3D Dynamics modele of the Martian ionosphere

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[1] LATMOS-IPSL ; [2] IAA-CSIC ; [3]LMD-IPSL, [4] IRAP,[5]ESA-ESTEC

Heliosares 2014

Martian Ionosphere

- First observation 1965 (Mariner 4)
- Main species : **O_2^+, CO_2^+ , O^+** (Viking) : 1976

$CO_2^+ + O \rightarrow O_2^+ + CO$ (Fehsenfeld et al. 1970)

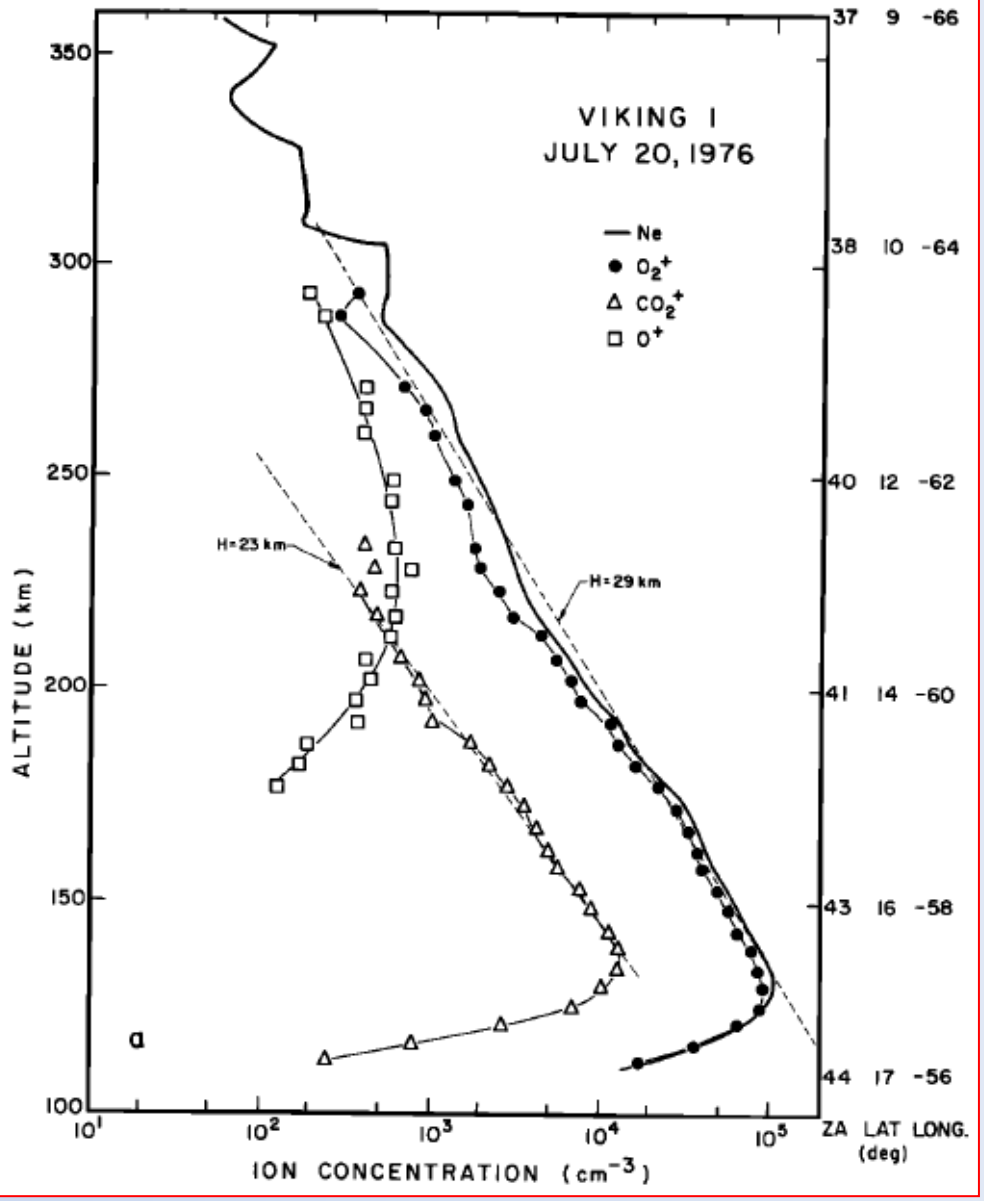
- Numerous observations MGS ; Mars Express (MaRS, MARSIS)
- Photochemical equilibrium : at daysied Z < 180 km

- Observations of sporadic ionosphere at nightside (transport SZA < 115° ; precipitations SZA > 115°),

