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Convection parameterization and model resolution impacts on Joule heating in T-I models

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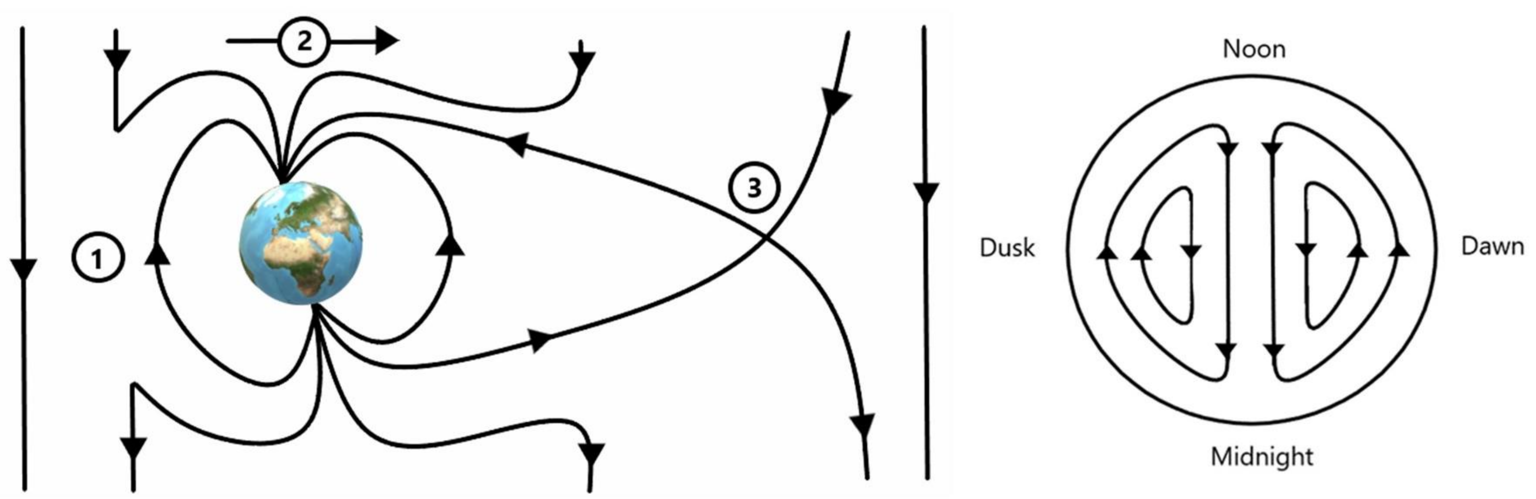
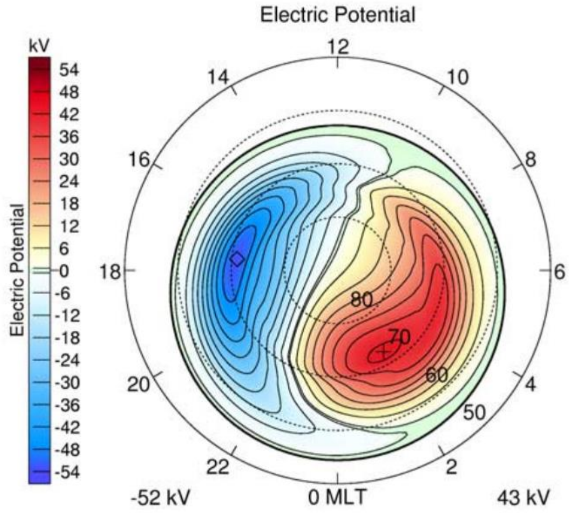
High-Latitude electrodynamics in models



