Ground truth validation of the CMIP energetic particle precipitation forcing

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Abstract

The forcing component of energetic particle precipitation (EPP) is recently added into the IPCC's official Coupled Model Intercomparison Project (CMIP) climate modelling. According to these simulations, the impact of inclusion of the medium energy electrons to the ozone variability was estimated to be 12-24% in the mesosphere and 5-7% in the stratosphere. However, to obtain a continuous particle forcing required for these multi-decadal simulations, the precipitating particle flux spectrum was parameterised by the magnetic Ap index to match statistically to the POES satellite's MEPED particle detector data. This rather simple approach has several uncertainties, but the most critical one is that the existing satellite-borne particle detectors, including the MEPED instrument, struggle to separate the loss cone populations from trapped particles, leading to biases in EPP forcing especially in the relativistic energies. In this presentation, we evaluate various EPP forcing models proposed for the future CMIP climate models against the EISCAT VHF data. This can be regarded as a ground-thruth approach for the mesospheric ionisation essential for the atmospheric consequences of the EPP.

EEP model outcomes for the spring 2010

The High Energy Particle Precipitation in the Atmosphere (HEPPA) community has selected an active period in April 2010 as a case study for an intercomparison of different EEP models to be used in the climate simulations (Tyssøy+, 2021, https://doi.org/10.1029/2021JA029128). Serendipitously, the EISCAT VHF radar was operated in a suitable D-region mode during the event (15-Apr-2010, 07:32–13:15UT), making it possible to compare the model predictions with the ground-truth measurement of the ionisation at one location. The ionisation rates of the different models at 80 km altitude are shown in Fig. 1.

