Electron density and temperature observed by satellites and incoherent scatter radars

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Electron energy equation in the ionosphere

$$\frac{3}{2} n_e k \frac{\partial T_e}{\partial t} - \frac{\partial}{\partial s}\left(\lambda_e \frac{\partial T_e}{\partial s} \right) = \sum Q_e - \sum L_e - \sum_{j=i,n} \frac{n_e m_e \nu_{ej}}{m_j} 3k\left(T_e - T_j\right)$$

Heating rate   Inelastic cooling rate   Cooling rate by collisions

Since the electron temperature in the ionosphere responds in a few seconds to changing conditions, the electron temperature is generally in a quasi-steady state.

Thermal conduction is not important at low altitudes (<300km) because of small heat flow by neutral effect.

=> The electron temperature is determined by a balance between local heating and cooling processes (LTE: Local Thermal Equilibrium) at low altitudes.

Local Thermal Equilibrium

$$\sum Q_e - \sum L_e - \sum_{j=i,n} \frac{n_e m_e \nu_{ej}}{m_j} 3k\left(T_e - T_j\right) = 0$$

Heating rate Inelastic cooling rate Cooling rate by collisions

For electron $$Q_e - \frac{n_e m_e \nu_{ei}}{m_i} 3k\left(T_e - T_i\right) - \frac{n_e m_e \nu_{en}}{m_n} 3k\left(T_e - T_n\right) = 0$$

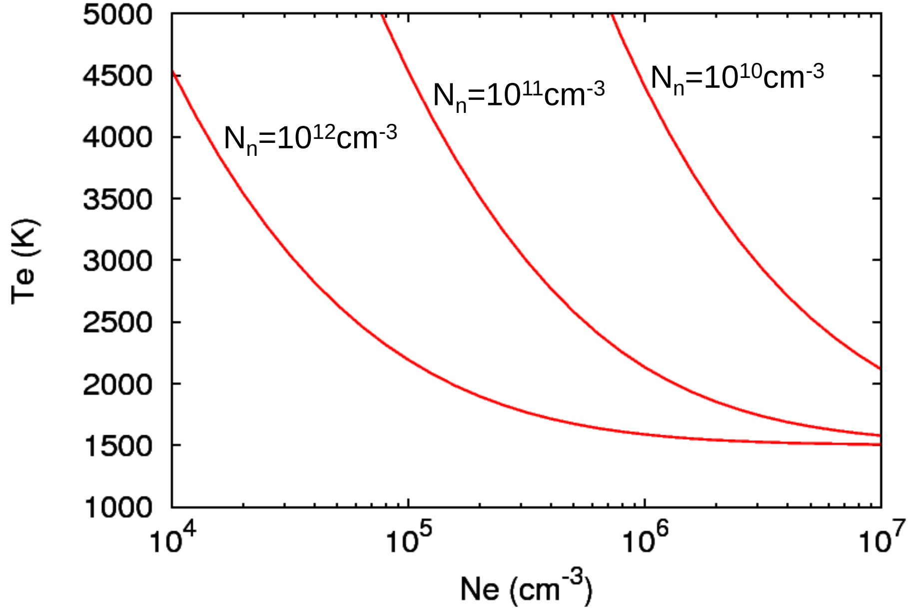
For ion (O^+) $$\frac{n_i m_i \nu_{ie}}{m_e} 3k\left(T_e - T_i\right) - \frac{n_i m_i \nu_{in}}{m_n} 3k\left(T_i - T_n\right) = 0$$