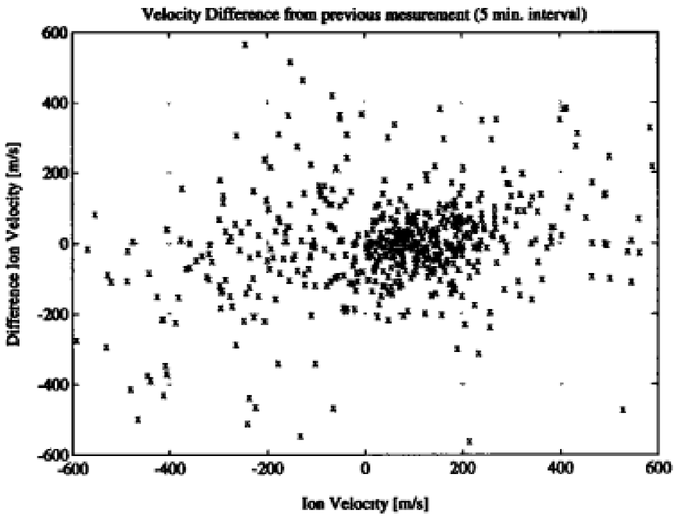
F. Günzkofer, PhD thesis, *LMU München*, 2024



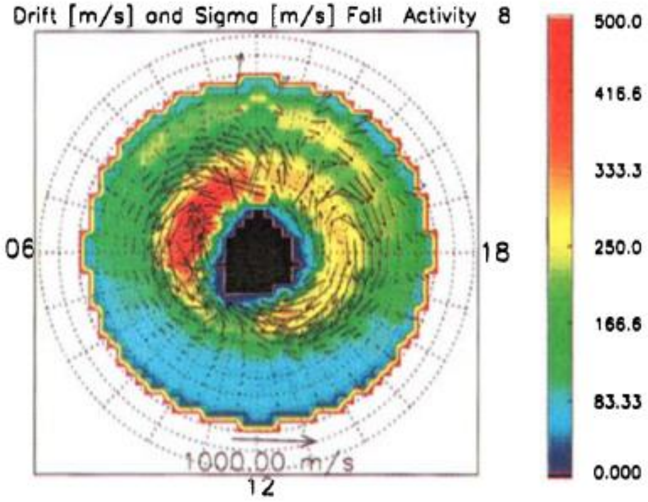
Weimer, *J. of Geophys. Res.*, **110**, A05306, 2005

convection model	type	parameters/data sources
Heelis	Empirical	Kp index
Weimer	Empirical	Solar wind and IMF parameters
AMIE	Data assimilative	SuperDARN, SuperMAG, Iridium, DMSP
AMGeO	Data assimilative	SuperDARN, SuperMAG, Iridium
GAMERA	MHD code	Solves MHD equations of the magnetosphere; also calculates particle precipitation rates/patterns

Resolution effects



[Codrescu *et al*., *Geophys. Res. Lett*., **22**, 2393-2396, 1995]

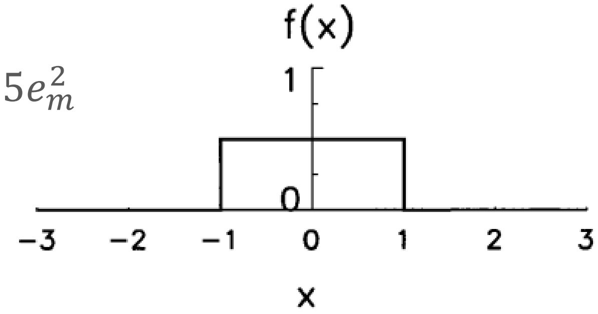


[Codrescu *et al*., *J. Geophys. Res*., **105**, A3, 5265-5273, 2000]

$$\frac{|v_i - v_{i+5min}|}{v_i} \sim 1.5 \longrightarrow E = e_m + x \cdot e_v \qquad (e_v \sim 1.5 e_m)$$

$$Q_J \propto \bar{E}^2 = \int_{-1}^{+1} (e_m + x \cdot e_v) \cdot f(x)\, \mathrm{d}x = e_m^2 + \frac{e_v^2}{3} \sim 1.5 e_m^2$$

$$\boldsymbol{Q_J \sim 1.5 \cdot Q_{J,m}}$$



JOULEFAC

Joule heating factor. This factor is multiplied by the joule heating calculation (see subroutine qjoule_tn in qjoule.F).

