Impacts of small-scale electric field and particle precipitation variabilities on Joule heating: GITM simulation

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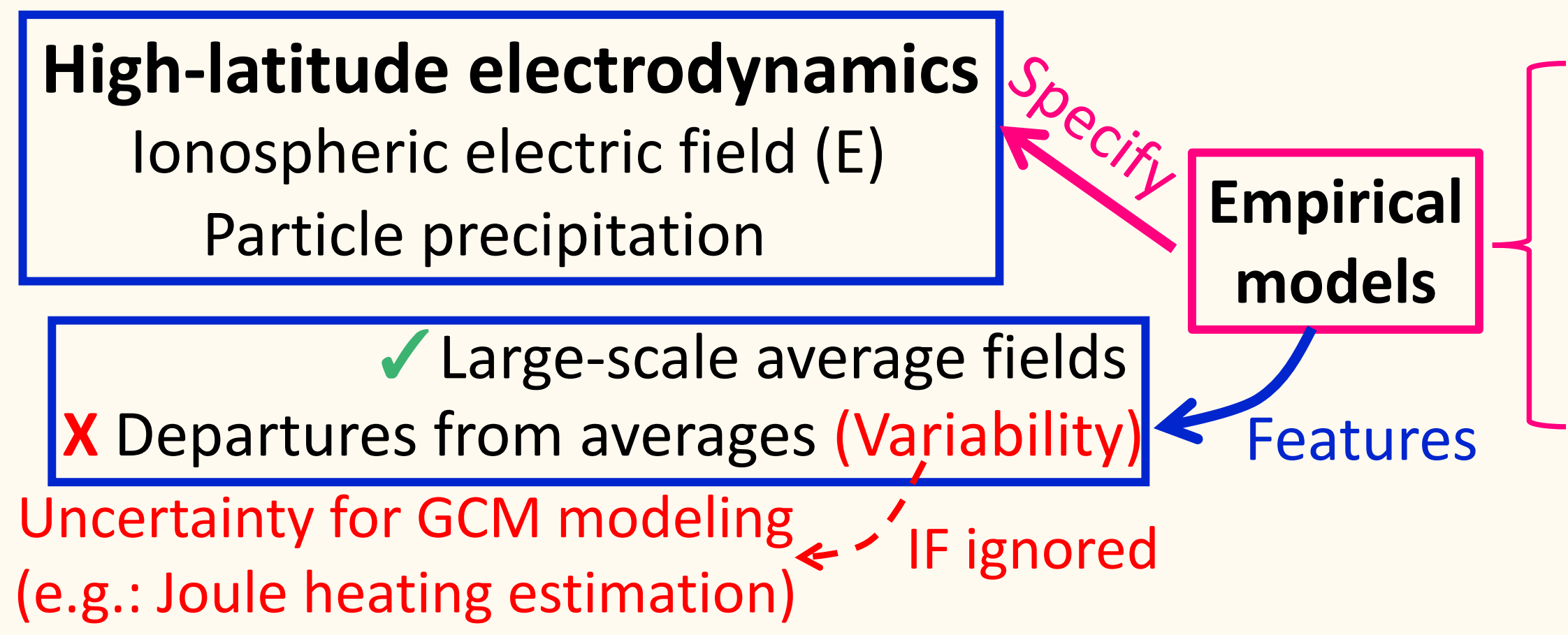
Abstract: The correlation between high-latitude electric field and particle precipitation has important implications on M-I-T system but has not been well quantified yet. In this study, such correlation is quantified for dominant southward IMF Bz cases. We found that the correlation depends on the location and the scale. Particularly on the small-scale (<500 km), the electric field is generally anti-correlated with the particle precipitation. Additionally, it is found that the impacts associated with the anti-correlation between the small-scale electric field and particle precipitation on Joule heating is not negligible from the simulation.

