Calculating Hemispheric Power and Joule Heating using Defense Meteorological Satellite Program (DMSP) F-13 data

Mina Khan (Mount Holyoke College), Barbara Emery (NCAR) and Astrid Maute (NCAR)

I. Motivation

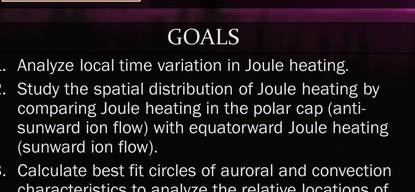
We aim to improve the parameterization of the aurora in the TIEGCM which uses the Weimer [2005, JGR] ion convection so that the total integrated hemispheric Joule heat (QJT in GW) is similar to the estimates from DMSP-F13 from this study.

II .Introduction

- *DMSP F13 satellite (1995)* was launched into a Sun synchronous, polar orbit in 6-18 local time frame.
- We use data from 2 DMSP instruments:
  (1) Special Sensor Precipitating Electron and Ion Spectrometer (SSJ/4)
  (2) Ion Drift Meter (IDM)

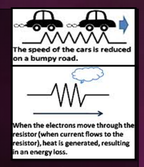
- *Interplanetary Magnetic Field (IMF)* is the Sun's magnetic field carried by solar wind.

- *Ion drift velocity* (Vi) = (ExB)/B^2 where E is Electric Field(*Emag*) and B is Earth's magnetic field.
- *Vy is the horizontal cross-track ion velocity, where we assume Emag∝Vy*Bz_Earth*
- *Convection Reversal Boundary (CRB)* is where Vy reverses direction.



- *Weimer 2005* is an empirical model of the high-latitude ion drift velocity .
- *TIEGCM* (Thermosphere-Ionosphere-Electrodynamics General Circulation Model) is a numeric model for Earth's upper atmosphere.
- *Hemispheric power* is the spatially integrated energy flux of precipitating electrons.

- *Joule heating (QJ)* is the heat loss due to passage of electric current through a conductor.
- In the ionosphere, it occurs due to the friction of ions moving through neutral atoms.

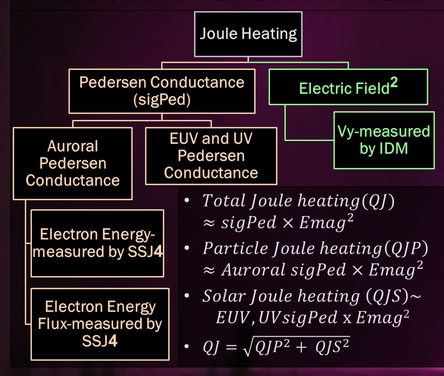


Importance

1. Joule heating is usually the largest heat source in high-latitude regions. During geomagnetic storms, Joule heating can exceed the global solar heating from UV/ EUV radiation [Knipp et al., Solar Physics, 2004].
2. Joule heating is the largest source of uncertainty in energetics of the thermosphere.

III .Research Strategy

Framework for Calculation & Analysis



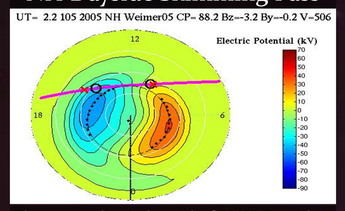
- $Total\ Joule\ heating(QJ) \approx sigPed \times Emag^2$
- $Particle\ Joule\ heating(QJP) \approx Auroral\ sigPed \times Emag^2$
- $Solar\ Joule\ heating\ (QJS) \sim EUV, UV sigPed\ x\ Emag^2$
- $QJ = \sqrt{QJP^2 + QJS^2}$

GOALS

1. Analyze local time variation in Joule heating.
2. Study the spatial distribution of Joule heating by comparing Joule heating in the polar cap (anti-sunward ion flow) with equatorward Joule heating (sunward ion flow).
3. Calculate best fit circles of auroral and convection characteristics to analyze the relative locations of the electron energy flux and Vy.
4. Quantitatively compare hemispheric power, particle Joule heating, and total Joule heating for different IMF values.