$$\nu_{ei} = 54.5 \frac{n_i}{T_e^{3/2}}$$

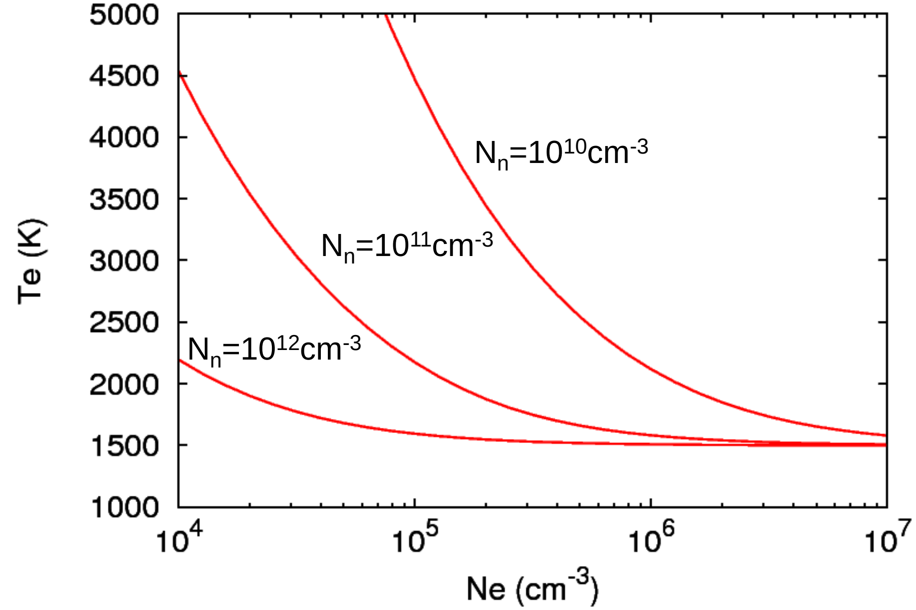
$$\nu_{in} = 2.6 \times 10^{-11} n_n(O)\left(T_i + T_n\right)^{1/2}$$

$$\nu_{en} = 8.9 \times 10^{-11} n_n(O)\left(1 + 5.7 \times 10^{-4} T_e\right) T_e^{1/2}$$

