Daytime Ion and Electron Temperatures in the Topside Ionosphere at Middle Latitudes

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Introduction

At middle latitudes, quiet time high latitude energy inputs can be neglected and the influences of plasma transport producing advection and adiabatic heating are minimized. Under these conditions plasma temperatures in the topside ionosphere are determined by photoelectron heating, conduction and collisional energy exchange between the ions and electrons.

- During the daytime the thermal electrons are heated by photoelectrons that are created by photoionization of the neutral gas in the thermosphere and stream along the flux tube.
- Electrons are cooled primarily by conduction and collisions with ions that are principally O^+ and H^+.
- Ions are heated by collisions with electrons and cooled by collisions with other ions and by conduction to lower altitudes where heat is lost to the neutral gas.
- Observations of the electron and O^+ temperatures at middle latitudes in the topside ionosphere suggest the ion temperature dependent on the plasma composition.

A full description of the balance between heating and cooling processes is important to understanding the evolution of ionospheric properties in the topside ionosphere.

- The electron temperature equation:

$$\frac{\partial T_e}{\partial t} + \frac{2}{3}\frac{1}{n_e k}\nabla\cdot\vec{\vartheta}_e = Q_{en} + Q_{ei} + Q_{phe}$$

Collision,cooling — Conduction — Photoelectron heating

- The ion temperature equation:

$$\frac{\partial T_i}{\partial t} + V_i\cdot\nabla T_i + \frac{2}{3}T_i\nabla\cdot V_i + \frac{2}{3}\frac{1}{n_i k}\nabla\cdot\vec{\vartheta}_i = Q_{in} + Q_{ii} + Q_{ie}$$

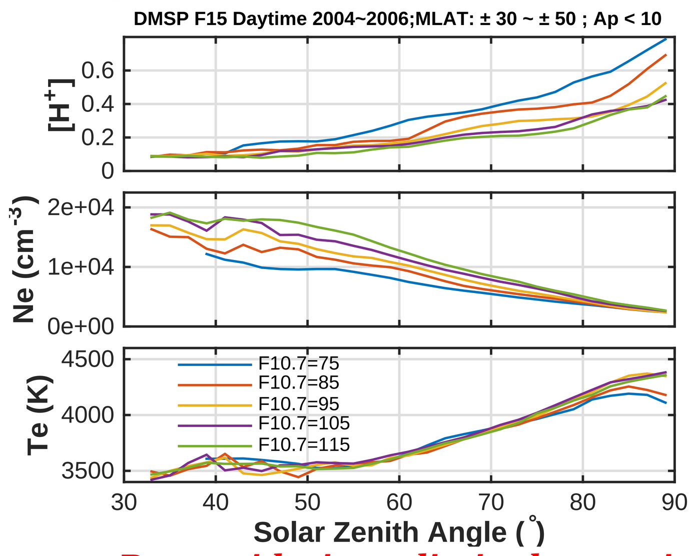
Advection — Conduction — Collision heating/cooling

Our objective is to use model to aid in further interpretation of observations of the electron temperature and constituent ion temperatures to investigate the energy balance in the topside ionosphere .

Observation vs. SAMI2

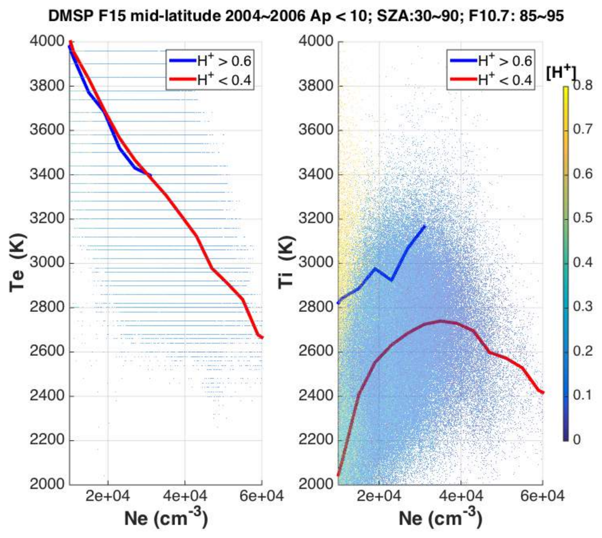
Observation

Observations of the electron and ion temperatures are taken in the 0600–1100 LT sector from 30° to 50° magnetic latitude by the DMSP satellite F15 from 2004 to 2006.



