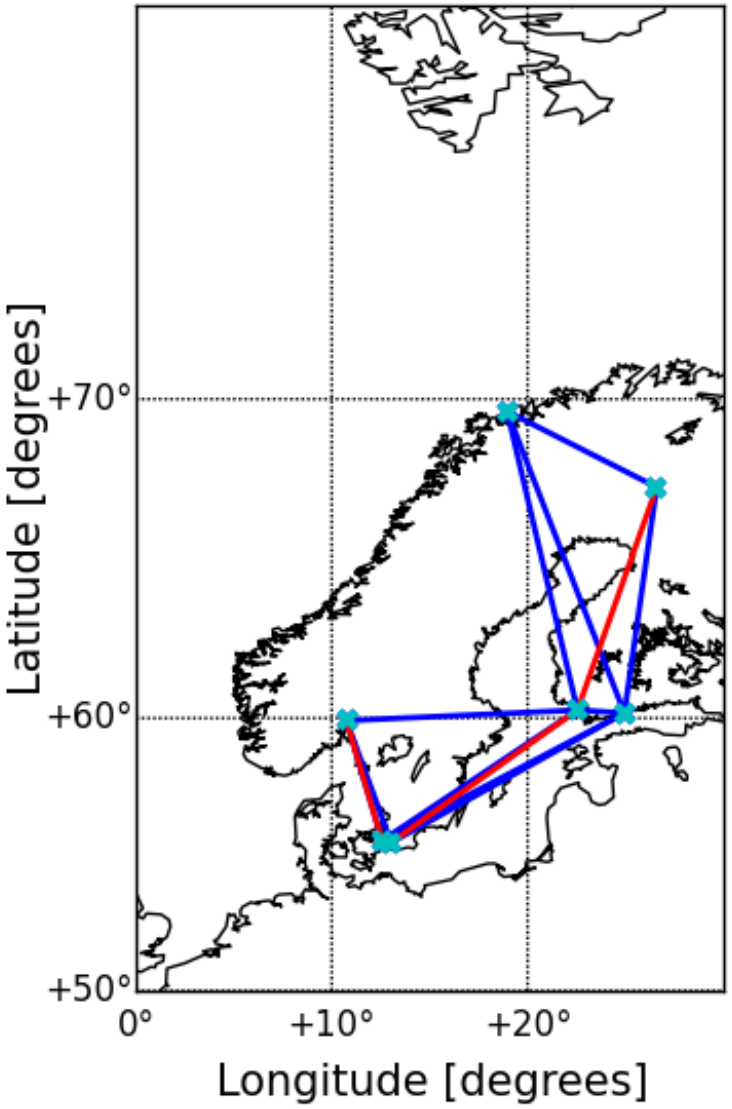
Comparison to forward oblique ionosonde data



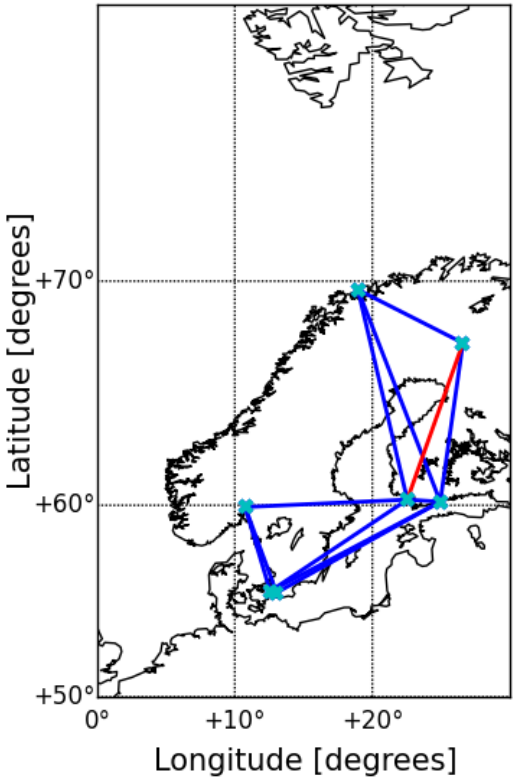
Comparison to simulated truth data – FOI

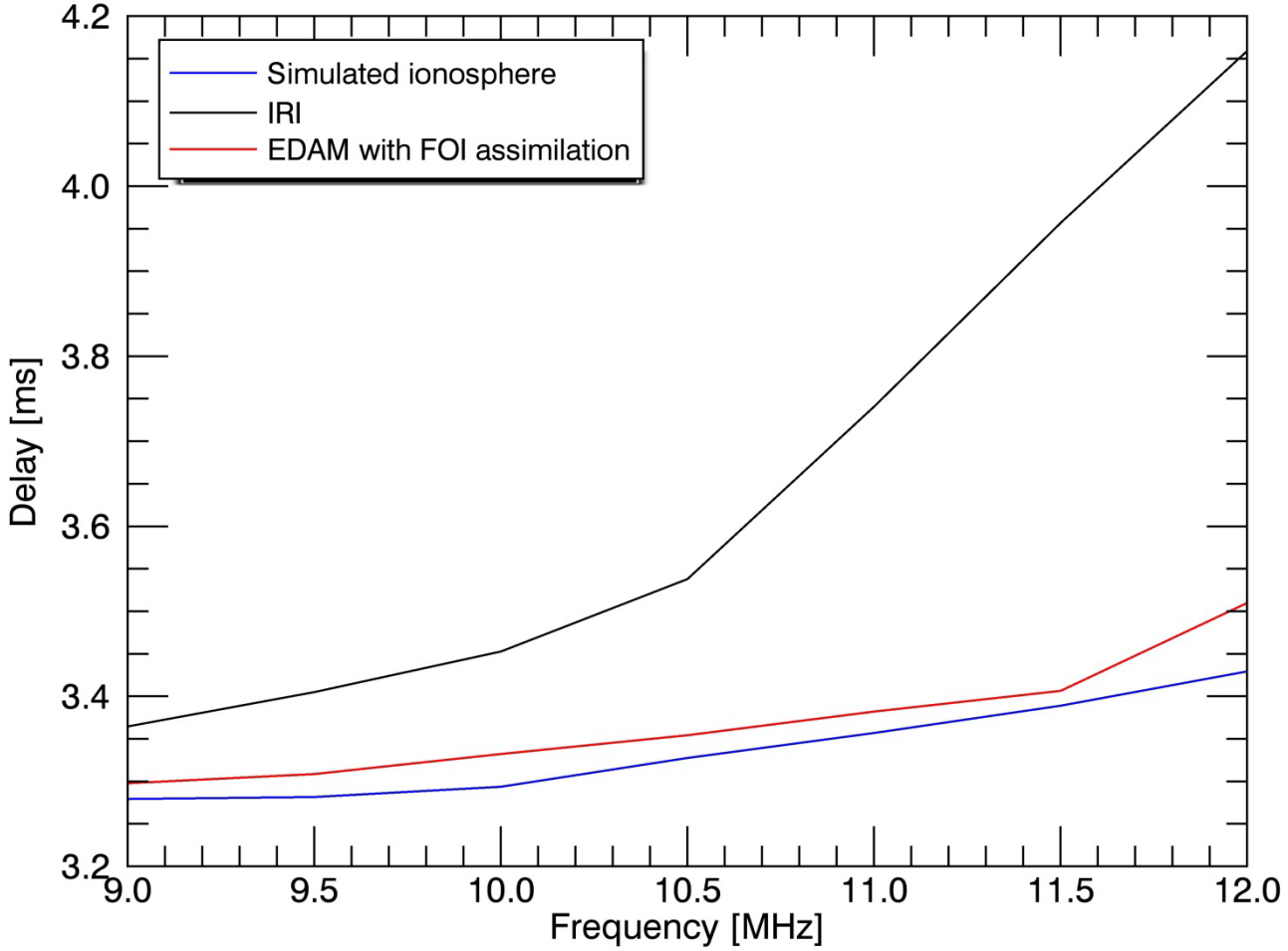
- **Three of the synthesised ionograms are extracted as 'truth' data. We do not assimilate these data into the background ionosphere, and instead use them to verify the success of the FOI assimilation technique.**

