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TAKING THE PULSE OF OUR PLANET FROM SPACE

The need for in-situ measurements at altitudes below 200 km to resolve ion-neutral interactions in the Lower Thermosphere - Ionosphere

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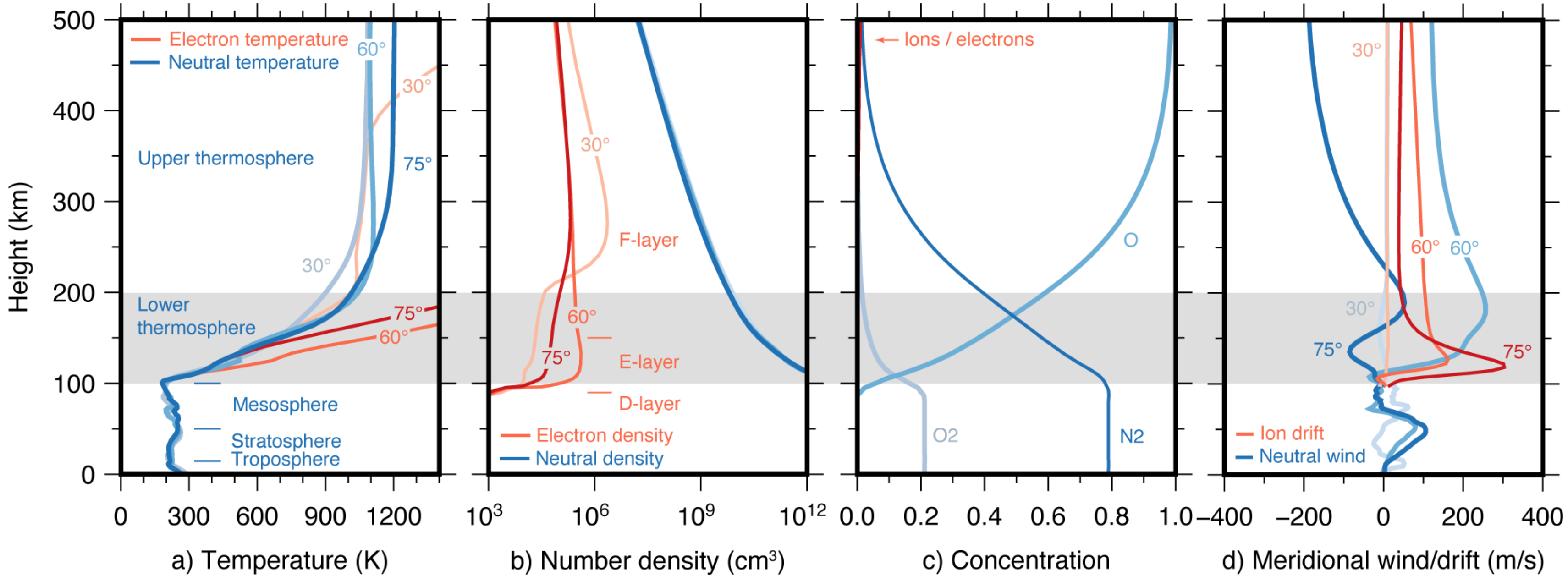
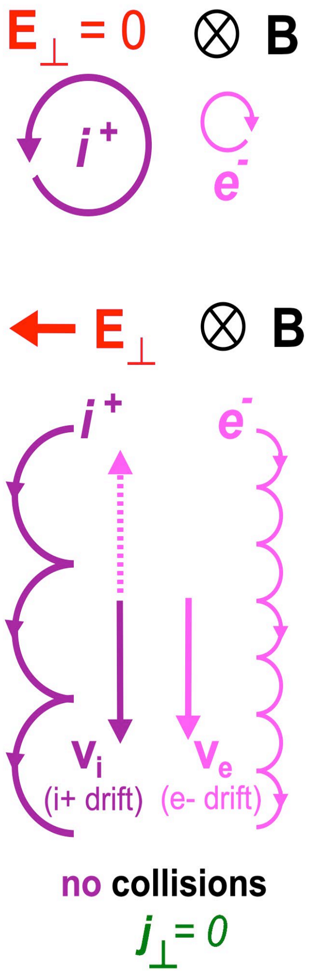
Overview

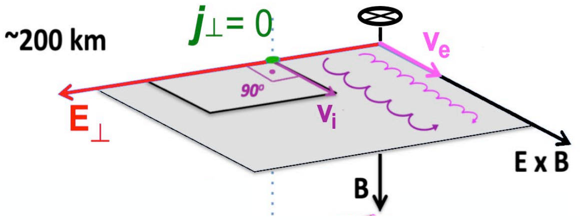
- In the altitudes between 100 and 200 km, the atmosphere transitions from being well-mixed and electrically neutral, to heterogeneous and partly ionized. Furthermore, in the altitudes between 100 and 200 km:
  - **a)** *neutral* and *electron temperatures* increase markedly;
  - **b)** *ion* and *electron density* increase, while *neutral density* decreases;
  - **c)** *ion* and *neutral composition* exhibits dramatic variation; and
  - **d)** *neutral wind* and *ion drift* patterns are governed by complex physical processes.