T_n=1500K, Q_e=6000eVcm^{-3}s^{-1}

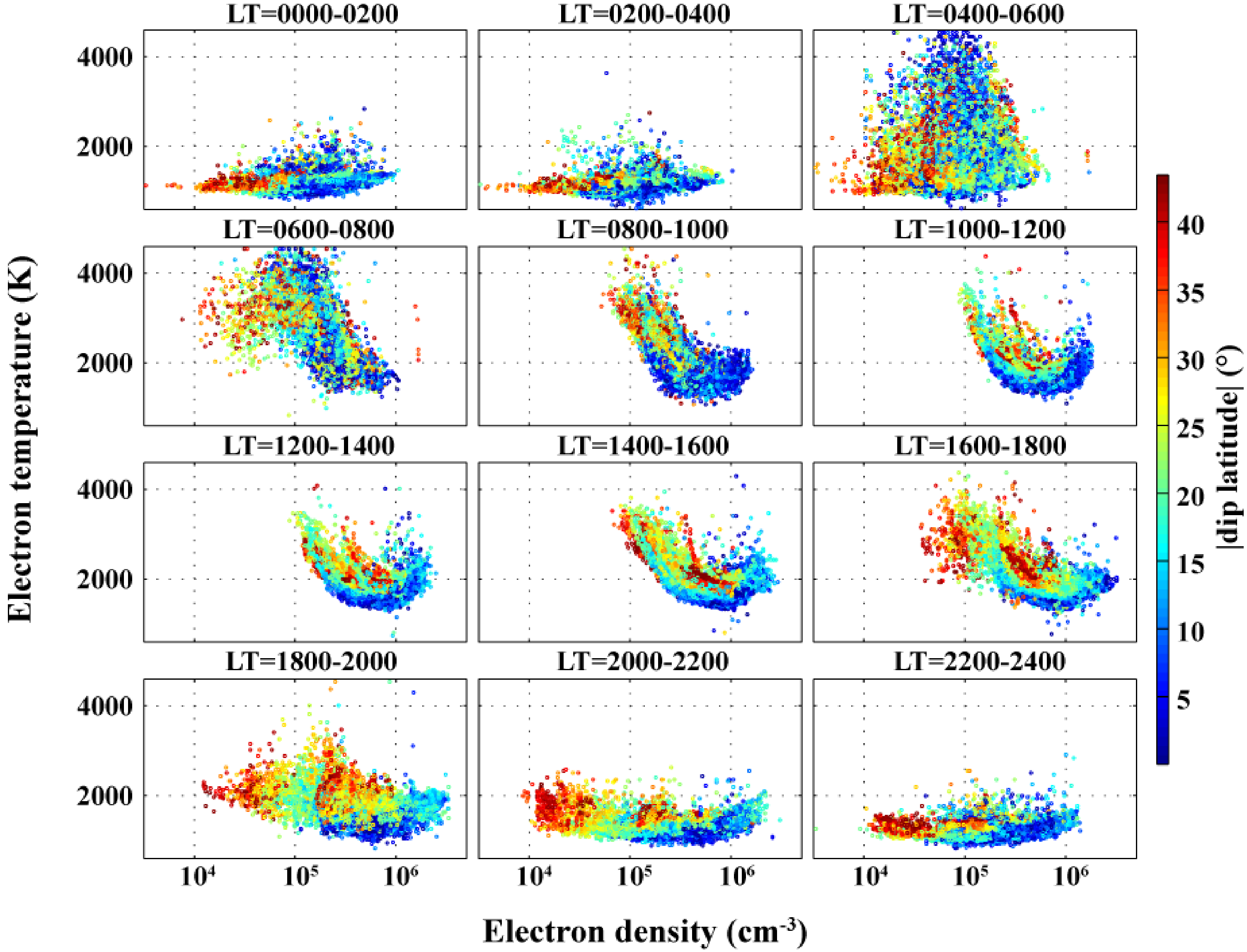


T_n=1500K, Q_e=600eVcm^{-3}s^{-1}



The electron temperature is inversely proportional to the electron density.