- **The data sets (highlighted in red) extracted as 'truth' data for this test are,**
  - Sodankylä to Karuna
  - Malmö to Karuna
  - Copenhagen to Oslo

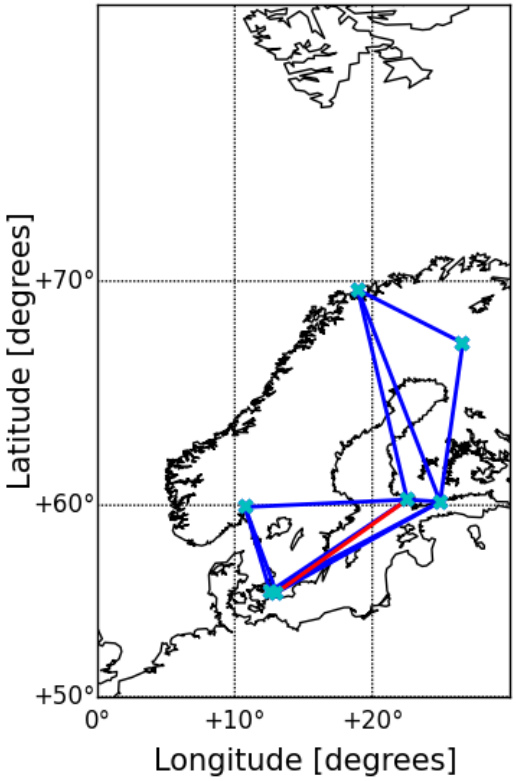


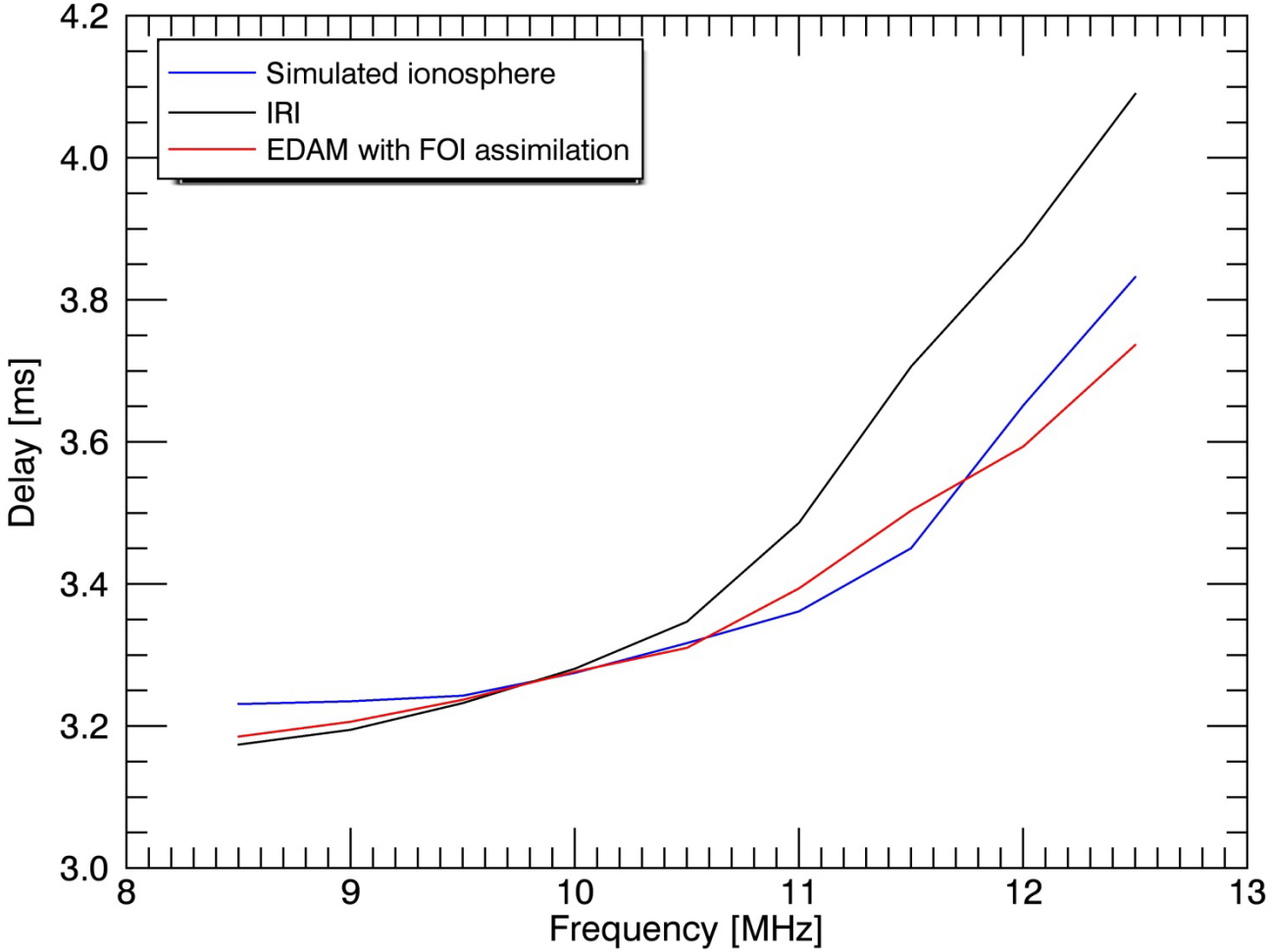
Comparison to simulated truth data – FOI Sodankylä - Karuna