- Higher levels of the solar ionizing flux ($F_{10.7}$) give higher values of the plasma number density with smaller fractions of H^+.
- The lowest plasma number density with highest H^+ fraction occurs at the largest solar zenith angles.
- The electron temperature for different $F_{10.7}$ levels has essentially the same variation with solar zenith angle.
- Changes in N_e are produced principally by changes in the solar zenith angle and are thus also associated with changes in the electron heating rate.

By considering a limited range in the solar ionizing flux we are able to investigate those changes in the electron and O^+ temperature that are produced by changes in plasma density and composition.



The observations show that T_i is strongly dependent on the H^+ fraction such that the O^+ temperature is generally higher when the H^+ concentration is significant (>50%).

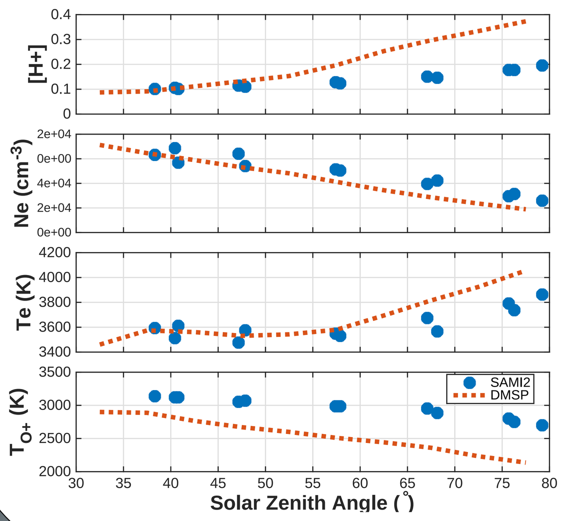
The variations of electron and ion temperature with plasma density and composition indicate how heat is exchanged between different constituent ions.

- Electron temperature decreases as plasma number density increases.
- O^+ temperature increases as plasma number density increases until $T_i \approx T_e$ then T_i and T_e decrease with increasing plasma number density.
- At low plasma density, the O^+ temperature is generally higher and T_e is slightly lower when the H^+ concentration is significant (>50%).

Modeling

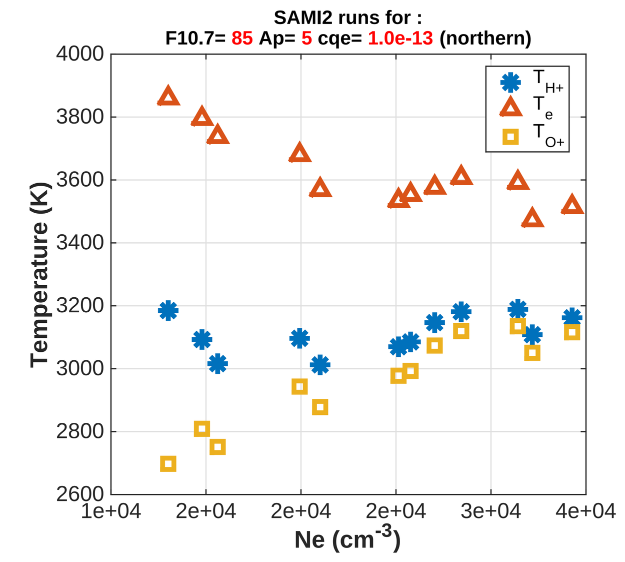
The observations suffer from limited ranges over which H^+ temperature is the dominant ion and the lack of independent H^+ temperature measurement.

The model solves one meridian plane with its 800 km apex heights located at 130° in GLON. and 9.5° in GLAT., where the magnetic longitude is almost parallel to geographic longitude and the whole flux tube is approximately at the same local time. We examine results for day 21 in every month of model year 2005 to simulate the observations of DMSP from 2004 to 2006. Only the results at 40° magnetic latitude in northern hemisphere are examined.



- The evolution of these ionospheric properties are driven by changes in solar zenith angle corresponding to changes in day of the year.
- Number density increases and electron temperature decreases with decreasing solar zenith angle.
- The fractional H^+ density is smaller and the O^+ temperature remains higher than is observed.

At the largest solar zenith angles, the model produces higher total density, lower T_e and higher T_{O+} than is observed indicative of a flux tube content that is higher than exists during the observations.



Both the electron temperature and the O^+ temperature in the SAMI2 model behave as observed.