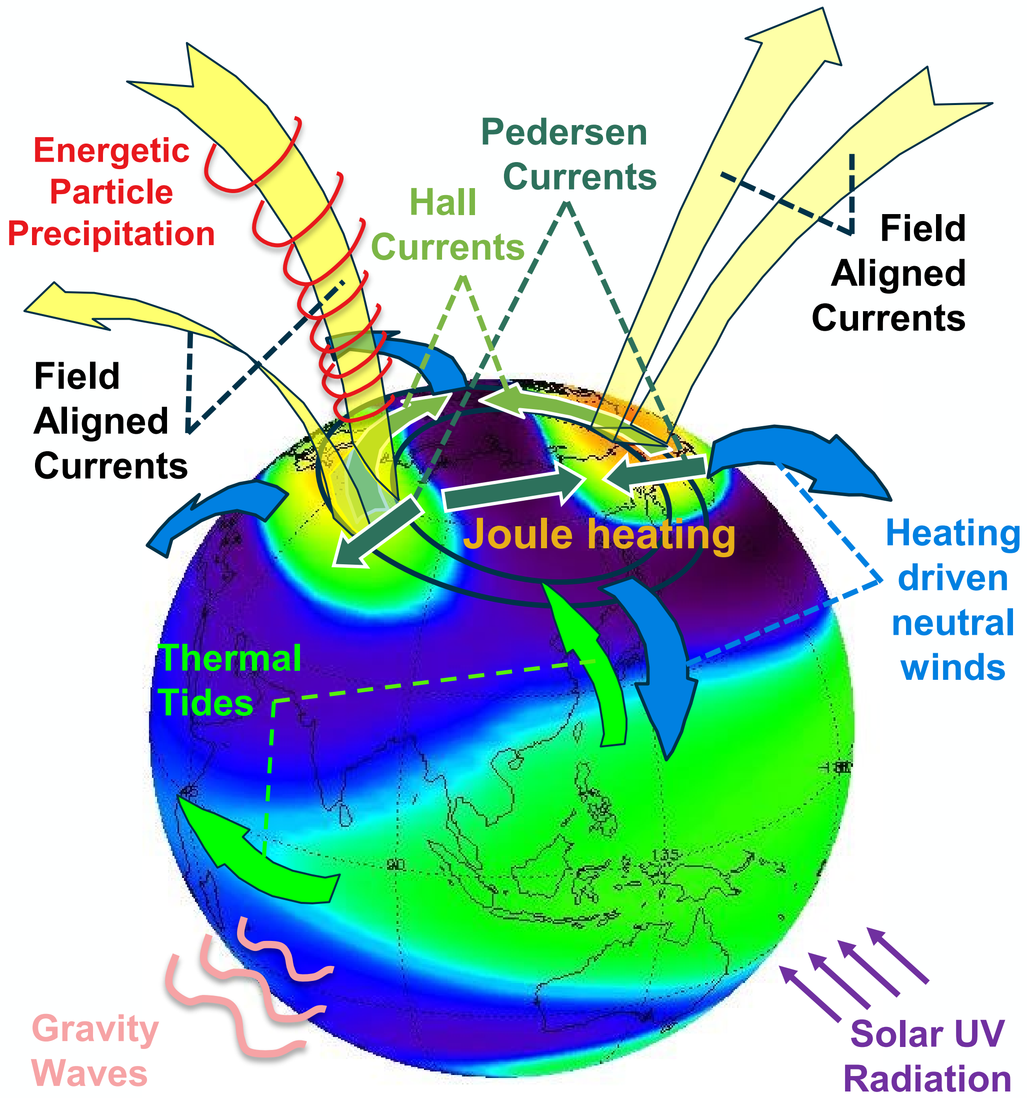
Ion - Neutral Interactions in the 100 to 200 km range



B : magnetic field
$E_\perp$: electric field perpendicular to **B**
$j_\perp$: perpendicular current
V_e: electron drift
V_i: ion drift



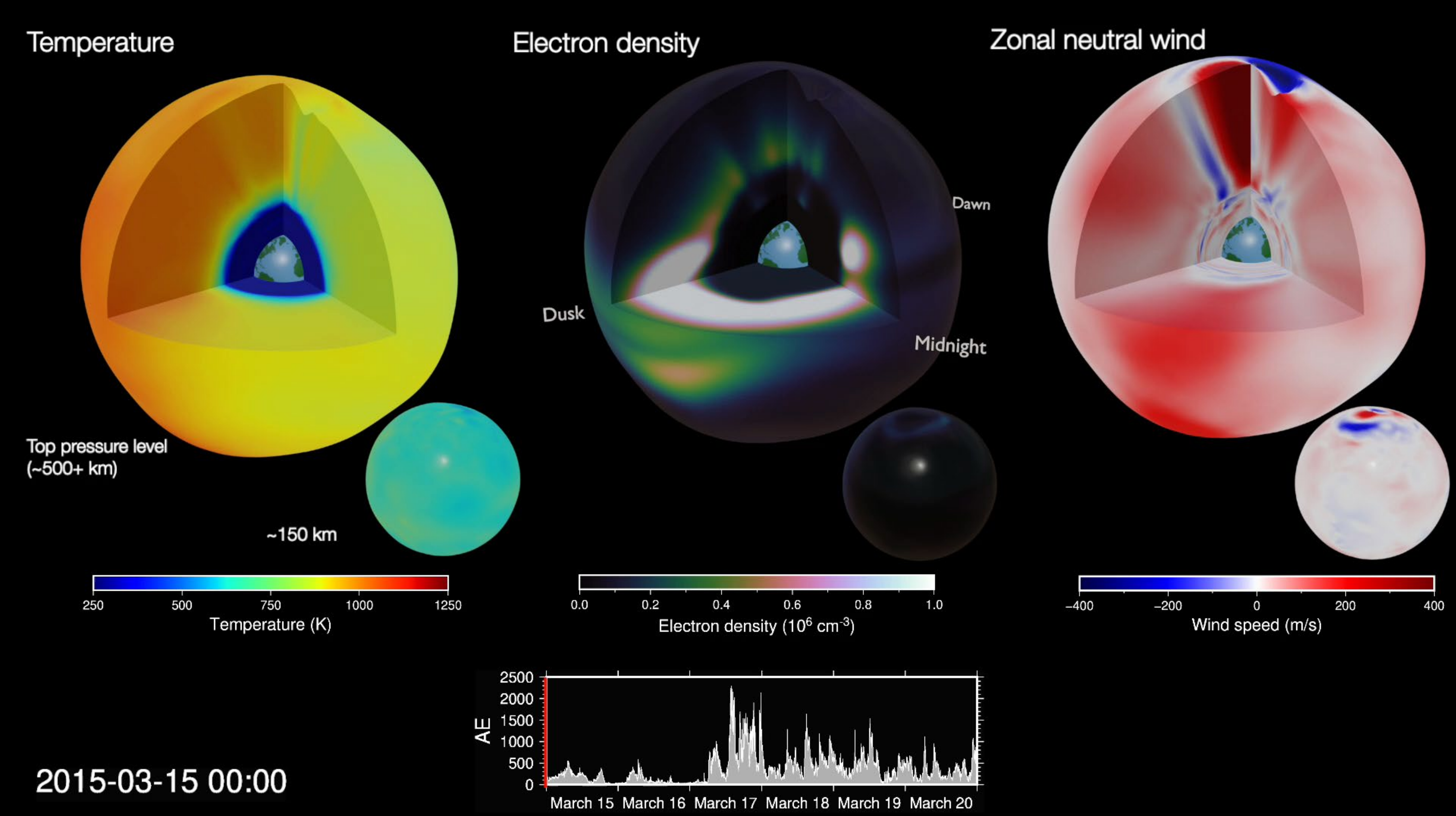
Processes in the 100 to 200 km altitude range



- **Solar UV Radiation** is an omni-present energy source, and the largest on long-term averages.