Data type: real

Default: 1.5

[from TIE-GCM userguide]

E-field variability depends on:

- Geomagnetic latitude
- Magnetic local time
- Geomagnetic activity

+

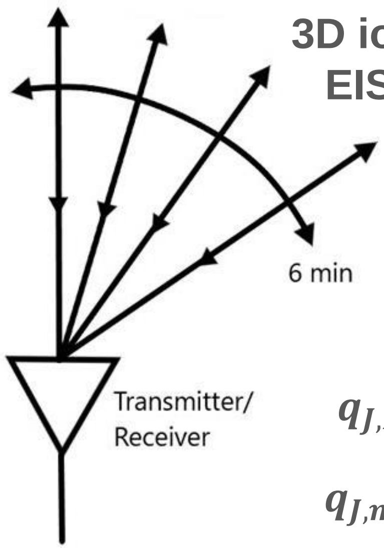
Model resolution affects:

- neutral dynamics
- resolution/sharpness of meso-scale plasma features (e.g. patches, arcs)

➔ **Pedersen conductivity**

Measurements and Models

3D ion velocity measurements with EISCAT beam-swing campaigns



$$q_{J,E} = \sigma_P(N_{e,E}) \cdot (E_E + u_m \times B)^2$$

$$q_{J,m} = \sigma_P(N_{e,m}) \cdot (E_m + u_m \times B)^2$$

Stochastic inversion, following Nygren *et al.*, (2011):

$$M = \mathbf{A} \cdot x + \epsilon \qquad \hat{x} = \mathbf{Q}^{-1} \cdot (\mathbf{A}^T \cdot \mathbf{\Sigma}^{-1}) \cdot M$$

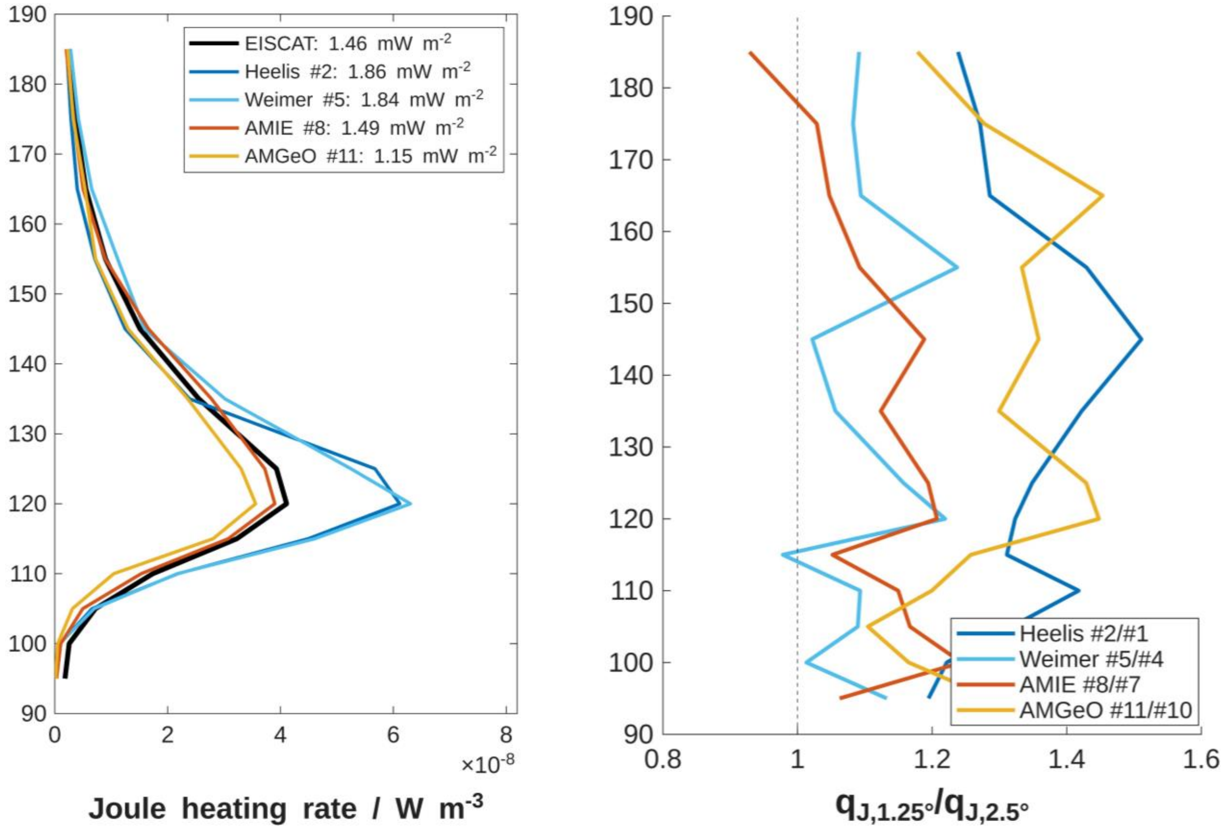
M: measurement vector
$\mathbf{A}$: theory matrix
x: unknow variables (v^F)
ϵ: measurement uncertainties