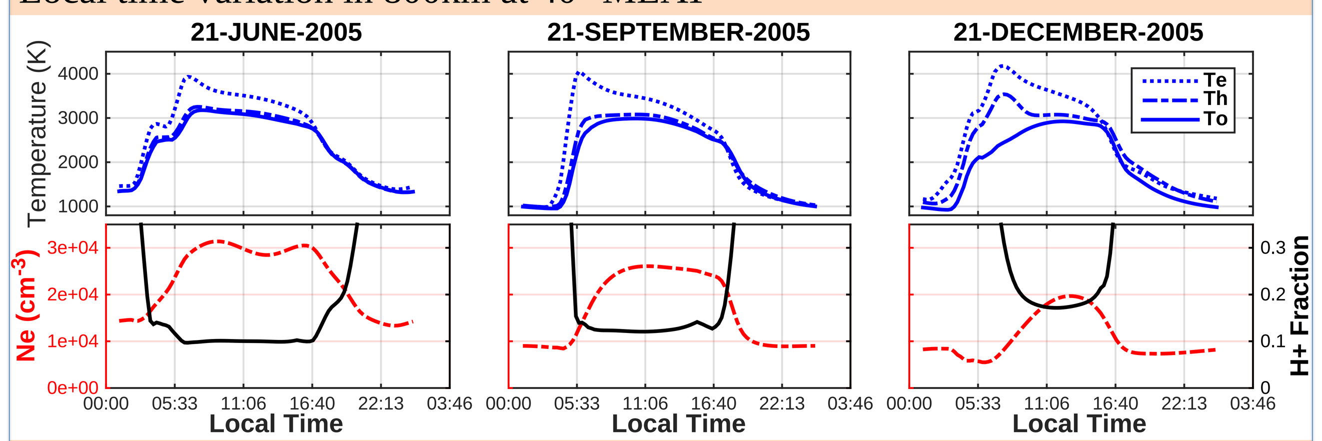
Difference in T_{H+} and T_{O+} is quantified.

- Electron temperature decreases as the plasma density increases due to the balance between the attenuated electron heating rate from the peak to the observation point and the plasma number density dependence of electron cooling rate.
- Electron temperature decreases less rapidly in higher plasma number density region.
- The ion temperatures are determined primarily by the flow of heat from electrons to ions and conduction such that both H^+ temperature and O^+ temperature increase as plasma number density increases. [3]
- The H^+ temperature is always higher than the O^+ temperature.

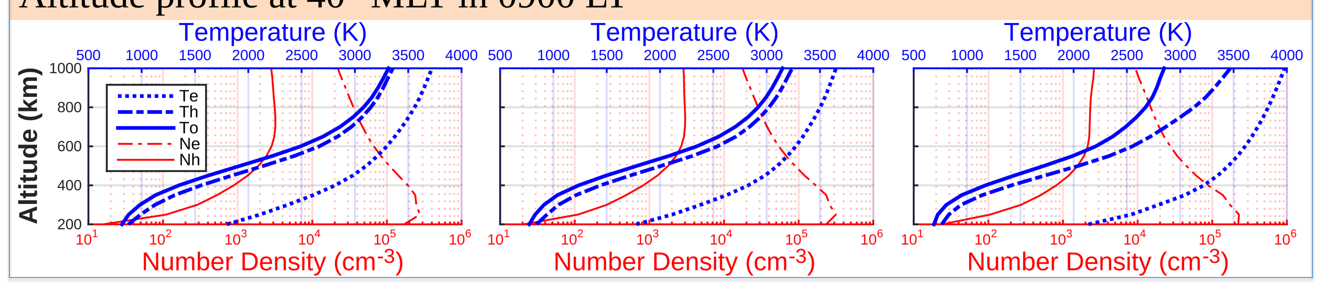
Details of Energy Balance

Further insights into the processes determining the ion and electron temperatures at mid-latitudes in the topside may be obtained by examining the heating and cooling terms as a function of local time and altitude.