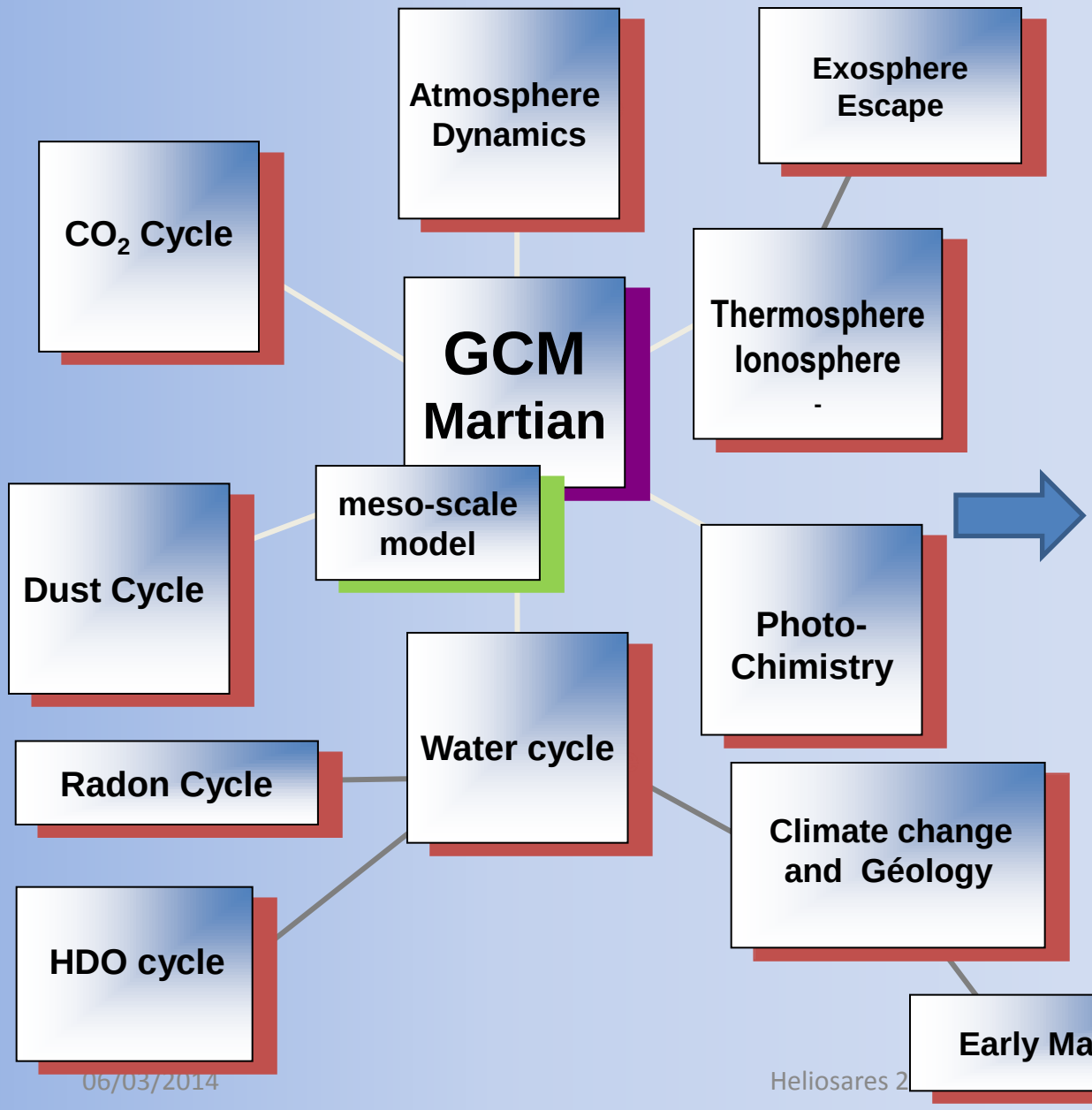
- Important source of escape (photochemical escape, pick-up)
- Obstacle to the solar wind

➔ Importance to understand its composition, dynamics and variations

Hanson et al. 1977



Martian GCM 3D (LMD)



« Mars Climate database »

- Reference tool for community
- Version « pro » on DVD-ROM commanded by ~150 teamss in ~20 pays
- Interactive website

Physical processes

- Photochemistry (production, loss) (Instituto de Astrofisica de Andalucia) ~ 90 réactions
- Atmospheric transport
- Ions dynamics (multifluid approach)

Possibility to choose which ions are described dynamically

  - O_2^+ ; O^+ ; CO_2^+ ; C^+ ; N^+, NO^+

- Ion-Neutral Rétroaction
- Ambipolar E field

Processes not included yet

- Ionospheric currents and magnetic fields
- Energy equation

Ionosphere : Mathematical model

- **Continuitt**

$$\frac{\partial \rho_k}{\partial t} = -\nabla_H \cdot (\rho_k V_n) - \nabla_H \cdot (\rho_k v_k) - \frac{\partial}{\partial z}(\rho_k W_n) - \frac{\partial}{\partial z}(\rho_k w_k) + S_k - L_k$$

- **Dynamics**

$$\frac{\partial V_k}{\partial t} + W_n \frac{\partial V_k}{\partial z} + w_k \frac{\partial V_k}{\partial z} + (\varsigma_k + 2\Omega) z \times V_k + \nabla_H (V_k^2) + \nu_{kn}(V_k - V_n) + \frac{1}{\rho_k}\nabla_H P_k - \frac{q}{m_k} E_H = 0$$

$$\nu_{kn}(W_k - W_n) + g + \frac{1}{\rho_k}\frac{\partial P_k}{\partial z} - \frac{q}{m_k} E_z = 0$$

