UNIVERSITY OF OULU

Ionospheric heating

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Ionospheric heating sources

Ionospheric heating is one of the sources of ion upflow/outflow.

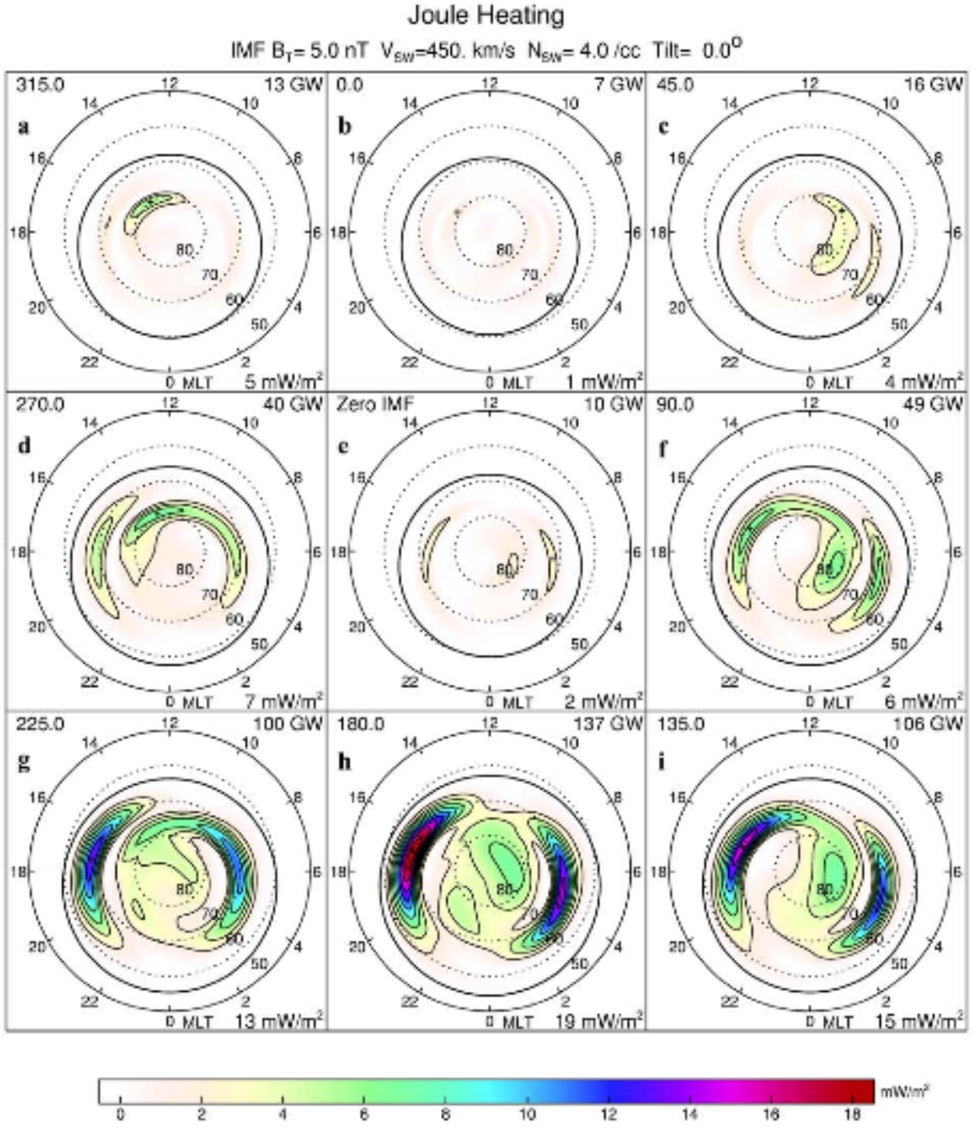
Sources of heating include:

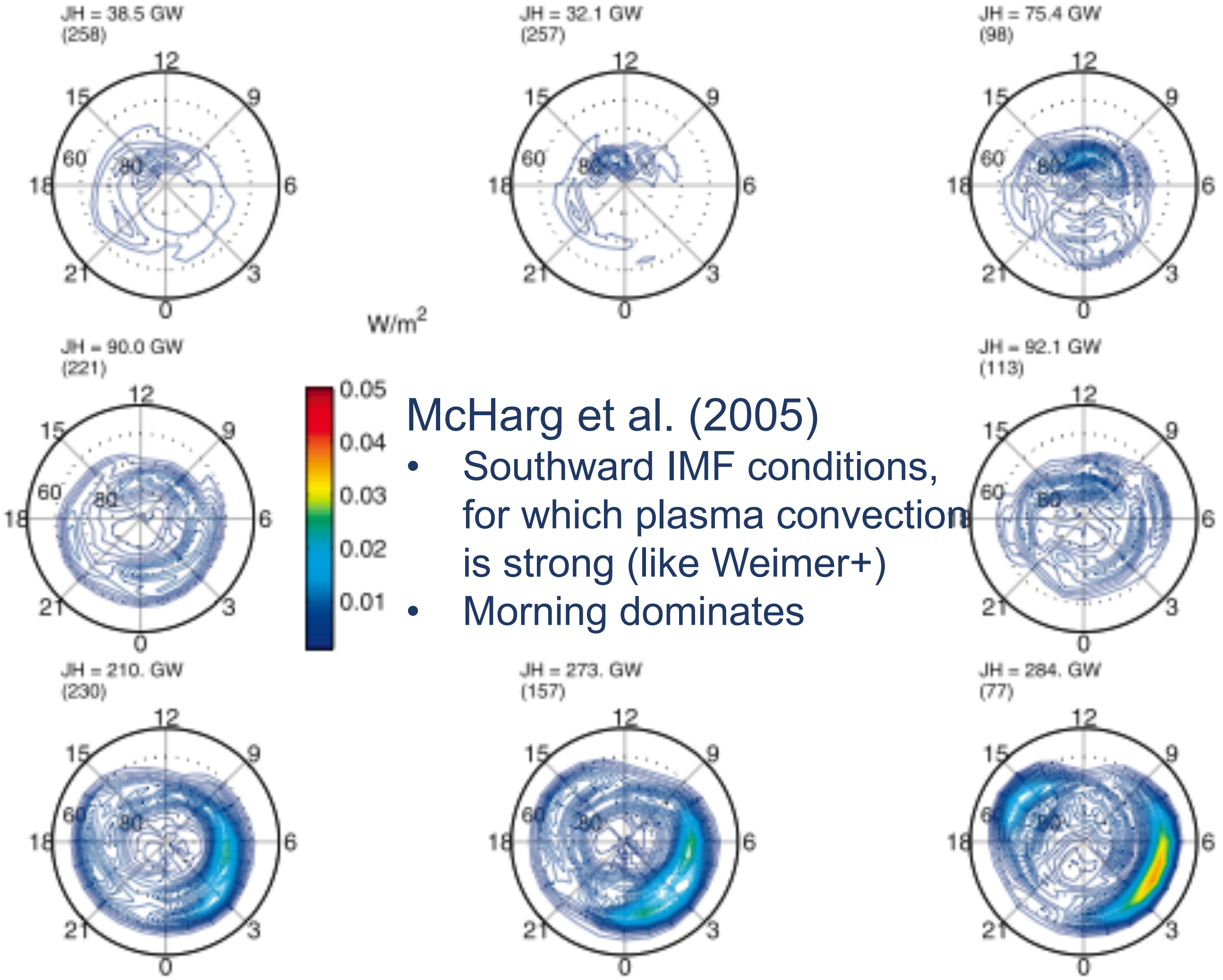
- solar EUV radiation
- particle precipitation
- Joule heating (~ion-neutral frictional heating)
- field-aligned current fluctuations
- turbulence, waves