Introduction

In general Circulation models



High-latitude electrodynamics
Ionospheric electric field (E)
Particle precipitation

Specify

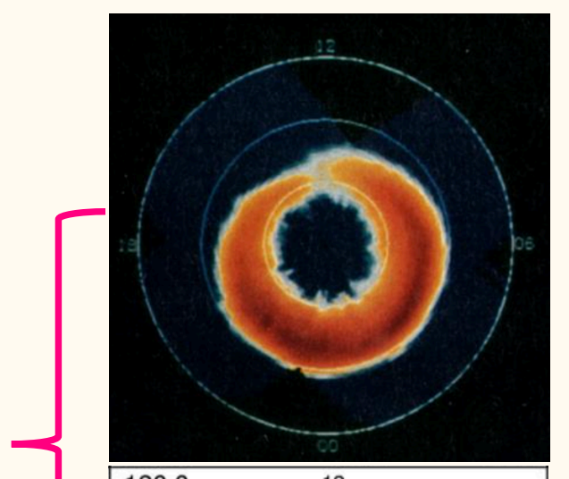
Empirical models

Features

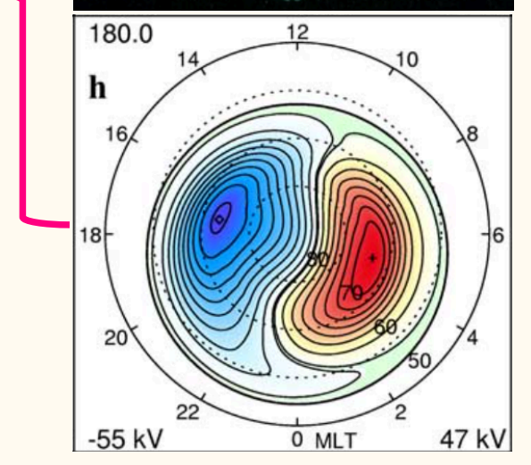
✓ Large-scale average fields
X Departures from averages (Variability)

Uncertainty for GCM modeling (e.g.: Joule heating estimation)

IF ignored



Particle energy flux (Φ_E) [Fuller-Rowell and Evans 1987]



Potential (Ψ)

$E = -\nabla\Psi$ [Weimer 2005]

If electric field variability is ignored, Joule heating is significantly underestimated: [Cordrescu et al., 1995]

$$\langle Q_J\rangle = \langle \Sigma_P \mathbf{E}^2\rangle = \bar{\Sigma}_P(\underbrace{\bar{\mathbf{E}}^2 + \sigma_E^2}_{\text{Same order}})$$