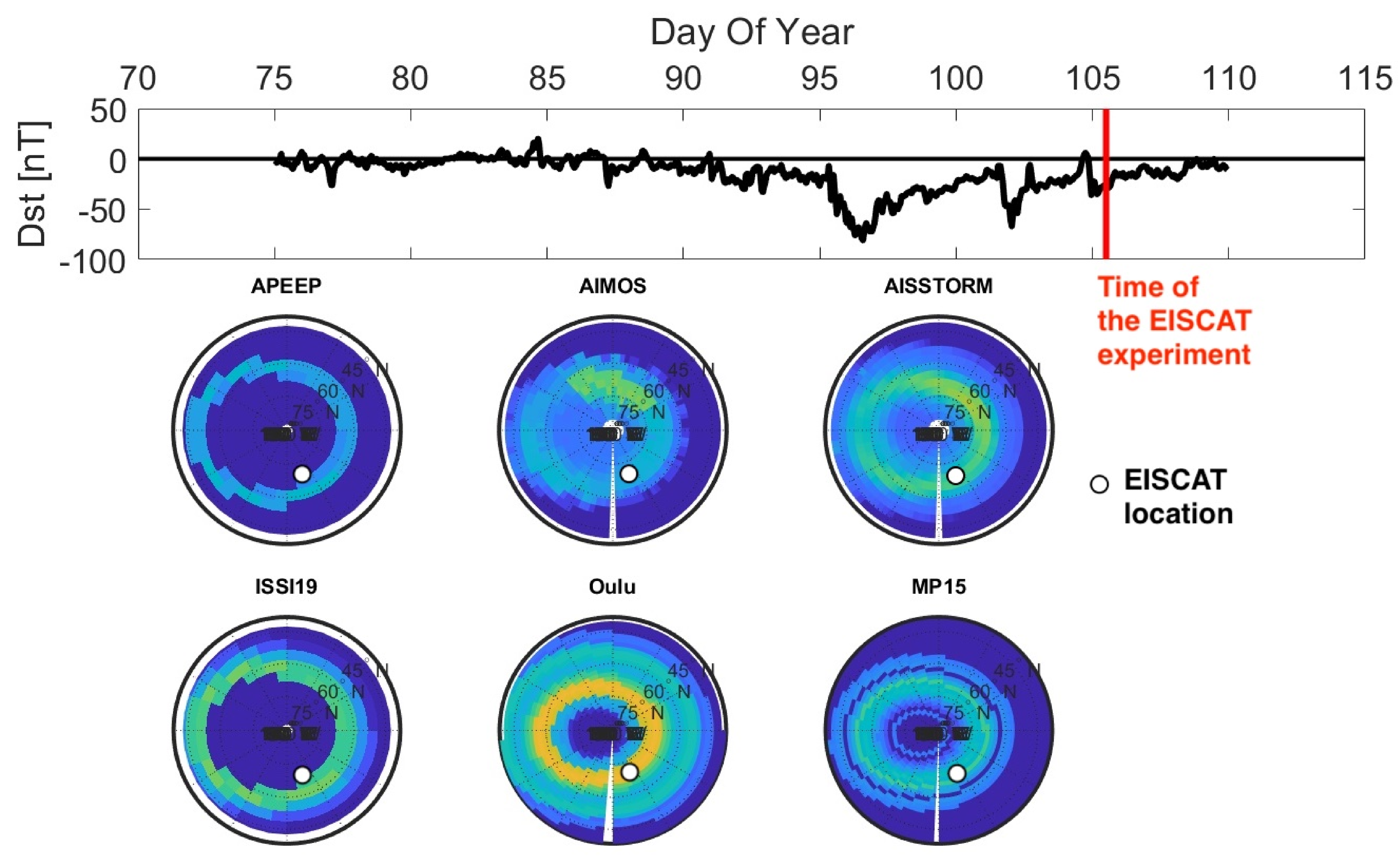


Figure 1: HEPPA III intercomparsion model outputs for the case studied: ionisation rate at 80 km.

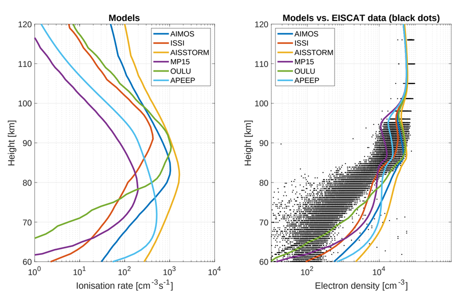
The modelling concept

Electron density height profile measured by the EISCAT radar can serve as a ground truth for the ionisation predicted by the models (Fig. 1). The EPP driven ionisation rate $Q(h)$ [cm^{-3}s^{-1}] at each altitude h depends on the electron energy (Fang et al., Parameterization of monoenergetic electron impact, GRL, 2010) making it possible to invert the flux spectrum of the electrons $\phi(E)$ [cm^{-2}s^{-1}keV^{-1}], if the atmospheric response (i.e., electron density $N_e(h)$) to the ionisation is known. For this, the Sodankylä Ion and neutral chemistry model (SIC) is used:

- Detailed 1-D time dependent chemistry model
- 63 ions (27 negative) & 13 neutrals
- 20-150 km in 1 km resolution
- Several hundreds of chemical reactions (370+)
- Start composition (+ static neutrals): NRL-MSISE model
- Solar EM flux (ionisation + dissociation): Solar 2000 model
- User defined electron and proton precipitation

By using the SIC model, we obtain the forward model: $\phi(E) \to Q(h) \to \mathrm{SIC} \to N_e(h)$. An example result of this approach is shown in Fig. 2

Models vs. EISCAT data



Ionisation rates (left) and the consequent electron densities (right) for the HEPPA III model ensemble vs. EISCAT data (black dots).

Chemical consequences

By using the full SIC ion chemistry model as a forward model in the inversion makes it also possible to estimate the chemical consequences of the EEP as in Fig. 3.

