Observational aspects of the IT energy budget at the multi-scales

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Sources for the energy budget

source	Spatial scales			Temporal scales		
	Large >500km	Meso 150-500	Small <150km	Large >15min	Meso 1-10 min	Small ~min – 10s sec
Measurements and data assimilation (AMIE, POES & DMSP, ISR, SWARM, rockets, TIMED/SABER)			coverage		campaigns	
Empirical models (OVATION Prime, Weimer05-based JH, Cosgrove et al., 2011, …)					statistical	
Global Circulation Models or physics-based modeling (TIEGCM, GITM, …)			drivers?		event-based	dynamic effects?

** Scale range definitions can vary for different physical parameters (in reference to particles, fields, currents).*

Relevant empirical models

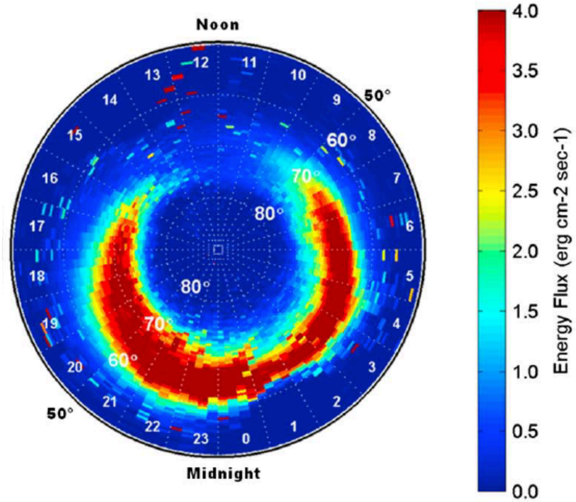
- Auroral heating: OVATION Prime (Newell et al., 2009); TIMED/GUVI model (Zhang & Paxton, 2008)
- Joule heating: Northern hemisphere (Knipp et al., 2005); based on W05 (Weimer, 2005; Rastätter et al., 2016)
- NO cooling: Thermosphere Climate Index (Mlynczak et al., 2015)
- CO_2 cooling: None
- Poynting flux: (Weimer et al., 2011; Cosgrove et al., 2014)

Features:

- Statistical parametrized models, smooth large-scale structures
- Global time series

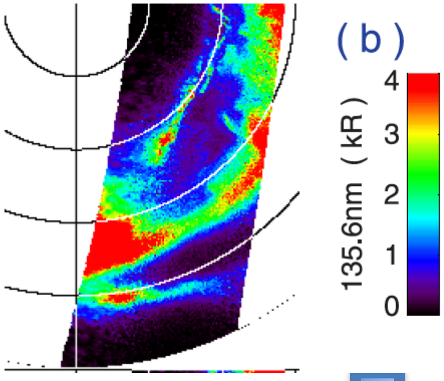
Auroral heating across scales

large-scale



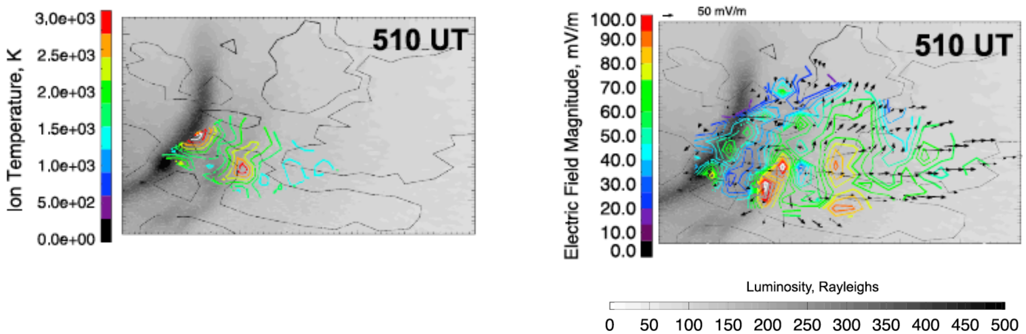
Energy flux from Ovation Prime at Kp=6 (*Lane et al., 2015*)

