Pathways to Predicting D and E Region Ionospheric Variability

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Abstract

The D and E region ionospheres reside in the transition region between the upper atmosphere and geospace. They respond to forcing from above (solar radiation and energetic particle precipitation) and from below via neutral atmosphere dynamics. Here we explore how these ionized regions can be used as a tracer for the two drivers through analysis of model simulations using the Whole Atmosphere Community Climate Model (WACCM). We survey the variability of the ionosphere in WACCM on timescales from hours to years and link its variability induced by variations in species such as nitric oxide. Understanding this linkage is the first step to predictive skill in ionospheric variability and will be critical in interpreting new observations made by the new EISCAT-3D facility.

Model Description

WACCM is a 'high top' global Earth system model that extends from the surface to around 140 km. Key features:

- Runs with interactive chemistry and solves for both ion and neutral constituents.
- Includes the chemical species important for the photolytic and ionization processes that initiate ion reactions in the mesosphere and lower thermosphere.
- Can be run with variable horizontal resolution, resolving a wide spectrum of waves from planetary waves to gravity waves.

For this study we use two versions of WACCM:

- Scandi WACCM-RR: regionally refined over Scandinavia (see Figure 1) for limited duration simulations to look at cross-scale coupling in the MLTI.
- WACCM-D: WACCM with a complete D-region ion chemistry scheme (See Figure 2).

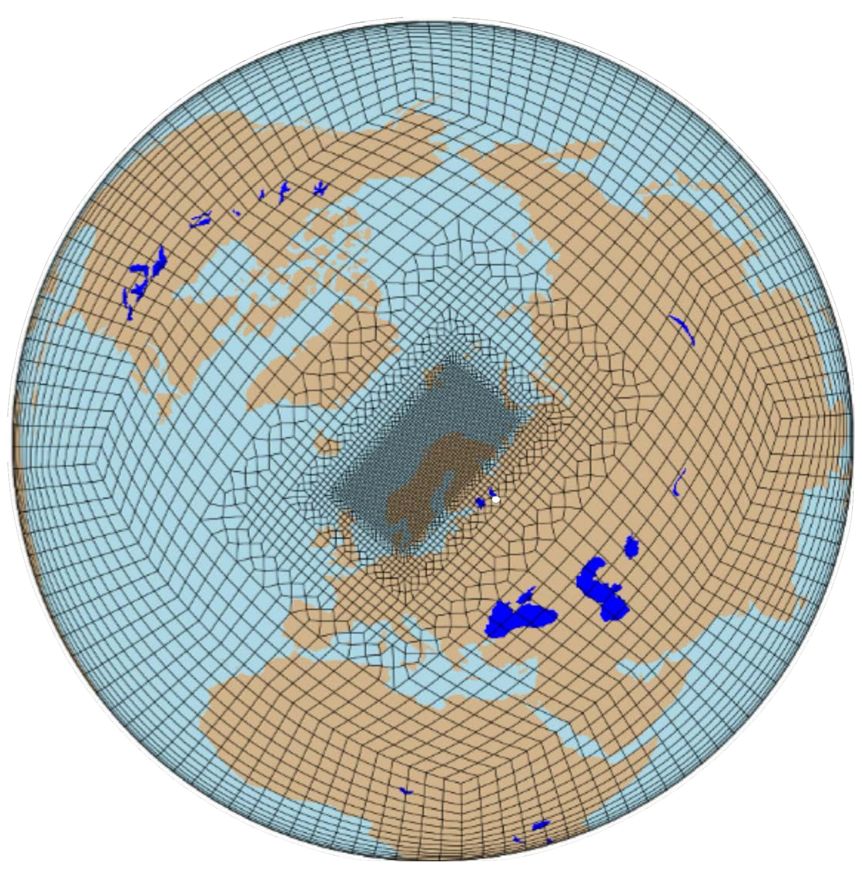


Figure 1: The regionally-refined grid used in Scandi WACCM-RR simulations. The nested grid is ~1/8˚ (14 km), two-way coupled to a global ~1˚ (111 km) grid.