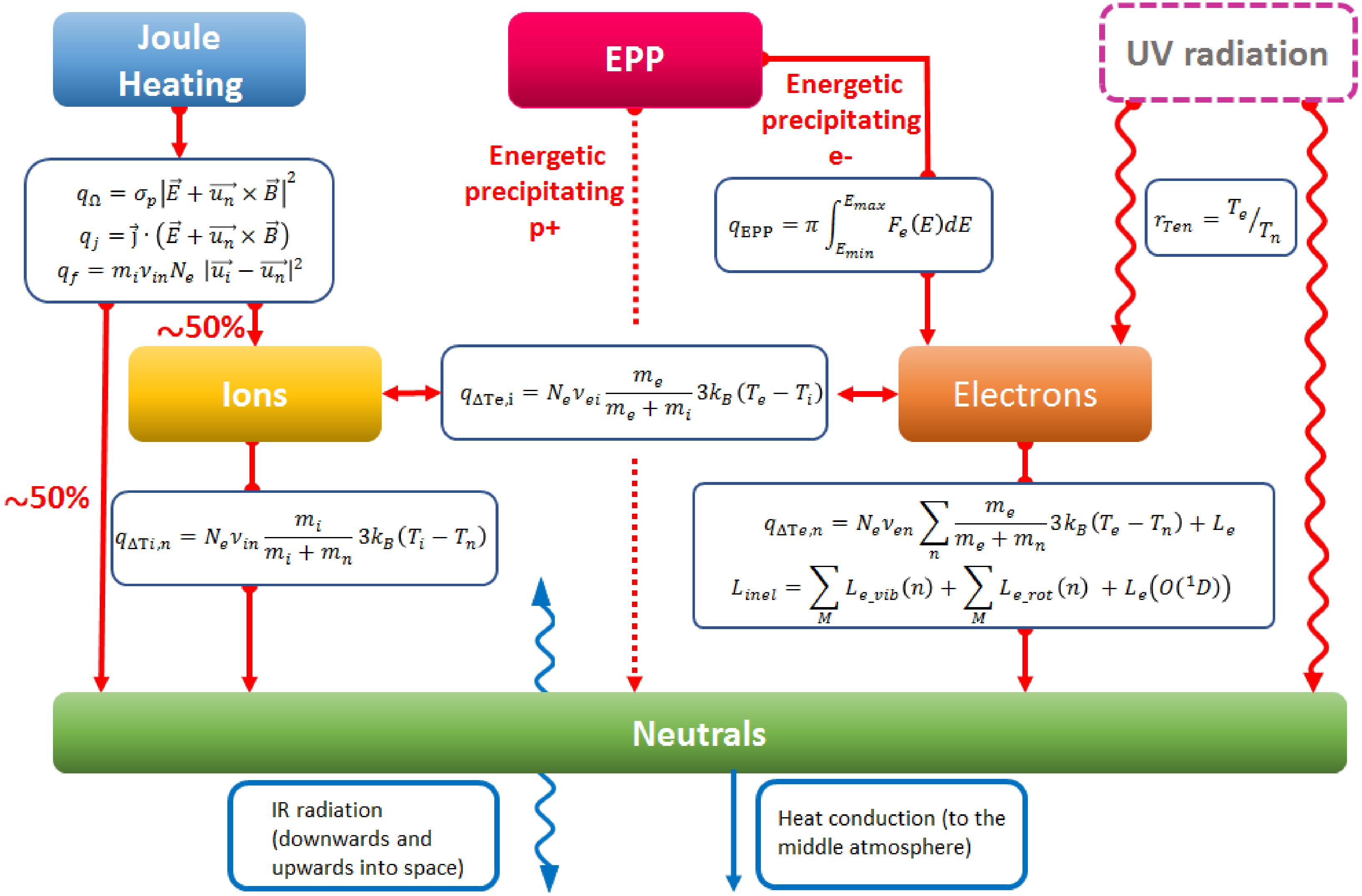
However, during active times:

- **Field Aligned Currents** close within the 100 to 200 km altitude range at high latitudes, within the altitudes where ion-neutral interactions maximize, leading to **Pedersen currents** and frictional or **Joule heating.**
- **Joule heating** subsequently modifies **neutral wind** and **neutral density paterns** as well as **thermal tides** at lower latitudes.
- **Energetic Particle Precipitation** alters conductivity and leads to heating and HOx – NOx production that destroys Ozone
- **Gravity Waves** deposit their momentum within these altitudes