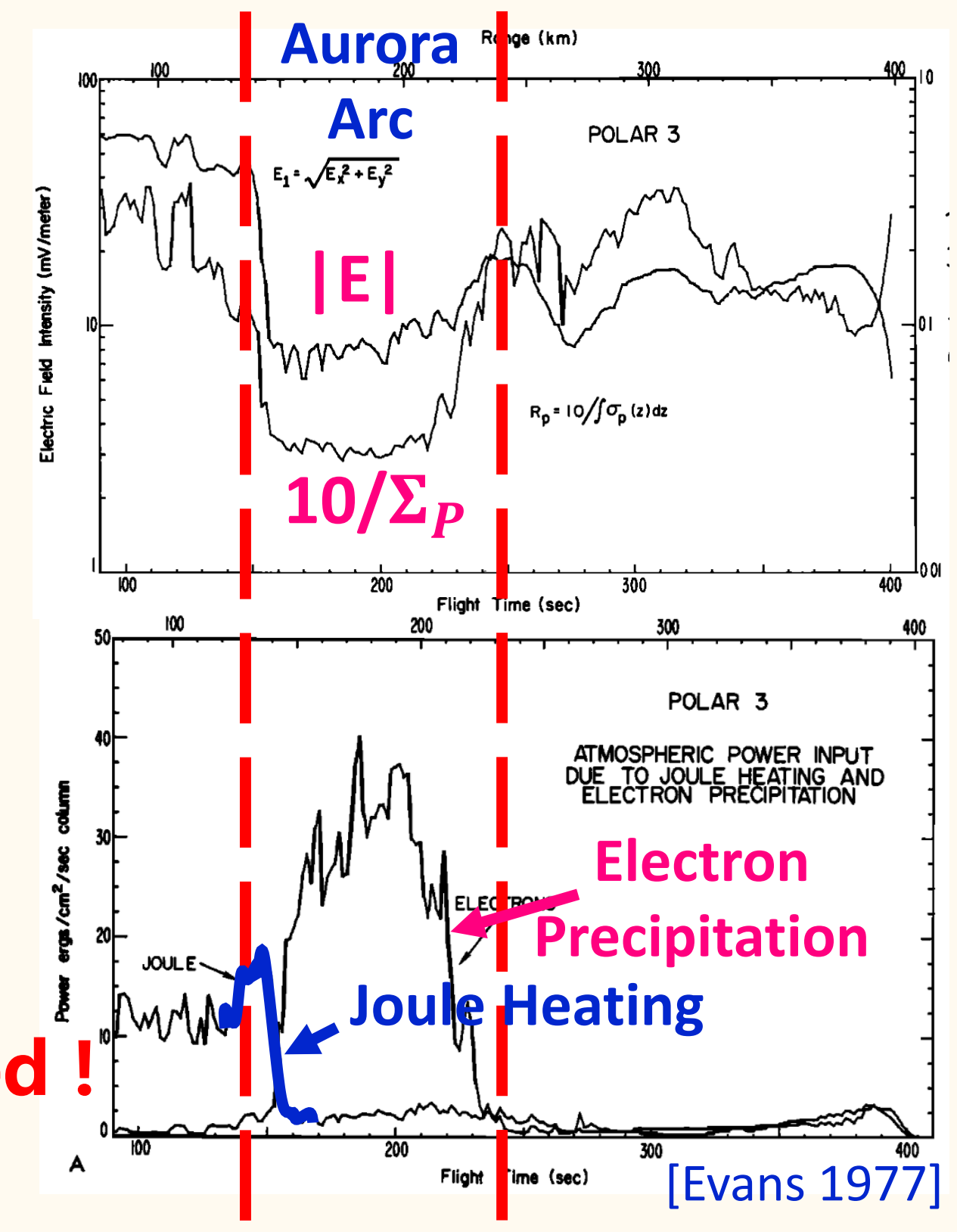
If Σ_P and E are independent

Σ_P and Electric field:

- At the nighttime, Σ_P is controlled by the particle precipitation;
- Particle precipitation is anti-correlated with electric field intensity in the aurora arc→ Depressing Joule heating [Evans 1977]
- If Σ_P and E are anti-correlated

$$\langle Q_J\rangle = \langle \Sigma_P E^2\rangle = \bar{\Sigma}_P(\bar{\mathbf{E}}^2 + \sigma_E^2)\boxed{- 2\Delta\Sigma_P\, \bar{\mathbf{E}}\cdot\sigma_E}$$

If ignored → Joule heating is overestimated !



[Evans 1977]

Objectives:

- **Quantify the correlation between the particle precipitation and the electric field:** Distribution? Scale-dependence?
- ☆ **Investigate the impacts of the correlation between small-scale electric field and particle precipitation on Joule heating.**

Data and Model

Dynamics Explorer (DE2) Satellite

Polar orbiting; Alt: 300 to 1000 km; Period: 98 min

Retarding Potential Analyzer (RPA)
Ion Drift Meter (IDM)