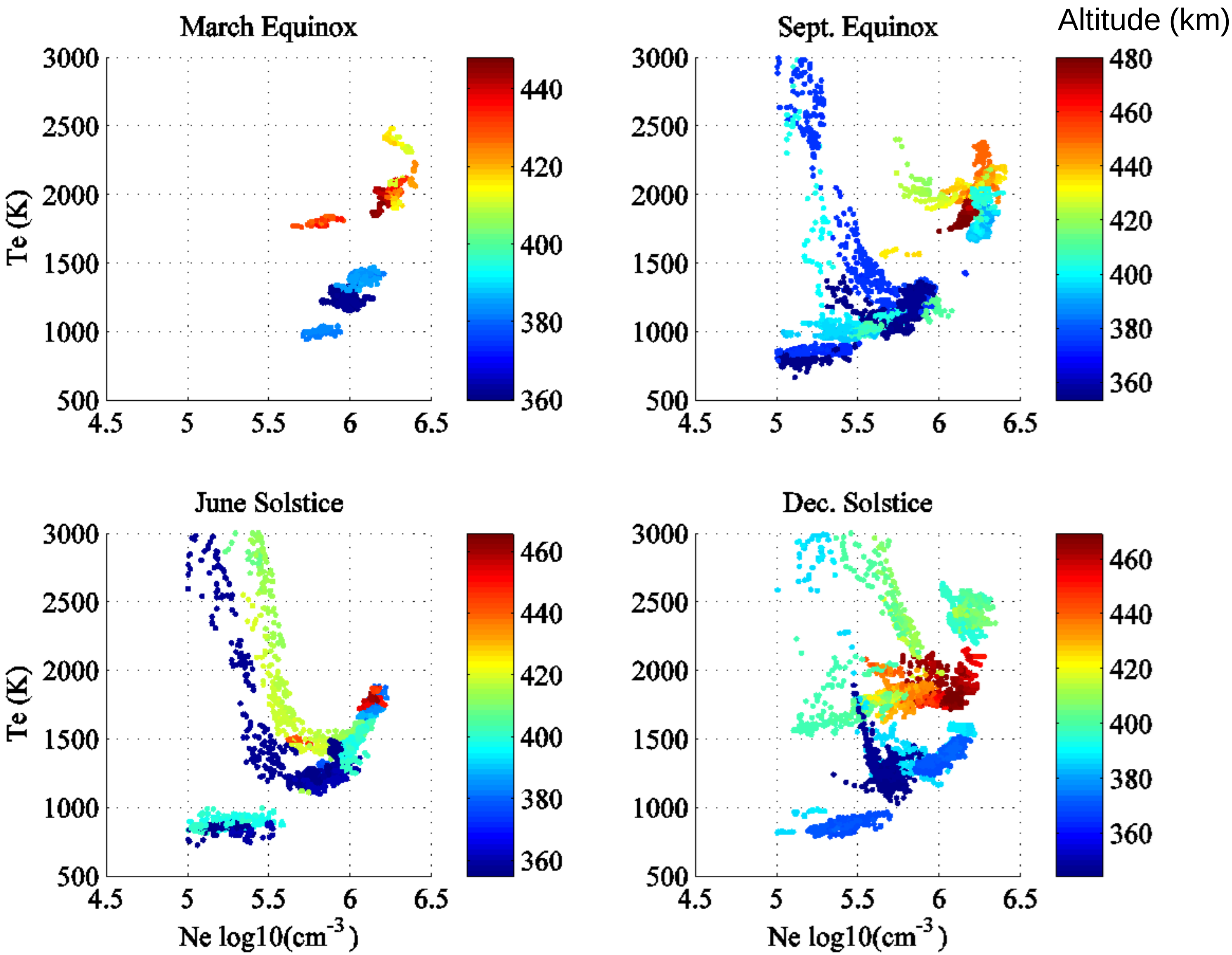
From Hinotori satellite



Correlation between Te and Ne under geomagnetically quiet conditions (Kp<3) in 2-h LT intervals. Color indicates magnetic dip latitude.

Positive correlation occurs near dip equator of >10^5 cm^{-3} Ne.