$\hat{x}$: most probable solution
$\mathbf{Q}$: Fisher information matrix
$\mathbf{\Sigma}$: covariance matrix of ϵ

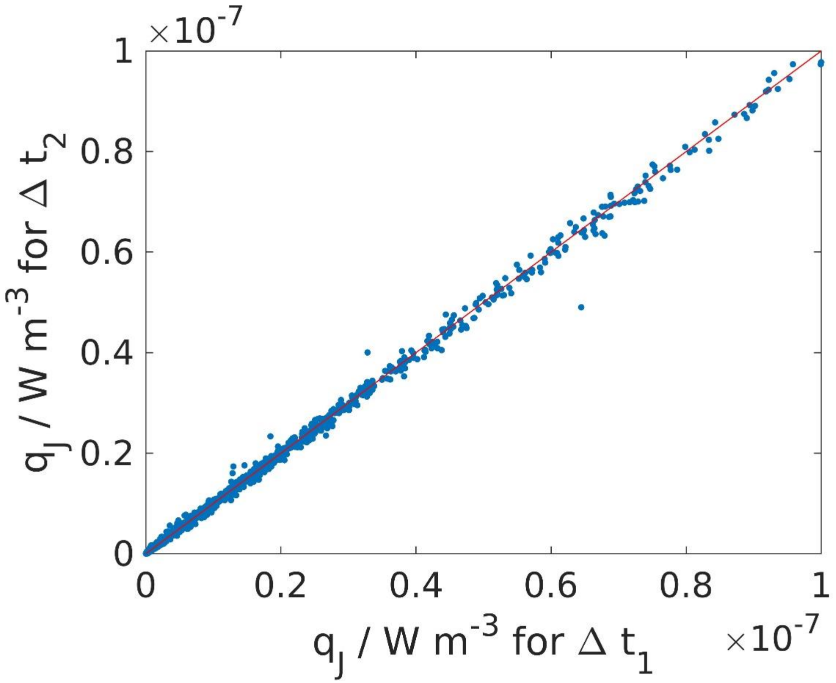
$$E_\perp = -v^F \times B$$

TIE-GCM	WACCM-X
1. Convection model: • Heelis • Weimer • AMIE • AMGeO	1. Convection model: • Heelis • Weimer • GAMERA
2. Model resolution: • 2.5° • 1.25°	2. Model resolution: • ~1° • ~100 km (1°) • ~25 km (0.25°)
3. Model version: • 2.0 • 3.0	3. Model version: • FV-SD (finite volume, specified dynamics) • SE (spectral elements)
4. EISCAT campaigns: • 09 – 28 Sep 2005 • 14 – 25 Sep 2009	4. EISCAT campaigns: • none