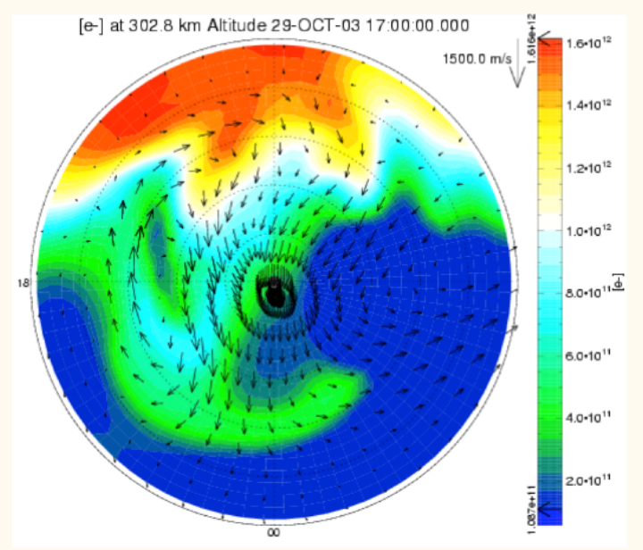
Electric field

Low Altitude Plasma Instrument (LAPI)

Particle Precipitation

Binning
Correlation

Data range: Aug, 1981 to Mar, 1983



[Ridley et al., 2006]

Global Ionosphere and Thermosphere Model (GITM)

Solves for:

6 Neutral & 5 Ion Species

Ion and neutral density, velocity and temperature

Flexible grid resolution

Can have non-hydrostatic solutions

Data Processing

Large scale: data smoothed with a 500-km sliding window (>500 km)

Small scale:
Observation - Large scale (<500 km)