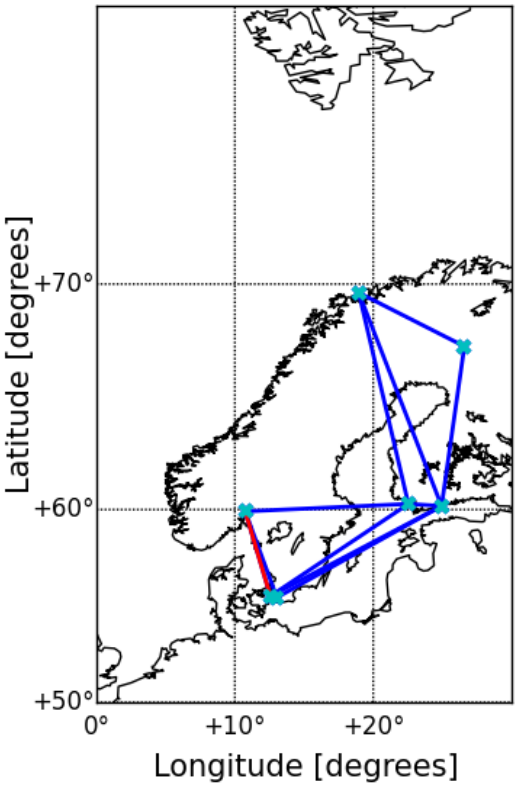


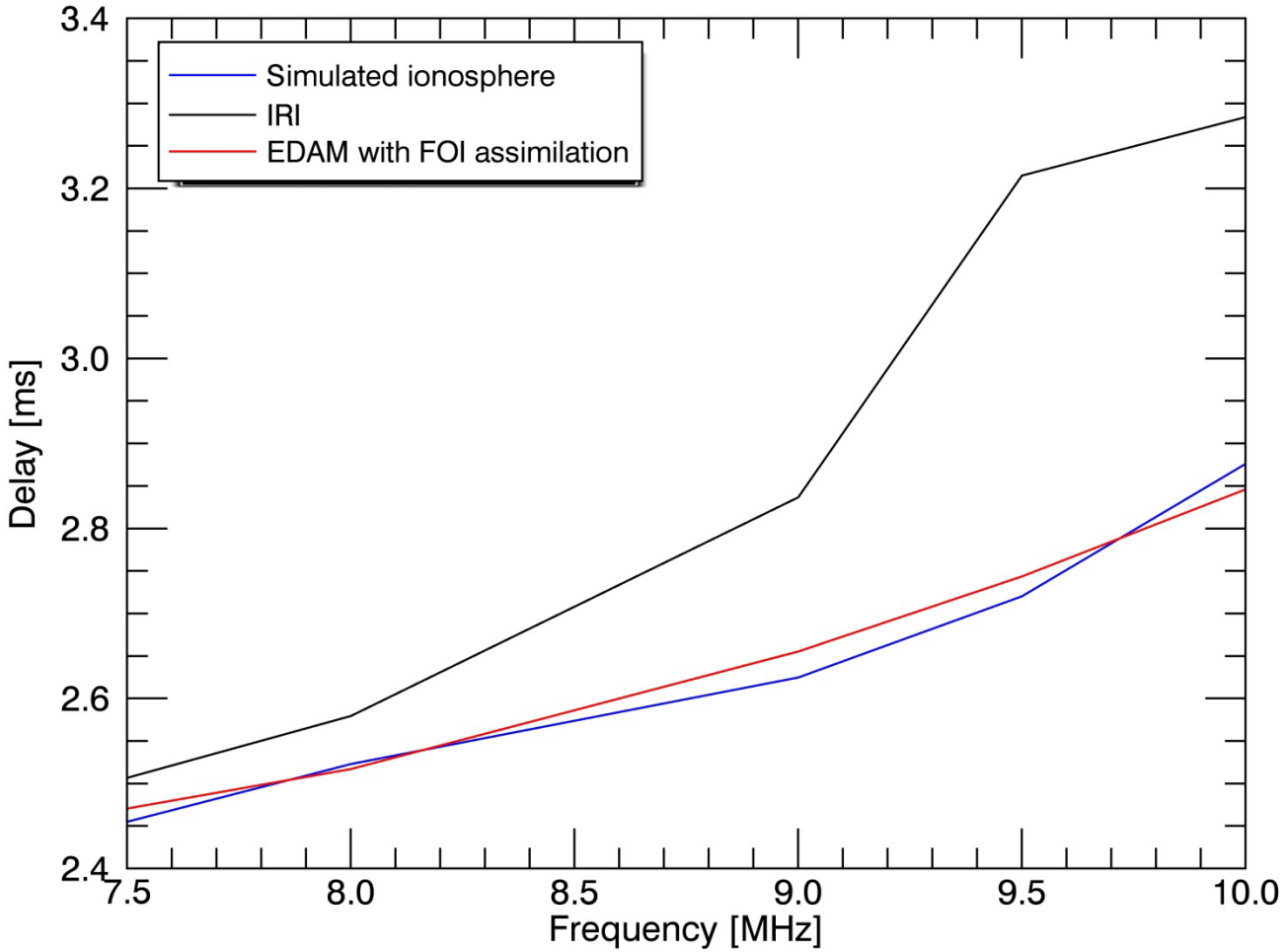
Comparison to simulated truth data – FOI Karuna - Malmö