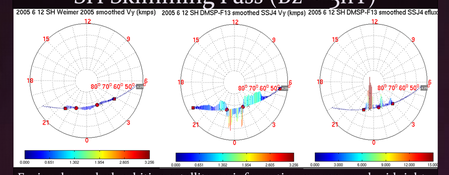
IV .Results

NH Dayside Skimming Pass



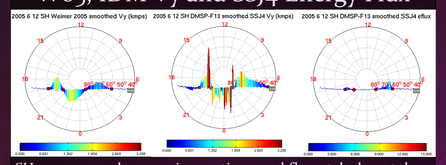
The magenta line is the track of DMSP-F13 with 'x's at the peak sunward ion drift Vy and circles at the Convection Reversal Boundary (CRB). Black dots are Weimer [2005] CRBs with fitted circle.

SH Skimming Pass (Bz ~–3nT)

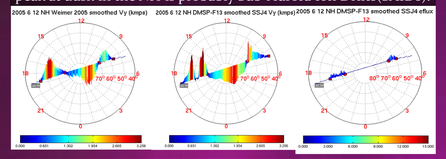


F13 is a dawn-dusk orbiting satellite, so information on noon and midnight regions is limited. SH passes go from dawn to dusk. Red circles mark the polar cap anti-sunward ion flow and the highest latitude of a skimming auroral pass with continuous electron energy flux. Red squares mark the equatorward ends of the sunward ion flow and energy fluxes, while X's mark the auroral and equatorward ion peaks. Weimer 2005 flows are slower.

W05, IDM Vy and SSJ4 Energy Flux

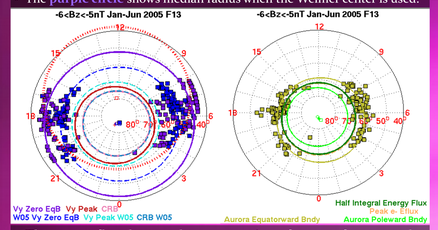


SH passes may show spurious antisunward flow at dusk past the red square. Energy flux is larger and wider on the dawn side. NH passes are on the dayside and go from dusk to dawn. Ion drifts are equatorwards and polewards of auroral precipitation giving rise to regions of Solar Joule heat. The second equatorward ion drift peak at dusk in the NH is probably Sub-Aurora Ion Drifts(SAIDs).



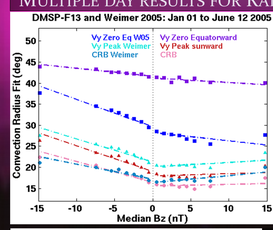
Radii Fits as a function of Bz (Single Day)

- Best fit circles were found for the poleward locations of the auroral and Convection Reversal Boundary (CRB), for equatorward locations of the auroral and sunward flow regions, and for the peaks in between as shown.
- The squares plot the locations found for the equatorward boundary of the sunward ion convection (blue=Weimer W05, purple=IDM) and of the aurora(green=SSJ4) for -5<Bz<-4nT. Because of nightside skimming passes, the original fit for Vy Zero equatorward is marked with a red square at the center of a red dotted circle.
- The purple circle shows median radius when the Weimer center is used.

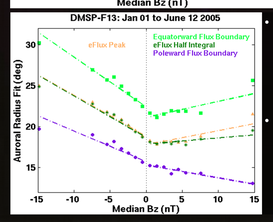


- The energy flux shows a clear progression of centers from near the pole towards 2 or 3MLT so that the aurora is wider at dawn than dusk. Convection centers are ~4 degrees towards midnight.

Multiple Day Results for Radii: Jan-June 2005



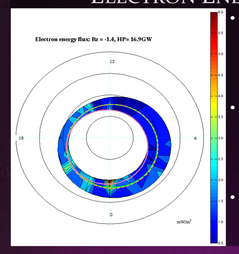
- All radii increase with decrease in Bz when Bz<0.
- The locations for DMSP-F13 and Weimer Convection Reversal Boundary (CRB) are similar.
- Weimer peak sunward drifts are equatorward of F13, and go to zero much faster.
- Large area of F13 sunward drifts leads to lots of Joule heat, especially in daylight.



- The difference between the radii of Equatorward and Poleward auroral boundaries increases with the absolute value of Bz.
- The peak energy flux position is similar to the position of half the integral energy flux and is in the approximate middle of the aurora.