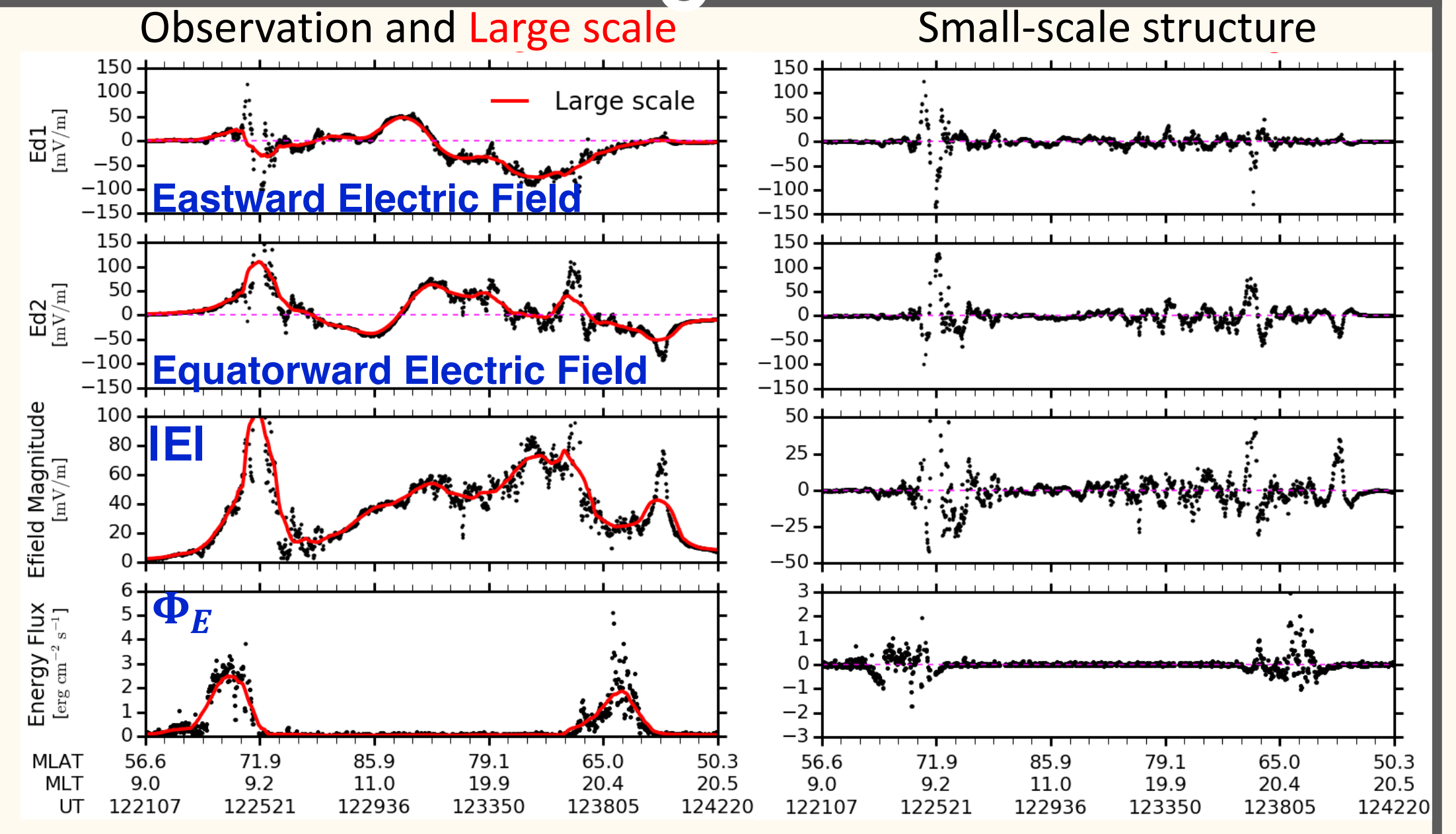


Fig 1. (Left) Observations and Large-scale Ed1, Ed2, electric field intensity and particle energy flux (Right) Small-scale of Ed1, Ed2, electric field intensity and particle energy flux.