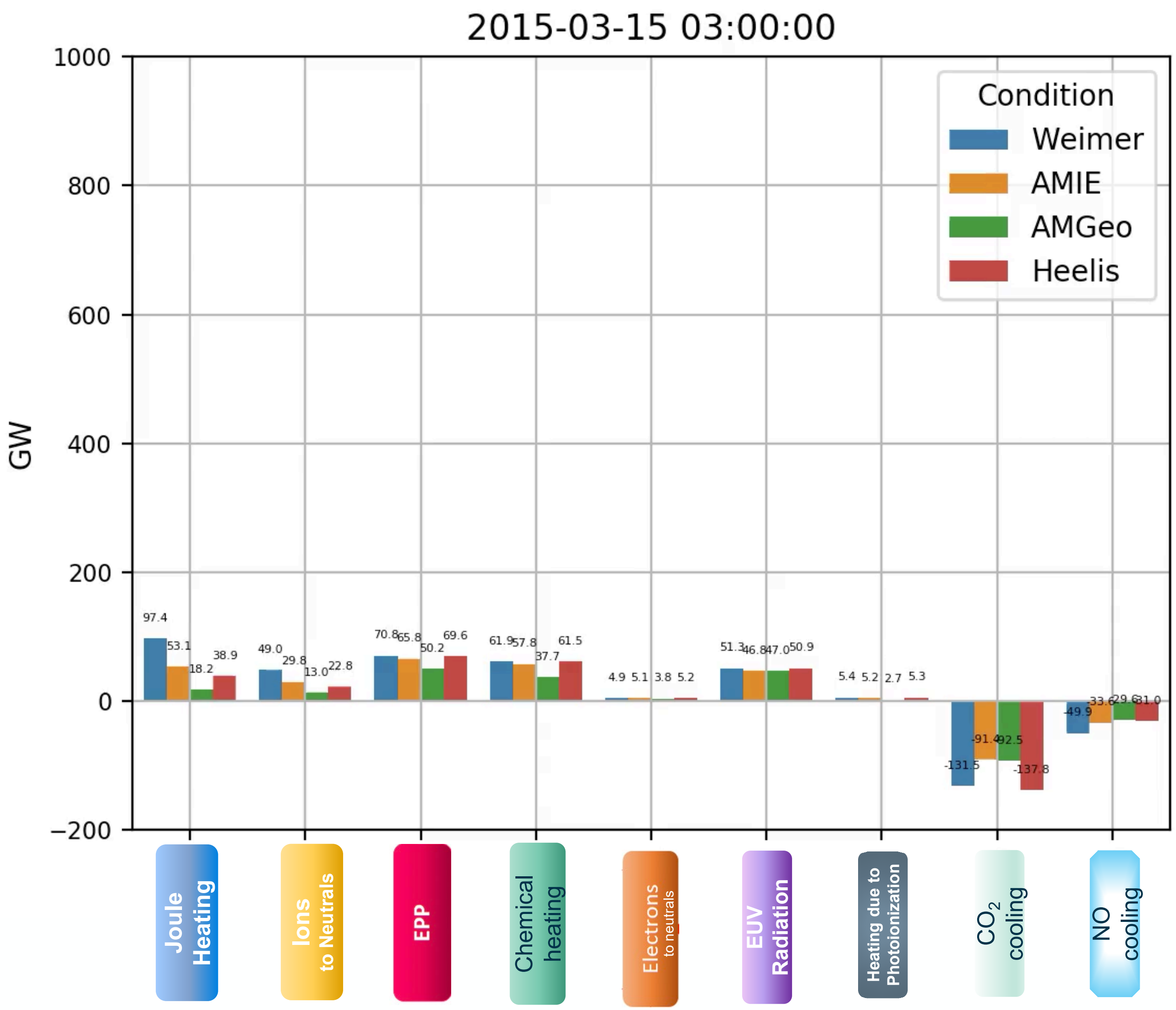


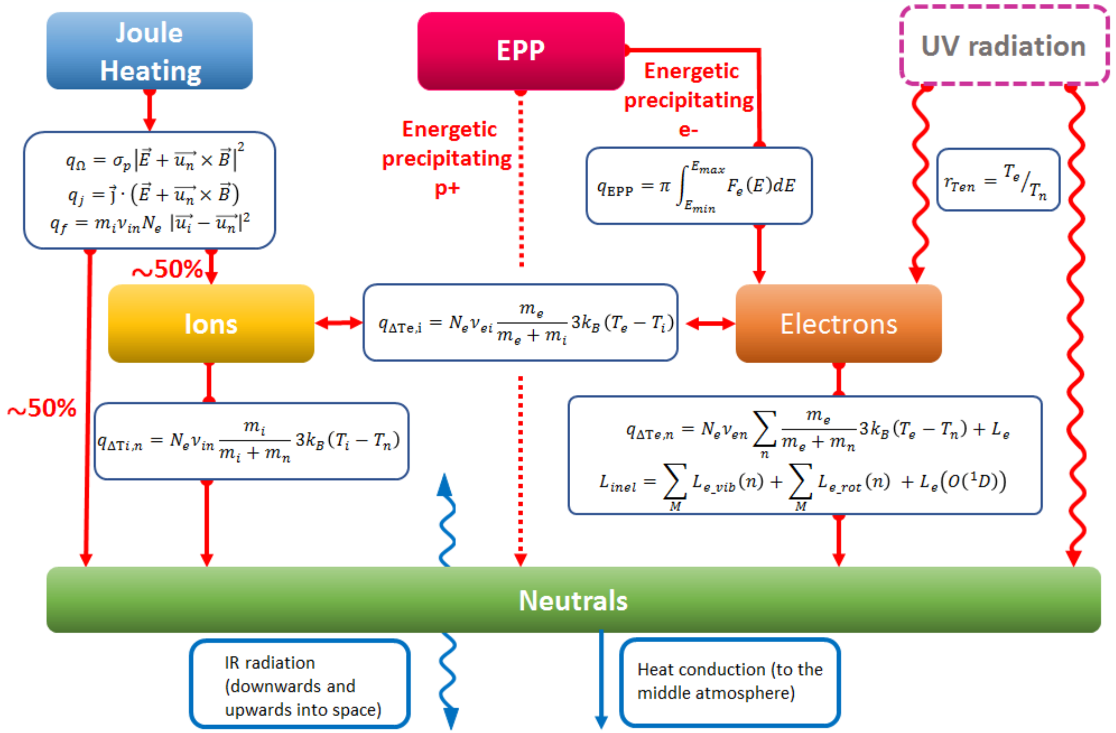
Temperature
Electron density
Zonal neutral wind
Dawn
Dusk
Midnight
Top pressure level
(~500+ km)
~150 km
250
500
750
1000
1250
Temperature (K)
0.0
0.2
0.4
0.6
0.8
1.0
Electron density (10^6 cm^-3)
−400
−200
0
200
400
Wind speed (m/s)
AE
2500
2000
1500
1000
500
0
March 15
March 16
March 17
March 18
March 19
March 20
2015-03-15 00:00

Energy input and flow in the 100 to 200 km altitude range



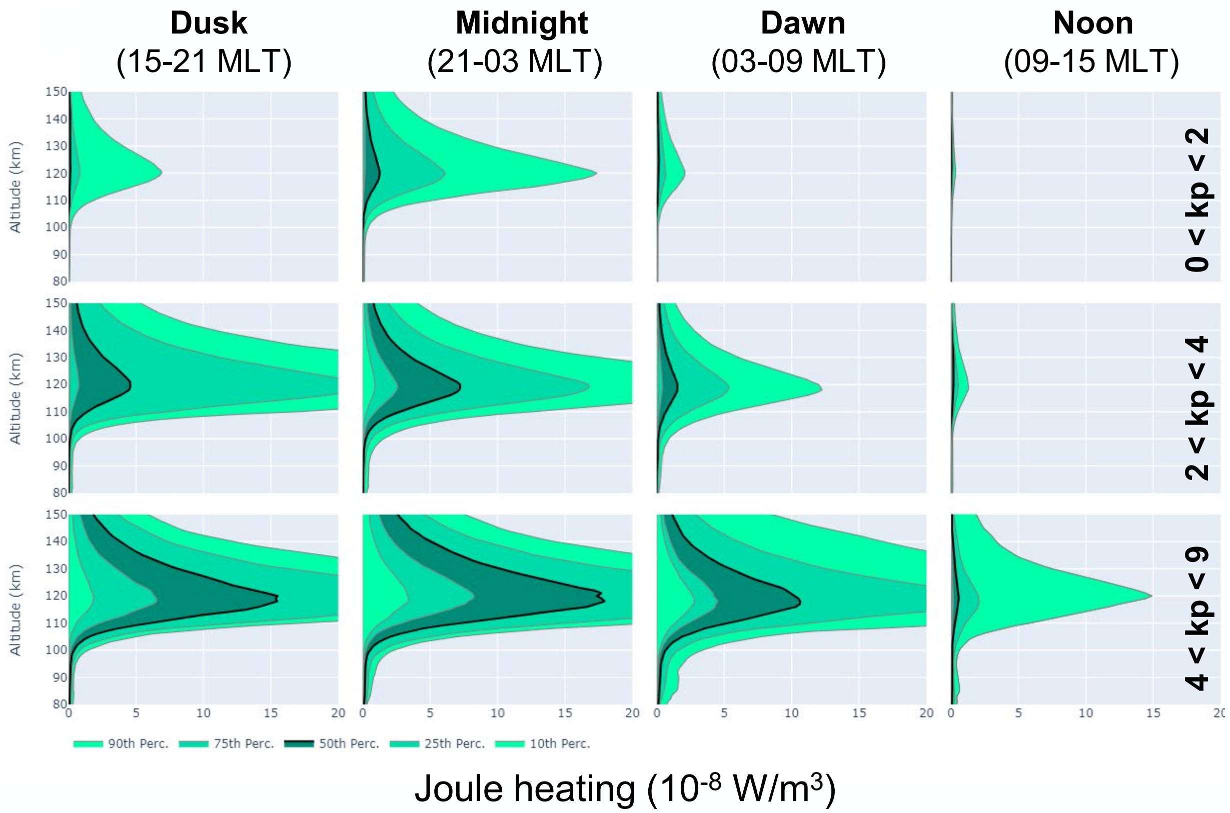
Energy input and flow in the 100 to 200 km altitude range