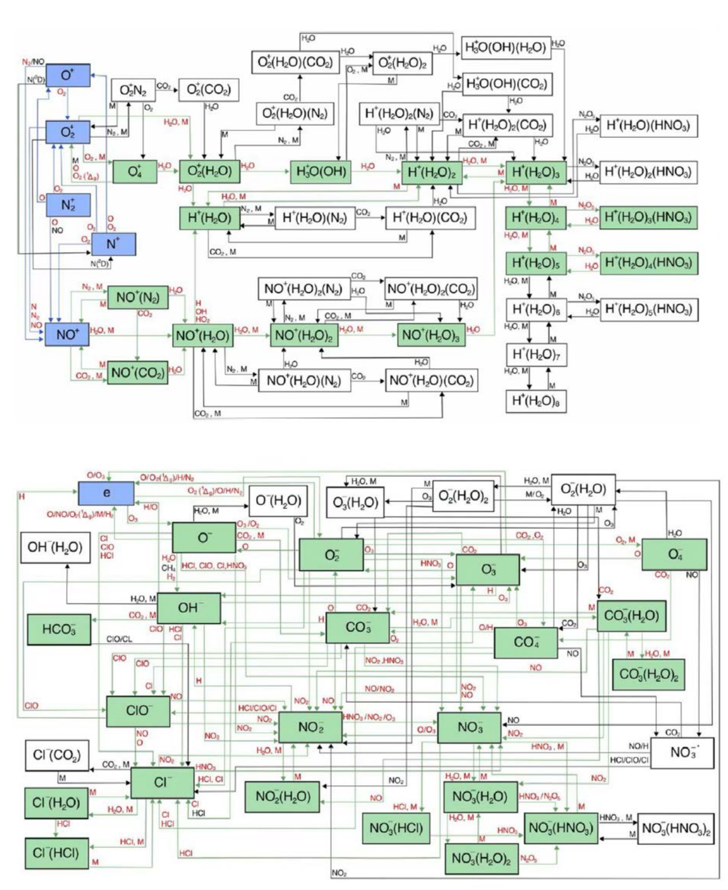


Figure 2: The positive and negative ions scheme solved for in WACCM-D simulations in green. Standard WACCM is in blue. See doi: 10.1002/2015MS000592 for details.