Result 1: Distributions of |E| and Φ_E

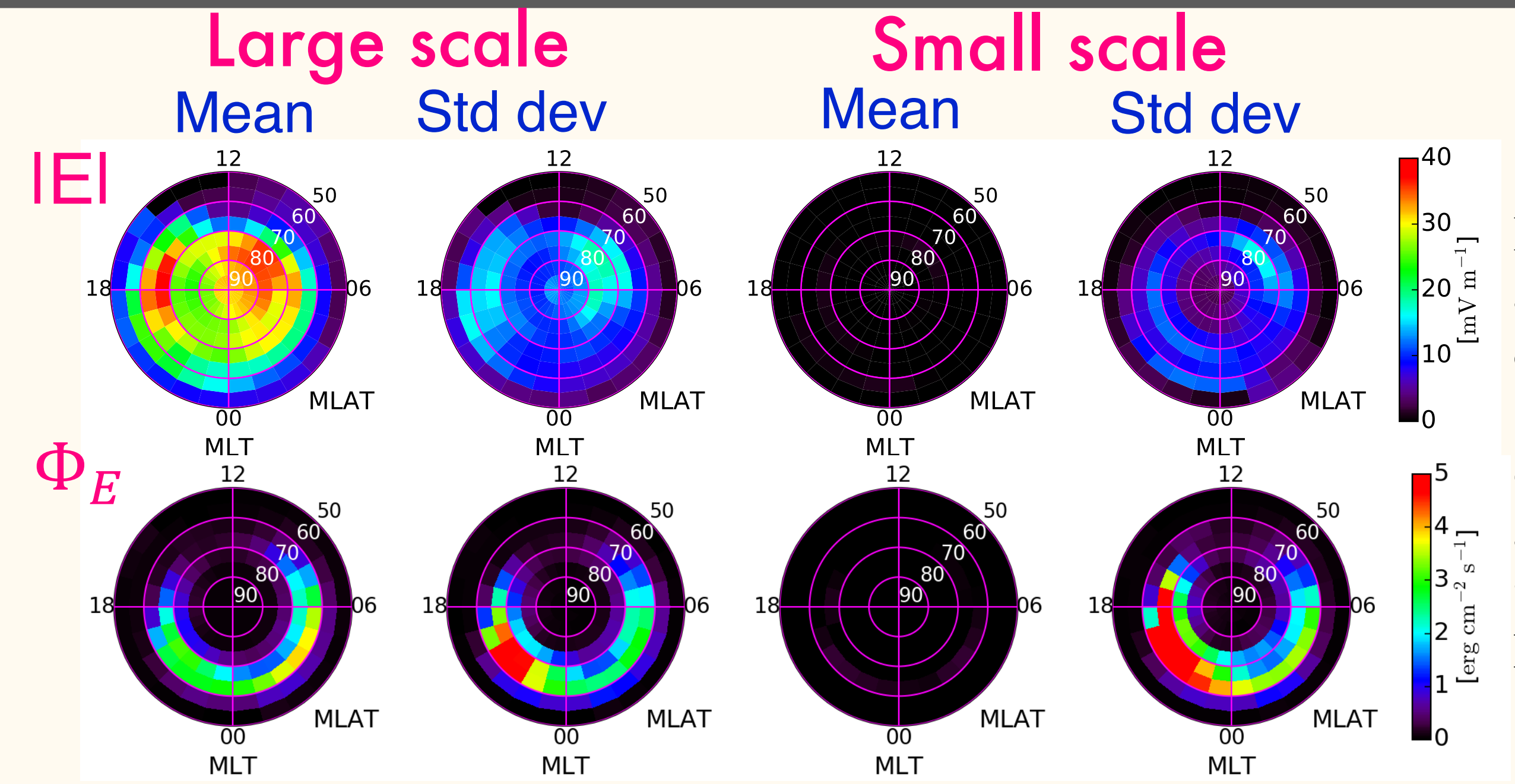


Fig 2. The averages and the standard deviations of large-scale and small-scale electric field intensity and particle energy flux as a function of MLT and MLAT.

Binning Condition:

- 5° MLAT x 500 km MLT
- IMF Bz southward and |By|<|Bz|
- IMF Bt: 4 nT<Bt<10 nT
- All seasons, both hemispheres

Distribution:

Large-scale: The averages are generally larger than the standard deviations except for the Φ_E at pre-midnight.

Small-scale: The averages are much smaller than the standard deviations.