Schunk (JASTP 2007): The classical polar wind is an ambipolar outflow of thermal plasma. If the outflow is driven by *energization processes* either in the auroral oval or at high altitudes in the polar cap, the outflow is called the ‘‘generalized’’ polar wind.

Global estimates of Joule heating by models

Weimer et al. (2005): Evening and morning maxima





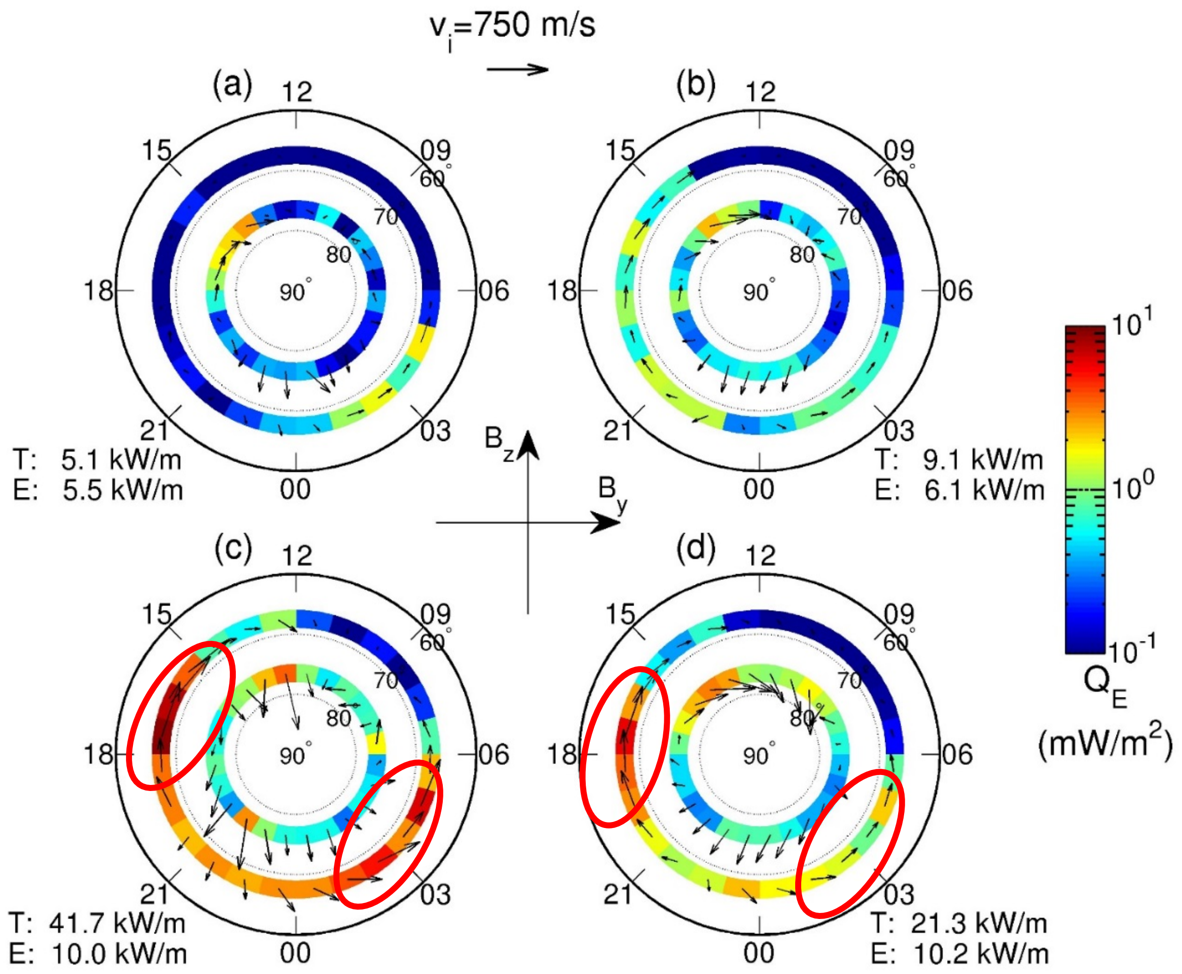
McHarg et al. (2005)

- Southward IMF conditions, for which plasma convection is strong (like Weimer+)
- Morning dominates