W_k at top : free (here 0) parameter, W_n =0

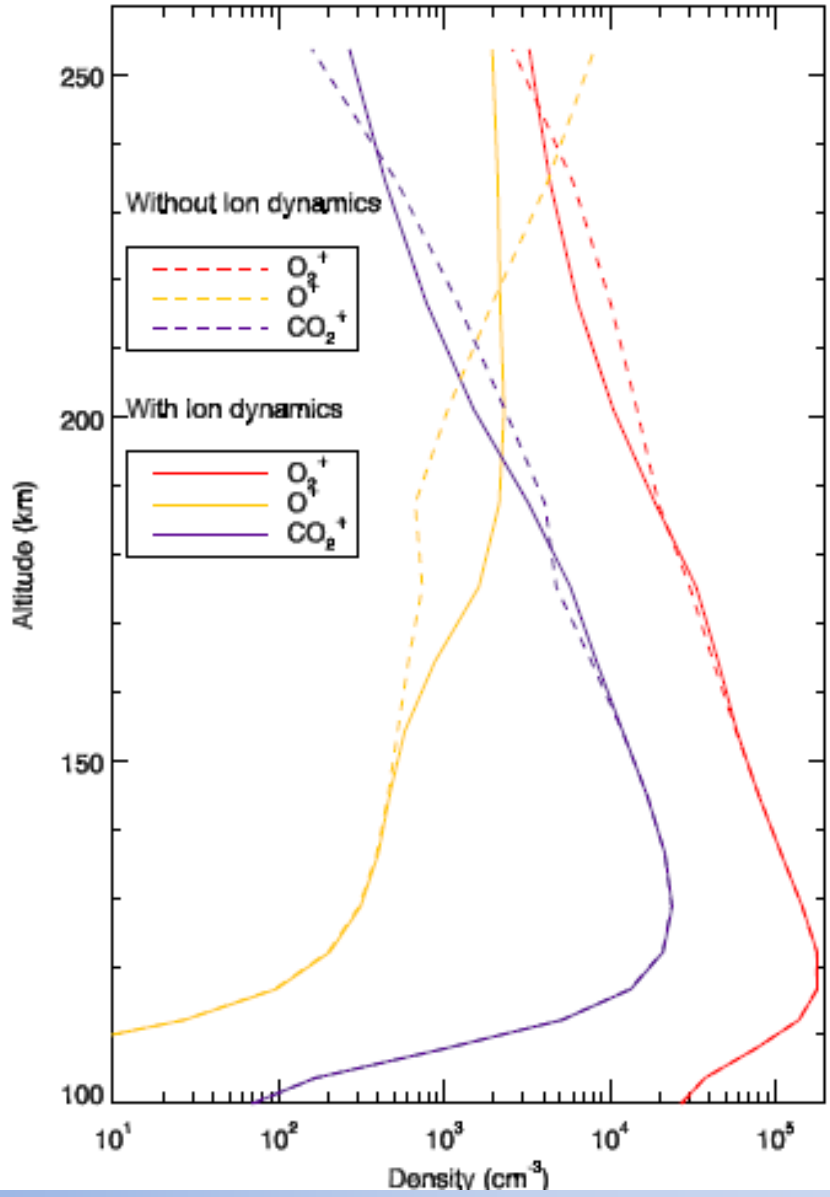
- **Electron dynamics ($m_e = 0$) ➔ E**

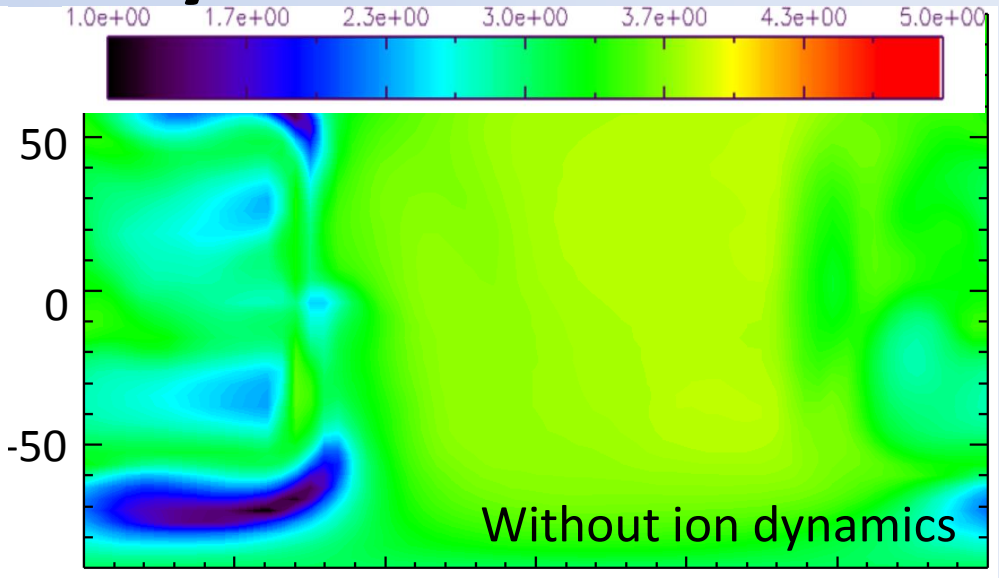
$$E_H = -\frac{m_e}{e}\left[\frac{1}{\rho_e}\nabla_H P_e\right] \qquad E_z = -\frac{m_e}{e}\left[\frac{1}{\rho_e}\frac{\partial P_e}{\partial z}\right]$$

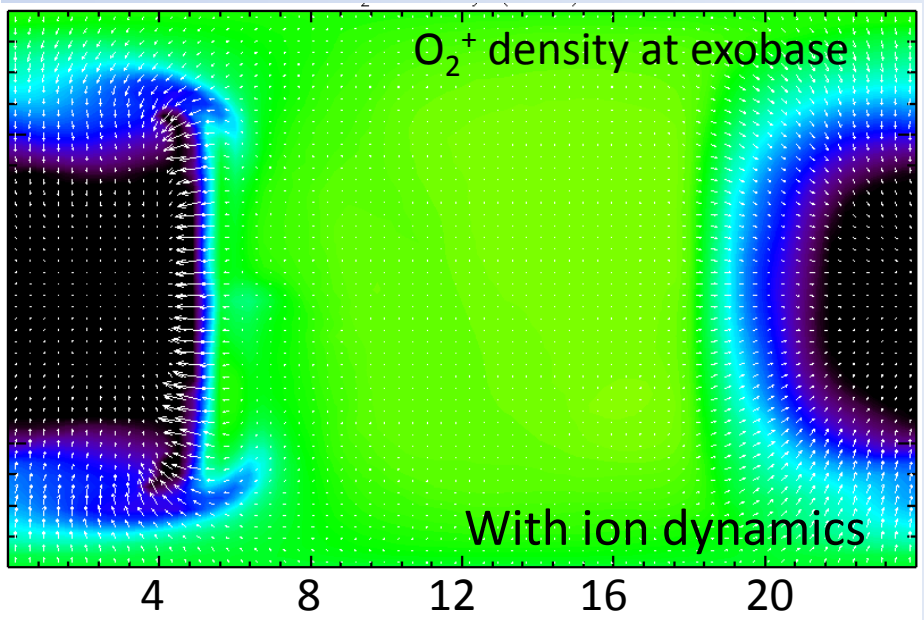
- **Electroneutrality, Charge conservations**

$$\rho_e = \sum_{k=1}^{k=9} \frac{m_e}{m_k}\rho_k \qquad \rho_e V_e = -\sum_{k=1}^{k=9} \frac{m_e}{m_k}\rho_k V_k$$

