

Importance of Magnetosphere-Ionosphere-Thermosphere coupling at meso- and small-scales

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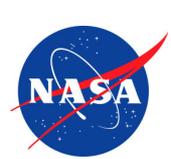
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$$\begin{array}{l} \text{IT} \\ \text{deposition} \end{array} \rightarrow \vec{j} \cdot \vec{E} + \nabla(\vec{S}) \stackrel{\text{Magnetospheric source}}{=} 0 \qquad \vec{S} = \frac{1}{\mu_0} [\vec{E} \times \vec{B}]$$

- Coupling, energy transport in the geospace environment and e/m energy deposition in the ionosphere-thermosphere (IT) depends on temporal and spatial scales (Huang and Burke, 2004; Semeter et al., 2010; Lyons et al., 2016; Huang et al., 2016; McGranaghan et al., 2017+)
- Physical mechanisms and efficiency of the magnetosphere-IT coupling also differ depending on their scale.
- Ignoring meso- and small-scale processes can lead to under-estimation of IT energy budget

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How do we estimate JH from observations?

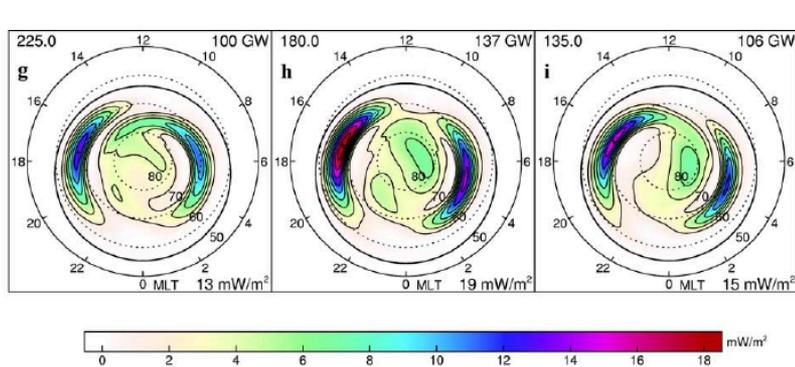
Across different spatial scales, there are different approaches for Joule heating estimates using satellite, rocket and ground-based measurements.

- Incoherent Scatter Radar (e.g., Thayer, 1998; Fujii et al., 1998; Fujii et al., 1999; Thayer, 2000, Cosgrove et al., 2009)
- Satellite-based: *The Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure* (e.g., Lu et al., 1995; Chun et al., 1999; Knipp et al., 2004; McHarg et al., 2005)
- Rocket-based (e.g., Evans et al., 1977; Sangalli et al., 2009; Hurd et al., 2016)

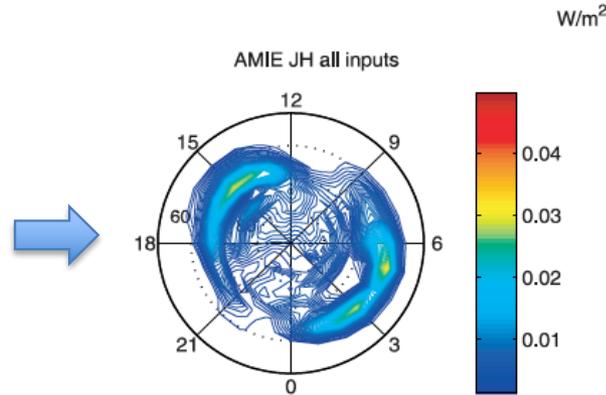
$$\overline{\sigma_p E^2}$$

$$\vec{j} \cdot \vec{E} = \vec{j} \cdot \vec{E}' + \vec{V}_n \cdot \vec{j} \times \vec{B}, \quad \vec{V} = \sum_{\alpha} \frac{n_{\alpha} m_{\alpha} \langle \vec{V}_{\alpha} \rangle}{n_{\alpha} m_{\alpha}}$$

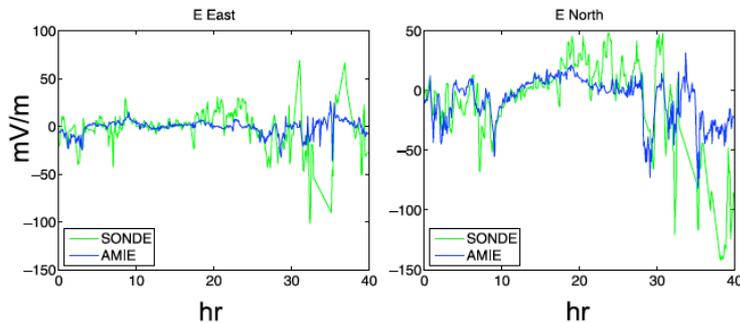
Joule heating at mesoscale



Empirical model at 110 km altitude
(Weimer, JGR, 2005)



AMIE reconstruction of Joule heating for 11:10 UT
on 15 May 1997 (McHarg et al., 2005)



Eastward and northward E components
measured by Sondrestrom (green) and
modeled by AMIE (blue) starting 9 Jan 1997
(Cosgrove et al., 2009)

✓ **JH estimation depends on spatial and temporal resolutions of the method**

Energy transfer rate is scale-dependent (Thayer and Semeter, 2004) and resolution-dependent (Deng and Ridley, 2007; Deng et al., 2009; Cosgrove et al., 2009, 2011)