meso-scale



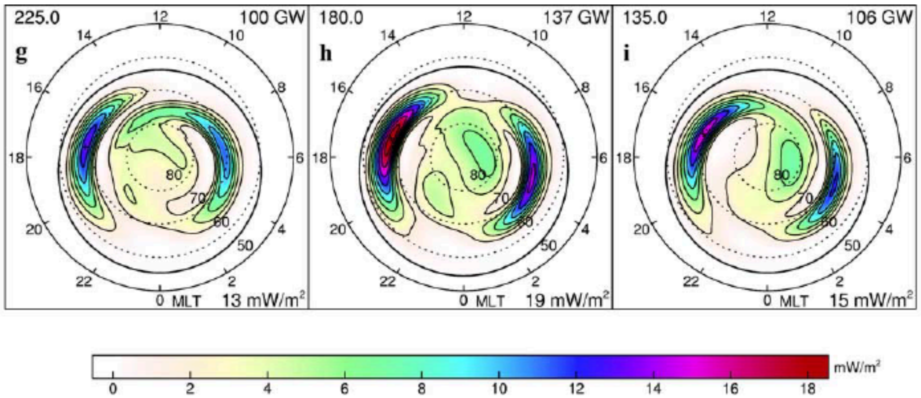
GUVI images of aurora (Zhang et al., 2005)

small-scale

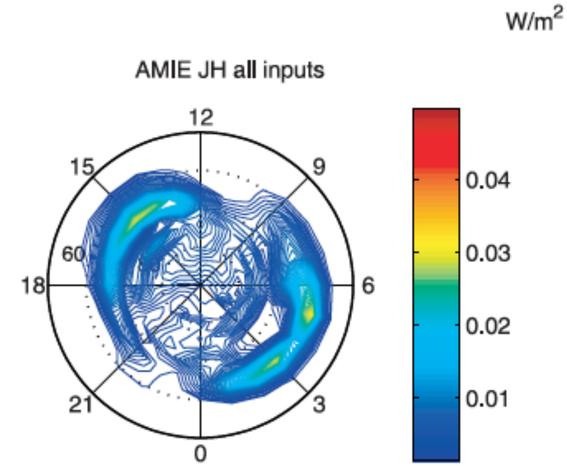


Combined plots of the optical data (grey background), Ti (left) and horizontal E (right) from RISR (Perry et al., 2015)

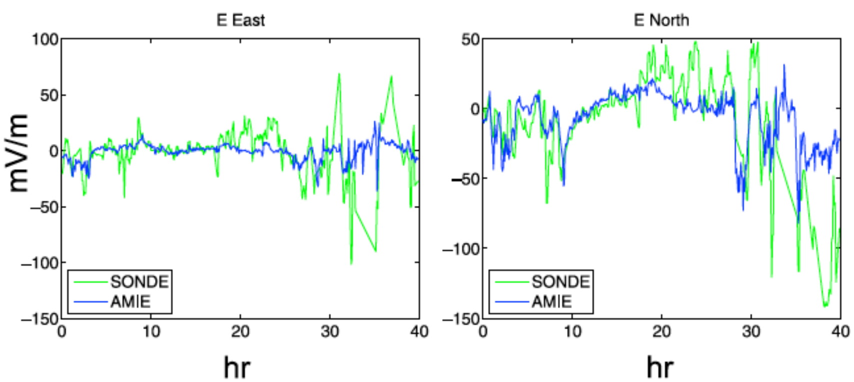
Joule heating at mesoscale



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*)