Effects of ions dynamics

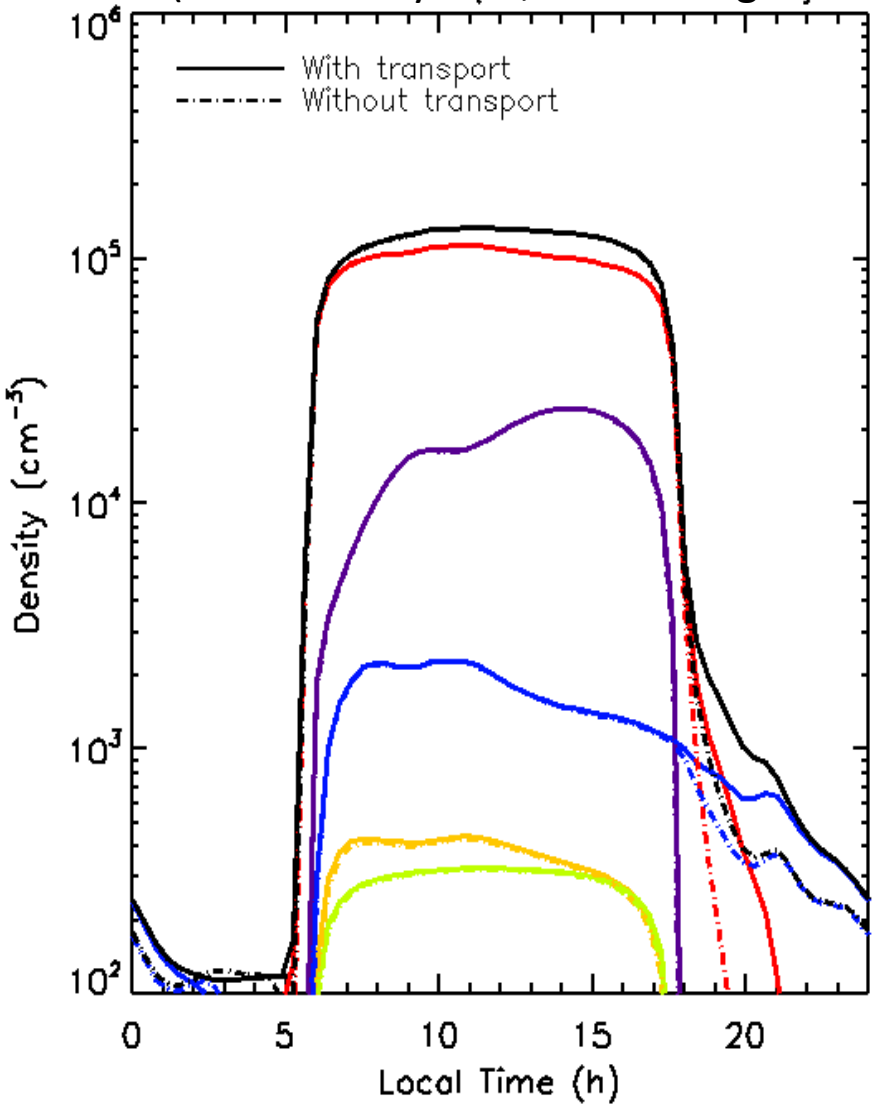




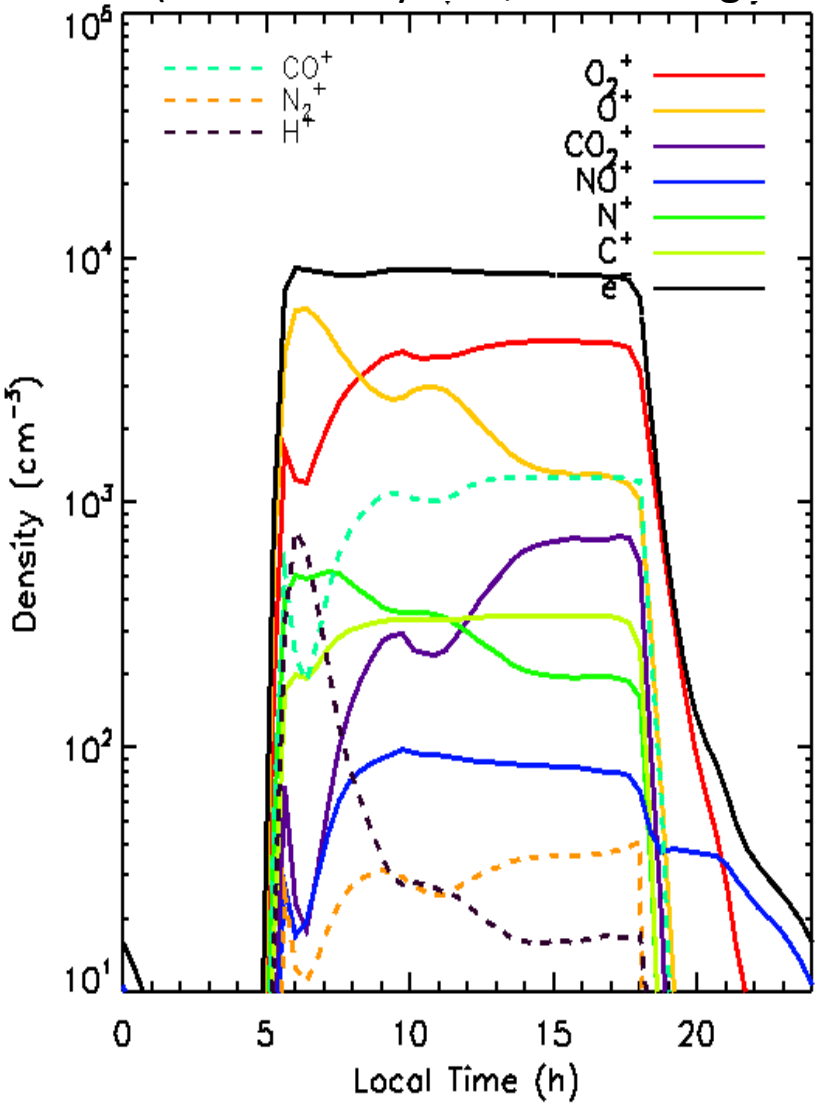


Ionosphere : Diurnal variations

P=10^{-4} Pa (~140 km dayside ; 110 km nightside)



P=10^{-7} Pa (~220 km dayside ; 180 km nightside)



