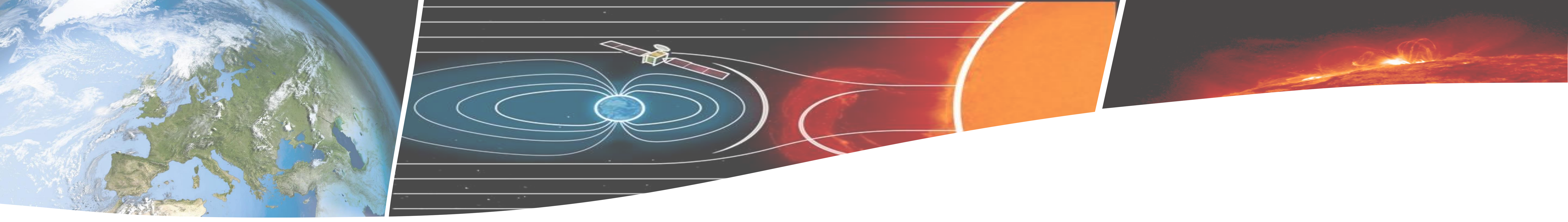

Joule heating scaling in thermosphere-ionosphere models compared to EISCAT incoherent scatter radar measurements

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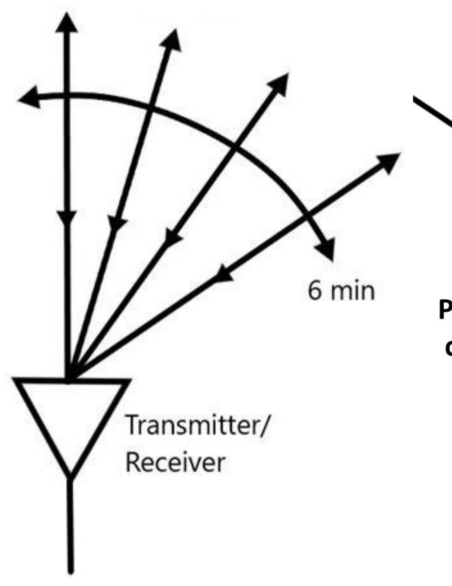
Dynamo Region Joule Heating and EISCAT Beam-Swing Measurements

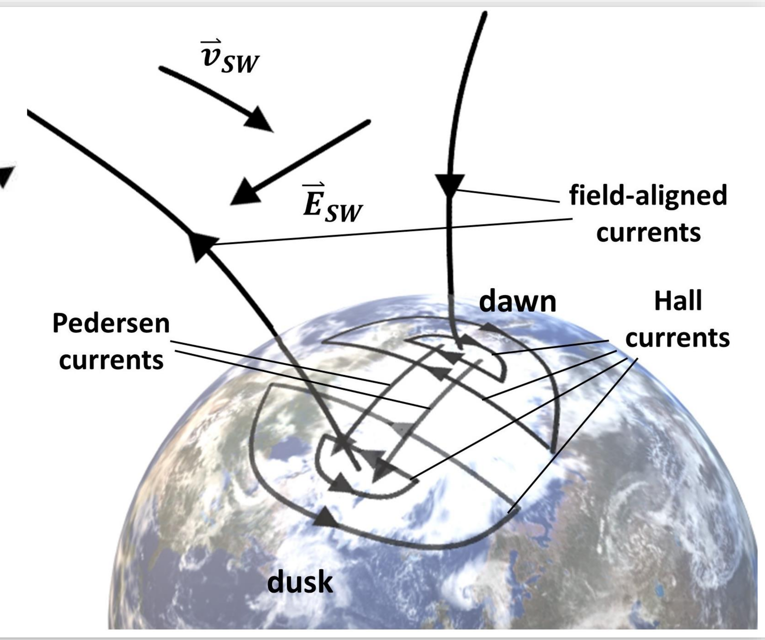
Ionospheric Dynamo Region

- transition from **highly-collisional plasma** $\nu_{xn} \gg \Omega_x$ to **collision-less** plasma $\nu_{xn} \ll \Omega_x$
- electrons de-couple at ~ **80 km** altitude and ions de-couple at ~ **120 km** altitude
- Pedersen and Hall conductivity maxima ➔ **"dynamo region"**
- **Joule heating** by Pedersen currents: $q_J = \sigma_P \cdot (\vec{E} + \vec{u} \times \vec{B})^2$