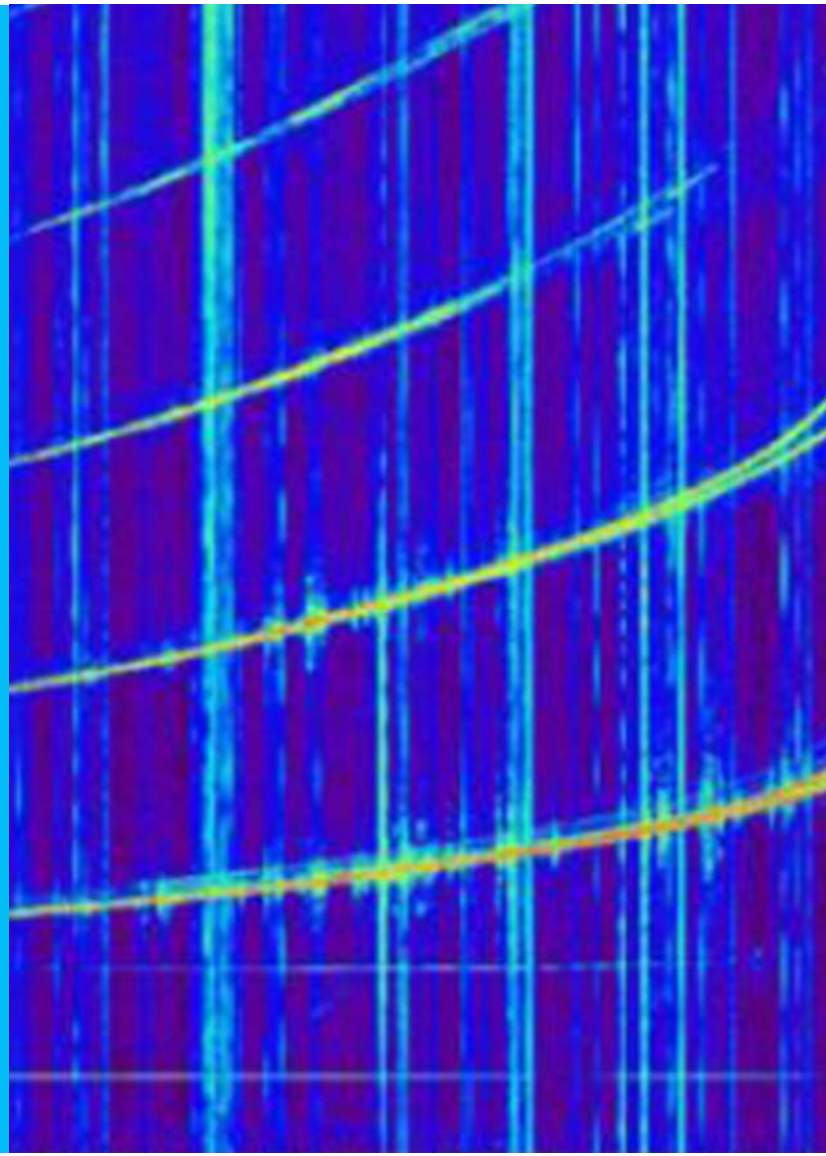


Comparison to simulated truth data – FOI Oslo - Copenhagen

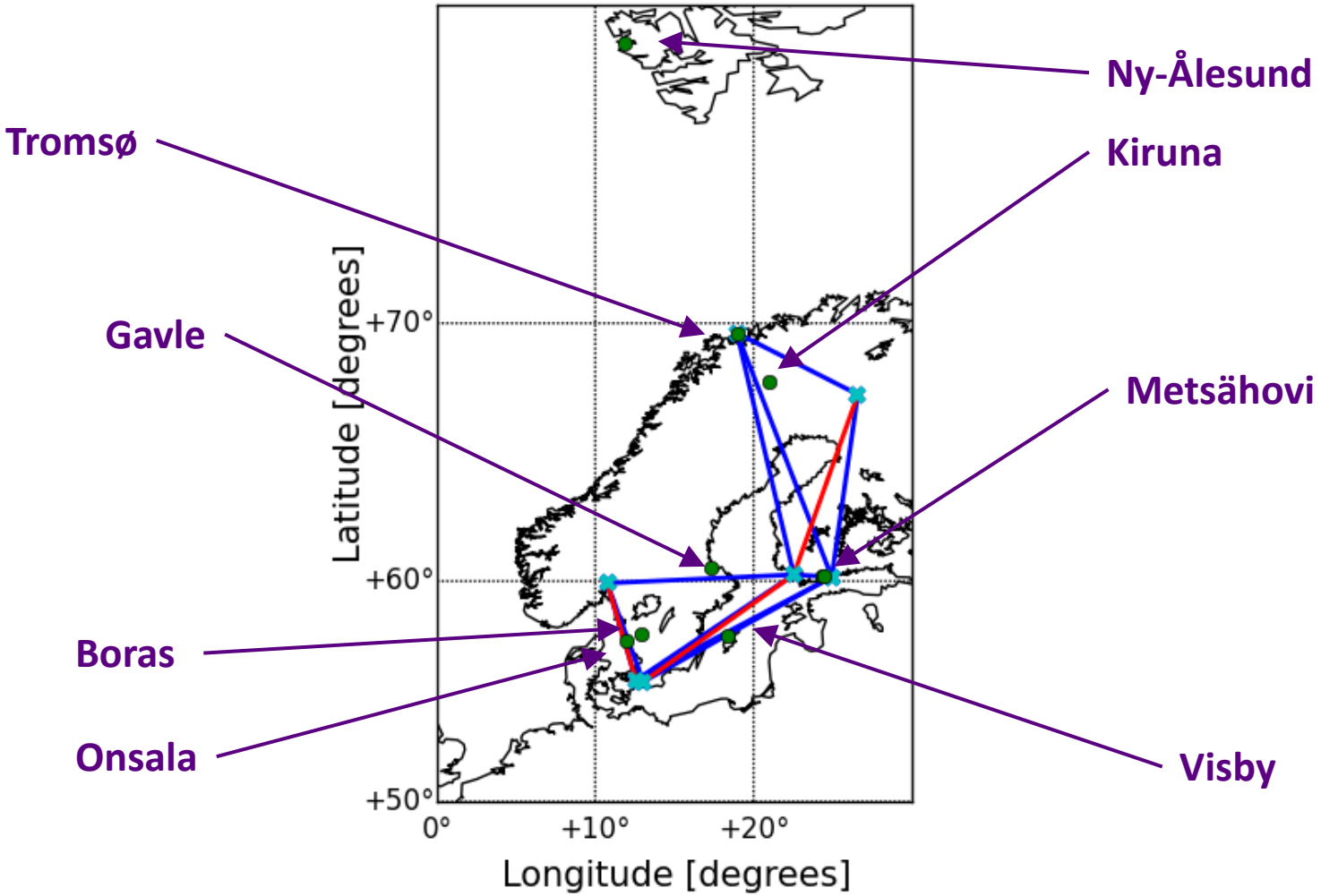




Comparison to GPS data

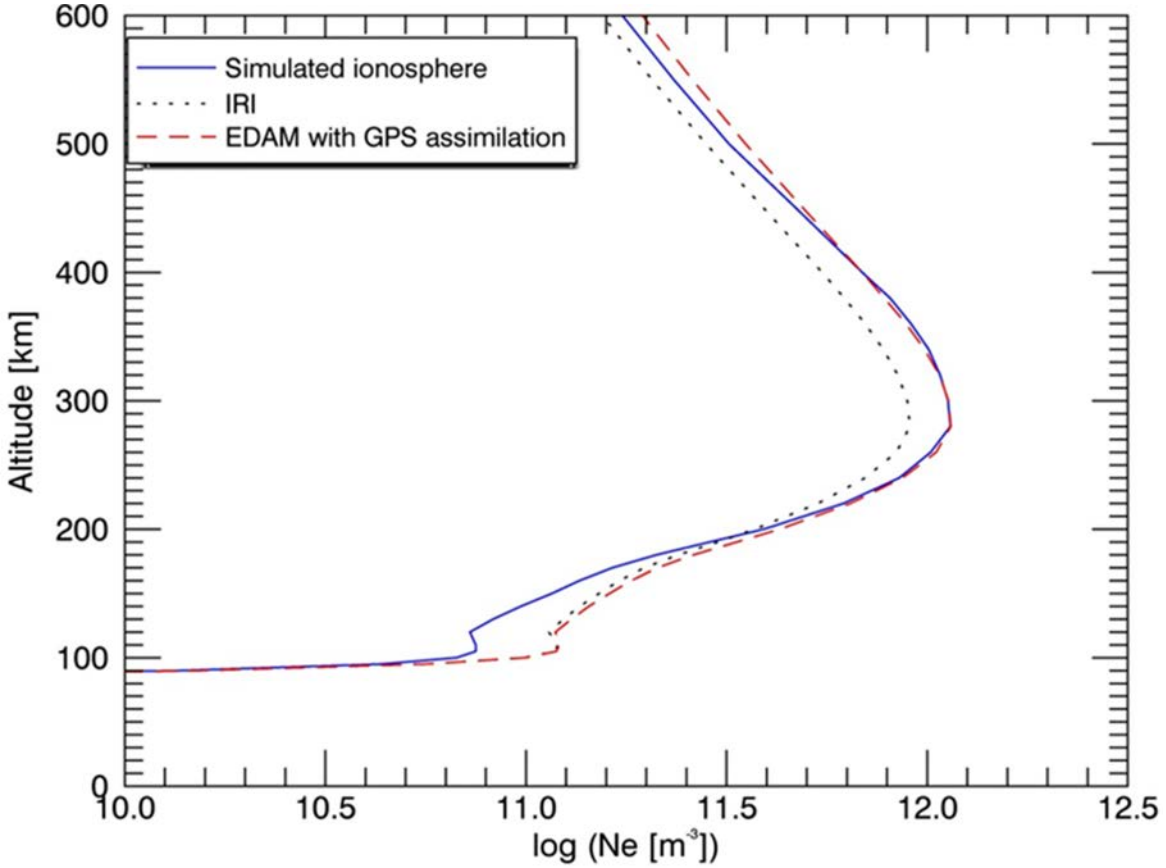