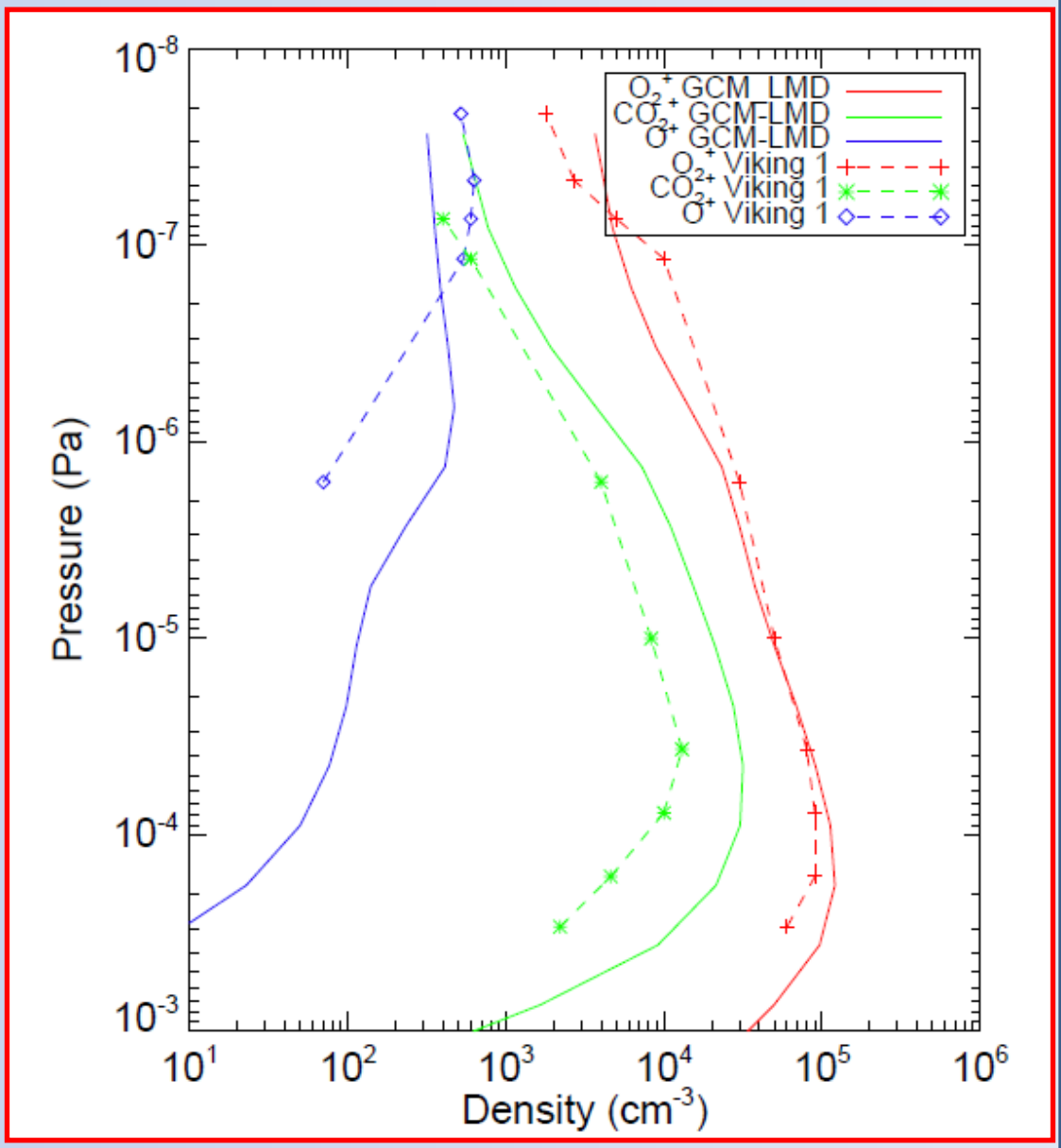
Ionosphere : Comparison with observations

- Comparison with Viking Observations

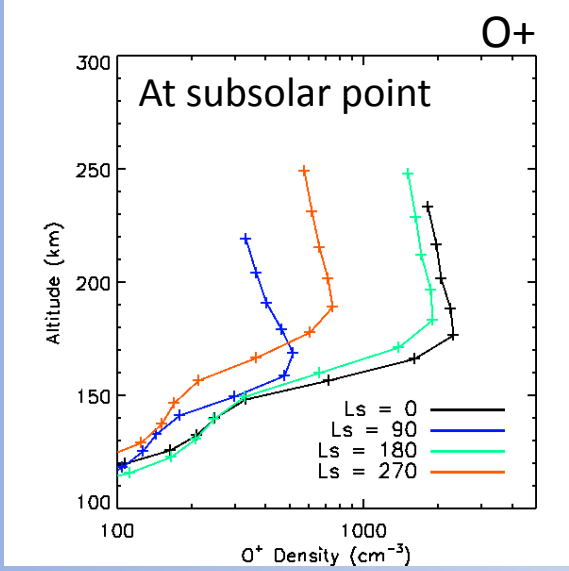
- Good description of O2+

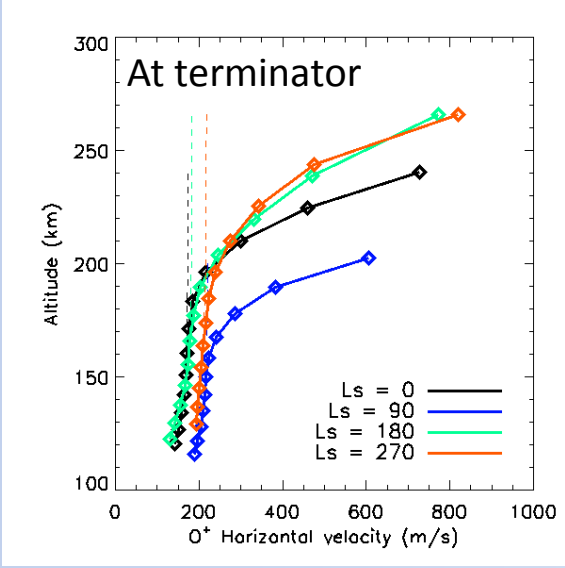
- Underestimate O+ and over-estimate CO2+ density : could be due to an understimate of O density

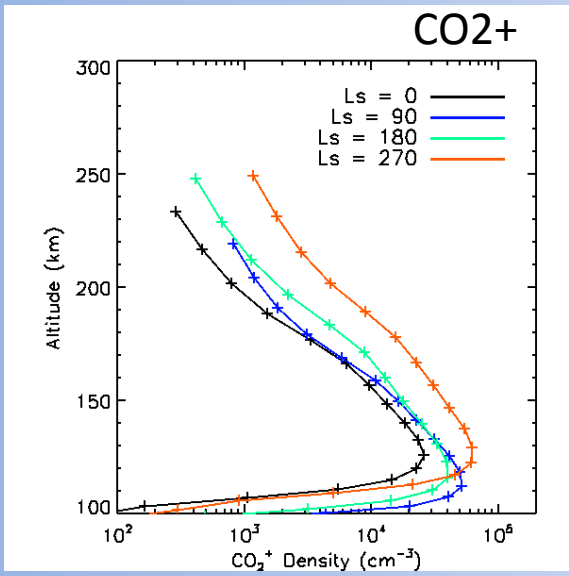
- Peak density of O+ too low : effect of B horizontal field ?