Diurnal and sub-seasonal variations

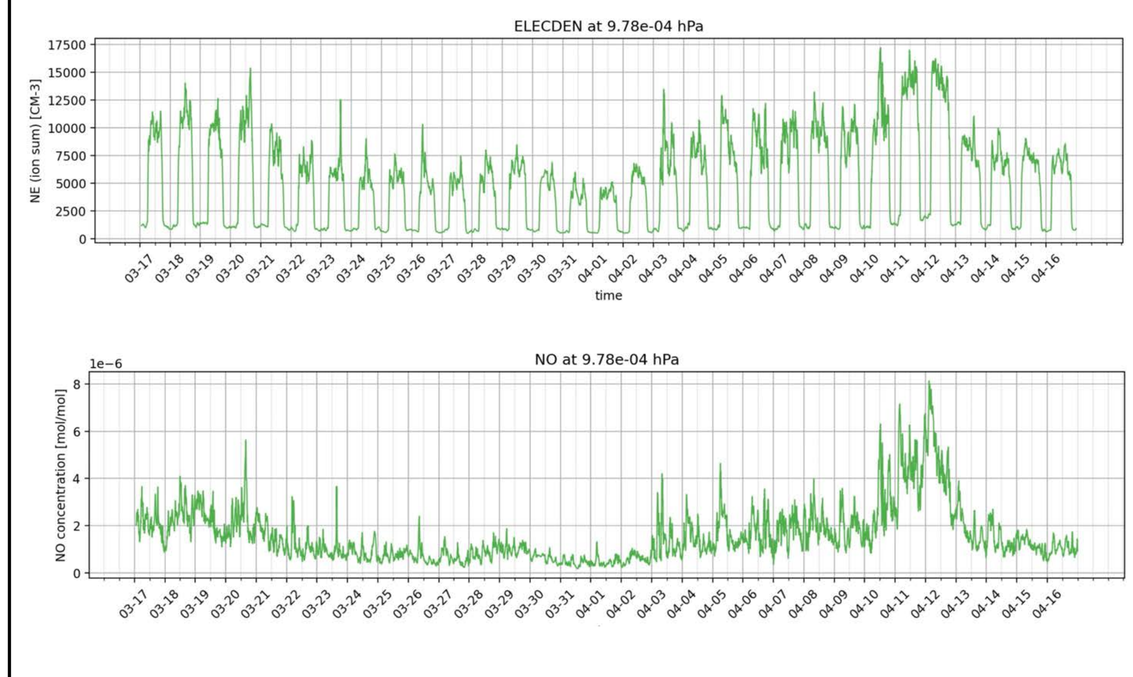


Figure 3: WACCM-RR day-to-day variability in electron density (top) and nitric oxide mixing ratio (bottom) at 10^{-3} hPa (~95 km) over the EISCAT-3D location for a 30-day interval.

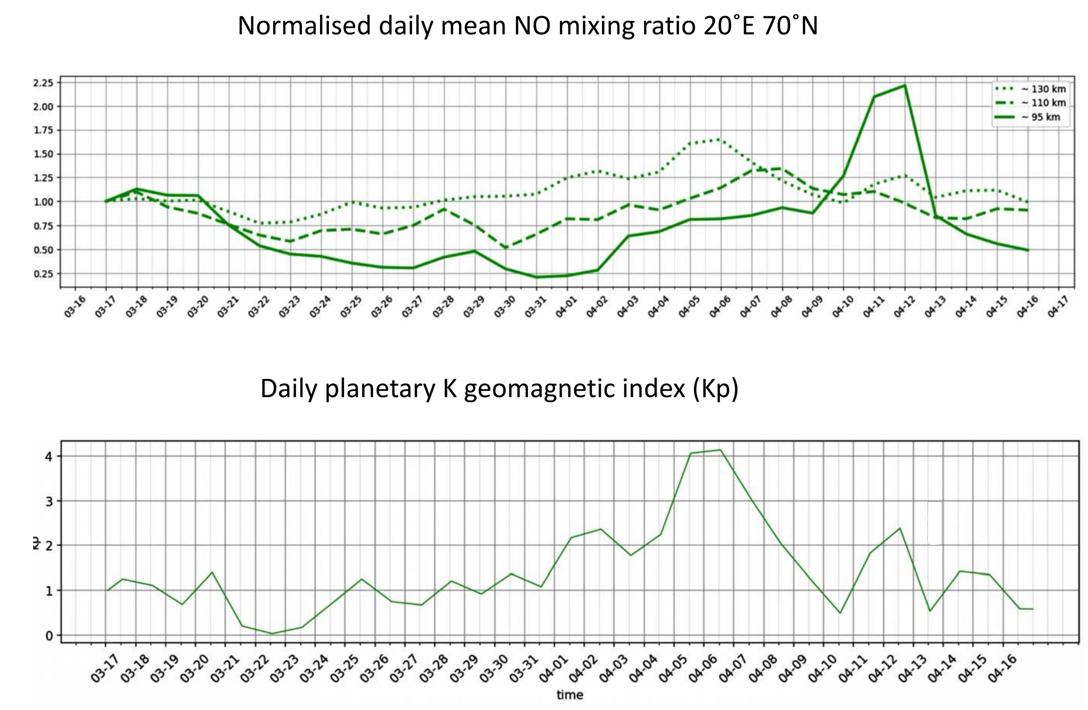


Figure 5: (top) Normalized daily-mean NO mixing ratios at 20˚E/70˚N (top) and Kp geomagnetic index (bottom), indicating sub-seasonal NO changes linked to geomagnetic activity but lagged with height.