Kakinami et al., 2011

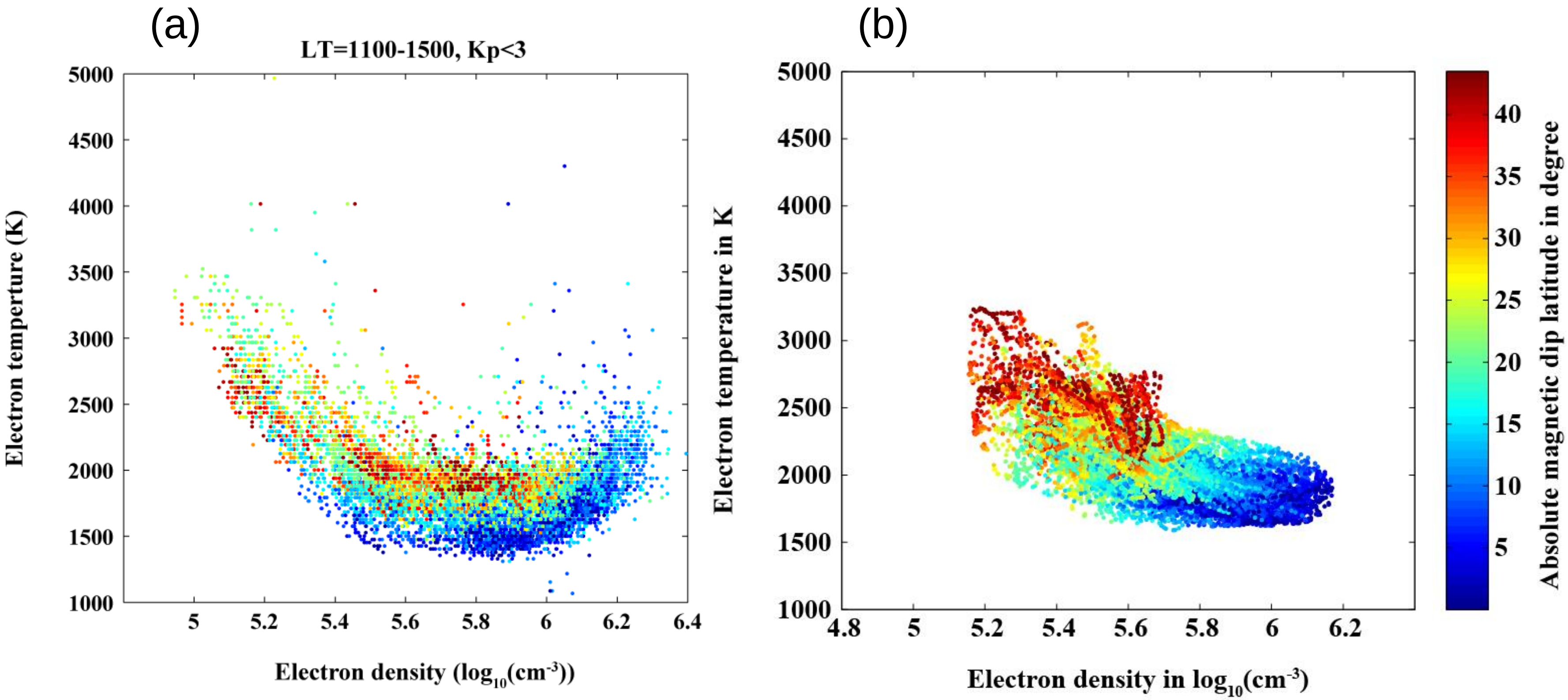


CHAMP

~400km altitude during daytiime, Kp<3, |Mlat| < 30degree

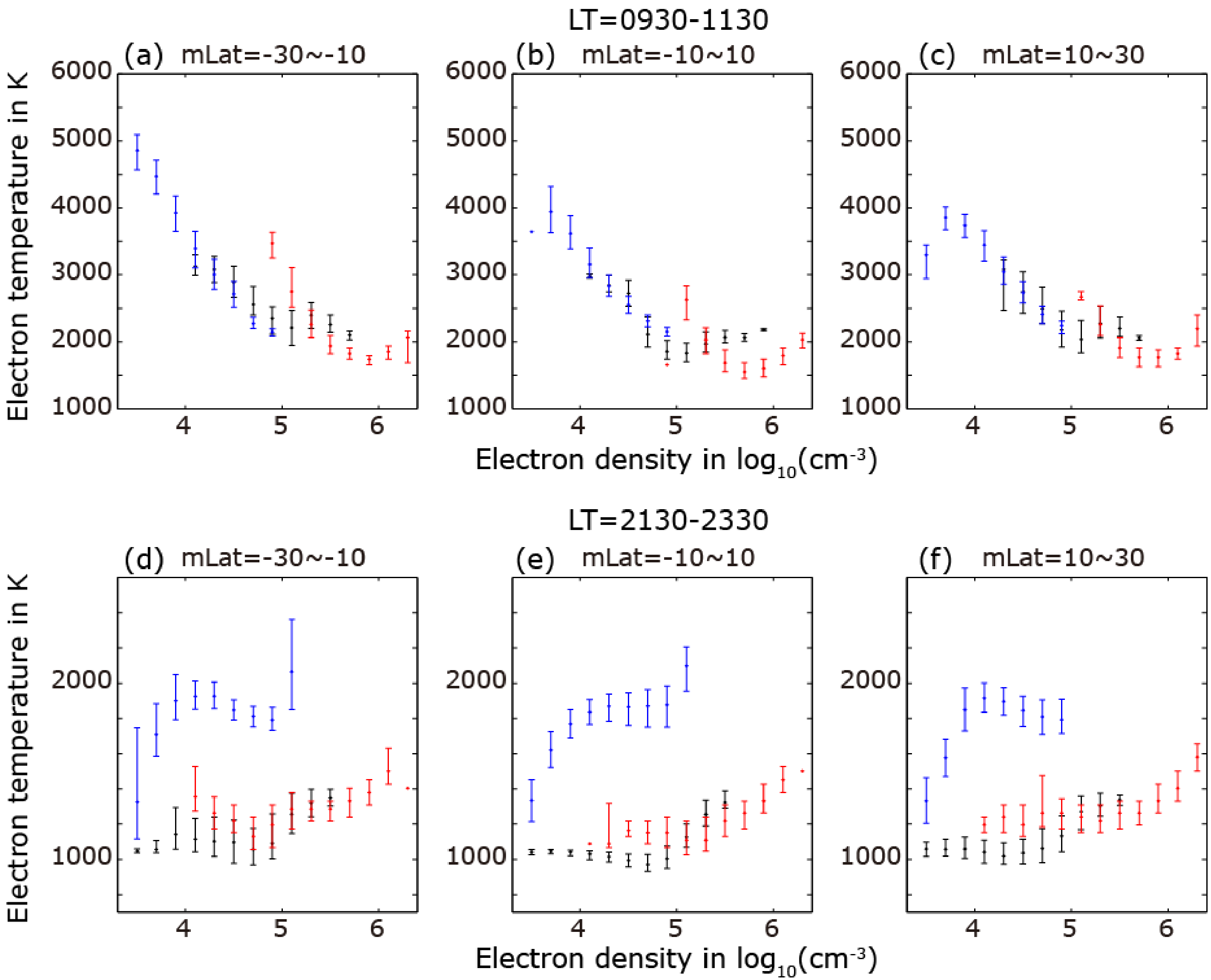
Hinotori satellite

IRI 2007



(a) Correlation between Te and Ne under geomagnetically quiet conditions (Kp<3) for LT=1100-1500. Color indicates magnetic dip latitude, (b) for IRI model.