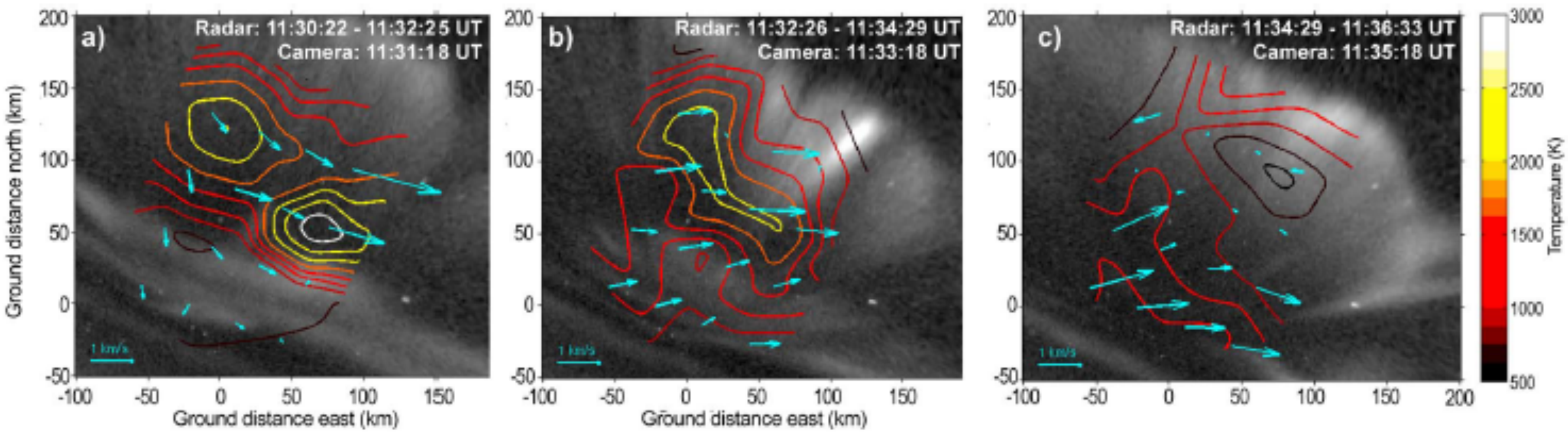


Eastward and northward E components measured by Sondrestrom (green) and modeled by AMIE (blue) starting 9 Jan 1997 (*Cosgrove et al., 2009*)

- ✓ ***JH estimation depends on spatial and temporal resolutions of the method***
- ✓ ***Different methods for JH estimation (neutral winds) (Thayer et al., 1998; Thayer and Semeter, 2004)***

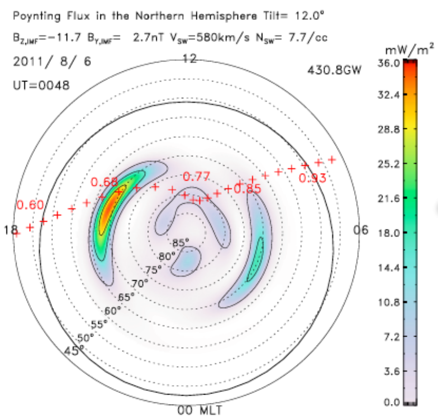
Small-scale perspective

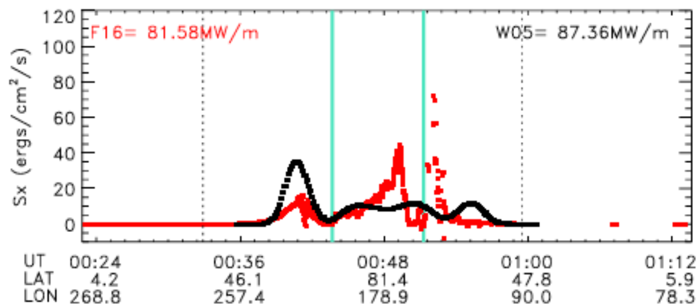
~2 min

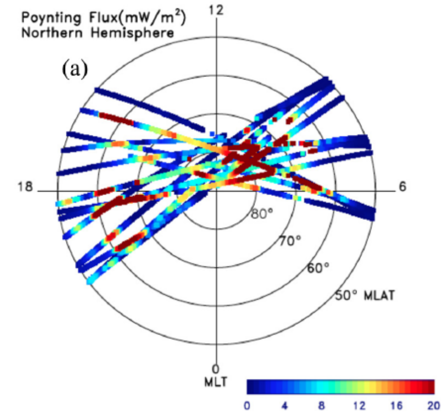


Composite presentation of flows (arrows), Ti (contours), and auroral forms during an auroral arc activation from PFISR (*Semeter et al., 2010*)