TIE-GCM Results



Günzkofer *et al.*, *Geophys. Res. Lett.*, **52**, e2025GL117647, 2025



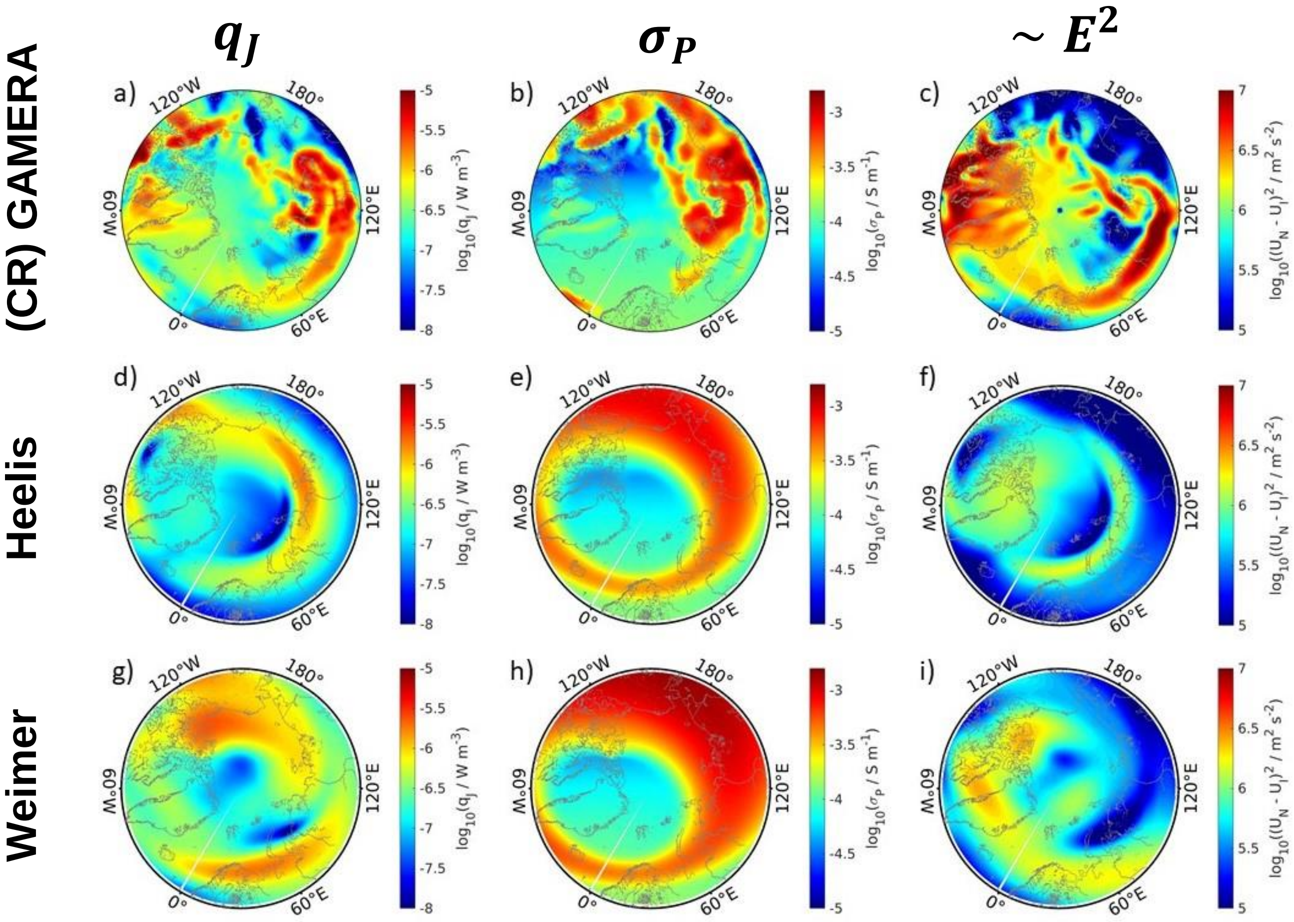
Günzkofer *et al.*, *Geophys. Res. Lett.*, **52**, e2025GL117647, 2025