Factor of 2-3 larger values in McHarg than in Weimer

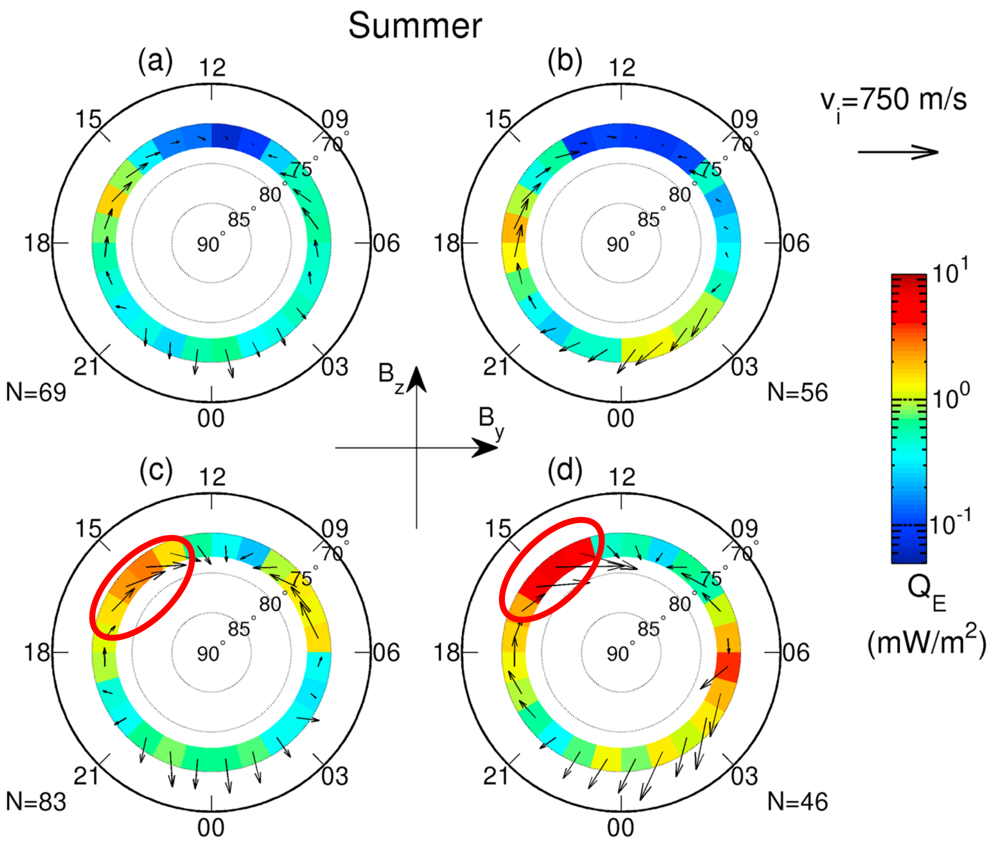
Local estimates of Joule heating, EISCAT at 67º and 75º MLAT

Cai, Aikio and Nygrén (JGR 2014)



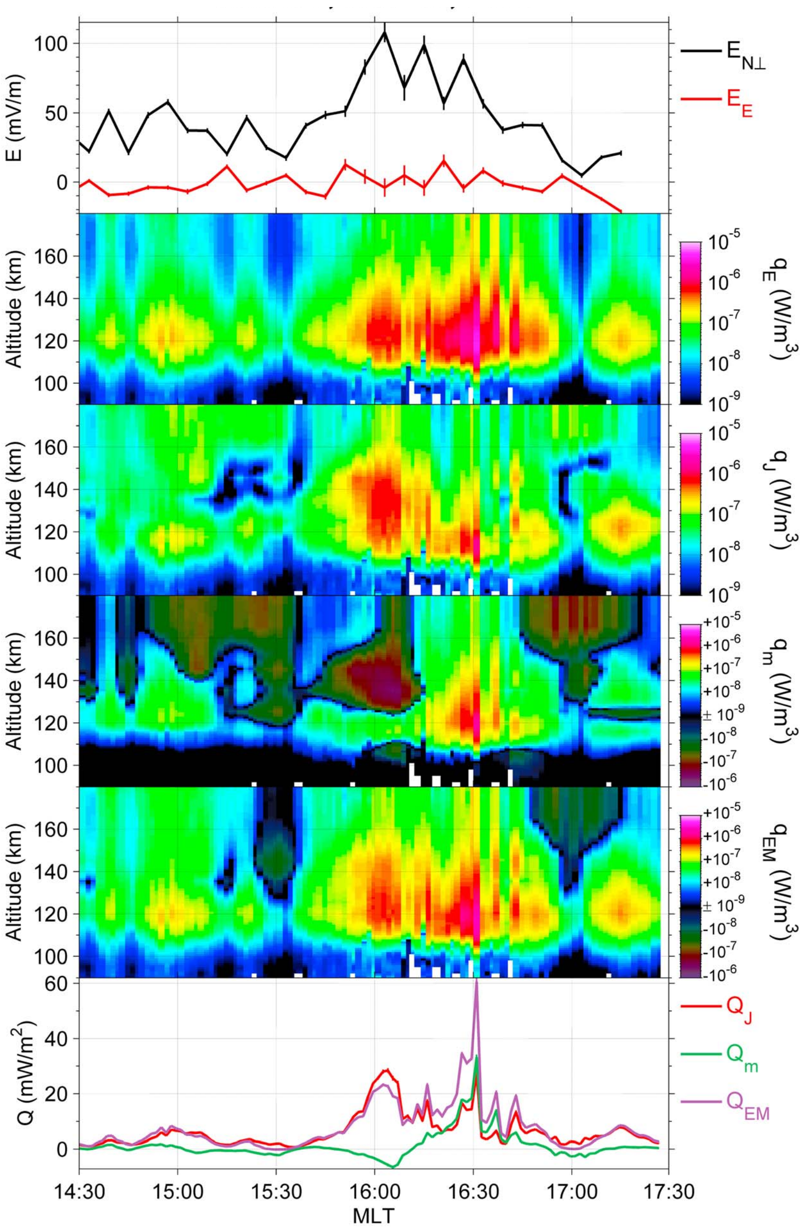
At 67º MLAT, evening and morning maxima like in Weimer+ (2005)

Cai, Aikio and Nygrén (JGR 2016): Afternoon hot spot at 75º MLAT- not in global models



At 75º MLAT, afternoon hot spot at ~15 MLT during Bz<0, Summer>Equinox>Winter, reason: large plasma convection velocity

Local estimates of Joule heating, effect of neutral winds, EISCAT



Aikio et al. (JGR 2012)

Two electric field **E** components
(this event shows an unusually large EF)