EISCAT UHF beam-swing measurements

- EISCAT UHF antenna is rotated through a cycle of **4 pointing directions in 6 min**
- **line-of-sight ion velocity** is measured at each position
- **stochastic inversion** method is applied to obtain 3D ion velocity vector (Nygrén et al., 2011)
- **electric field** is calculated at collision-less F region: $\vec{E} = -\vec{v}_F \times \vec{B}$

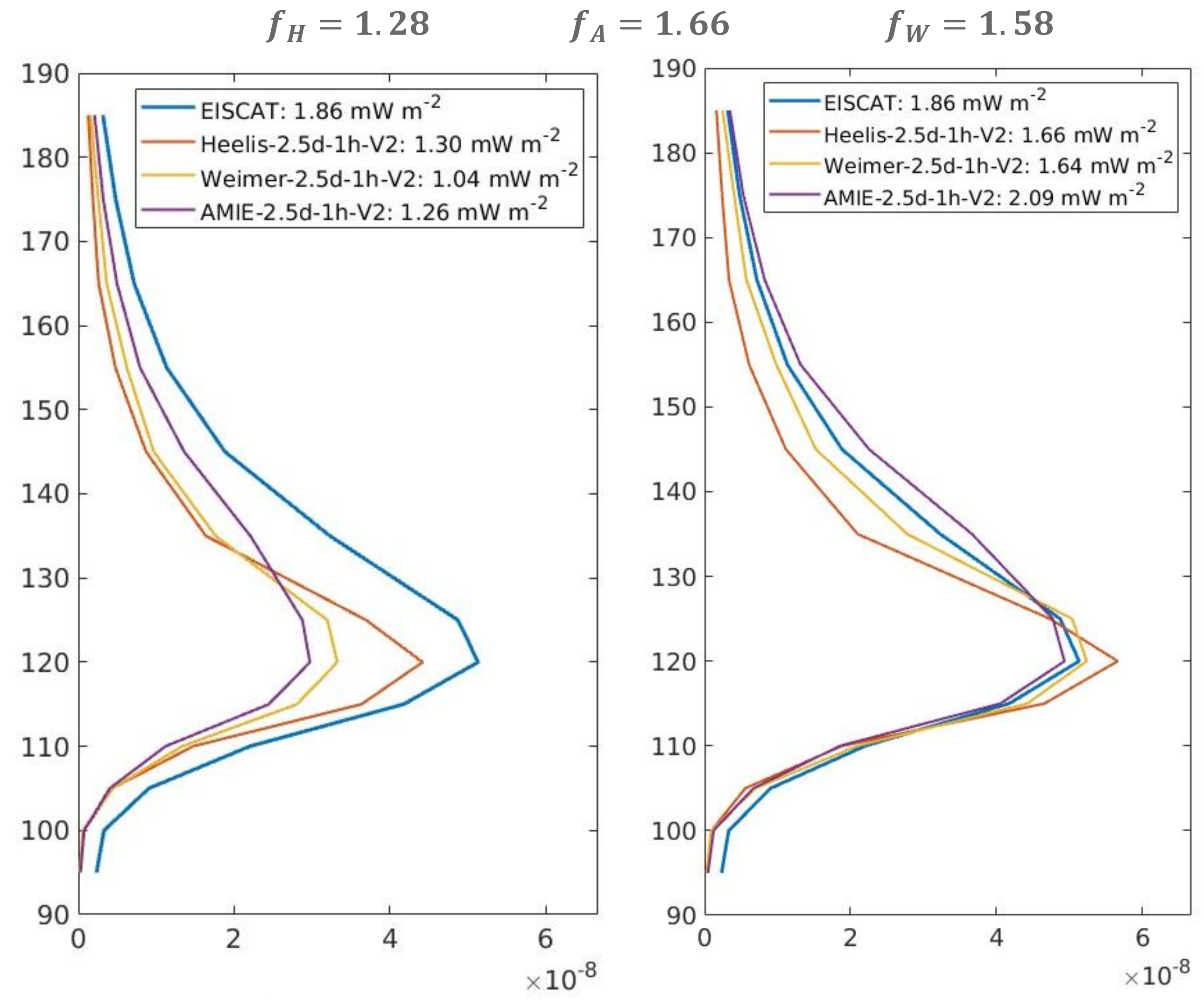




Joule Heating Scaling Factor in TIE-GCM ($q_J = f \cdot q_{J,m}$ default: $f = 1.5$)