Validation of the FOI assimilation technique using simulated GPS data



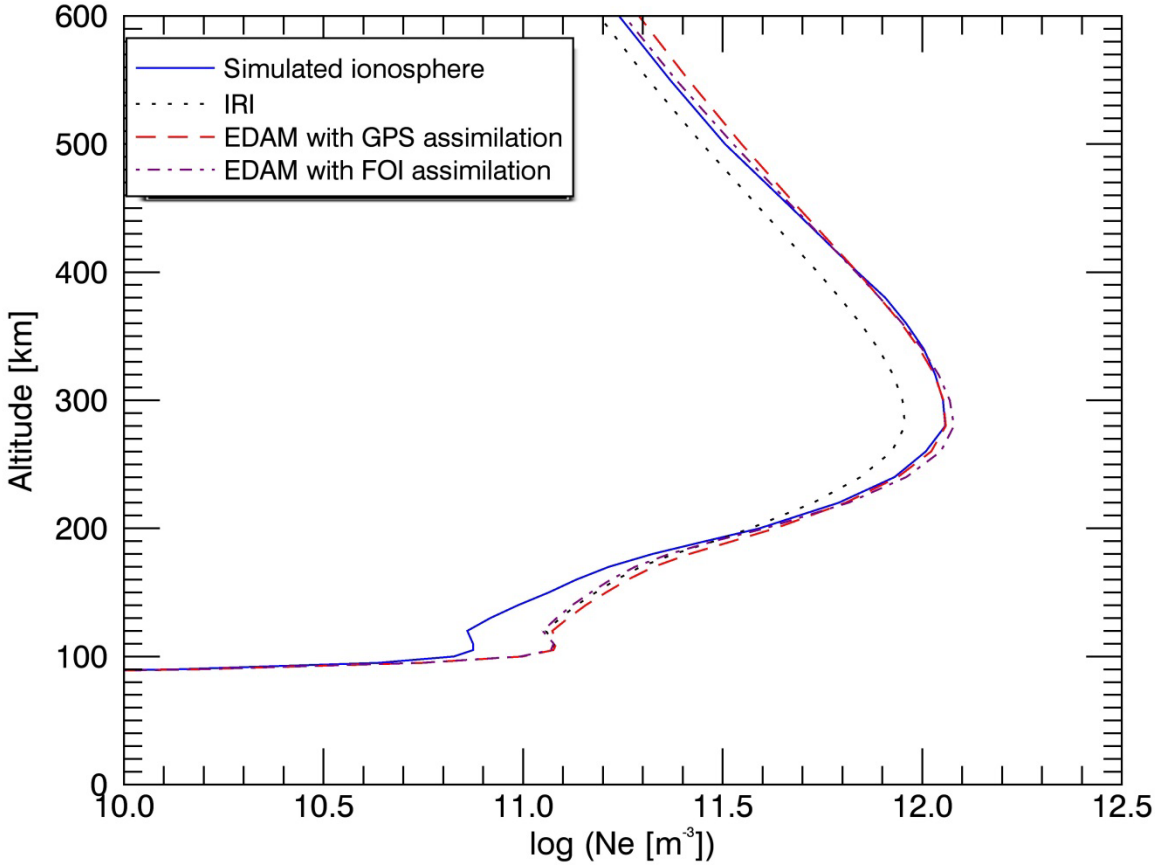
- For further comparison, we select a range of GPS receiver sites distributed over the same area.