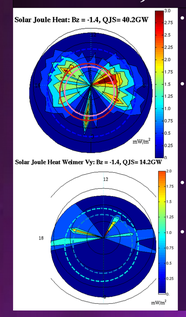
V .Key findings

Electron Energy Flux



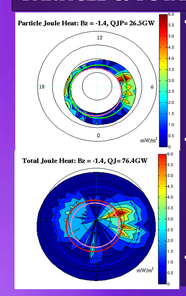
- The area for Hemispheric Power is mostly bigger on the dawn side compared to the dusk side.
- The pink circle is the CRB for -1<Bz<-2nT, and is very similar in location to the auroral poleward boundary.
- Most of the energy flux is in the sunward drift region

Solar Joule Heat (QJS) region



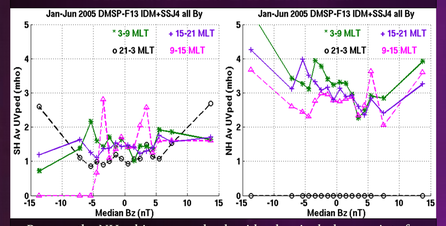
- QJS ~ solar conductance*$Emag^2$. QJS is calculated from the pole to the equatorward boundary of the sunward ion drifts (VyOEq).
- For IDM/DMSP QJS on top, the outer boundary of VyOEq is ~40°. The circles are pink for CRB, red-brown for peak sunward Vy, and dashed blue for the Weimer 2005 (W05) VyOEq (VyOEqW05~30°).
- W05 QJS is on a larger grid where the CRB is a dashed aqua circle and the peak sunward Vy is dashed turquoise.
- The area is about half as big for Weimer as for IDM, but the total QJS is 3 times smaller, where the additional decrease is the ~30% decrease in the Weimer Vy compared to IDM Vy or Emag values.

Particle & Total Joule heating regions



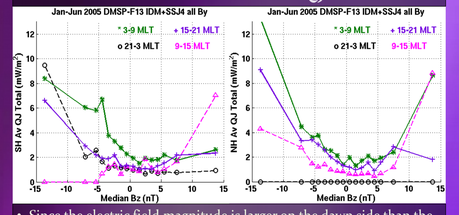
- Particle Joule heat (QJP) is found from the equatorward auroral boundary to the half-way point of the energy flux (green circle), to the CRB (pink circle) and then to the poleward auroral boundary. It only only uses auroral Pedersen conductance.
- Total Joule heat (QJT) includes UV conductance from equatorward boundary of the sunward ion drifts (VyOEq) to the dashed blue circle for VyOEqW05, to the red-brown circle for peak sunward Vy, to the pink CRB, to the pole.
- QJT is about 3 times larger than QJP because it includes QJS.

Hemispheric Differences



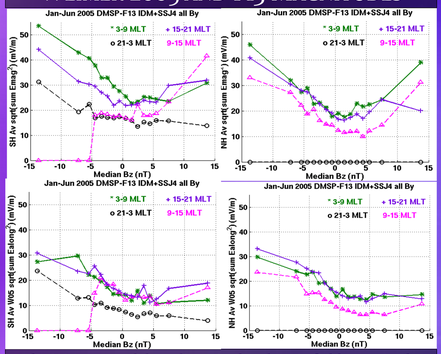
- Because the NH orbits are on the dayside, they include no points from 21-3MLT. The SH orbits include all the nightside orbits, but their coverage of the dayside is not as good as the NH. Naturally, the UV Pedersen conductance is largest for the NH, and approximately equal for dawn and dusk.

Dawn>Dusk for QJT



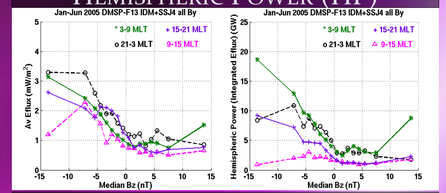
- Since the electric field magnitude is larger on the dawn side than the dusk side, squaring it enhances its effect on the particle or total Joule heating. In addition, the UV Pedersen conductance in the NH dawn is slightly larger than at dusk, further enhancing the dawn NH QJT.
- Thus, because of the excessive ion drift in the post-midnight, especially SH orbits, the total average Joule heat is largest on the dawn side compared to the dusk side. Since the areas are about equal with nearly colocated centers for the CRB and the equatorward sunward drift boundaries, we expect these average results to hold for the integrated total Joule heat also.