Local time variation in 800km at 40° MLAT



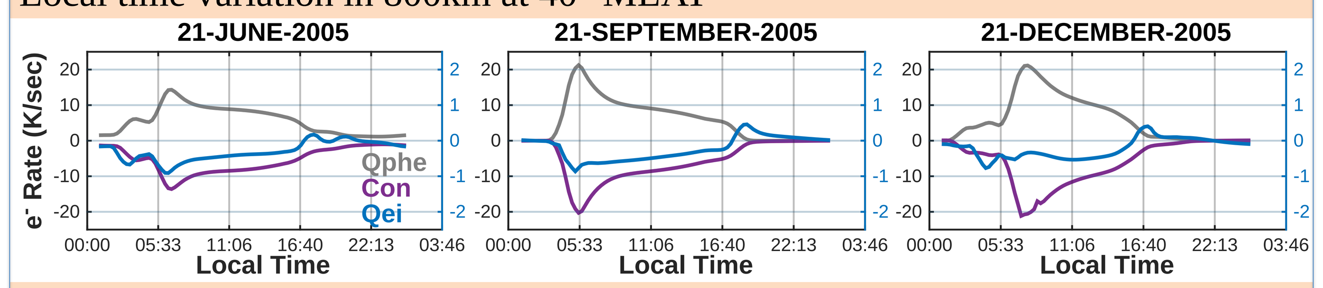
Altitude profile at 40° MLT in 0900 LT



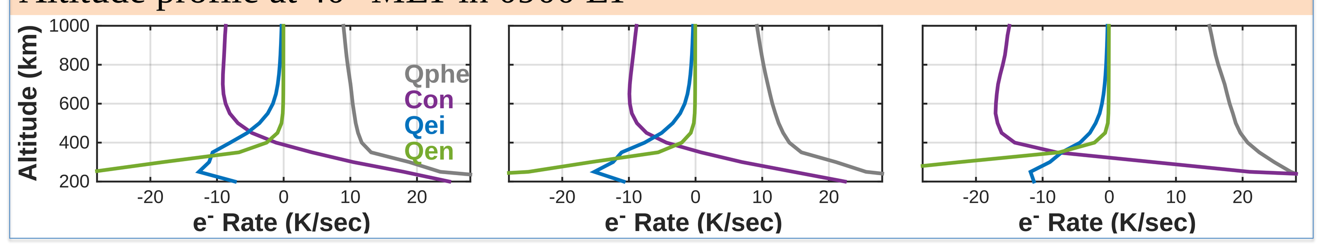
- After sunrise the electron temperature rises rapidly then it decreases as the local time increases.
- Ions start to warm in response to the increased electron temperature but a large temperature difference between the O^+ and electron temperature is present.
- When the ionosphere is fully sunlit, the plasma more nearly approaches a diffusive equilibrium state and the ion-electron temperature difference becomes small.
- In the topside, T_{H+} is generally higher than T_{O+} during the daytime. Particularly, T_{H+} approaches the electron temperature in winter.

Electron Balance

Local time variation in 800km at 40° MLAT



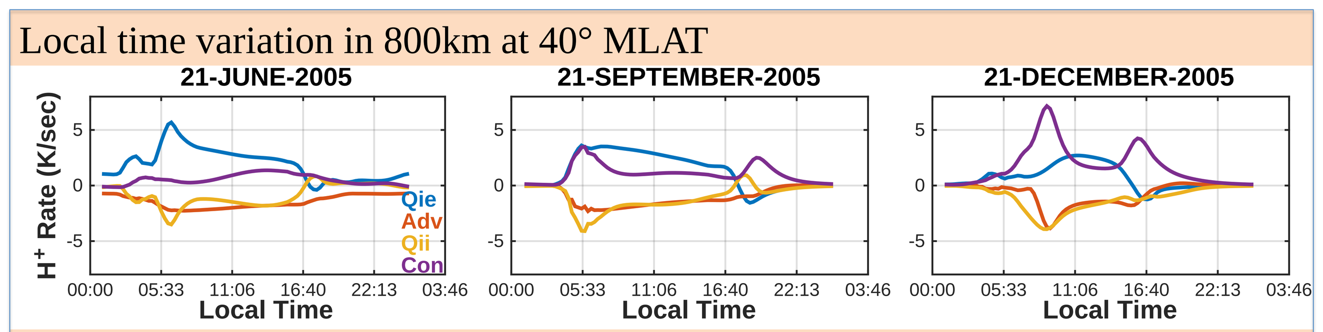
Altitude profile at 40° MLT in 0900 LT



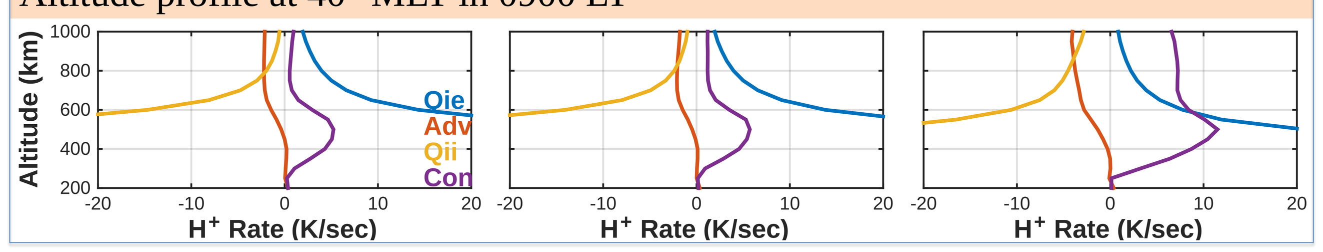
- Electron heating rate is dominated by attenuated photoelectron heating from the peak to the topside.
- Electron cooling rate is dominated by conduction, which reflects the integrated effect of collisional cooling to the ions in the region below.
- After sunrise the photoelectron heating rate rises rapidly as does the electron temperature. Subsequently T_e decreases as does the photoelectron heating rate due to attenuation by the increasing flux tube content.