September 09-16, 2005 ($Kp > 2$; ~180hr): $\boxed{\bar{f} = 1.505}$

$f_H = 1.28$ $f_A = 1.66$ $f_W = 1.58$



Joule heating rate / W m^{-3}

- **convection models** applied for high-latitude **plasma potential**
  Heelis (Heelis et al., 1982) ➔ empirical
  Weimer (Weimer, 2005) ➔ empirical
  AMIE (Richmond and Kamide, 1988) ➔ assimilative
- **short-scale variability** of electric fields increases q_J (Codrescu et al., 1995)

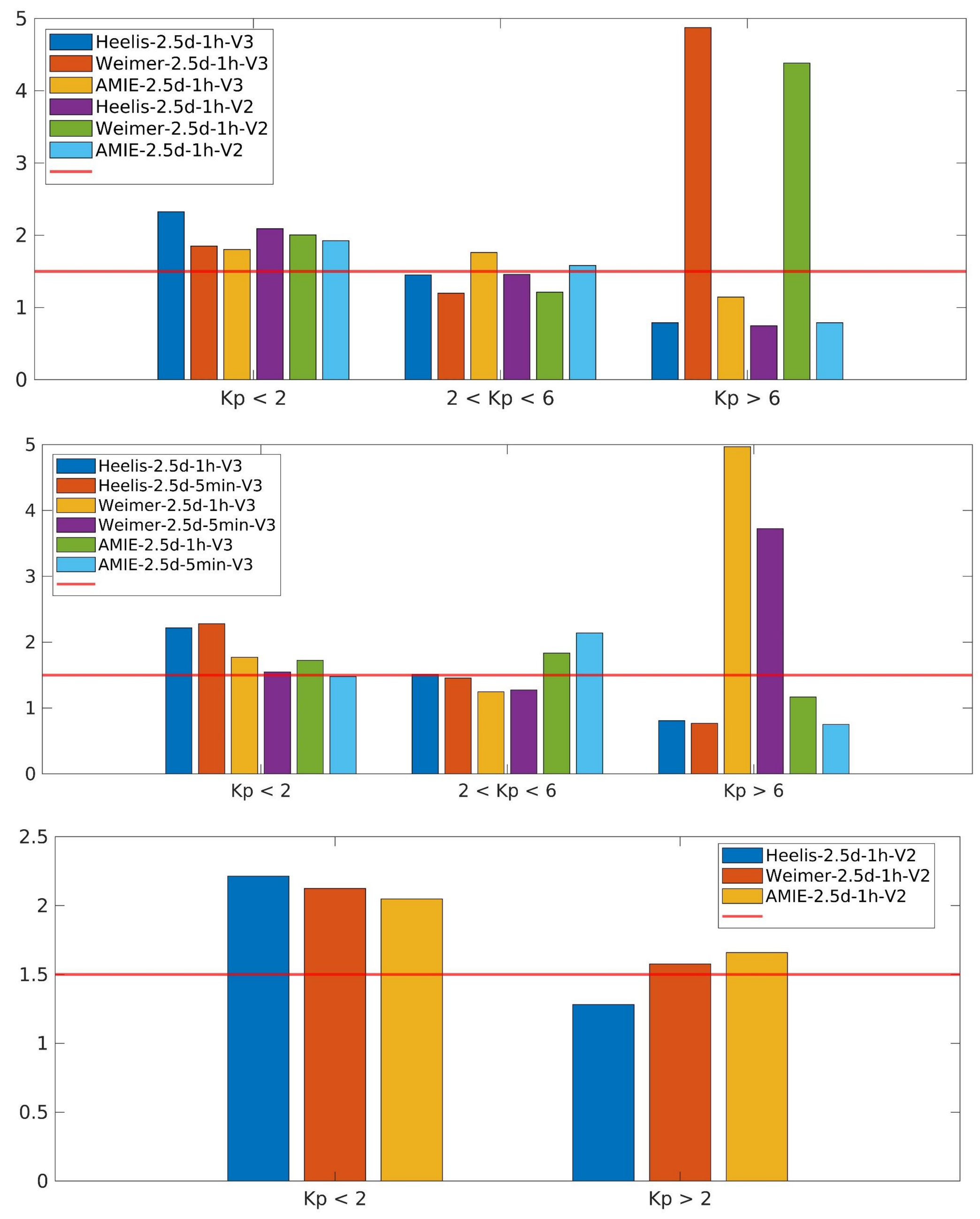
$$E = e_m + x \cdot e_v \qquad e_v \sim 1.5 \cdot e_m \qquad f(x) = \frac{1}{2} \cdot \theta(|x| - 1)$$