Validation of the FOI assimilation technique using simulated GPS data



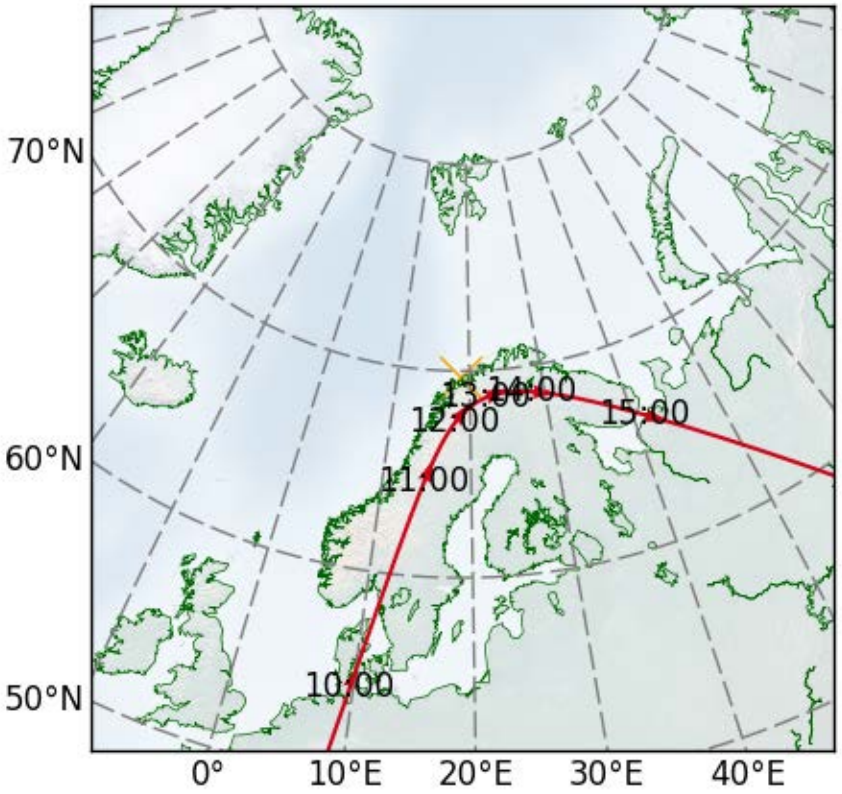
- **Slant TEC data for the ray paths through the 'truth' electron density grid between the satellites and stations are calculated and these values are assimilated into the background electron density grid.**

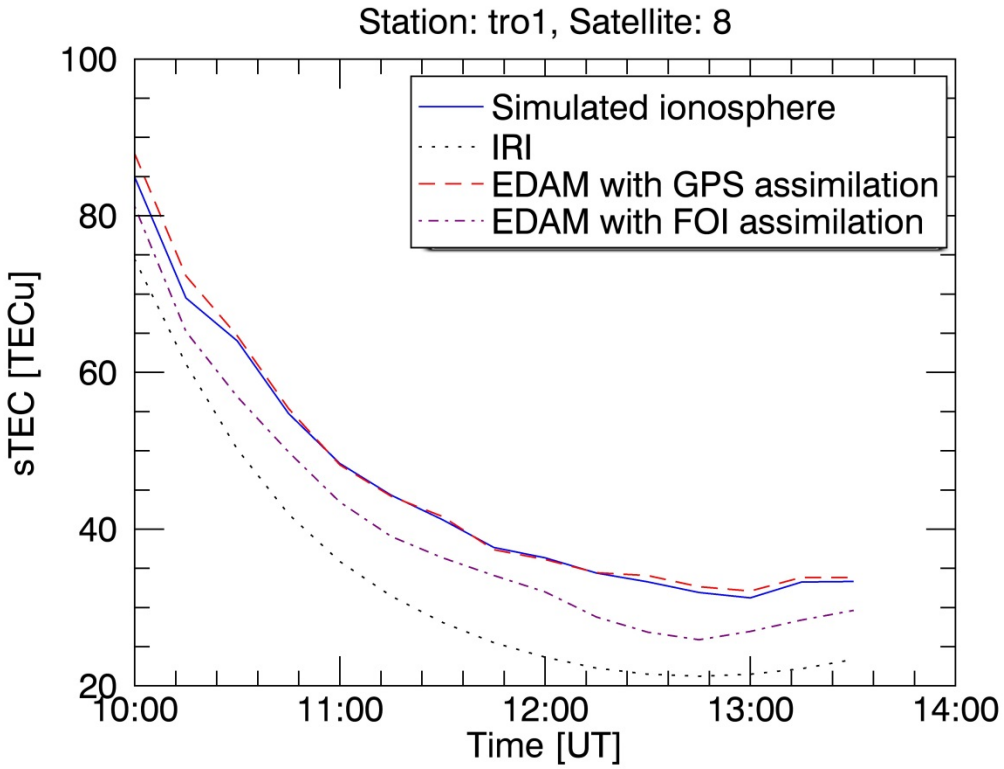
Validation of the FOI assimilation technique using simulated GPS data



- **FOI data are also synthesised for the ray paths through the 'truth' electron density grid between the transmitters and receivers and are assimilated into the background electron density grid.**