Generally used proxy for Joule heating:
$q_E(z) = \sigma_P(z)\, E^2$

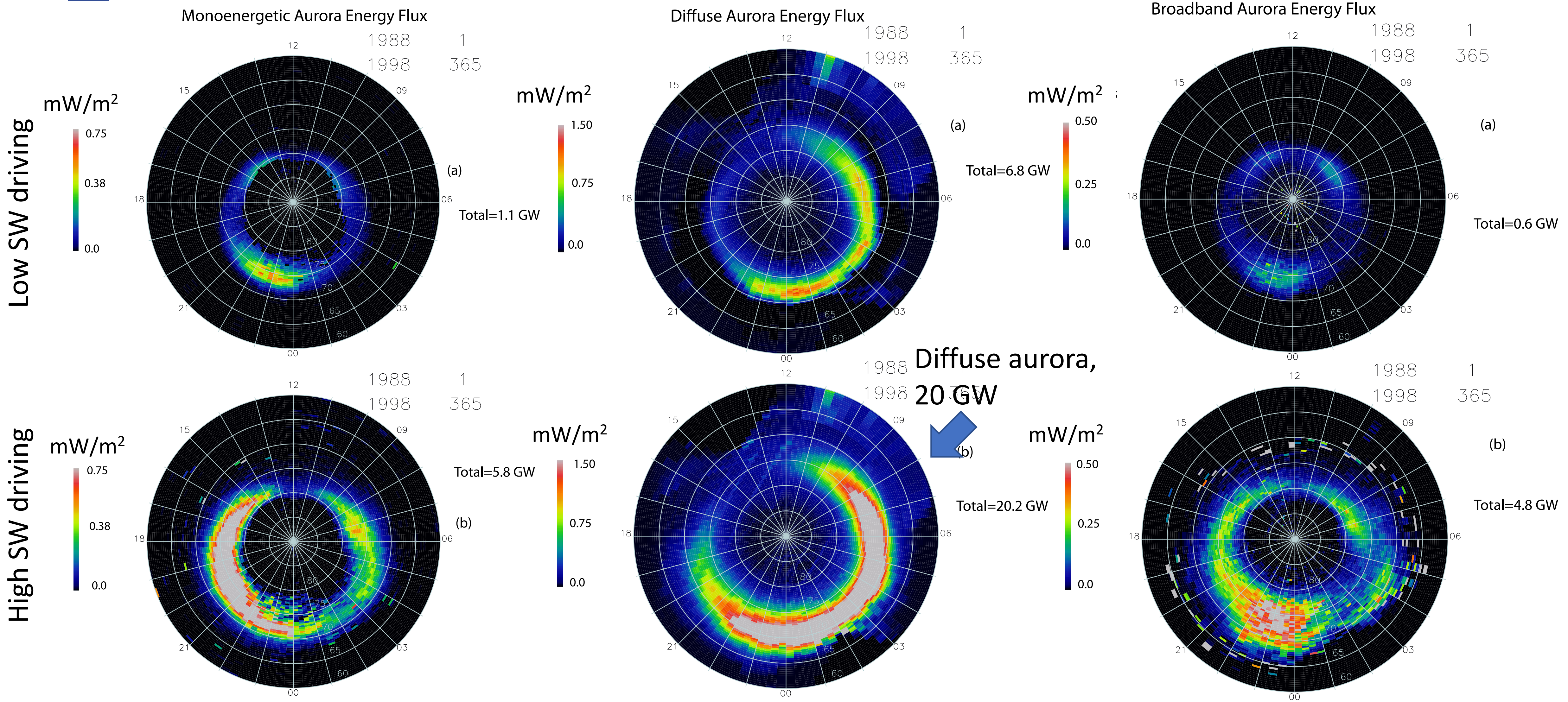
Joule heating with neutral wind **u**:
$q_J(z) = \sigma_P(z)\, |\mathbf{E} + \mathbf{u}(z) \times \mathbf{B}|^2$

=> Altitude-dependent thermospheric winds change Joule heating altitude profiles (decrease or increase)

Height-integrated (70 – 180 km) Joule heating rates Q_J (red curve). When $Q_J > Q_{EM}$, neutral winds increase Joule heating (and vice versa)

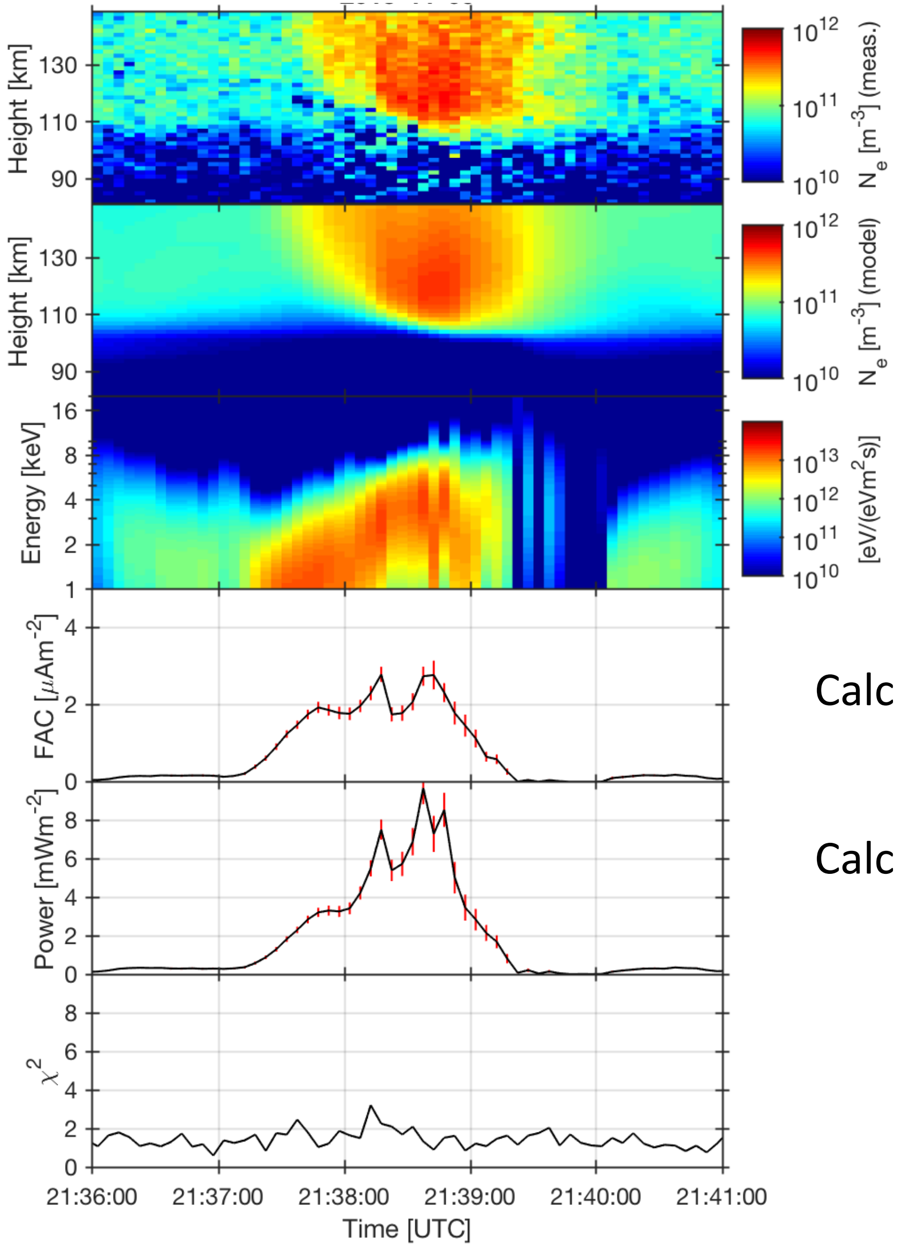
Global estimates of electron precipitation power

Newell et al. (JGR 2009)



Note that global Joule heating was estimated as 100 – 280 GW during IMF southward conditions