$$q_J \propto E^2 = \int (e_m + x \cdot e_v)^2 \cdot f(x)\, dx = 1.5 \cdot E^2$$

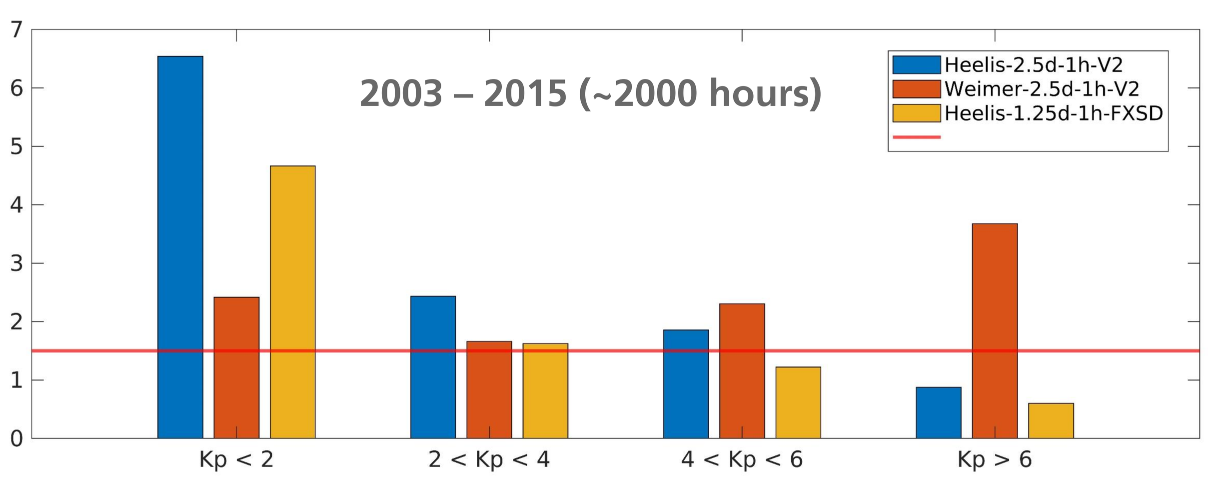
Günzkofer et al., 2024:

default scaling very accurate on average, but does not consider variations with **geomagnetic activity, magnetic local time,** or **plasma convection parameterization**

- Joule heating rates compared for **Heelis-, Weimer-, and AMIE-driven** model runs (AMGeO to be added…)
- variations of scaling factor f investigated with respect to:
  - geomagnetic activity (**Kp index**)
  - TIE-GCM version (**Version 2 and Version 3**)
  - model resolution (**2.5° and 1.25°**; not shown)
  - output sampling frequency (**1 hour and 5 min**)