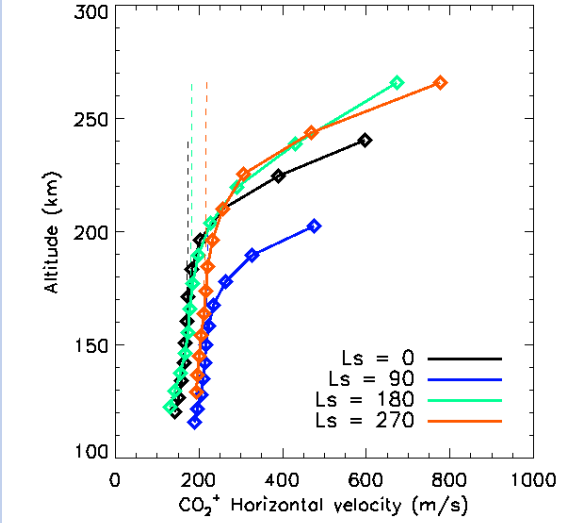


Seasonal Variations





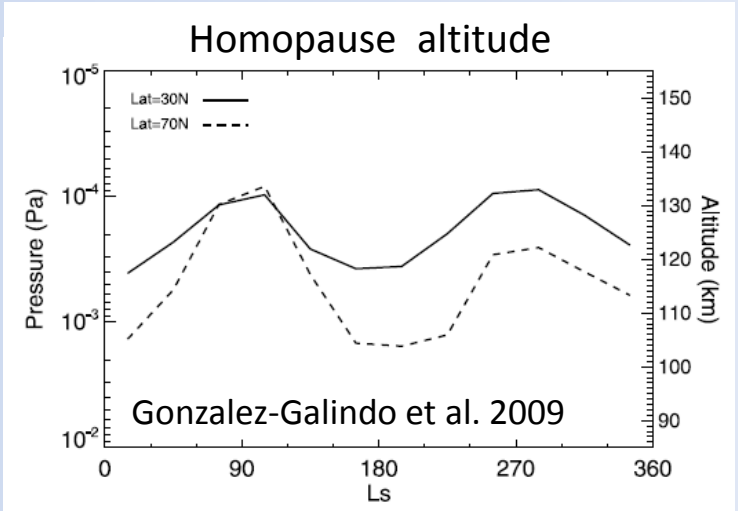


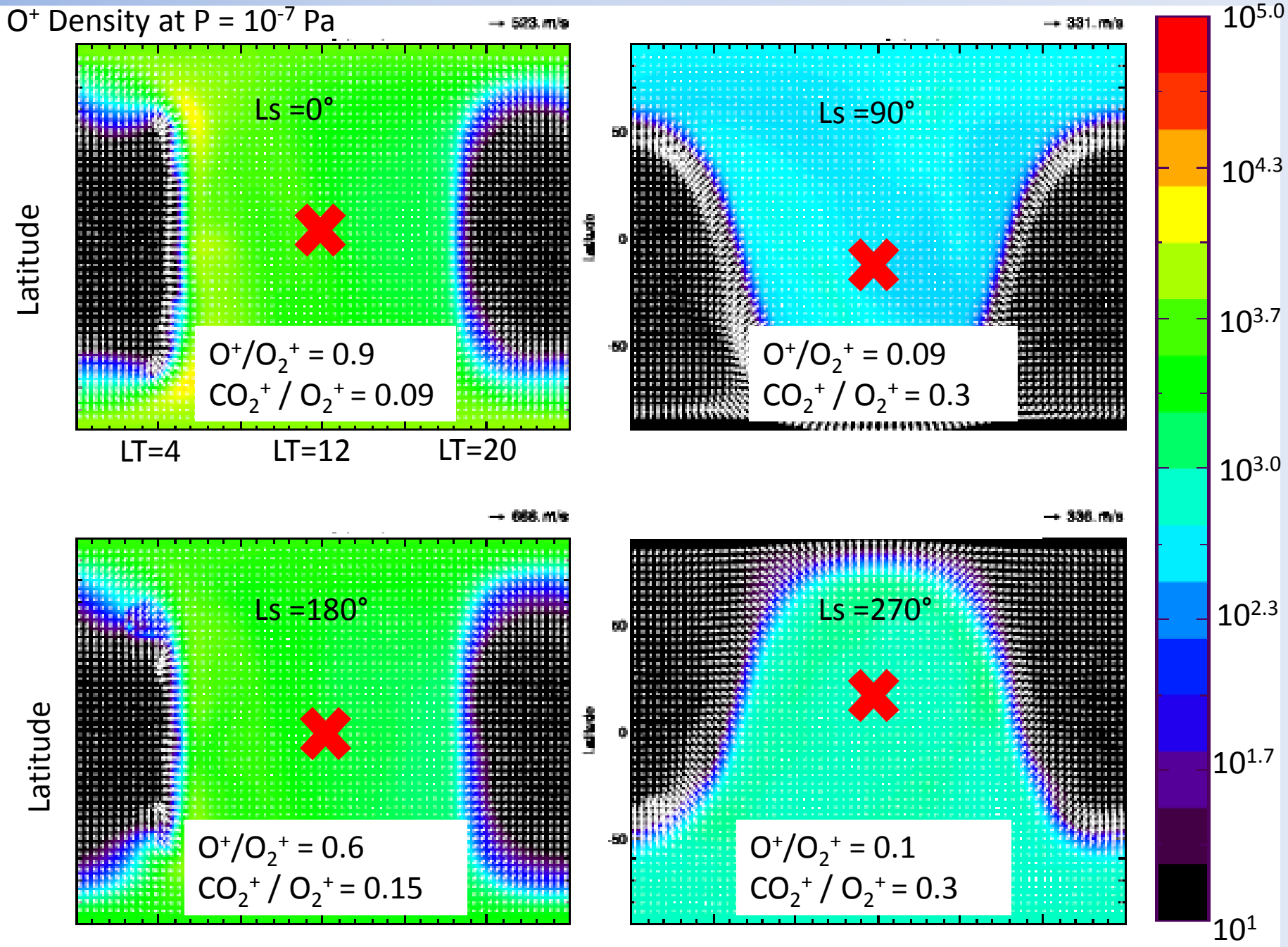


- No large effects on the ions dynamics
- Strong variations of the O+ and CO2+ densities
- Anti-correlation between CO_2^+ and O^+ due to variations dof O density