Kakinami et al., 2011

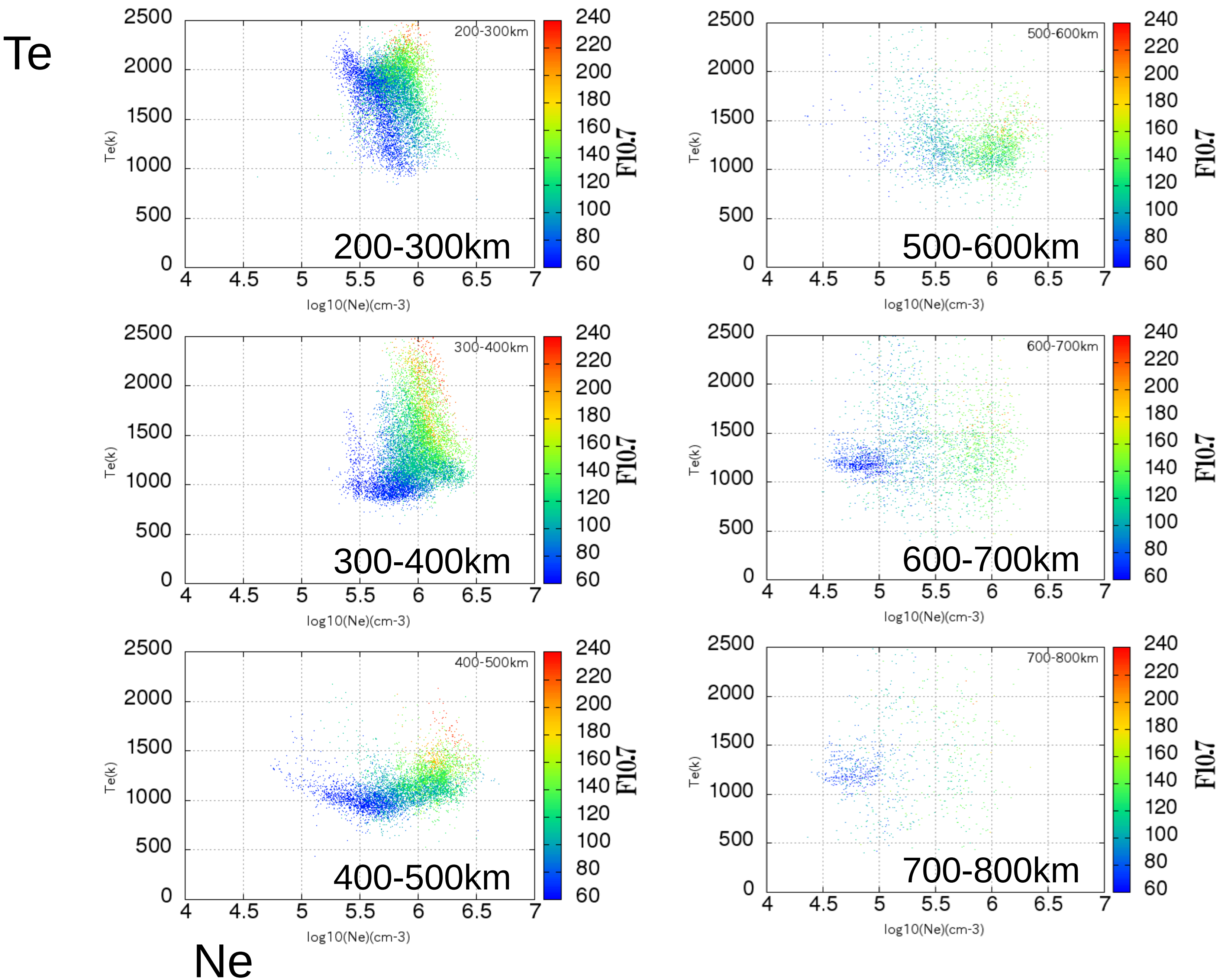


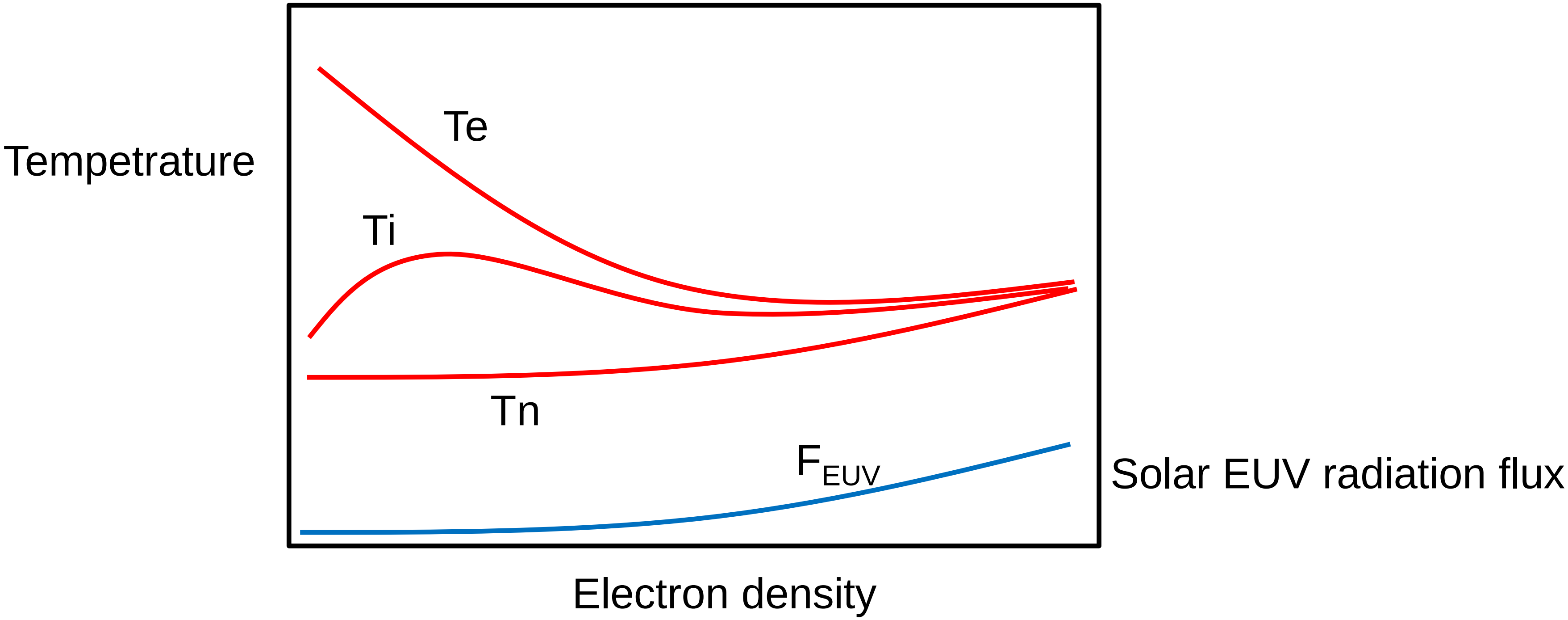
Correlation between Ne and Te for **DEMETER** (**blue**), **HINOTORI** (**red**) and **IRI2012** (**black**) in three magnetic latitude ranges for day time (a-c) and nighttime (d-f) under Kp<4.

Ne-Te map is useful to check Plasma observations on satellite.

Kakinami et al., 2013

Jicamarca (Ne, Te) 10:00 – 17:00 LT





Electron density	low	→ → → → → → →		high
Solar radiation flux	low			high
Neutral temperature	low			high
Ion temperature	low	high	low	high
Electron temperature	high	high	low	high
Te–Ti	high			low

Thermal electron heating by photoelectron

Photoelectron –thermal electron stopping cross section

$$\frac{1}{N_e}\frac{dE}{dz} = \frac{3.37\times 10^{-12}}{E^{0.97}N_e^{0.03}}\left(\frac{E-E_e}{E-0.53E_e}\right)^{2.36} \qquad \left(eV\cdot cm^2\right)$$

$$E_e = 8.618\times 10^{-5}T_e$$ Swartz and Nisbet (1971)

E Photoelectron energy

N_e Electron density

T_e Electron temperature

F_p Photoelectron flux

E_T Transition Energy from thermal to nonthermal

Heating rate

$$Q_e = \int_{E_T}^{\infty} F_p\left(\frac{dE}{dz}\right)dE \qquad \propto N_e^{0.97} \qquad \left(eV\cdot cm^{-3}s^{-1}\right)$$