Poynting flux at the mesoscale

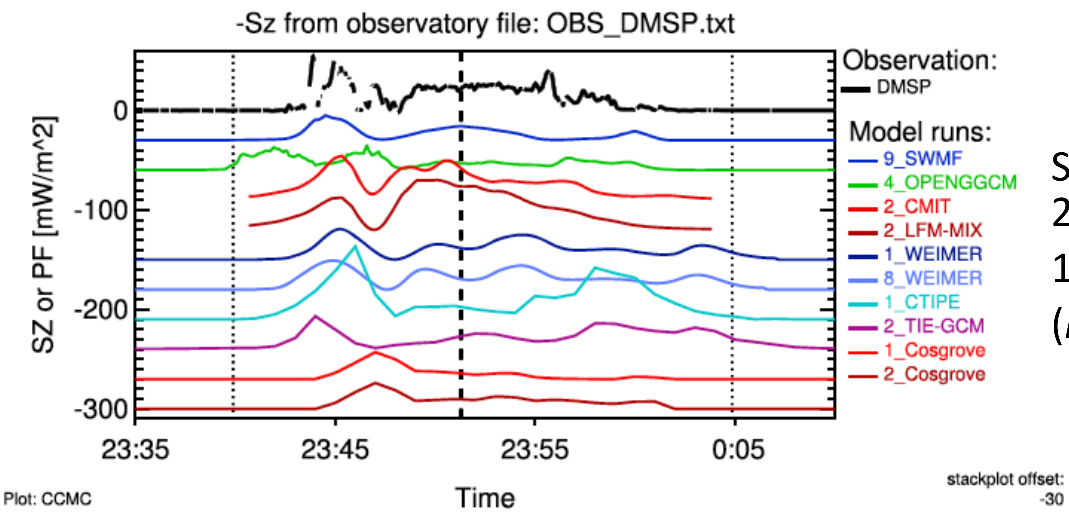






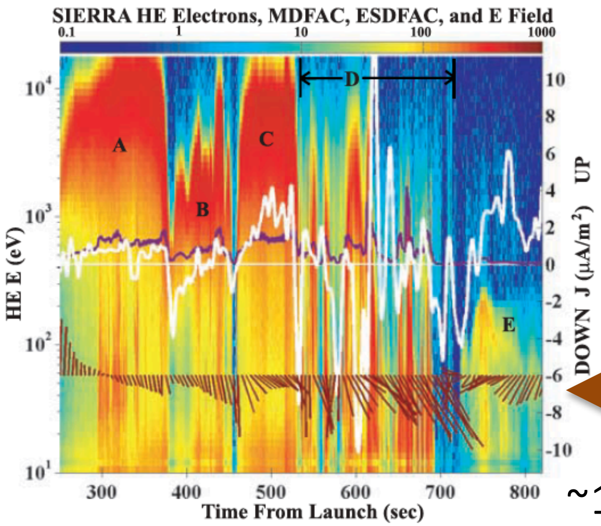
Spatial distribution of **modeled PF** (black) and derived from DMSP F16 observations (red) at ~0005UT on 6 August 2011 (*Y. Huang et al., 2014*)

Evidence for PF in polar cap (*C. Huang et al., 2016*)



Single auroral pass on 14 December 2006 23:35 to 15 December 2006 00:10 with 10s averaged DMPS observations (*Rastätter et al., 2016*)

Alfvénic processes: small scales

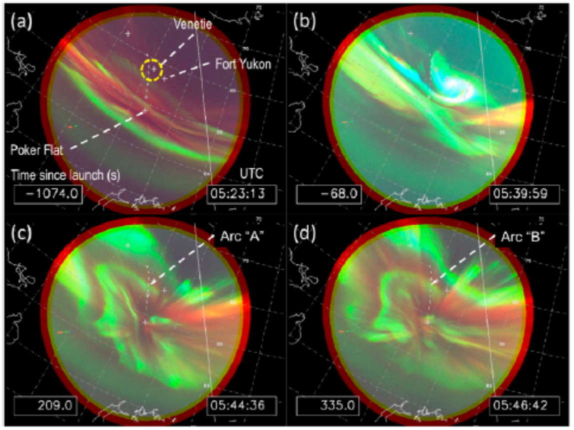


NASA SIERRA rocket mission (Klatt et al., 2005)

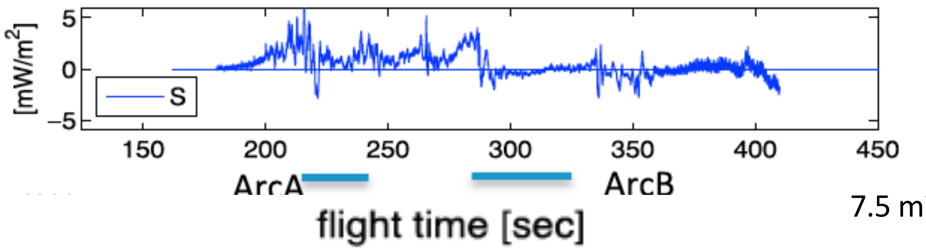
14 January 2002 above PFISR (<735 km)
Differential electron flux (left axis) and
FAC structures (right axis)

E field ~ 100 mV/m

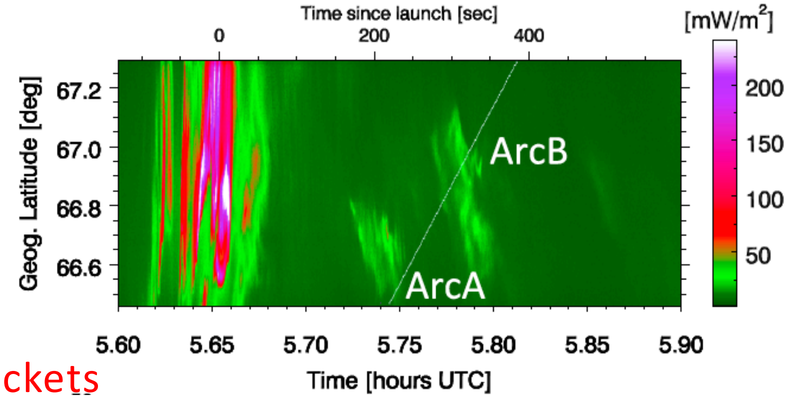
~13 min



Ground-based + rocket campaign (Lynch et al., 2014):
Poynting flux from MICA on 19 Feb 2012 at <325 km