Local estimates of precipitating particle power



Virtanen, Gustavsson, Aikio et al. (submitted to JGR 2018)

Measured Ne by EISCAT (auroral arc)

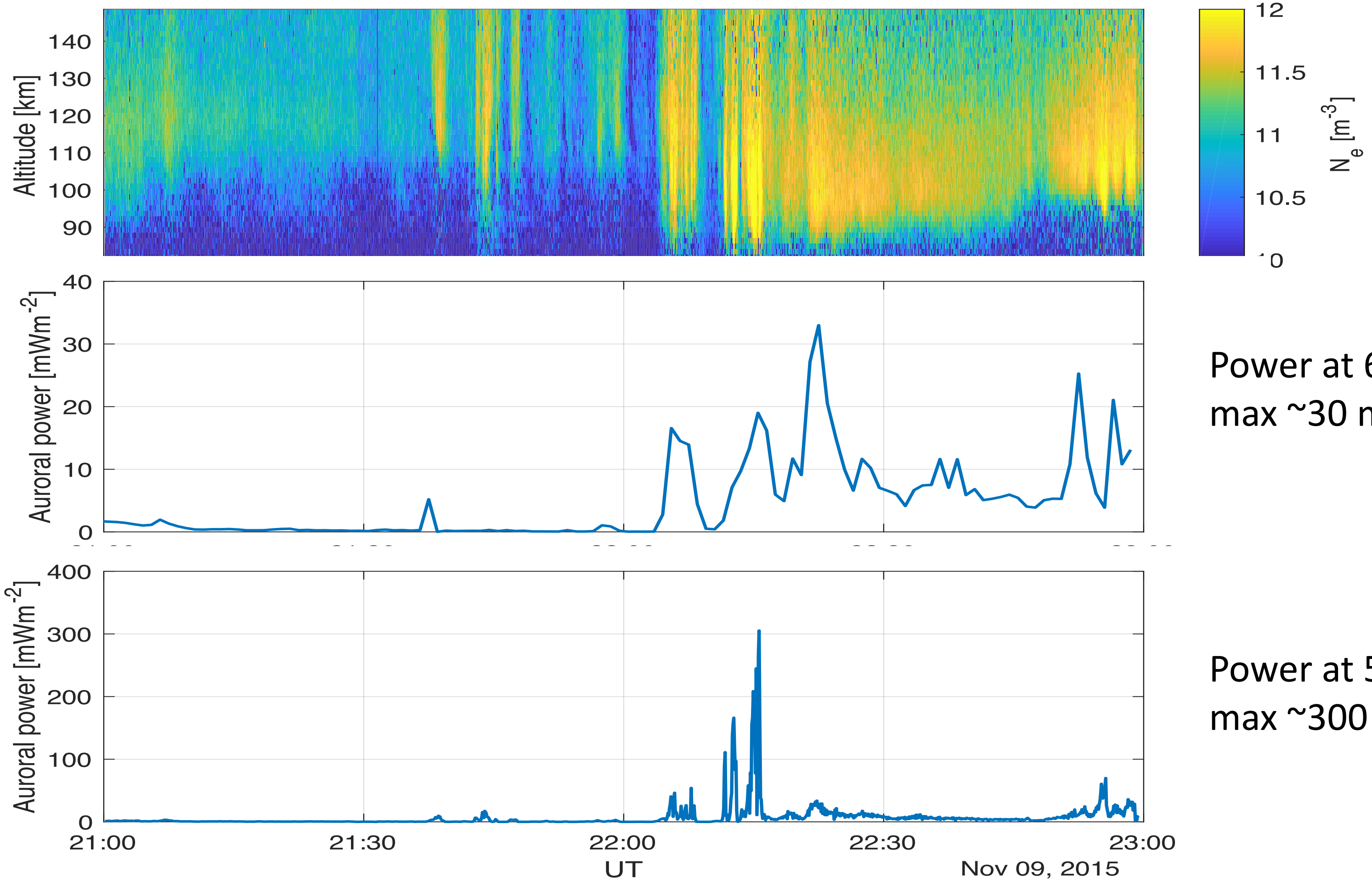
Calculated Ne (from spectra)

Inverted electron spectra (the method is introduced in the submitted paper)