Result 2: Correlation between |E| and Φ_E

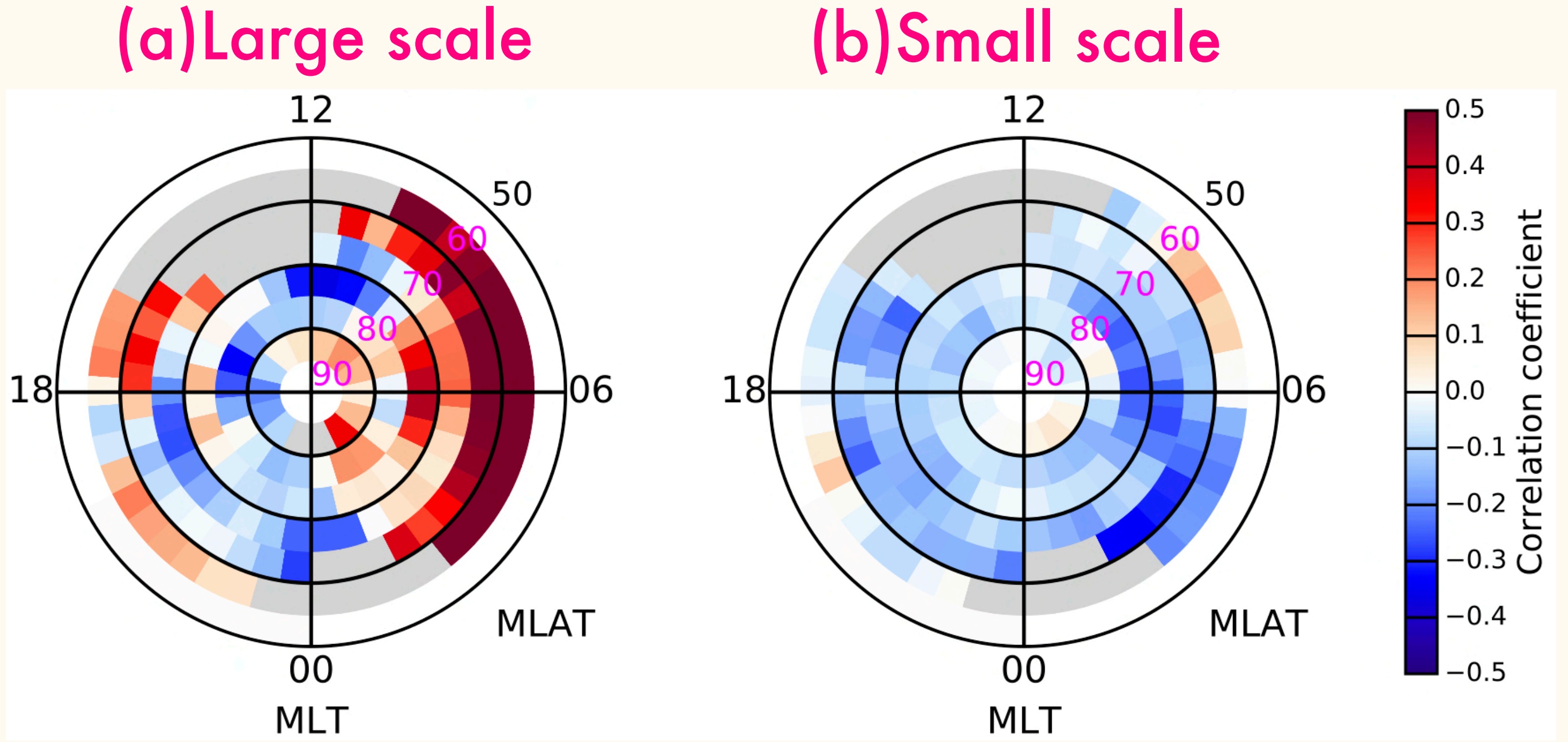


Fig 3. Distributions of correlation between particle energy flux and electric field intensity on (a) Large scale (b) Small scale.

Correlation distribution differs on different scales:

Large scale: Positive correlation mostly in post-midnight and morning side
Also below 60°, almost all MLT;
Anti-correlation mostly in pre-midnight and afternoon side.

Small scale: Anti-correlation in general.

Result 3: Impacts of small-scale variabilities on Joule heating

Simulation summary: Grid: 5° LON x 5° LAT; $F_{10.7}$=150; Sep Equinox

Run	Large-scale fields	Small-scale Evar	Small-scale PP var	Output
1	YES	NO	NO	Fig 4a
2	YES	YES	NO	Fig 4b
3	YES	YES	YES	Fig 4c