7.5 min

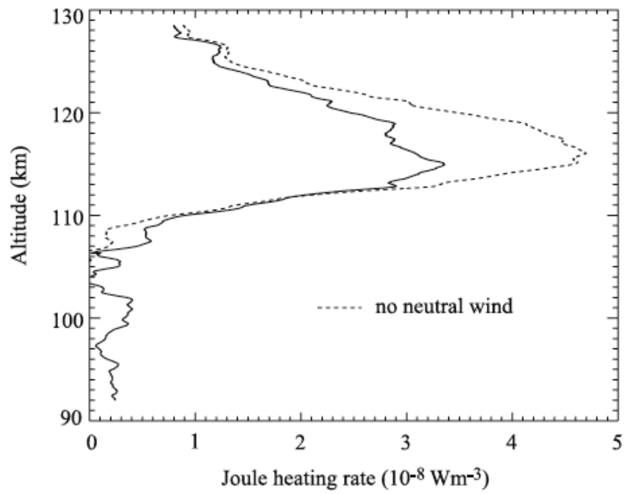


Under-utilized dataset for energy budget: sounding rockets

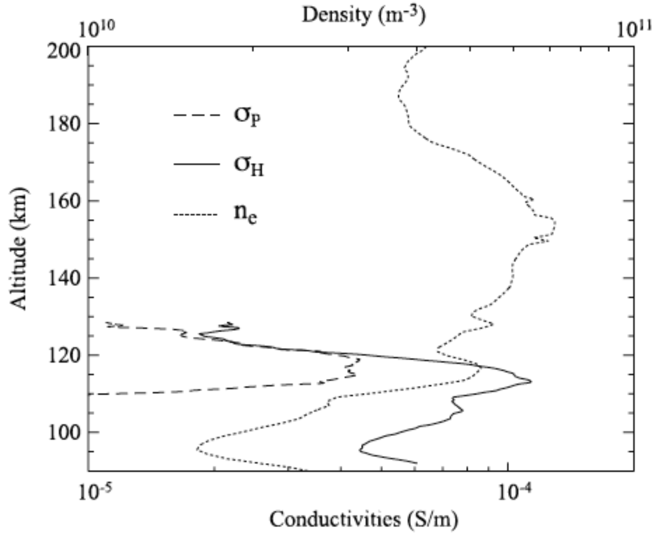
Alfvénic processes: small scales

Measurements of **ion velocity, neutral wind, and electric field** in the collisional transition region of the auroral ionosphere (Sangali et al., 2009)

From Joule II sounding rocket measurements above PFISR on 19 January 2007:



Joule heating rate profiles (not true vertical due to rocket motion)



Conductivity profiles

- Alfvén wave Poynting flux from SWARM (Park et al., 2017)
- Role of Alfvén waves in auroral arc dynamics at 1-10 km (Miles et al., 2018)
- Role of Alfvén waves in MIT coupling (Pakhotin et al., 2018)

Measurements/Data Assimilation

Energy channel	Data Sources
Auroral heating	NOAA-POES & DMSP datasets (Emery et al., 2006; 2008) AMIE+ (Richmond and Kamide, 1988; Richmond et al., 1992; Lu et al., 1996) incorporates AMPERE, ground magnetometers; DMSP/SSUSI, SuperDARN, sounding rockets (Klatt et al., 2005)
Joule heating	AMIE+ (McHarg et al., 2005; +), radars (Thayer et al., 1998; Cosgrove et al., 2009; Sojka et al., 2009), sounding rockets (Sangalli et al., 2009)
NO cooling	TIMED/SABER: critical for estimating thermospheric cooling (Mlynczak et al., 2003; 2010; 2018; Lu et al., 2010)
CO_2 cooling	
Poynting flux	DMSP (Huang and Burke, 2004; Knipp et al., 2011; Huang et al., 2014; 2017; Rastätter et al., 2016); sounding rockets (Lynch et al., 2014)

Conclusions

Energy is important parameter characterizing the IT system:

- Energy estimates can give an insight into the IT response to different external driving and solar wind-magnetosphere-IT coupling mechanisms.
- Energy estimates can provide important information on completeness of an IT model.
- Energy input and dissipation at small- and mesoscales need to be analyzed and understood.