Calculated FAC

Calculated power, max ~10 mW/m^2 in this auroral arc

Precipitating particle power, effect of resolution

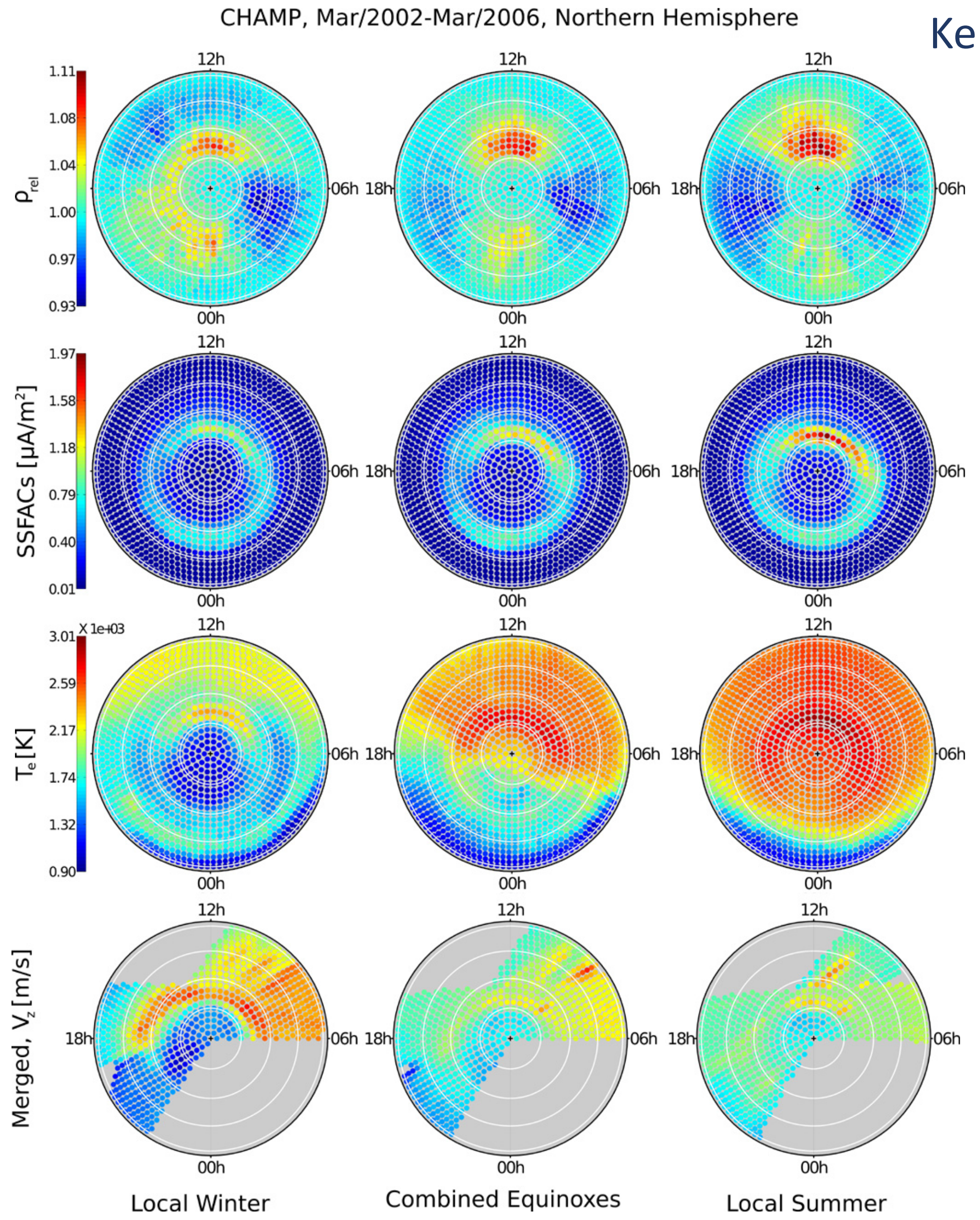


Power at 60-s resol., max ~30 mW/m^2

Power at 5-s resol., max ~300 mW/m^2

Virtanen, Gustavsson, Aikio et al. (modified from manuscript submitted to JGR 2018)

Heating within cusp, by small-scale FACs(?)



Kervalishvili and Lühr (AG 2013): CHAMP satellite at 320-460 km

Mass density anomaly (no strong seasonal dependece)

Small-scale field-aligned current intensity

Electron temperature (largest increase in winter)

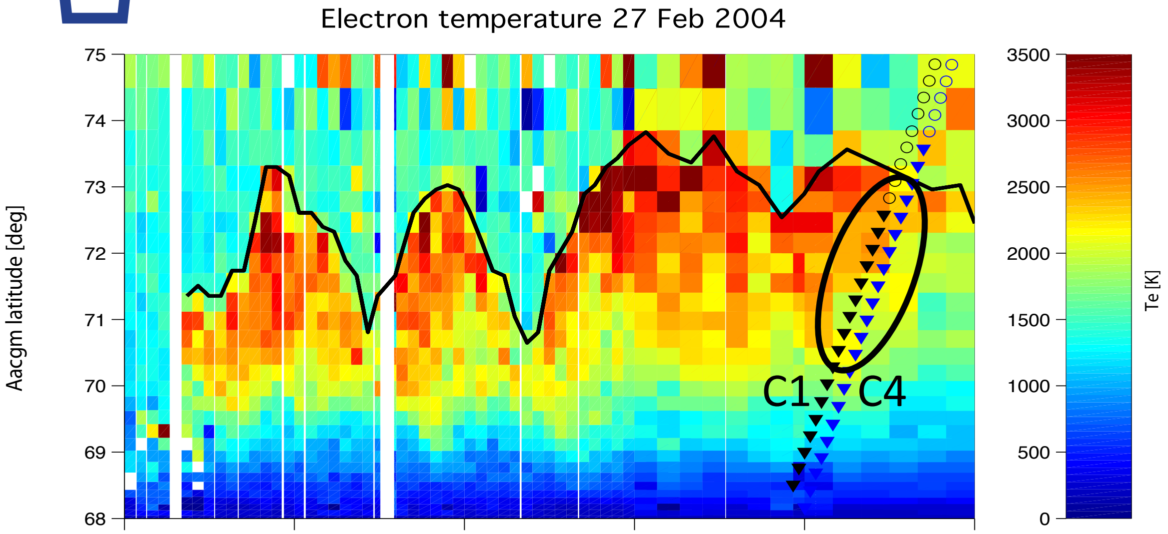
Linear correlation between Te and viz,
Strongest increases in winter

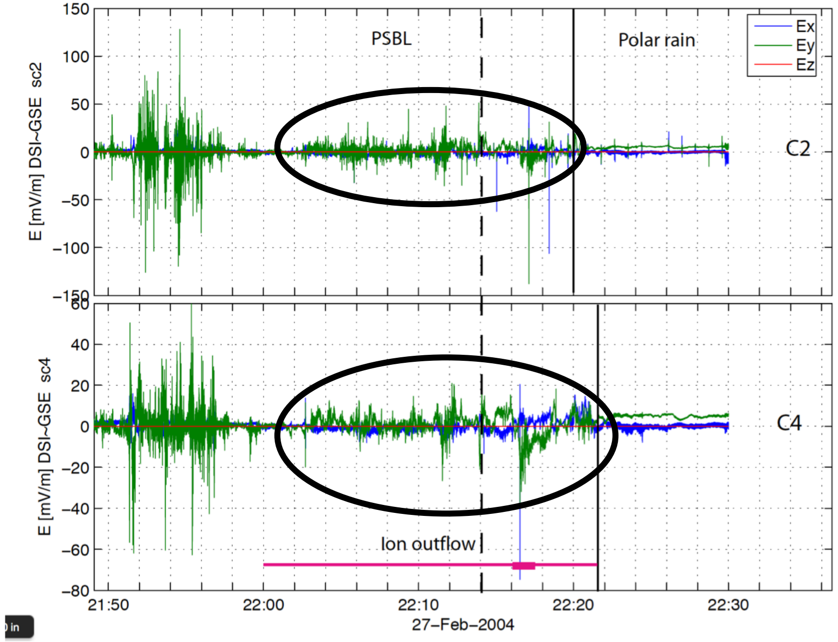
DMSP F13&F15 upward ion velocity at 840 km altitude

Conclusion: "Mechanisms for moving the neutral and the charged particles may be quite different".