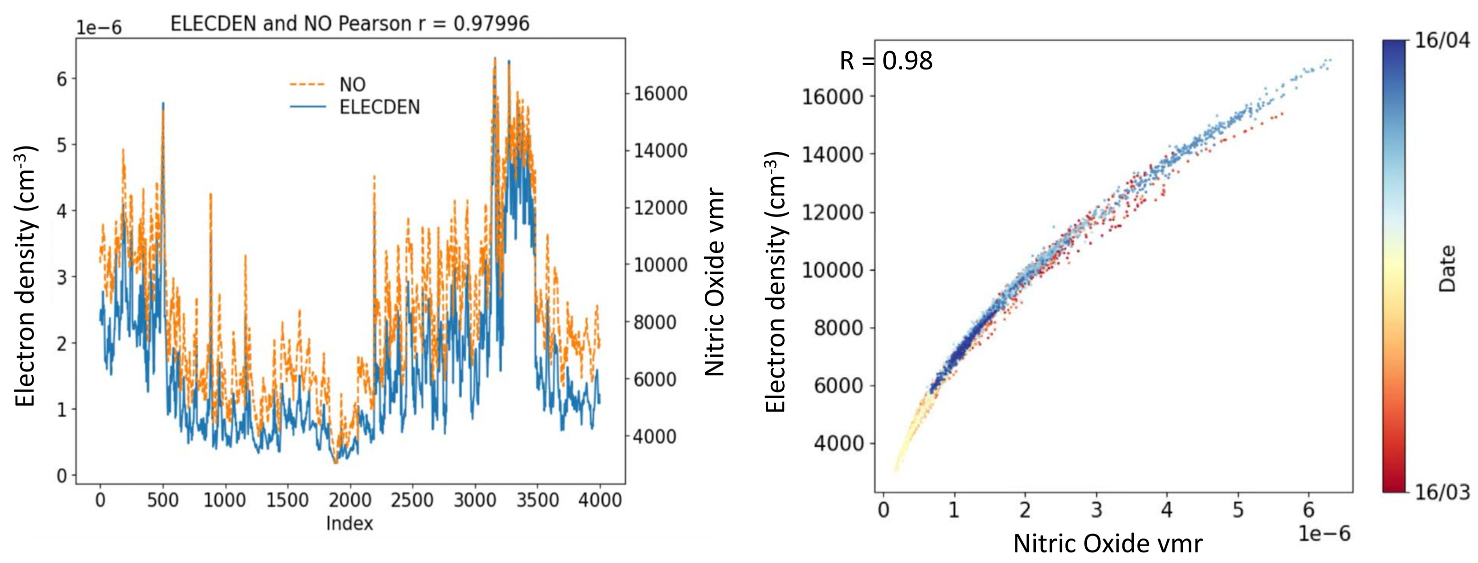


Figure 4: Daytime only electron density and nitric oxide mixing ratio for same interval as Figure 2.

- Electron density and nitric oxide are temporally correlated.
- NO photoionization is the primary source of electrons.
- Electron lifetimes are short, so [e] follows [NO].

$$\frac{\partial[e]}{\partial t} = P - L[e] = 0$$

Production of ions:

$$NO + h\nu(Ly - \alpha, 121.6nm) \rightarrow NO^{+} + e$$

Solar cycle variations

WACCM-D simulations show a factor of 3 variation over the solar cycle that follows solar UV variability (as indicated by f10.7).