Validation of the FOI assimilation technique using simulated GPS data





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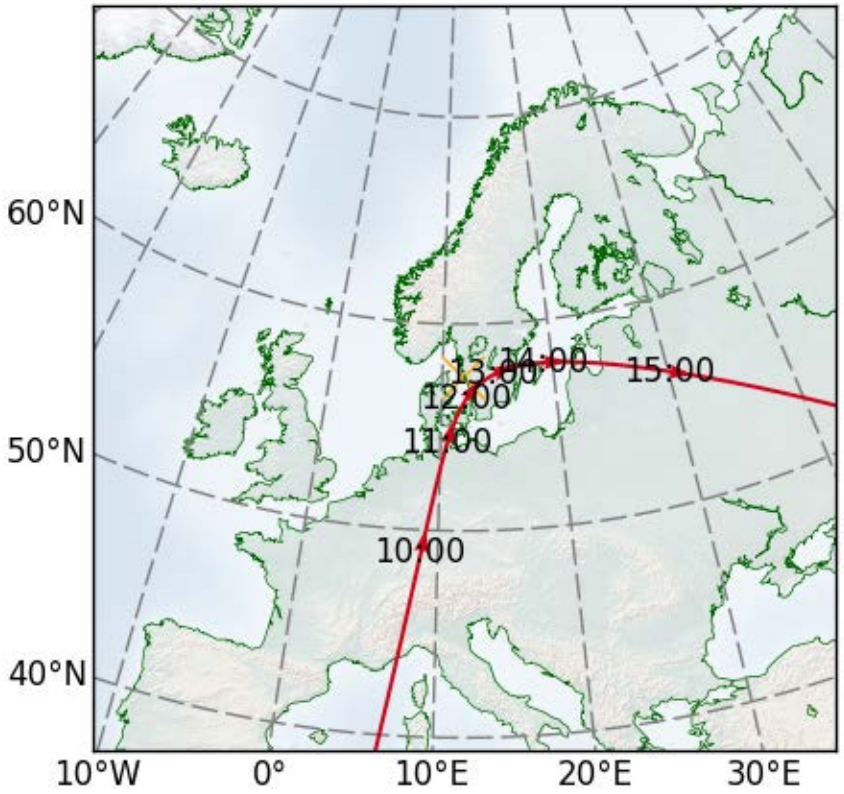
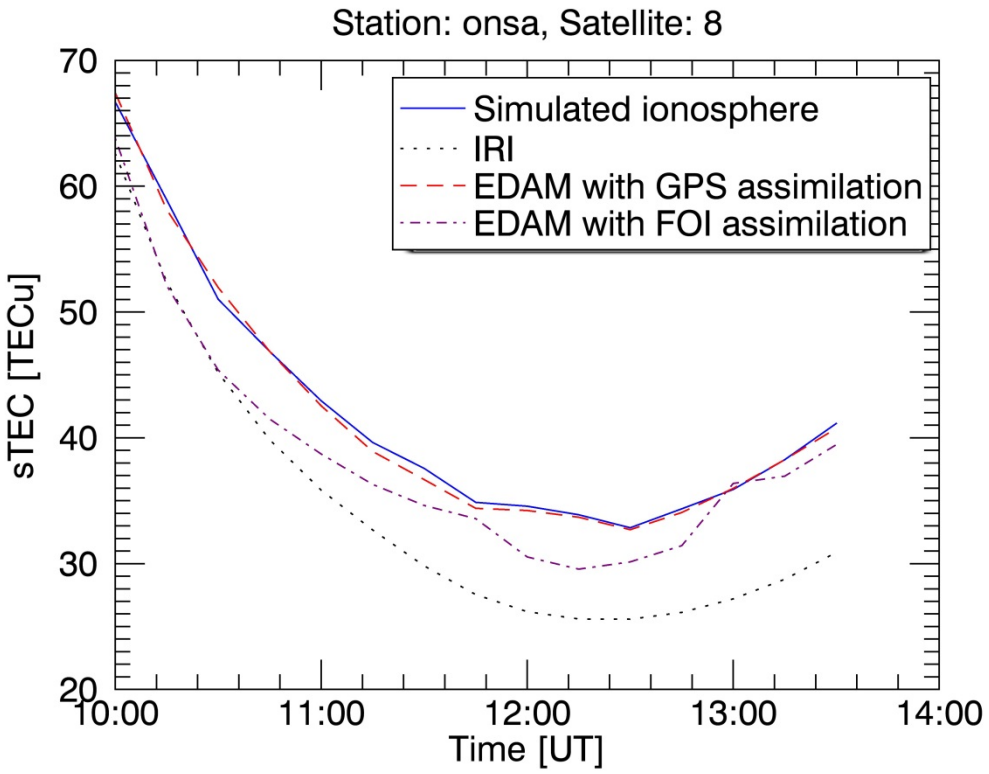
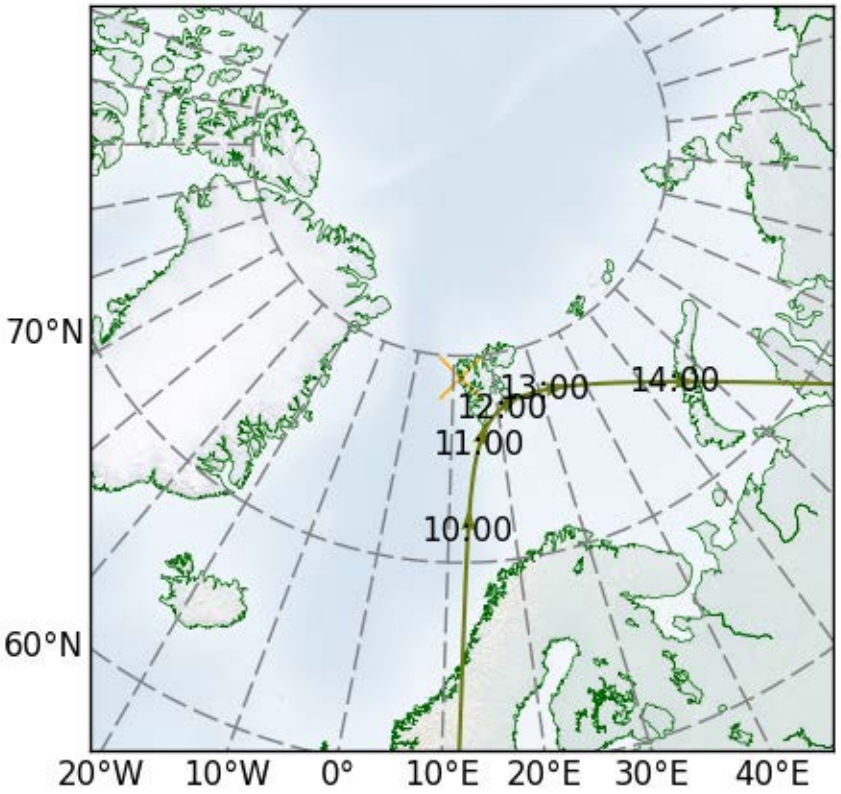
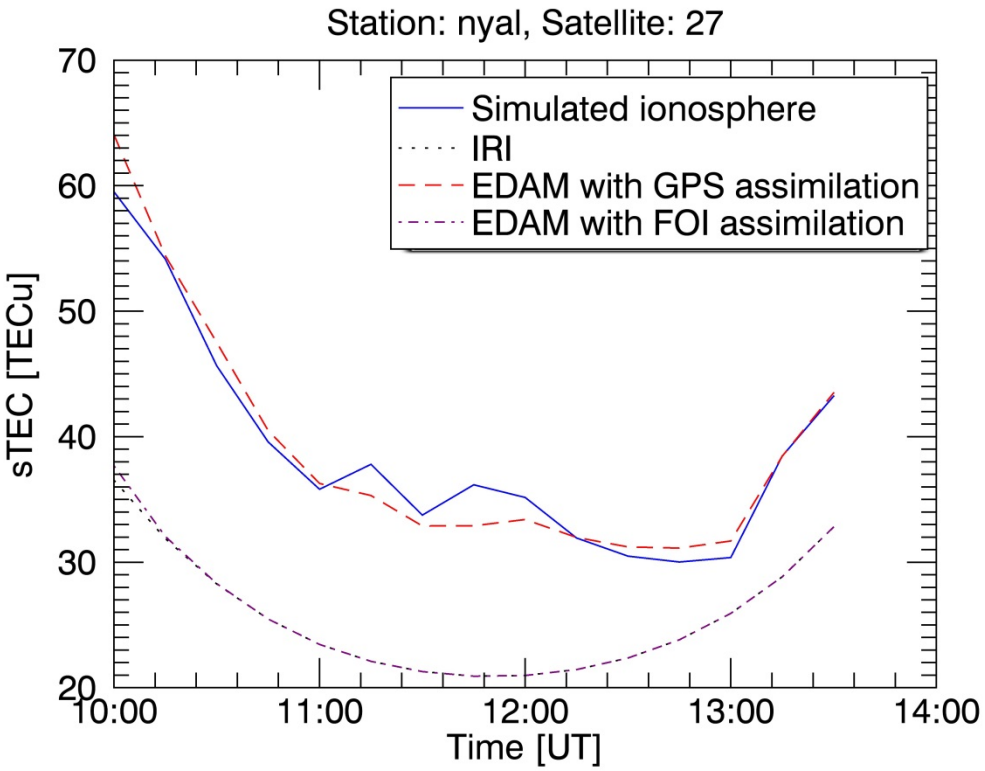