*Evar: Electric field variability *PP var: Particle precipitation variability

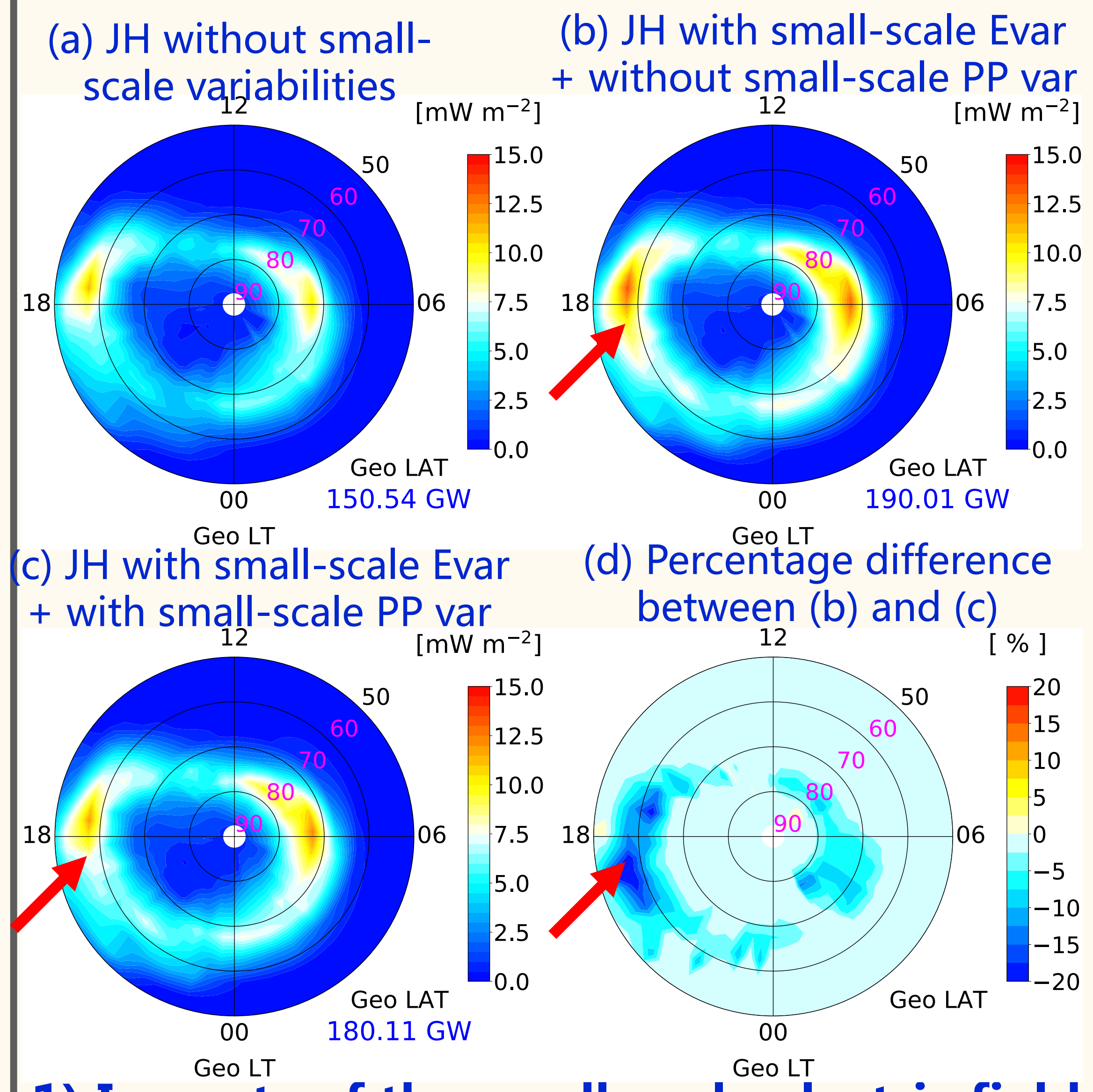


Fig 4. Height-integrated Joule heating from (a) Run 1 (b) Run 2 and (c) Run 3. The percentage change between Figs 4b and 4c is shown in Fig 4d. All results are represent in the geographic coordinate.

1) Impacts of the small-scale electric field variability (Figs 4b vs 4a):

- 27% enhancement in Joule heating (150.54 GW→190.01 GW);

2) Impacts of the small-scale particle precipitation variability (Figs 4c vs 4b):

- The variable Φ_E is calculated according to Fig 3b;
- Total Joule heating reduced by ~10 GW (190.01 →180.11 GW, 5%)
- **Fig 4d indicates that the localized reduction can reach ~17.5% at the dusk side, which is not negligible!**

Summary

High-latitude electric field and particle precipitation:

- Their correlation depends on the location as well as the scale;
- On small scale, they are generally anti-correlated (→Current generator on small scale).

Impacts of the small-scale electric field and particle precipitation variabilities on Joule heating:

- The small-scale electric field variability leads to a significant enhancement in Joule heating;
- The anti-correlation between the small-scale particle precipitation and the small-scale electric field results in an overall 5% decrease in Joule heating. But the localized reduction can reach 17.5 %, which is not negligible.

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