Te enhancement in the ionosphere, waves at 4.4 Re (Cluster)

Aikio et al. (AG 2008)

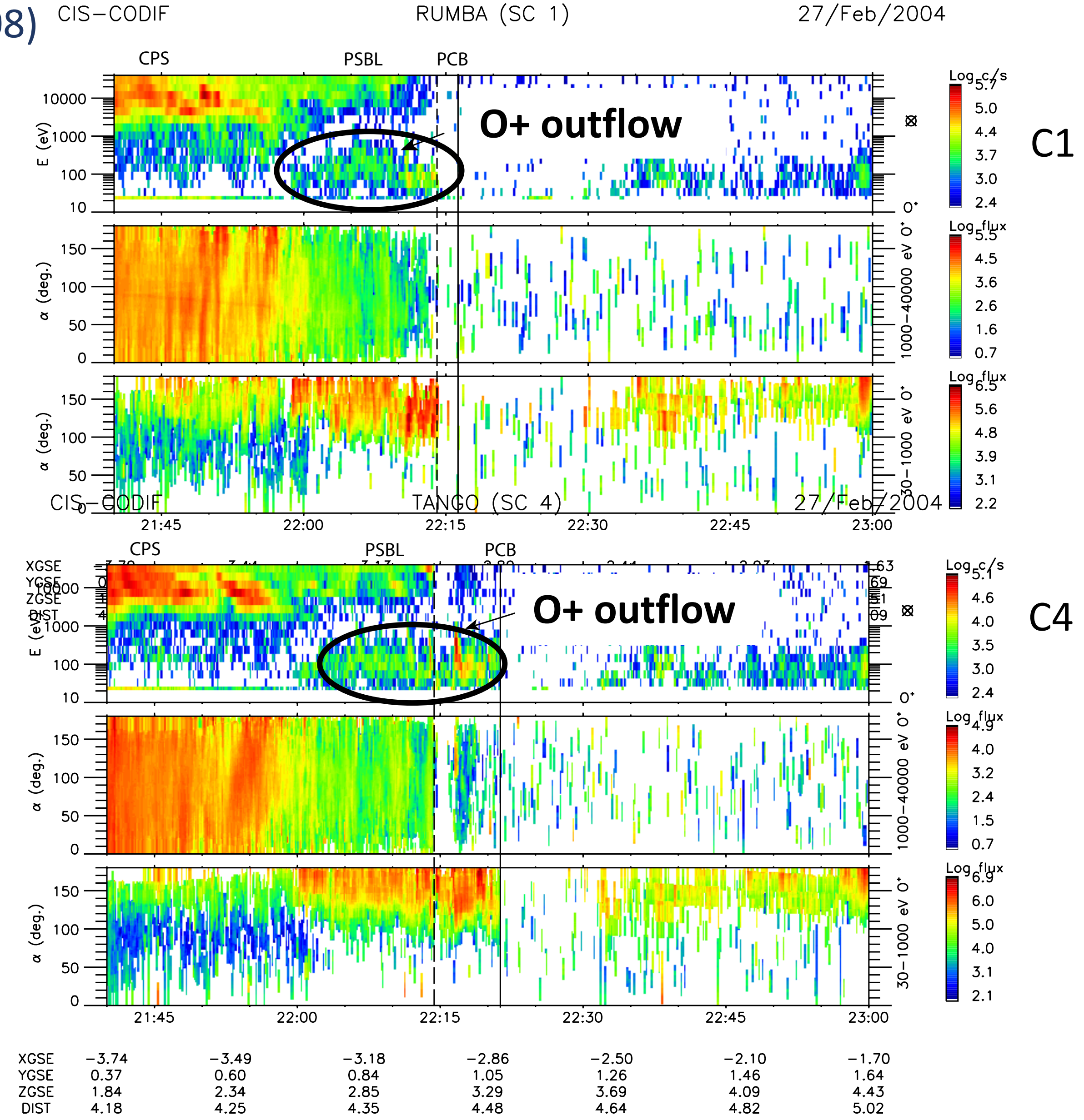




C1

BBELF fluctuations In EF

C4

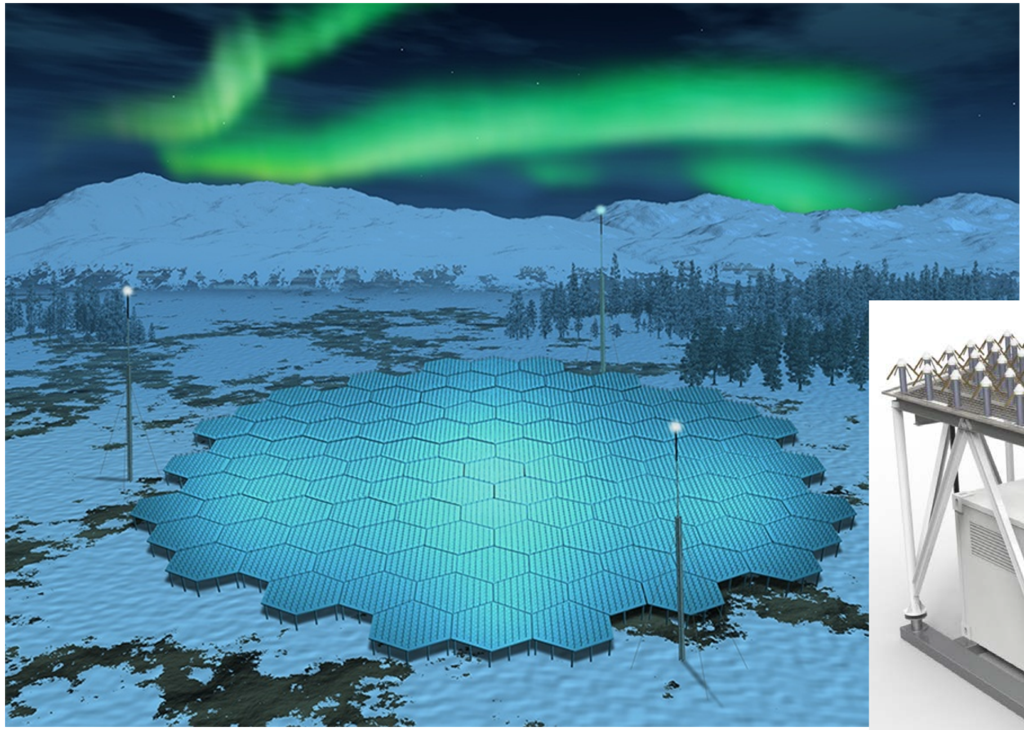


Some open questions

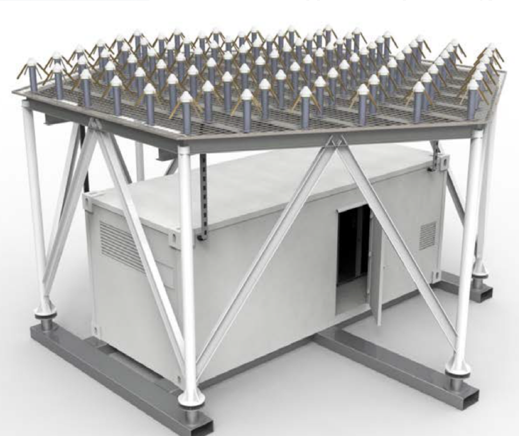
- Which processes are important for ion outflow?
- **Several processes** at different altitudes may play a role: Ionospheric heating in the E and lower F regions; wave-particle interactions, turbulence and ion acceleration by parallel EFs at intermediate altitudes (several 1000's km to 10 000's km)
- How important are **small-scale processes**? Deng and Ridley (2007): Possible reasons for underestimating Joule heating in global models: E field variability, *spatial resolution*, and vertical velocity. => They may be important.
- Neutral upflow versus ion upflow (I-T coupling)? Role of **neutral dynamics** is poorly known at thermospheric altitudes; neutral density and ion composition are also poorly known.
- Heating produces **upflow**, but what part of that will become **outflow** (and when escape)?
- How to get simultaneous measurements in the ionosphere at altitudes where heating takes place and at higher altitudes, where ions and neutrals escape? (Answer: radars + satellites)

