Plasma Temperatures in the Topside Ionosphere

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Introduction

At middle latitudes 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 the solar zenith angle (SZA) and the solar ionizing flux (F10.7) at the top of the atmosphere. These two parameters in turn determine the total plasma density and the ion composition.

During the daytime the thermal electrons are heated by collisions with other ions and by conduction to lower altitudes where heat is lost to the neutral gas.

Our objective is to discover how the relationships between ion and electron temperature are influenced by changes in solar ionizing flux and plasma composition in the topside ionosphere.

Data

We utilize data from the polar orbiting DMSP satellite F15 which measures the ion and electron temperature, the plasma number density and the plasma composition near 860 km altitude in the local time meridian traversing 0900 to 2100 local time.

We restrict our observations to the daytime region from 30° to 50° magnetic latitude in each hemisphere for quiet times when Ap<10. This data selection is made to minimize the effects of plasma transport and high latitude energy inputs.

We collect data for the period 2004-2006 during which the F10.7 radio flux varies from 69 to 180. In the space and time volume in which the data are gathered the solar zenith angle varies from 30° to 90°.

The data analysis technique utilized to retrieve the ion temperature provides a measure of the O⁺ temperature except when the H⁺ fraction exceeds 0.95.

Results

- Higher levels of the solar ionizing flux (F10.7) 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 F10.7 levels has essentially the same variation with solar zenith angle.
- Lower levels of ionizing flux provide the largest range in plasma density and composition.

Satellite observations are taken in a confined location and a confined solar activity level.

Changes in plasma number density are produced principally by a change in the solar zenith angle from 90° to 35° and are thus also associated with a change in the electron heating rate.

- Electron temperature decreases as plasma number density increases.
- Electron temperature increases as solar ionizing flux increases.
- Electron temperature decreases less rapidly with plasma number density as solar ionizing flux increases.
- O⁺ temperature increases as plasma number density increases until T_e=T_i, then T_e and T_i decrease with increasing plasma number density.
- O⁺ temperature increases as solar ionizing flux increases in higher plasma number density region.

- The electron-ion temperature difference is a key parameter in the balance between electron heating, electron cooling, and ion heating.
- Electron-ion collision term is: Q_e = \sum \frac{2.7 \times 10^{-7} N_i}{A_i} (T_i - T_e)

Where the A_i is the atomic number of ions.

- Here the distribution of T_e-T_i is shown for variations in SZA, N_e, and H⁺ fraction.

Discussion

Near the ionosphere peak layer

- Volume photoelectron heating rate is proportional to N_e. Collisional cooling rate is proportional to N_e². [1]

Topside ionosphere

- Heating rate is attenuated by plasma content from peak to the observation height. T_e decreases with increasing plasma density less rapidly than observed near F peak.

At all heights, the ion temperature is determined primarily by the flow of heat from electrons to ions and then to neutrals. [2]

Considering the thermal conduction in the topside ionosphere, this local equilibrium is adjusted by remote conduction term. Thus

\[ N_e (T_i - T_e) \propto (T_i - T_e) \]

Hence, T_e moves toward T_i when N_e increases and T_i moves toward T_e when N_e decreases [3]

Ion heating through electron-ion collision is proportional to \[ \left( \frac{e}{2} \right) (T_e - T_i) \]

H⁺ has more efficient thermal contact with electrons compared to O⁺. H⁺ is heated by e⁻ and cooled by O⁺. O⁺ is heated by collisions with e⁻ and H⁺ and cooled by conduction.

T_e > T_H⁺ > T_O⁺.

Conclusions

- Local equilibrium provides a balance between the electron heating rate and the electron cooling rate, which specifies the electron-ion temperature difference.
- Electron temperature decreases as plasma density increases.
- T_e is weakly dependent on H⁺ fraction.
- O⁺ temperature increases as plasma density increases until T_e=T_i, then it decreases.
- At low plasma density, the ion temperature is higher when H⁺ is dominant than when O⁺ is dominant.
- The electron-ion temperature difference decreases with increasing plasma density with smaller values when the H⁺ fraction is high.

References