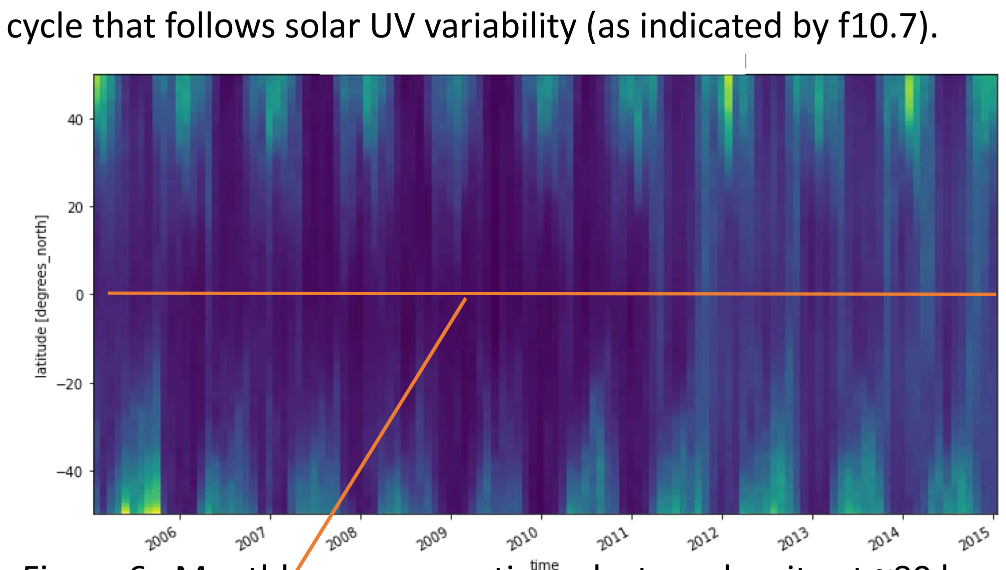
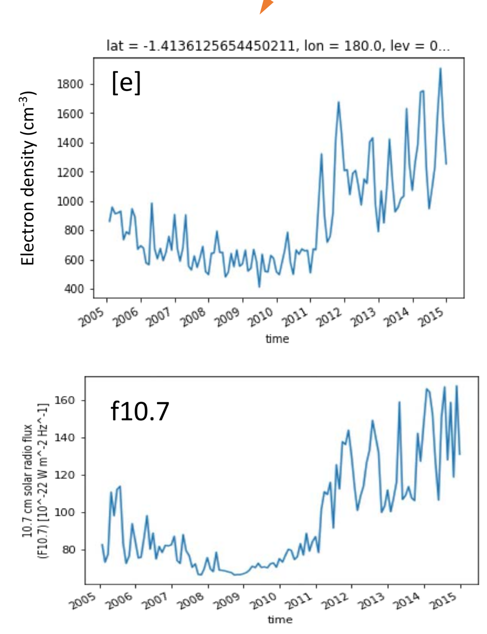


Figure 6: Monthly mean noontime electron density at ~80 km.



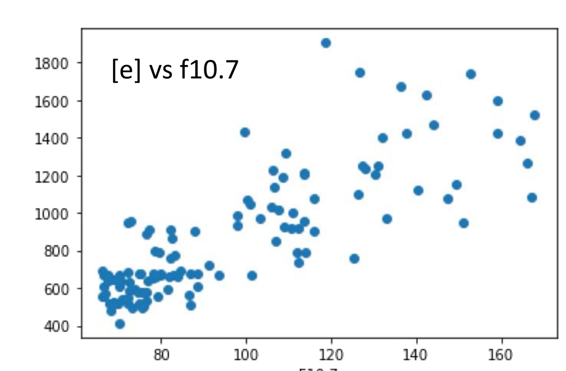


Figure 7: Monthly mean noontime electron density at the equator at ~80 km and the f10.7 cm solar index.

Forcing from the lower atmosphere

- Gravity wave (GW) signatures seen in electron density and NO that are again highly correlated.
- A broad spectrum of GWs are resolved in the WACCM-RR at 1/8˚ that originate in the troposphere.
- These variations will be resolved with EISCAT-3D.