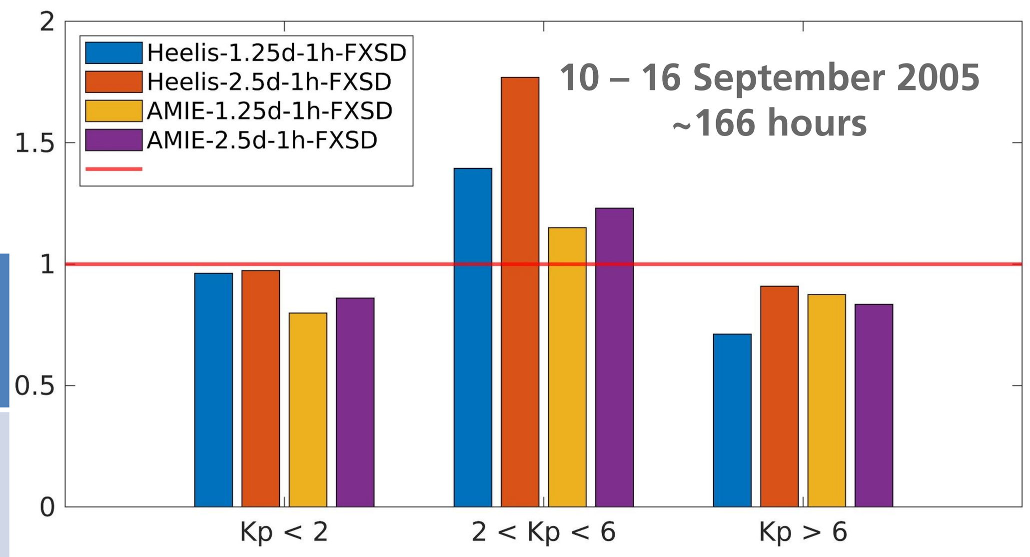


Joule Heating in (SD) WACCM-X



- (SD) WACCM-X (Heelis) Joule heating rates are larger than TIE-GCM (Heelis) rates **by a factor of 1.4 – 1.55**
- WACCM-X **does not apply** a scaling factor ($f = 1$)
- (SD) WACCM-X Joule heating rates also **very accurate on average**

	Heelis 1.25°	Heelis 2.5°	AMIE 1.25°	AMIE 2.5°
$\bar{f}$	1.02	1.22	0.94	0.98



Conclusions

1. Joule heating rates in both TIE-GCM and (SD) WACCM-X agree very well with EISCAT measurements on average.
2. Additionally to the variations described in Günzkofer et al., 2024, model accuracy also varies with model version, resolution, and output sampling frequency.
3. Different convection models are the main source of differences.
4. Both maximum Joule heating rate and shape of profile are significantly different for different convection models.