EISCAT_3D incoherent scatter radar

- ~10 000 antenna elements, 5 MW power
- Digital beamforming, multiple simultaneous beams yielding volumetric measurements
- Lowest elevation angle 30^o
- ~230 MHz (VHF)



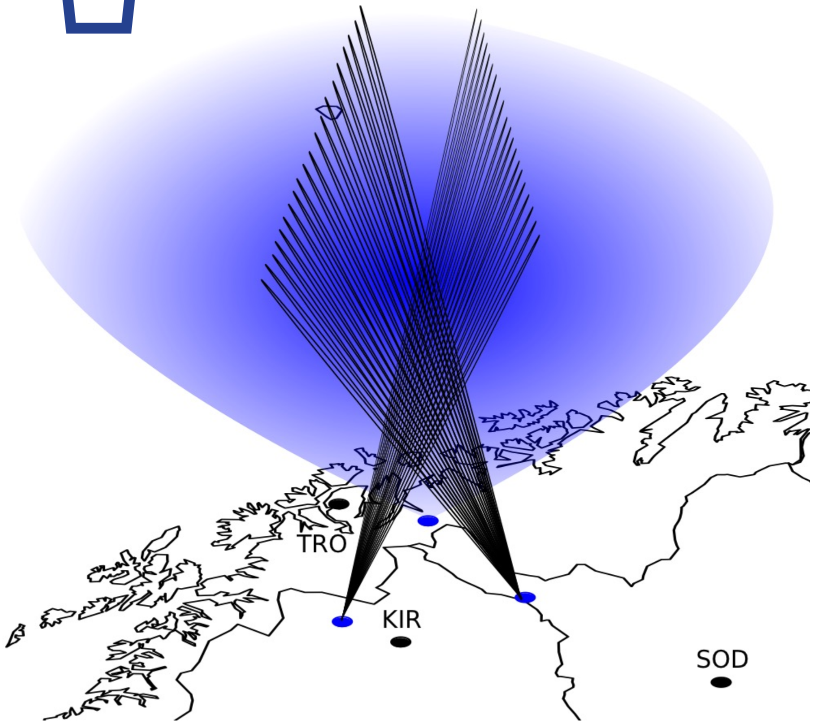
109 subarrays



91 antenna elements/subarray

- Transmitter site at Skibotn (Norway)
- Two additional receiver sites, one in Finland and one in Sweden => vector measurements of ion drifts are possible
- Ground work starting, tendering of transmitter units going on, first 3-static measurements expected in 2022.

EISCAT_3D radar measurements at high altitudes

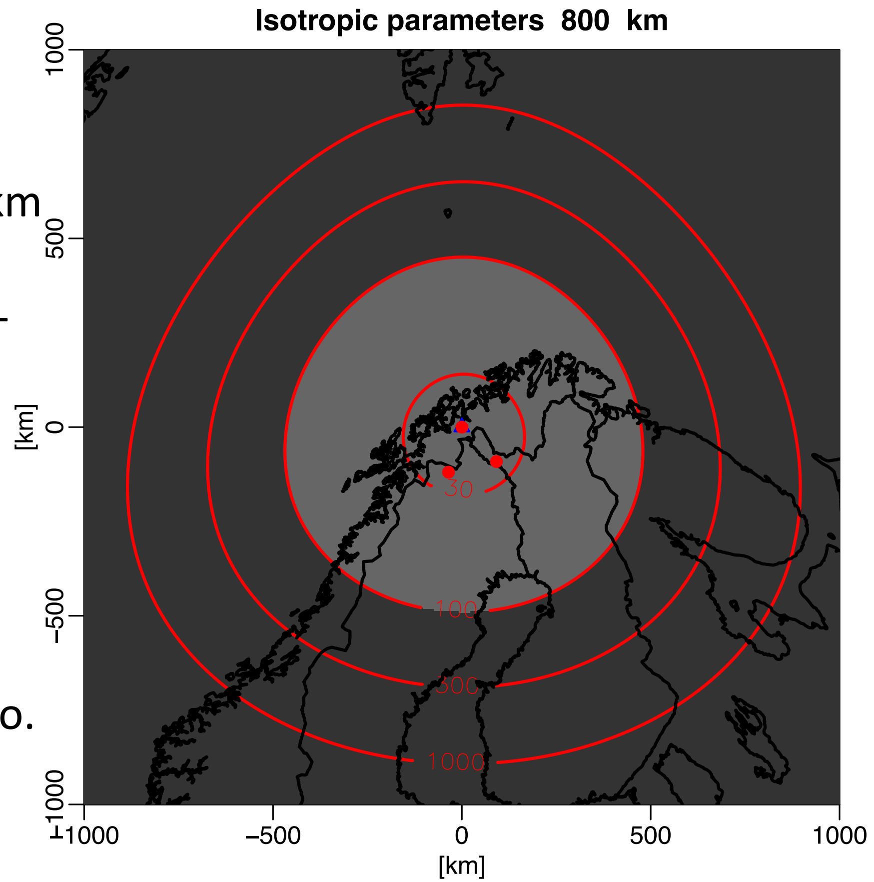


Advantages of EISCAT_3D compared to current EISCAT radars

- 5 MW power, large effective antenna area
- Debye length limitation less severe for VHF than present F-A UHF.
- Multiple beams at different elevation angles: an experiment can be planned that measures the F-A ion velocity at different altitudes, taking into account the curvature of magnetic field-lines.

Speedmap for EISCAT_3D

- Ne assumed as $2 \cdot 10^{10}$ m^{-3}
- 30 s integration time at 800 km is required to get measurements e.g. of line-of-sight ion velocity with 5% accuracy



Conclusion:

We expect to carry out good observations of ion upflows with EISCAT_3D, but additional measurements and modeling of the I-T system are needed, too.