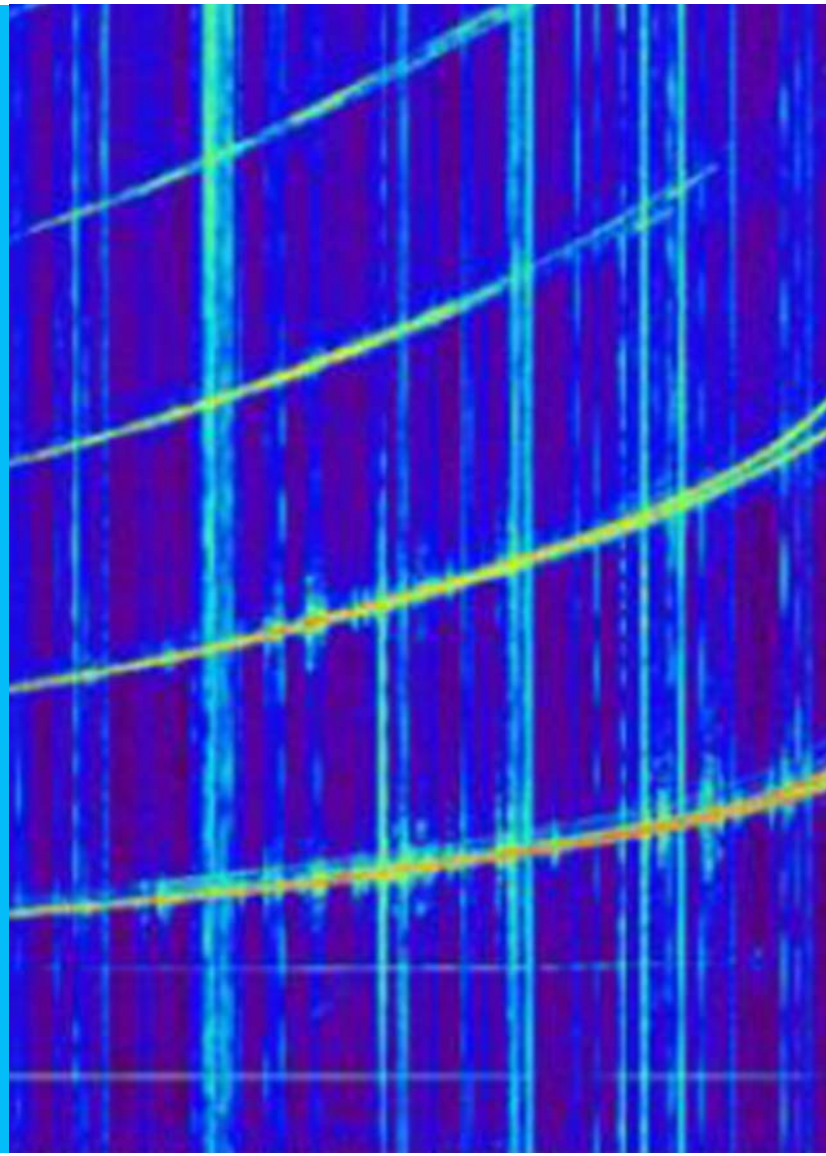


Validation of the FOI assimilation technique using simulated GPS data





Conclusions



Conclusions

- **We have successfully demonstrated that FOI data can be assimilated into EDAM.**
- **The assimilation of FOI data into EDAM results in bottomside electron density profiles that are similar to those produced by the assimilation of GPS TEC measurements into EDAM, and are closer to the truth profile than IRI.**
- **This shows that the assimilation of FOI data into EDAM is comparable to the assimilation of GNSS data into EDAM, demonstrating that the assimilation of FOI data is a useful alternative over underobserved regions, such as oceans.**

Any Questions?

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