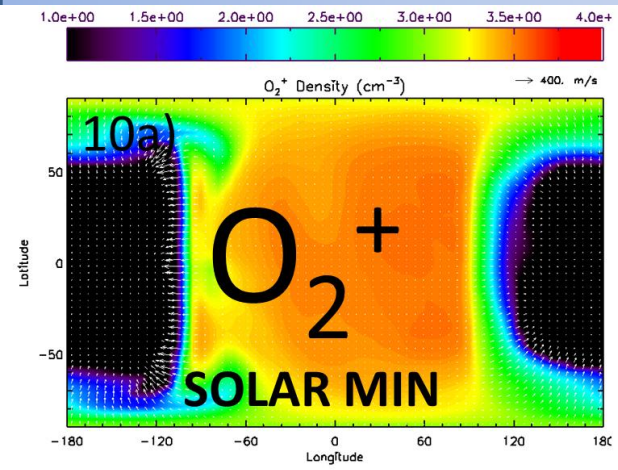
$O + h\nu \rightarrow O^+$

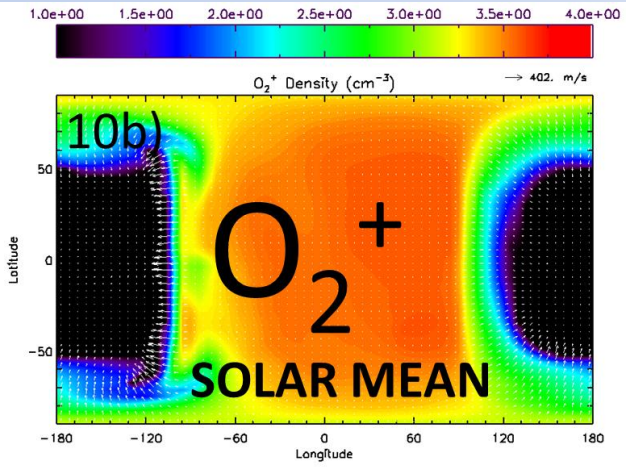
$CO_2^+ + O \rightarrow O_2^+ + CO$

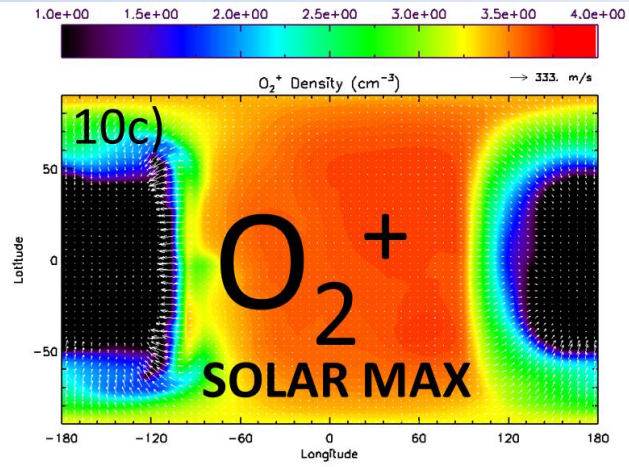


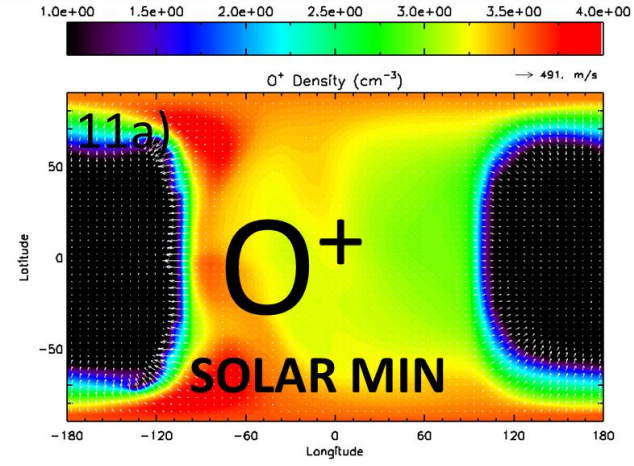

O+ Density at P = 10-7 Pa
Ls =0°
O+/O2+ = 0.9
CO2+ / O2+ = 0.09
Ls =90°
O+/O2+ = 0.09
CO2+ / O2+ = 0.3
Ls =180°
O+/O2+ = 0.6
CO2+ / O2+ = 0.15
Ls =270°
O+/O2+ = 0.1
CO2+ / O2+ = 0.3
Latitude
LT=4
LT=12
LT=20
10^5.0
10^4.3
10^3.7
10^3.0
10^2.3
10^1.7
10^1