Weimer 2005 and F13 Magnitudes



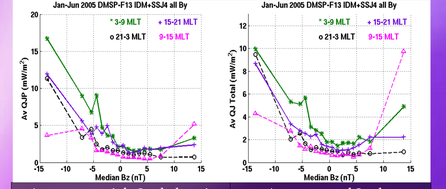
- The Weimer model predicts similar electric field magnitudes for dawn and dusk ~15mV/m. F13 magnitudes are ~20mV/m or 30% more. The F13 NH dawn is slightly larger for Bz positive, especially in the polar cap anti-sunward flow (not shown). For the SH, the dawn magnitudes are clearly larger for Bz negative in all regions (not shown).

Average Electron Flux and Hemispheric Power (HP)



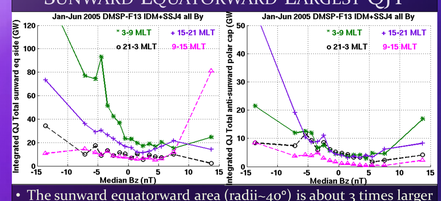
The average energy flux is about the same at dawn or dusk, but the integrated energy flux, or the hemispheric power (HP) is highest on the dawn side because of the larger area, and HP for the dusk side is relatively small.

Average Particle & Total Joule heating



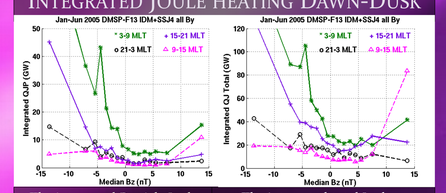
- Average particle Joule heating for dawn side is almost equal to average particle Joule heating on the dusk side except for larger Bz negative.
- Average total Joule heating for the dawn side usually exceeds that for the dusk side.

Sunward Equatorward Largest QJT



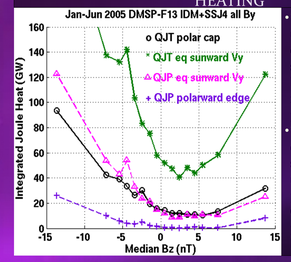
- The sunward equatorward area (radii~40°) is about 3 times larger than the poleward anti-sunward velocity region (CRB ~20°).
- The integrated total Joule heating is 2-3 times larger than in the polar cap.
- In the equatorward region, dawn>dusk but in the polar cap, the dawn and dusk values are approximately equal.

Integrated Joule heating Dawn-Dusk



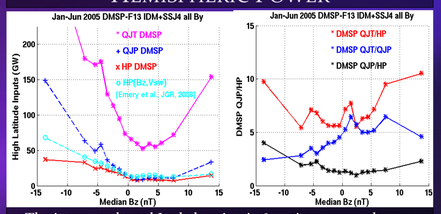
- The integrated Particle Joule heating is higher on the dawn side than on the dusk because of larger area.
- The integrated total Joule heating is higher on the dawn side than on the dusk because of larger electric fields.

Area Integrated Particle & Total Joule heating



- The integrated total QJ in the polar cap is about 30% of that in the equatorward sunward Vy region because the equatorward region is about 3 times the polar cap region.
- The integrated equatorward QJP for sunward Vy is more than the integrated QJP poleward of CRB since CRB is closer to the poleward auroral boundary.

Integrated Joule heating Vs. Hemispheric Power



- The integrated total Joule heating is 6-10 times more than Hemispheric Power, while the integrated Particle Joule heating is about the same as HP for Bz>-3nT.
- The hemispheric power from auroral electrons is similar to the HP from Emery et al. [2008, JGR] and similar to the Particle Joule heat except for large Bz negative

VI .Conclusions

- The Particle Joule heating is largest equatorwards of the CRB because most of the auroral area is there.
- The total Joule heating is largest equatorwards of the CRB because this area (πR^2) is 3 times larger than the polar cap area (since CRB~20° and VyZeroEQ~40° or 1600π-400π=1200π vs 400π).
- The total Joule heating is largest in the dawn compared to dusk because the F13 ion drifts are largest in the dawn, especially in the SH.
- The DMSP-F13 ion velocity results in an electric field drifts extending ~10 degrees equatorwards of those from W05 so the W05 QJ area is about half that for DMSP. The resultant QJS for W05 is 3-4 times smaller than for IDM. Thus, models which use Weimer [2005] should consider multiplying the electric potential pattern by ~1.3 to get ~30% increases in the ion drifts and electric fields, and possibly also consider stretching out the electric potential to lower latitudes.