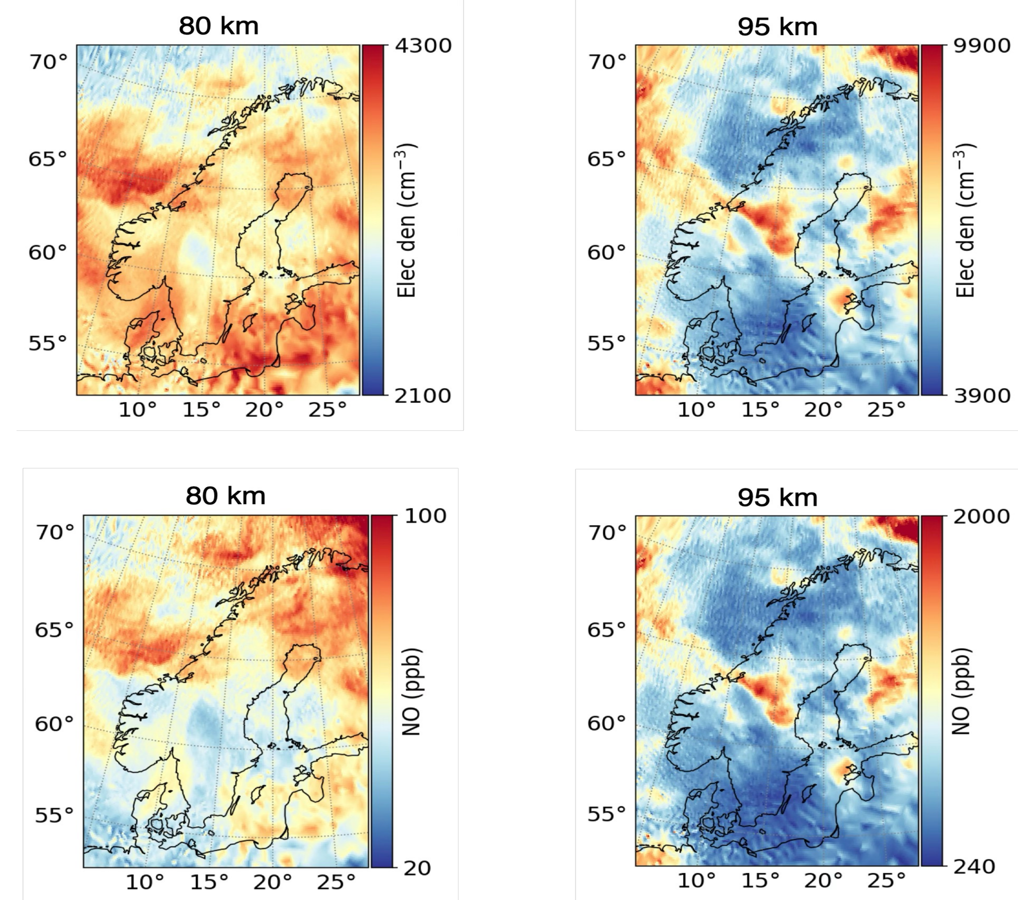


Fig 8: A 'snapshot' from WACCM-RR of electron density (upper row) and nitric oxide mixing ratio (lower row) on 27 February.

Conclusions

- EISCAT-3D will likely see a highly variable ionosphere influenced by forcing from above and below and coupling across scales.
- WACCM-D and Scandi WACCM-RR provides a new modelling tool to explore this variability.
- Sources from below (tides and gravity waves) dominate the short term (<24 hr) variability over EISCAT-3D.
- These waves alter the mean state of the atmosphere including the distribution of minor constituents such as nitric oxide.
- Sub-seasonal variabilityat high latitudes linked to geomagnetic variations.
- In both cases it seems we need to 'follow the NOx'.
- Seasonal to decadal timescales variations at low-latitudes tied to the solar cycle in UV output.

Sporadic E layers

See our recent paper titled "Characteristics of Sporadic E Layer Occurrence in a Global Chemistry-Climate Model: A Comparison With COSMIC-Derived Data" in *JGR Space Physis*.

Acknowledgements

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