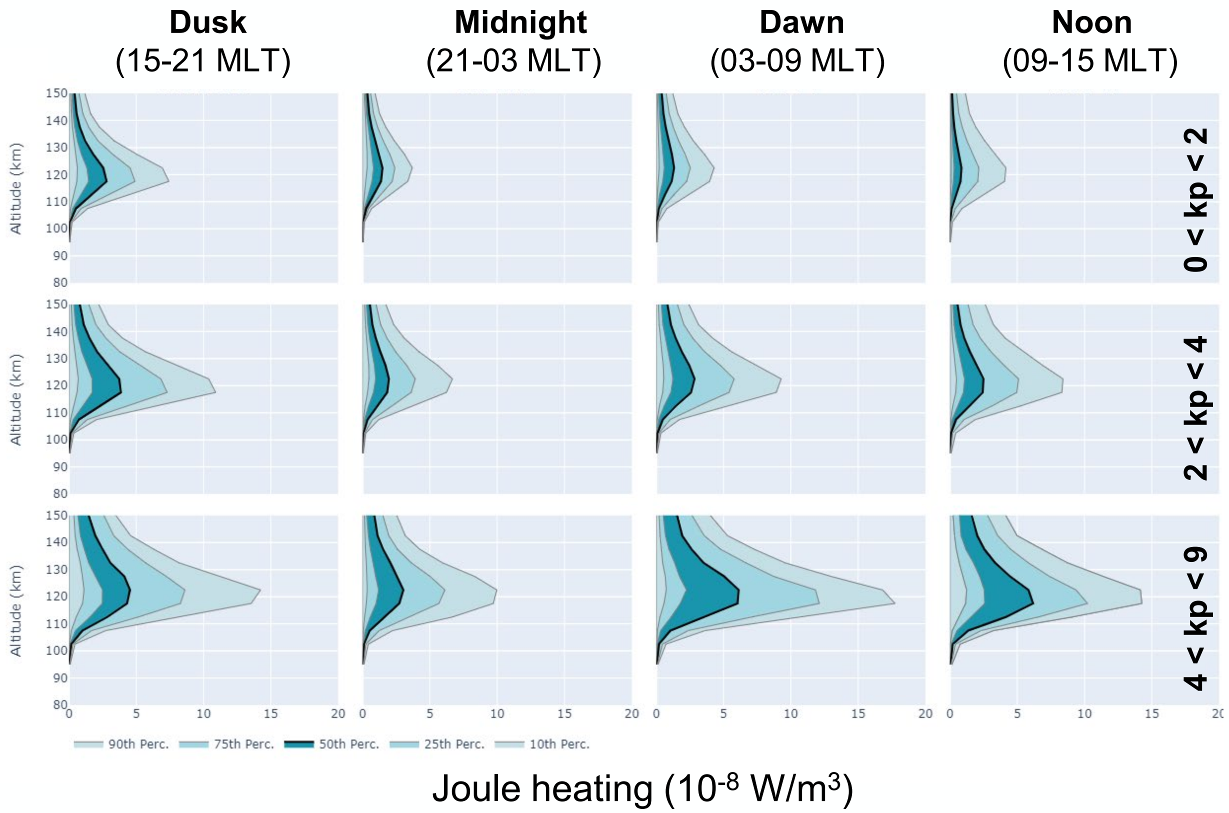


Joule heating distribution in altitude and MLT

EISCAT 11-year measurements



TIEGCM 11-year run

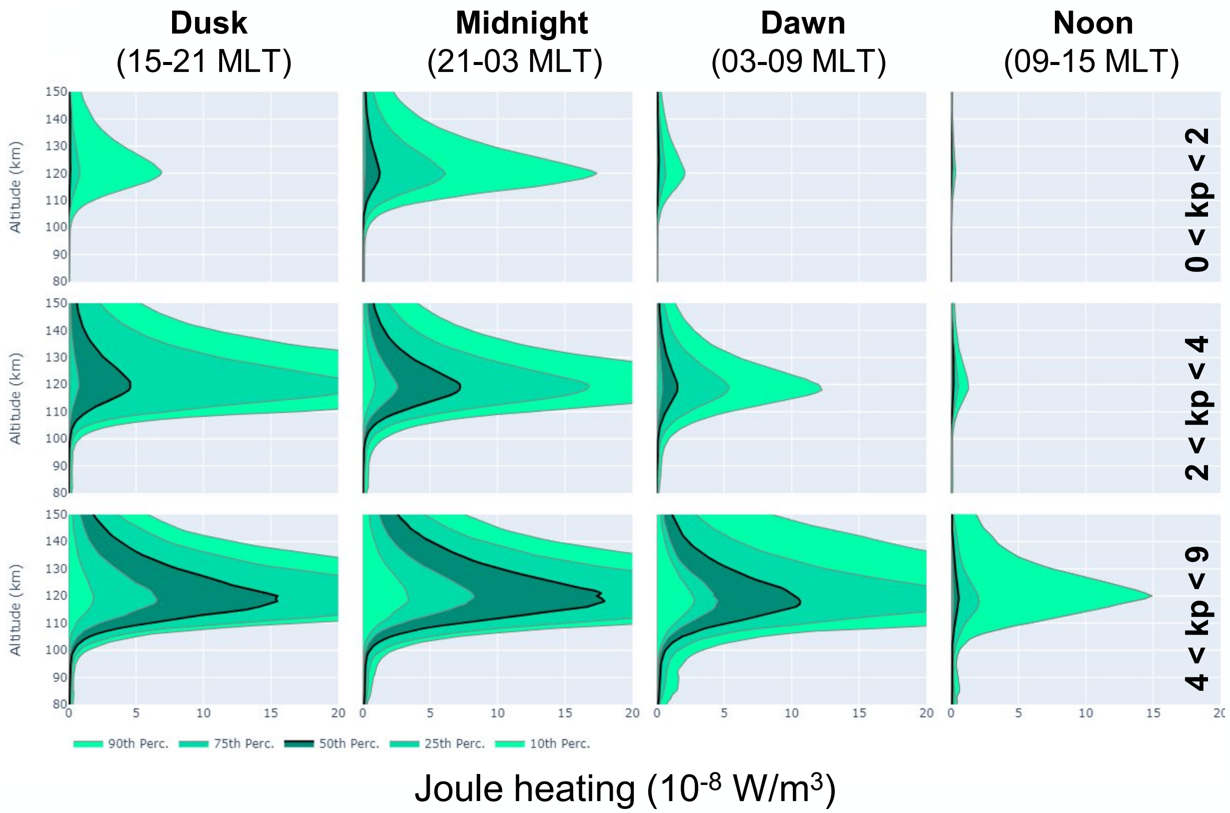


EISCAT data provided by Anita Aikio

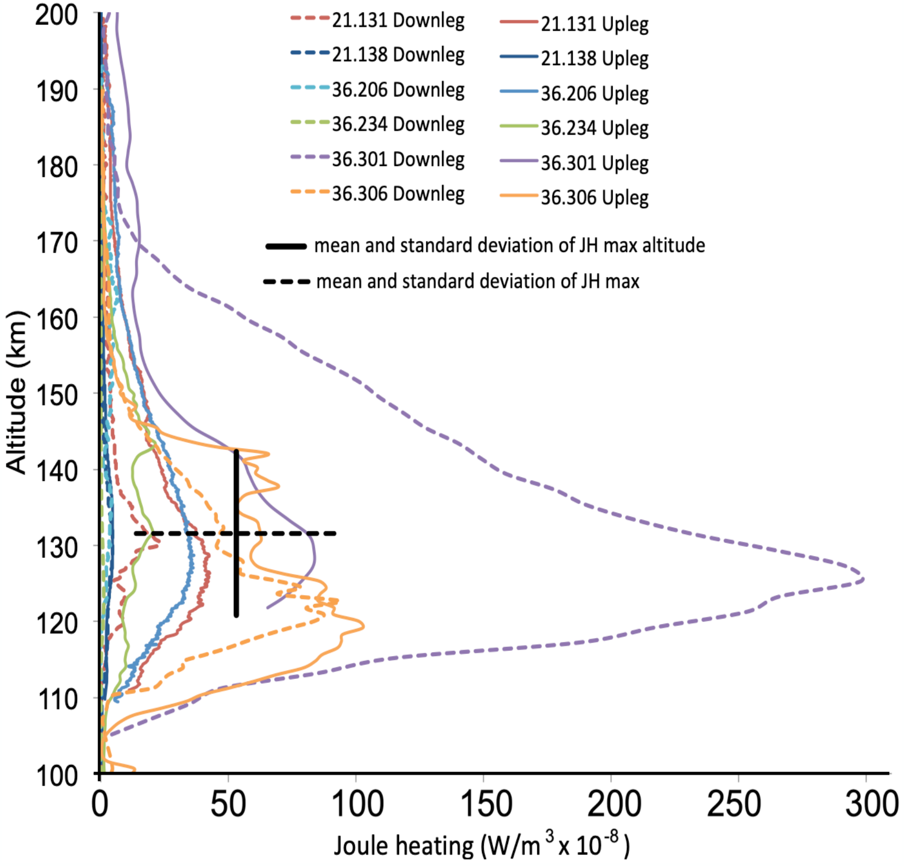
11-year TIEGCM data produced by DUTH

Joule heating distribution in altitude and MLT

EISCAT 11-year measurements



Joule heating profiles from Rocket launches



EISCAT data provided by Anita Aikio

Rocket data provided by Rob Pfaff

Key observables in the 100 to 200 km altitude range