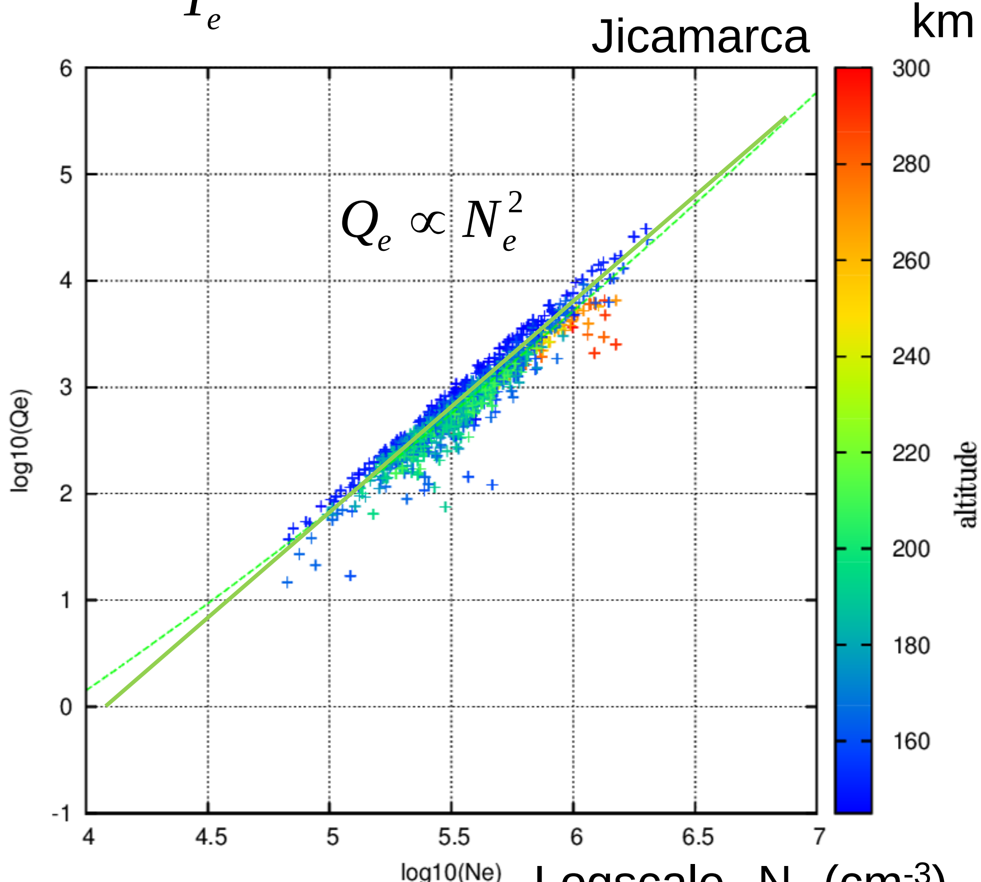
The heating rate depends on thermal electron density!

Assuming Local Thermal Equilibrium

$$Q_e - \frac{n_e m_e \nu_{ei}}{m_i} 3k(T_e - T_i) = 0$$

$$\nu_{ei} = 54.5 \frac{n_i}{T_e^{3/2}}$$

Logscale
Q_e (eV/cm^{3}s)



Logscale N_e (cm^{-3})

145-300km
1000-1700LT

Additional heating should be included !

Discussion/Summary

We investigated the correlation between Ne and Te in the low latitude ionosphere. The U-shape relationship is seen in the correlation plots of Ne and Te during early morning (0600-0800 LT) and daytime (1000-1600 LT) hours. The positive correlation is present when Ne is sufficiently high and is centered at magnetic equator.

Photoelectron heating rate is known to increase with the increase of ambient plasma density [*Hoegy* 1984]. The energy dissipation of photoelectrons is proportional to the integrated Ne along the magnetic field line [*Nagy and Banks*, 1970]. The heating rate of electrons is possibly high in the region where the integrated Ne is high.

Other mechanisms may be neutral temperature increase with the increase of solar radiation flux and/or Joule heating of neutral atmosphere, because the fast neutral wind flows near geomagnetic equator and the velocity difference between neutral atmosphere and plasma is large in the low latitude thermosphere. This is one of the Ionosphere-Thermosphere Coupling processes.