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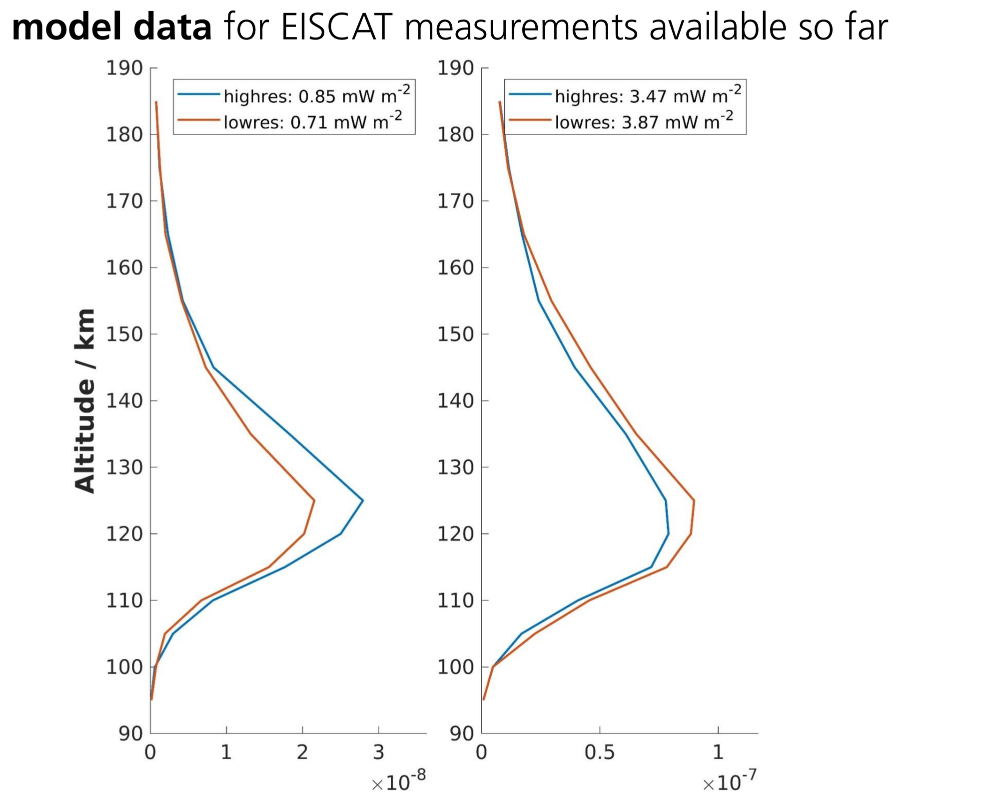
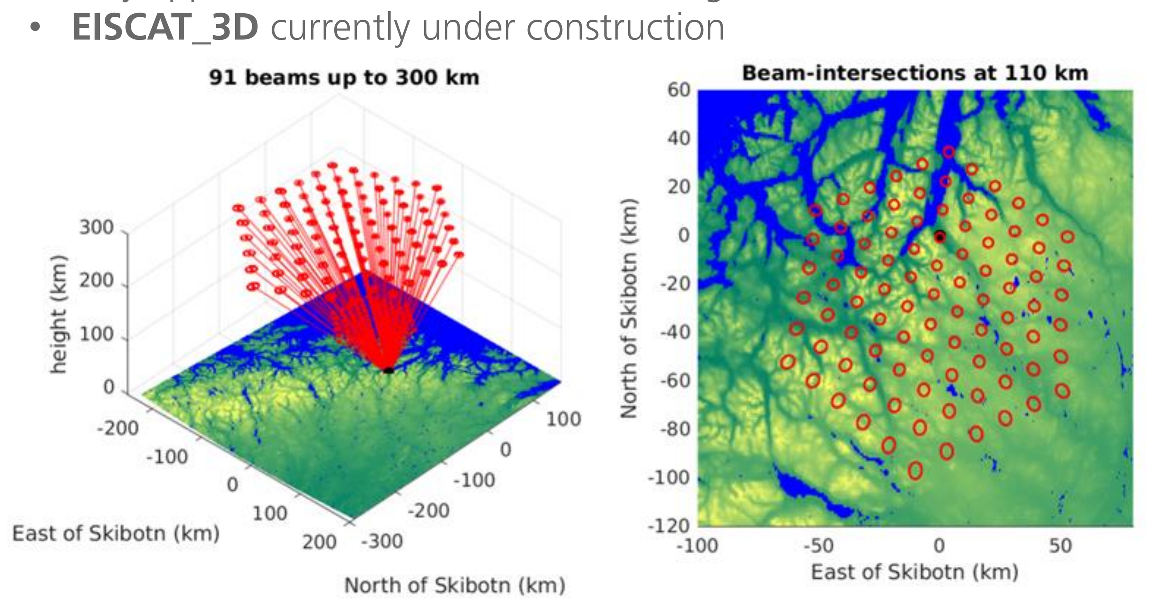
Outlook – (HR) WACCM-X

- Liu et al, 2024 performed **0.25° and 1.25°** resolution runs with WACCM-X spectral element (SE) dynamical core
- high-latitude electrodynamics forced with **GAMERA** (Lyon et al., 2004)
- **no model data** for EISCAT measurements available so far



Outlook – PFISR and EISCAT_3D

- **phased array ISRs** allow for electronic beam steering
- significantly faster cycle times and **higher temporal resolution** of ion velocity measurements
- **Poker Flat ISR (PFISR)** is a phased array radar on approximately the same **geomagnetic latitude** as EISCAT
- test scaling factors for **longitudinal variations** ➔ scaling factors only applicable if **constant** at same magnetic latitude
- **EISCAT_3D** currently under construction



from "Recommendation for initial stage of EISCAT_3D common programmes and their future directions" by the EISCAT_3D Common Programme working group

Deutsches Zentrum für Luft- und Raumfahrt

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