1. Data assimilative convection models improve agreement of local Joule heating rates and EISCAT measurements by 8%, 28%, and 54% for low, moderate, and high geomagnetic activity

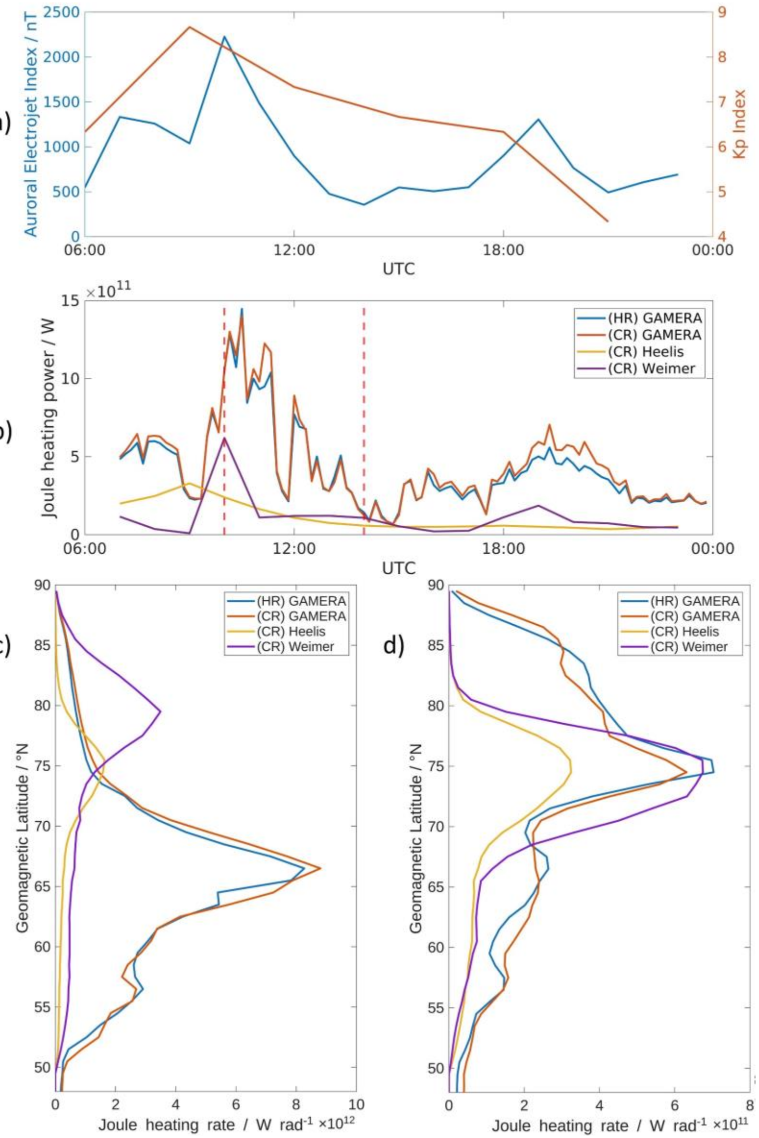
2. Increasing the horizontal resolution from 2.5° to 1.25° increases the Joule heating rates by 20% on average

3. The internal model time step does not affect the Joule heating rates

WACCM-X Results 1 (24 August 2005 storm)



Günzkofer *et al.*, under review for *Geophys. Res. Lett.*, 2025



1. Total Joule heating power increased by 276% in GAMERA coupled runs compared to Heelis and Weimer forcing
2. GAMERA forcing shifts maximum Joule heating further south (geomagnetic latitude)
3. Small-scale structures resolved in GAMERA-coupled WACCM-X run