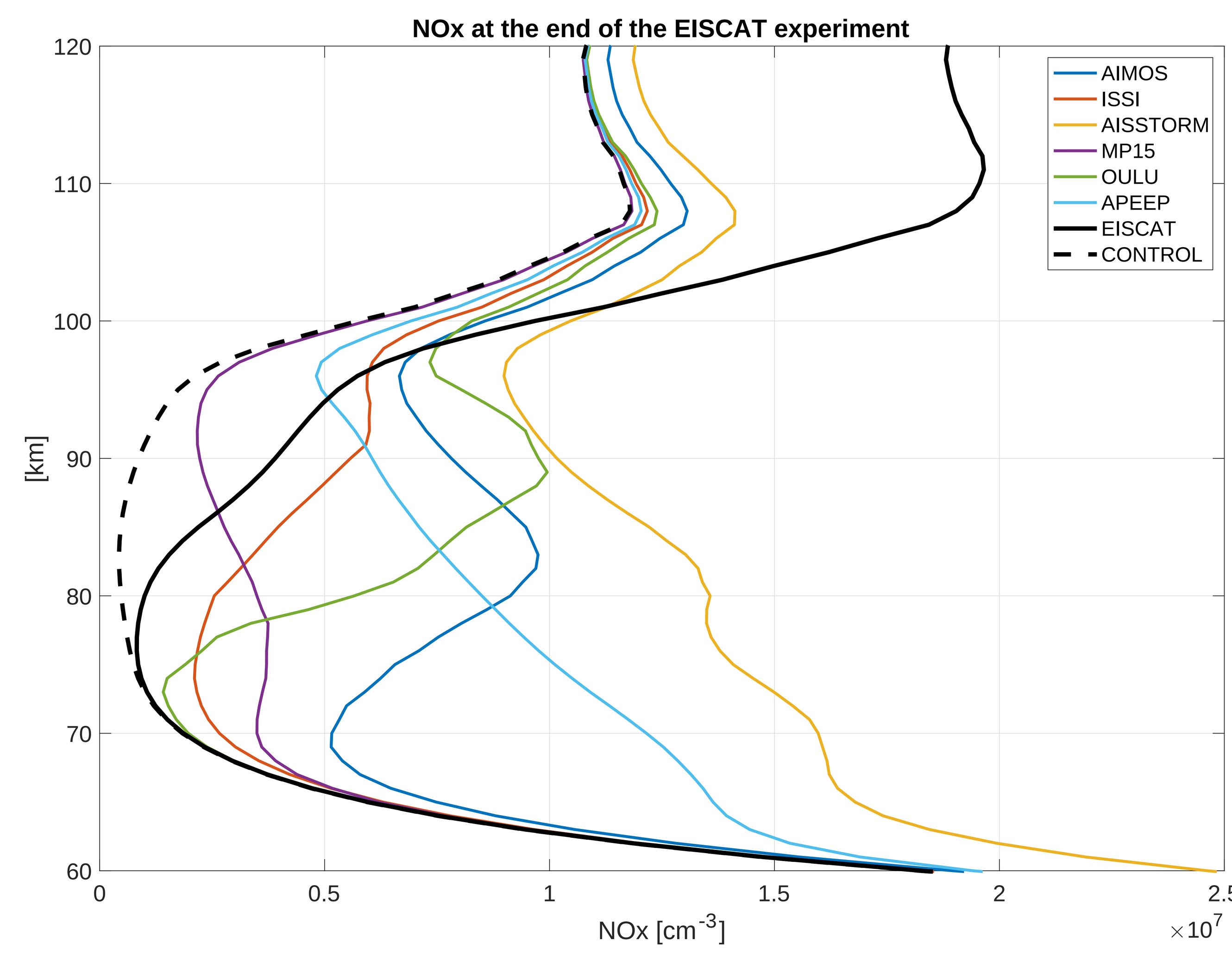


Figure 2: SIC modelled relative change of the mesospheric NO_x level due to the EEP.

Conclusions

- Models underestimate the EEP flux at low-energies and overestimate the relativistic energies
- This might contribute to the NO_x discrepancy between the climate simulations and satellite data
- All existing EISCAT D-region data should (and will) be utilised!