H^+ Balance

Local time variation in 800km at 40° MLAT



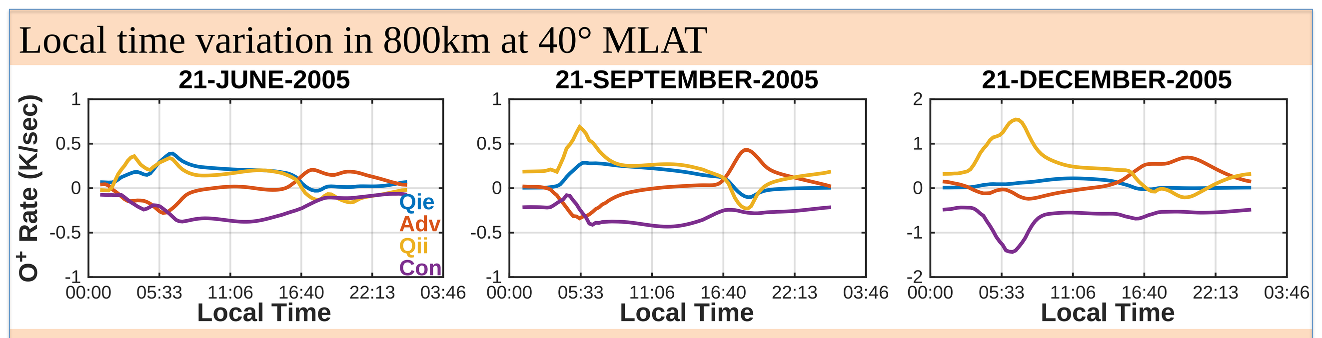
Altitude profile at 40° MLT in 0900 LT



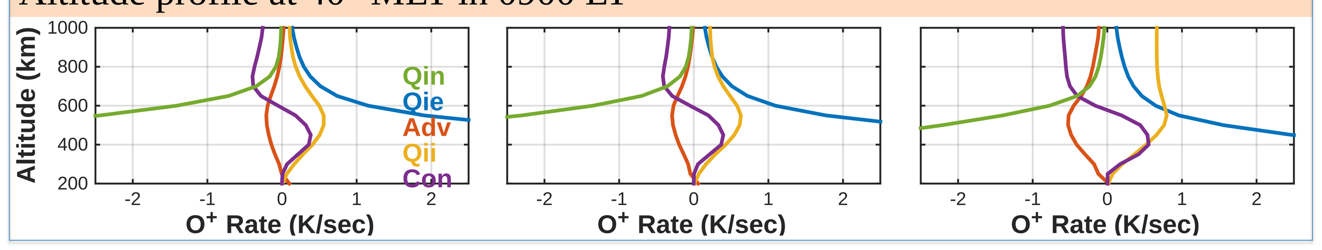
- In summer daytime, H^+ is heated by collisions with electrons.
- In winter daytime, H^+ has strong conduction heating from ion-electron exchange above.
- In all cases, H^+ is cooled principally by local collisions with heavy ions and advection.

O^+ Balance

Local time variation in 800km at 40° MLAT



Altitude profile at 40° MLT in 0900 LT



- In lower altitude, O^+ is heated by ion-electron collisions and conduction and cooled by ion-neutral collisions.
- In the topside, the O^+ warms by colliding with both electrons and light ions and cools by conduction to lower altitude.
- In winter, the rate of O^+ heated through light ions is larger than the rate of O^+ heated through electrons because of high H^+ concentration.

Summary

- The SAMI2 has successfully modeled the behavior of plasma temperature in the topside ionosphere and provided a detailed description of the complex heat balance with additional T_{H+} information.
- In the topside ionosphere, the electron temperature is principally dependent on the balance between the electron heating and the integrated effect of collisional cooling.
- Collisional heating between O^+ and light ions contributes can become the major heat source for O^+ in the topside. The O^+ is cooled through remote conduction to lower altitude and collisional cooling to the neutrals.
- H^+ serves as an intermediary for thermal balance between electrons and O^+ ions. Electrons cooled through collisions with H^+ and the heat further transferred through collisions between H^+ and O^+.
- Model T_{O+} is high and H^+ fraction is low probably due to inadequate description of neutral atmosphere.

References

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