Günzkofer *et al.*, under review for *Geophys. Res. Lett.*, 2025

WACCM-X Results 2 (24 August 2005 storm)

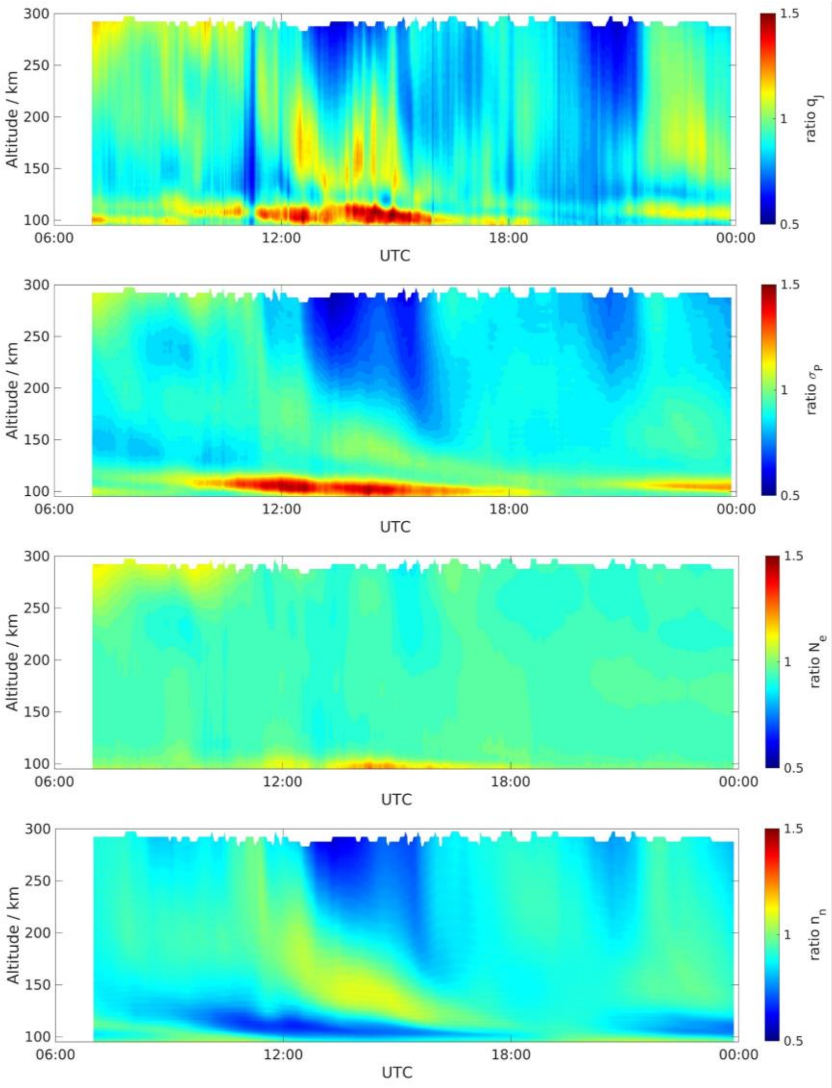
Ratio between high- (25 km) and coarse-resolution (100 km) runs