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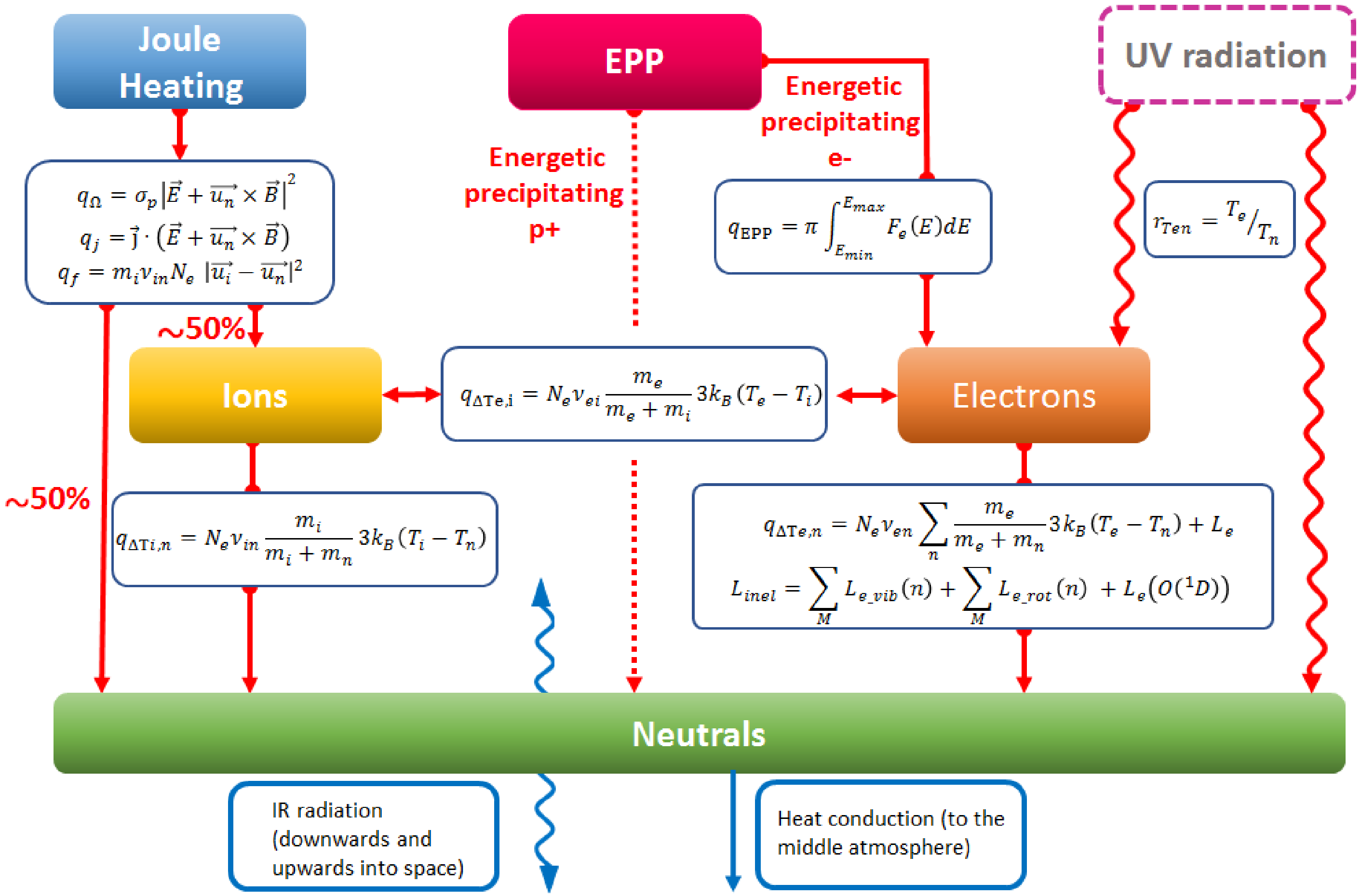
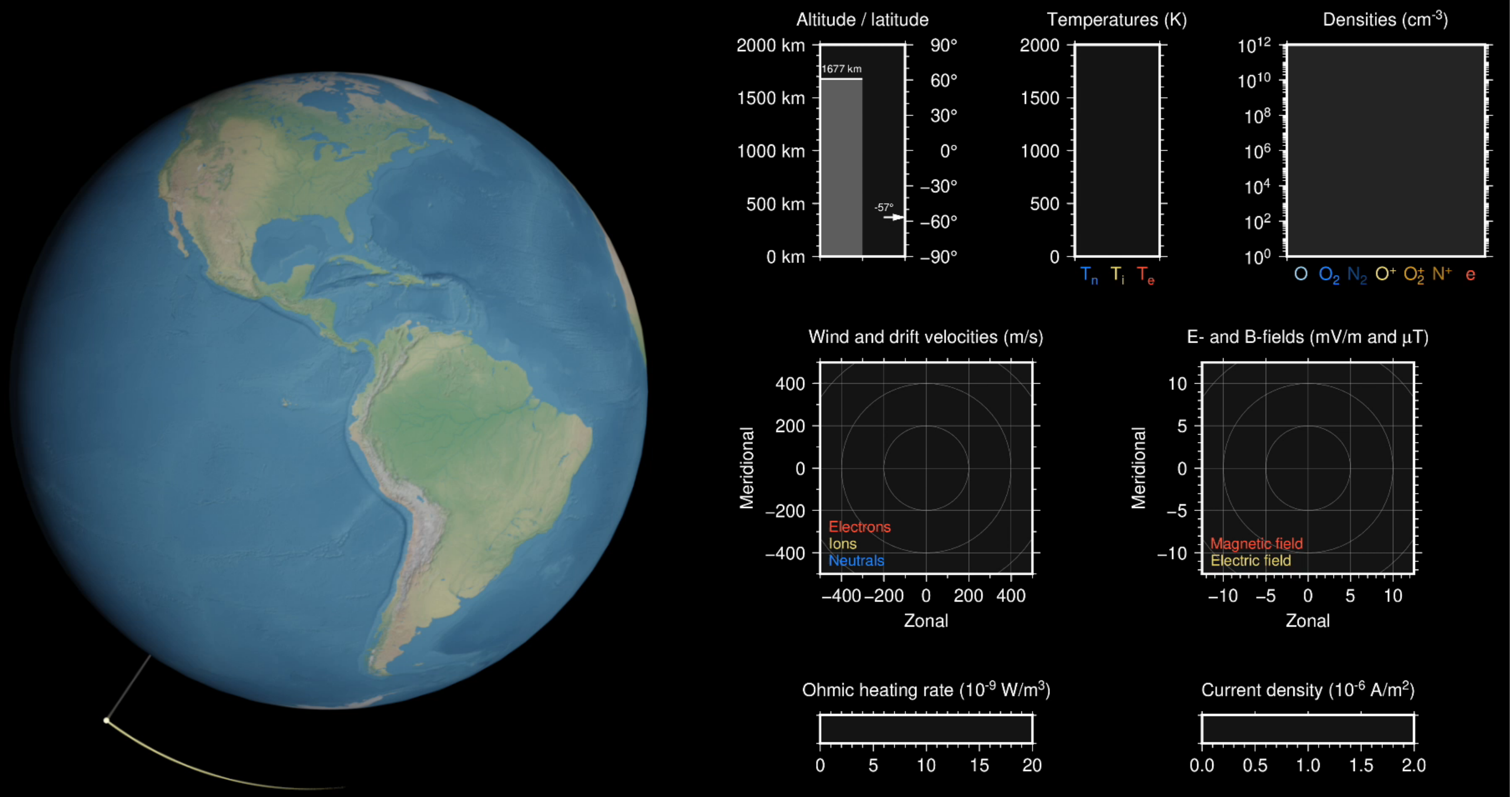
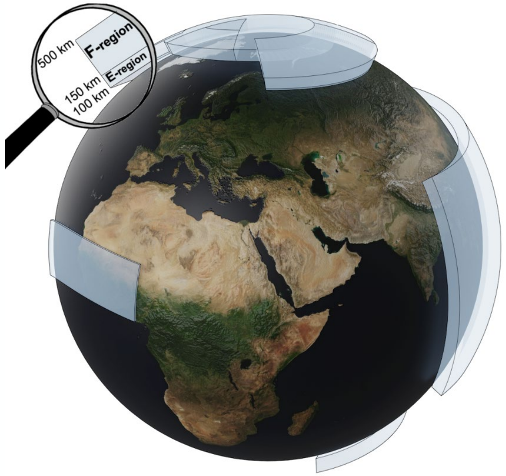


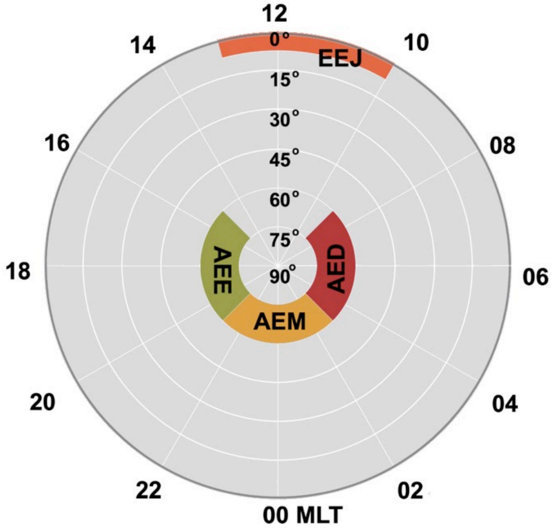
	Abbreviation	Geophysical Observable	Commonly used instruments
Ionosphere	$\vec{v}_i$	Ion Drift velocity	Thermal Ion Imager or Ion Drift Meter and Retarding Potential Analyzer
	T_i	Ion Temperature	
	T_e	Electron Temperature	Langmuir Probe and Mutual Impedance Probe
	N_i	Ion Number Density	
	N_e	Electron Number Density	
	TEC	Total Electron Content	GNSS Receiver
	n_{ix}	Ion Composition	Ion Mass Spectrometer
Thermosphere	$\vec{u}_n$	Neutral Wind Velocity	Ram Wind Sensor and Cross-Track Wind Sensor
	ρ	Neutral Mass Density	Accelerometer
	a_{ng}	Non-gravitational acceler.	
	T_n	Neutral Temperature	Neutral Mass Spectrometer
	n_{nx}	Neutral Composition	
fields	$\vec{B}$	Magnetic Field	Magnetic Field Instrument
	$\vec{E}$	Electric Field	Electric Field Instrument
EPP	Fl_e, Fh_e, Fl_i, Fl_e	Energetic Precipitating Particles (ions, electrons)	Energetic Particle Detector