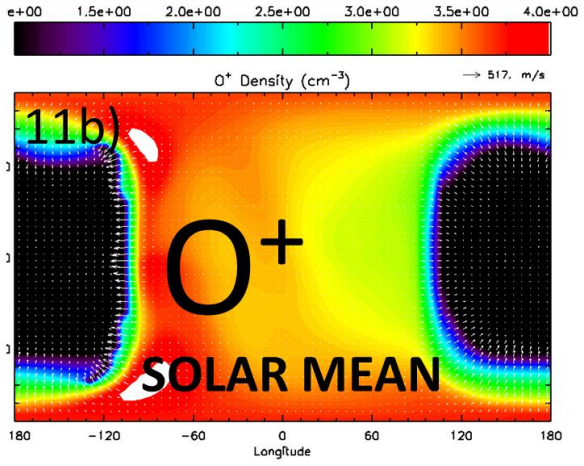
Solar Activity

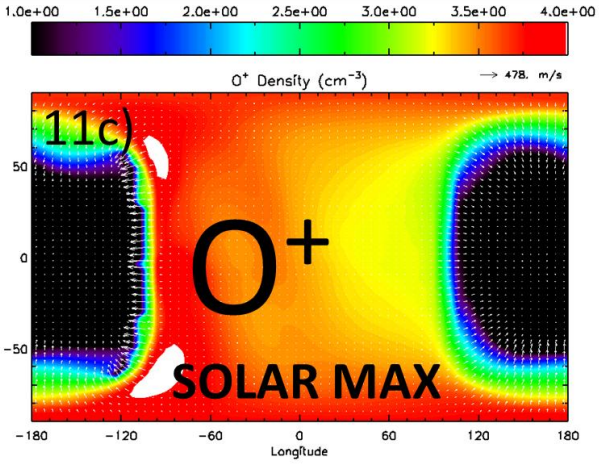






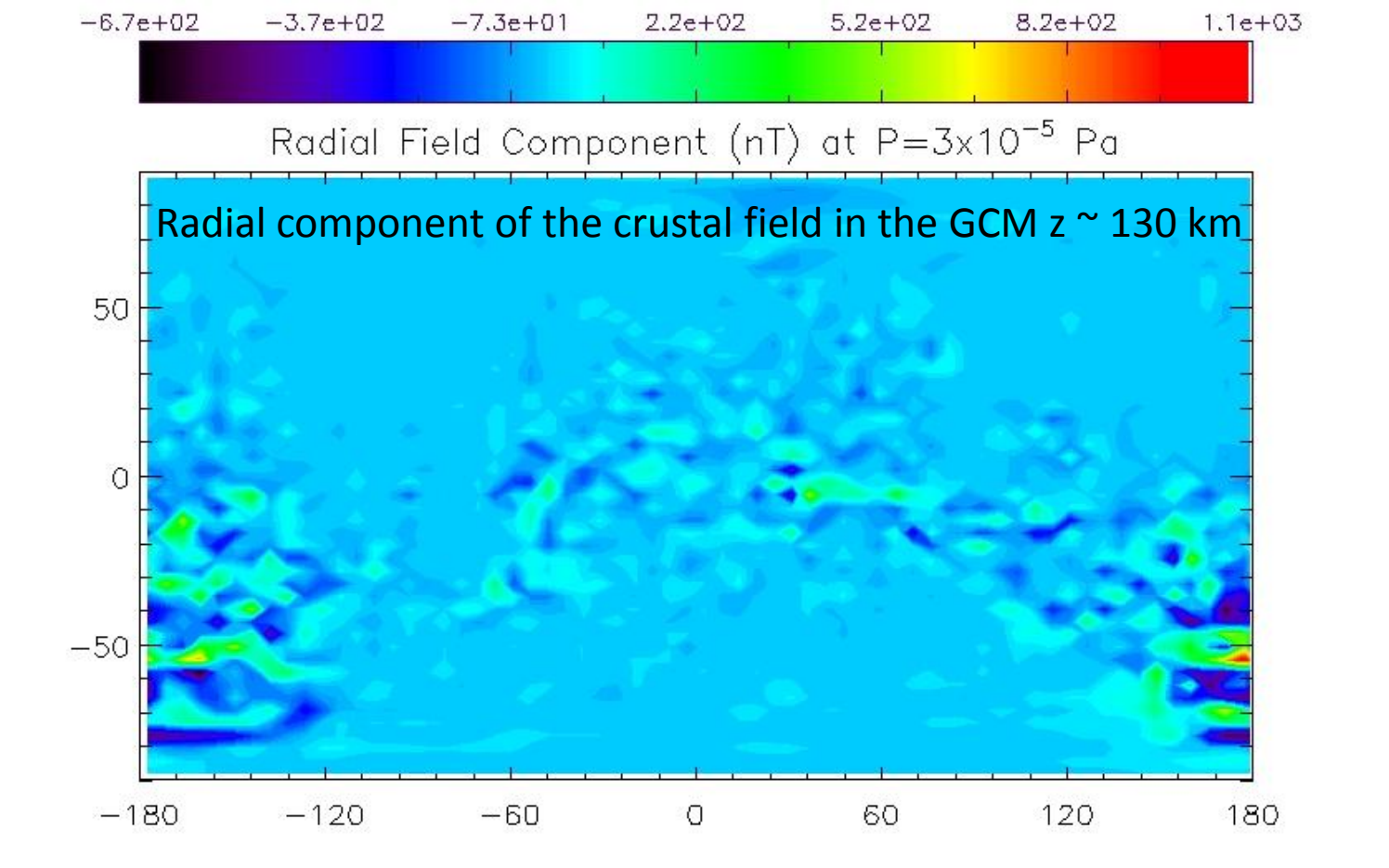




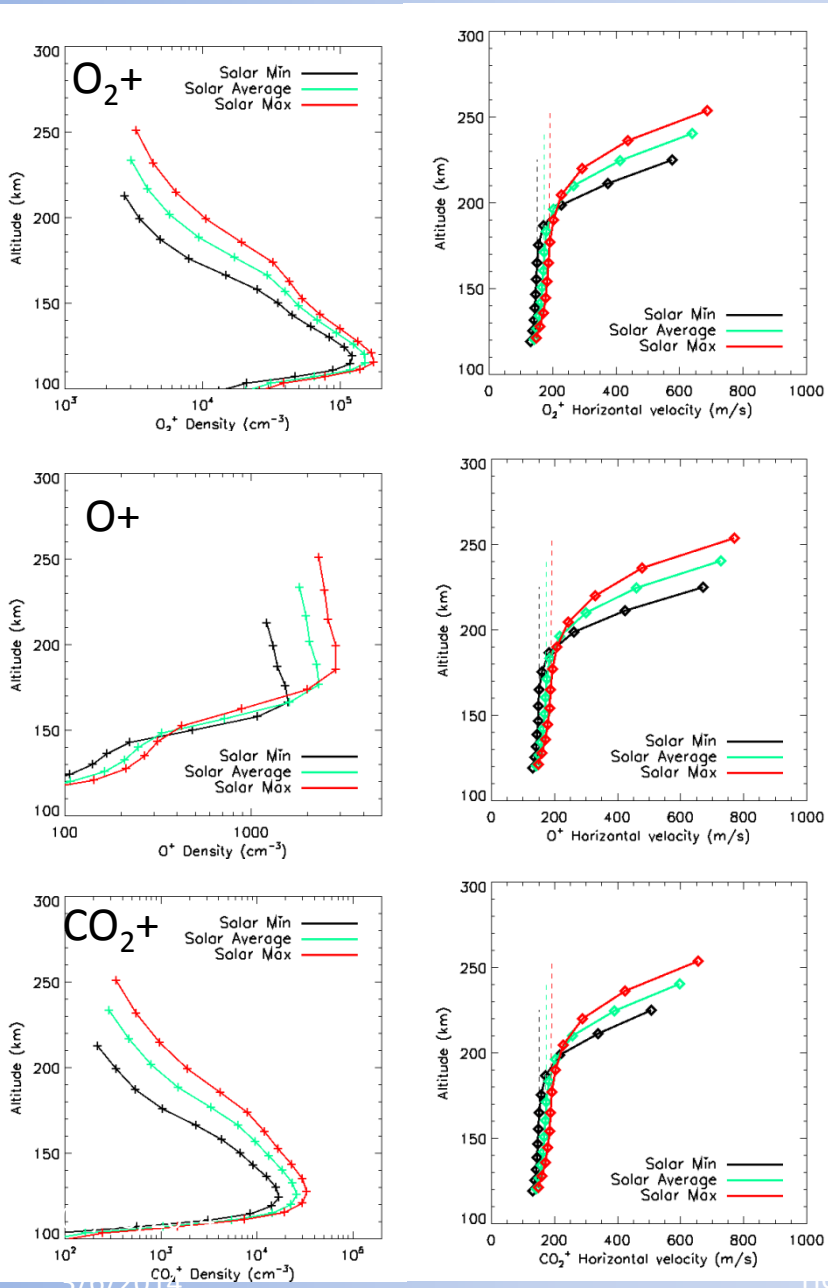


Perspectives

- Input for solar wind interaction model (started)
- Validation with MAVEN observations
- Add magnetic field (started) & ionospheric currents J
- Energy equations : Te, Ti ...



Solar Activity



- Small increase of the horizontal ion velocity ~ 20% with solar activity
- No effects on the ion horizontal distributions
- Increase of all ions density
- Increase of the dayside average O^+/O_2^+ and CO_2^+/O_2^+ ratios at the exobase (~ 30%)