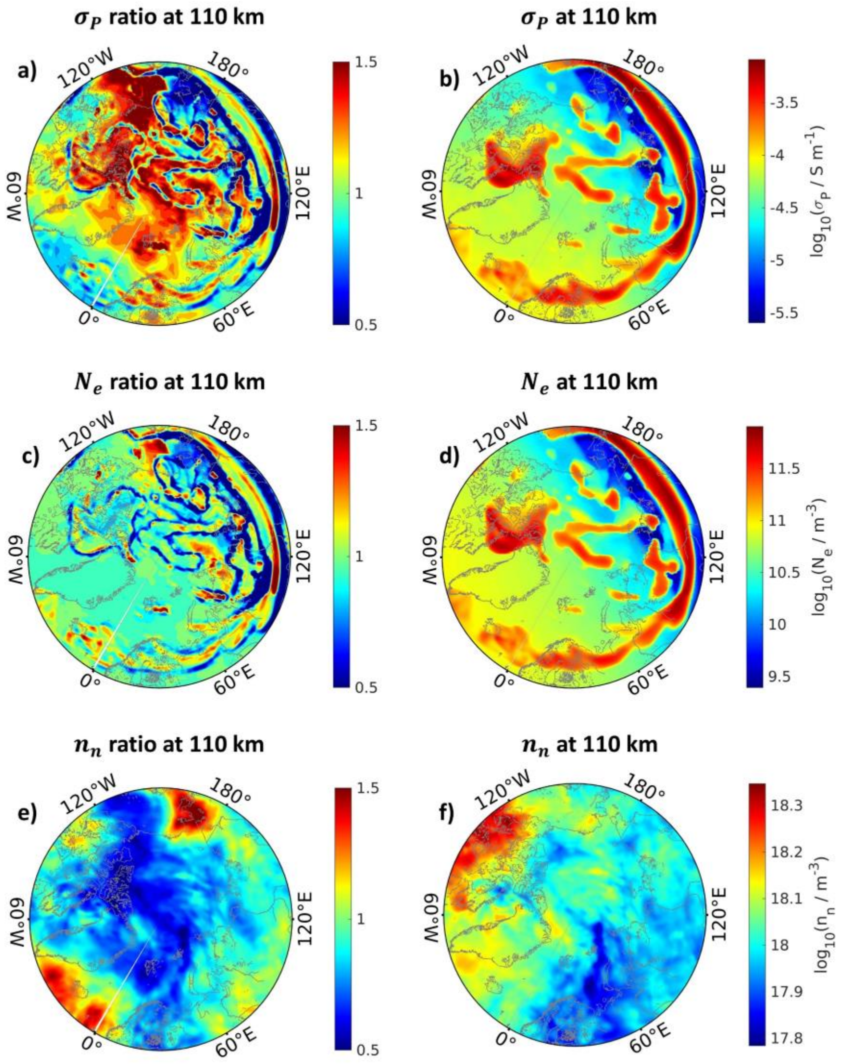
$\boldsymbol{q_J}$

$\boldsymbol{\sigma_P}$

$\boldsymbol{N_e}$

$\boldsymbol{n_n}$





Günzkofer *et al.*, under review for *Geophys. Res. Lett.*, 2025

neutral atmosphere dynamics in the storm recovery phase are strongly altered in high-resolution run

- neutral density n_n is decreased at < 120 km and > 200 km
- impact on Pedersen conductivity and Joule heating
  - $\nu_{in} \gg \omega_i$ $\sigma_P \propto n_n^{-1}$
  - $\nu_{in} \ll \omega_i$ $\sigma_P \propto n_n$
- small-scale effects on electron density (sharpness of pathches and arcs)

Summary

1. **Data assimilative** convection models **improve** agreement of **local Joule heating rates** and EISCAT measurements by **8%, 28%, and 54%** for low, moderate, and high geomagnetic activity

2. Increasing the horizontal resolution from **2.5° to 1.25° increases** the **TIE-GCM Joule heating** rates by **20%** on average

3. The **internal model time** step does **not affect** the **Joule heating** rates

4. Total **Joule heating power increased by 276%** in **GAMERA coupled** runs compared to Heelis and Weimer forcing

5. **GAMERA** forcing shifts maximum **Joule heating further sout**h (geomagnetic latitude)

6. **High-resolution** WACCM-X configuration **affects neutral dynamics** on a global scale

7. **Sharpness** of **small-scale electron density structures** increased by **high-resolution** model configuration, resulting in **local Joule heating variability**

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