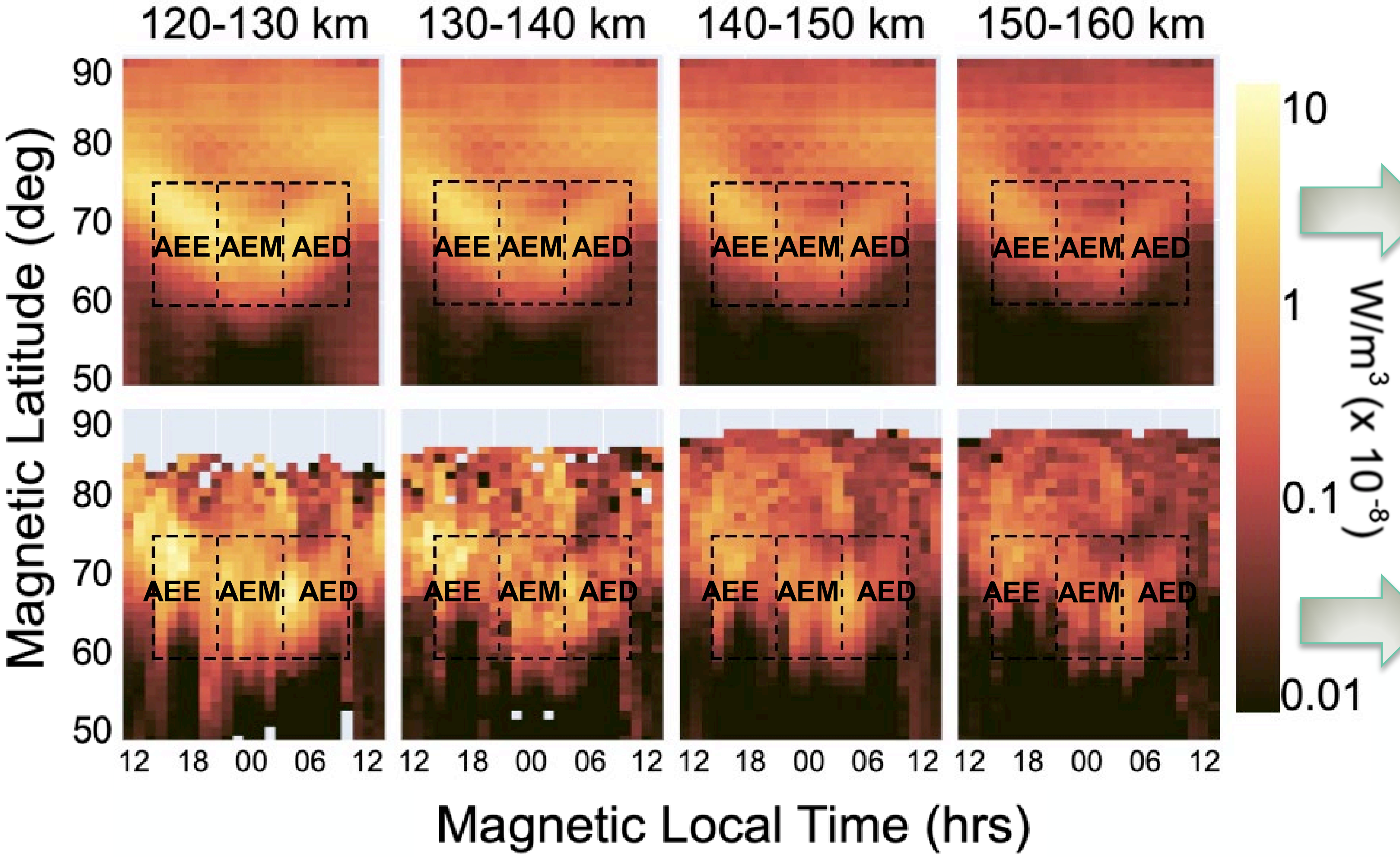


Altitude / latitude
2000 km
1500 km
1000 km
500 km
0 km
1677 km
-57°
90°
60°
30°
0°
−30°
−60°
−90°
Temperatures (K)
2000
1500
1000
500
0
T_n T_i T_e
Densities (cm^{-3})
10^{12}
10^{10}
10^8
10^6
10^4
10^2
10^0
O O_2 N_2 O^+ O_2^+ N^+ e
Wind and drift velocities (m/s)
Meridional
Zonal
400
200
0
−200
−400
Electrons
Ions
Neutrals
E- and B-fields (mV/m and μT)
10
5
0
−5
−10
Magnetic field
Electric field
Ohmic heating rate (10^{-9} W/m^3)
0 5 10 15 20
Current density (10^{-6} A/m^2)
0.0 0.5 1.0 1.5 2.0

Obtaining global statistics with an in-situ mission







Joule heating average in 3-year TIEGCM simulation

Joule heating as reconstructed from along-orbit sampling of TIEGCM over 3 years

Science Questions in the 100 to 200 km altitude range

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Goal: to fundamentally advance our understanding of the **energetics**, **dynamics**, and **chemistry** of the atmosphere-space transition region and of the neutral-plasma interactions that shape it

	Key question	Path to advancement
Energetics – Science Question 1	• **How and to what extent is energy deposited as Joule, or frictional, heating in the LTI?** • **How does this heating affect, and is affected by, the thermal structure, local transport, and composition within LTI altitudes?**	➢ Measure simultaneously all the parameters relevant to Joule, or frictional, heating within the 100 to 200 km altitude region; ➢ characterize its variability within the high-latitude regions and at altitudes where it maximizes; ➢ relate its evolution to co-located plasma and neutral dynamics.
EPP effects – Science Question 2	• **What are the effects of Energetic Particle Precipitation (EPP) on the ionization and composition of the LTI?** • **To what extent does EPP impact the mesosphere and stratosphere?**	➢ Measure the flux of energetic charged particles traveling through the 100 to 200 km region at high latitudes to precipitate into the middle atmosphere; ➢ characterize the ionization, energy deposition and effects of EPP on conductivity in the LTI.
Dynamics – Science Question 3	• **What are the relative contributions of magnetospheric, solar and atmospheric forcing in influencing LTI fluid dynamics and electrodynamics at high, middle and low latitudes?**	➢ Measure all relevant parameters across a range of latitudes and altitudes between 100 and 200 km, to discover how atmospheric and magnetospheric forcing and collisions between charged and neutral gases in the LTI affect the density, composition, winds and drifts in the region.

Conclusions

- Co-spatial, co-temporal measurements of all relevant geophysical observables are needed for the unambiguous quantification of key processes in the LTI
- These geophysical observables need to be quantified by an in-situ mission sampling the LTI below 200 km, with statistically representative sampling over the mission lifetime.
- Extensive synergies with various ground-based measurement techniques and space missions will enable to place in situ measurements in a global context as well as providing cross-comparison possibilities.
- Such an in-situ mission will fill a major gap and are in great need for LTI process understanding and quantification.
- A joint ESA-NASA Lower Thermosphere-Ionosphere (ENLoTIS) Working Group has recently been formed to explore agency cooperation on a future LTI mission concept targeting in situ sampling of geophysical parameters that enable advancements in understanding neutral-ion interactions in the 100 - 200 km altitude range, and the ionospheric E-region in particular.