Thermospheric and ionospheric modeling with the LMD-MGCM

HELIOSARES kick-off meeting

Paris, 5-6 October 2009

Outline

- Validation of the temperature/density predicted in the upper atmosphere
  - SPICAM temp/dens profiles
  - MO thermospheric polar warming
  - MGS ER density
  - MGS POD temperature
- Chemical module
  - NO nightglow
- Ionospheric modeling and results

Lower/upper atmosphere coupling

- Waves propagating from below strongly affect temperatures in the upper atmosphere

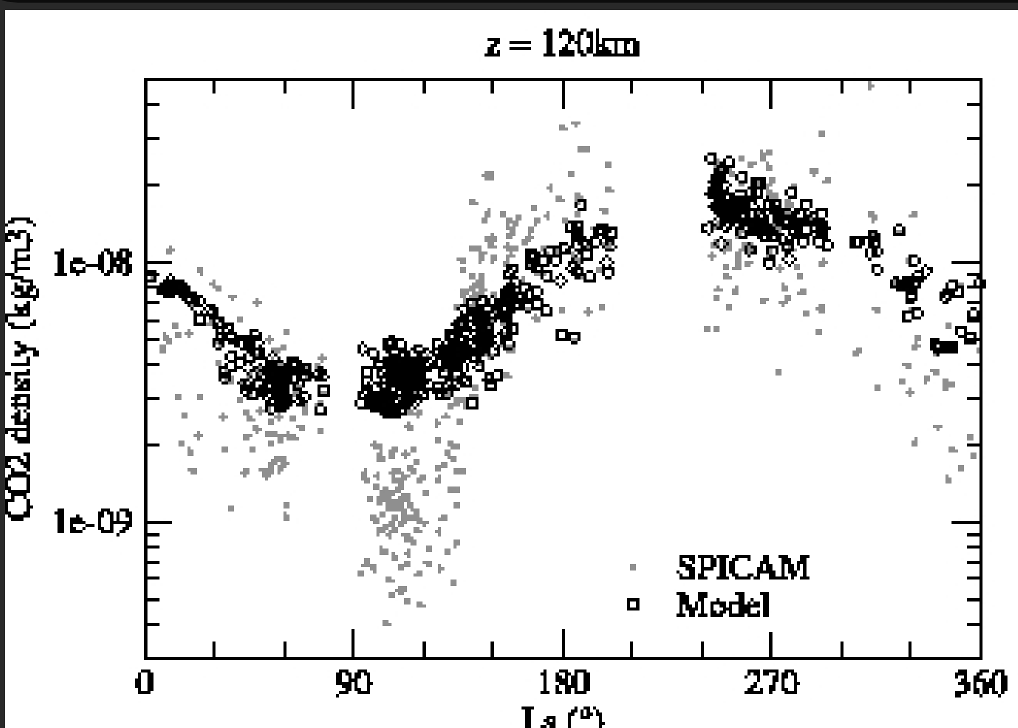
Validation (I): SPICAM profiles

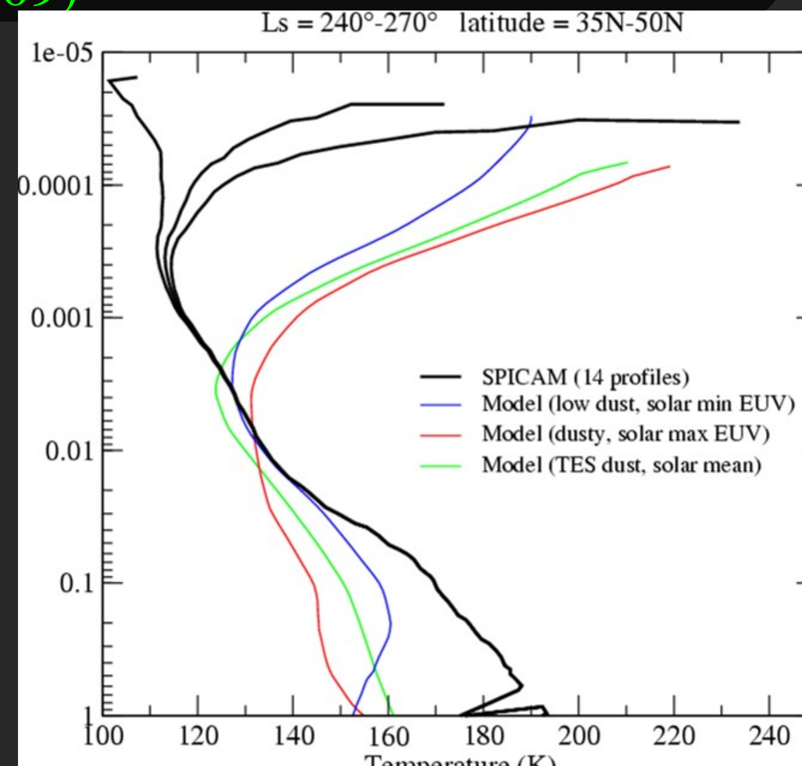
- SPICAM obtains atmospheric density profiles (60-130 km) by stellar occultation (Forget et al., 2009)
  - Temperature profiles can be obtained
- ≈660 profiles (1st Martian year)
  - Mostly nighttime profiles
- Effects of dust felt in the thermosphere
- Temperatures below CO_2 condensation found

Validation (I): SPICAM profiles

Comparisons of density and temperature profiles

(Forget et al., 2009)

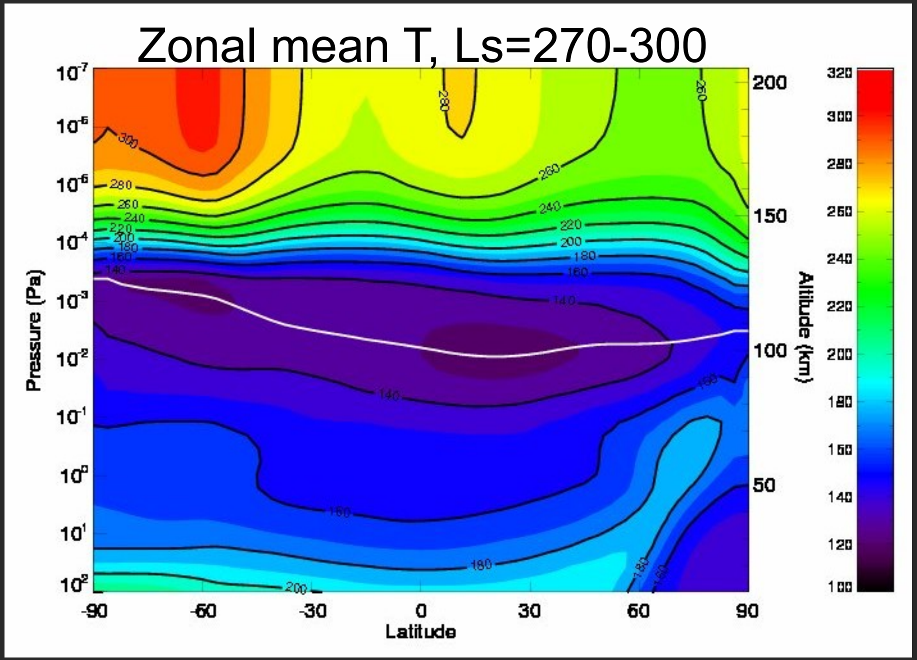


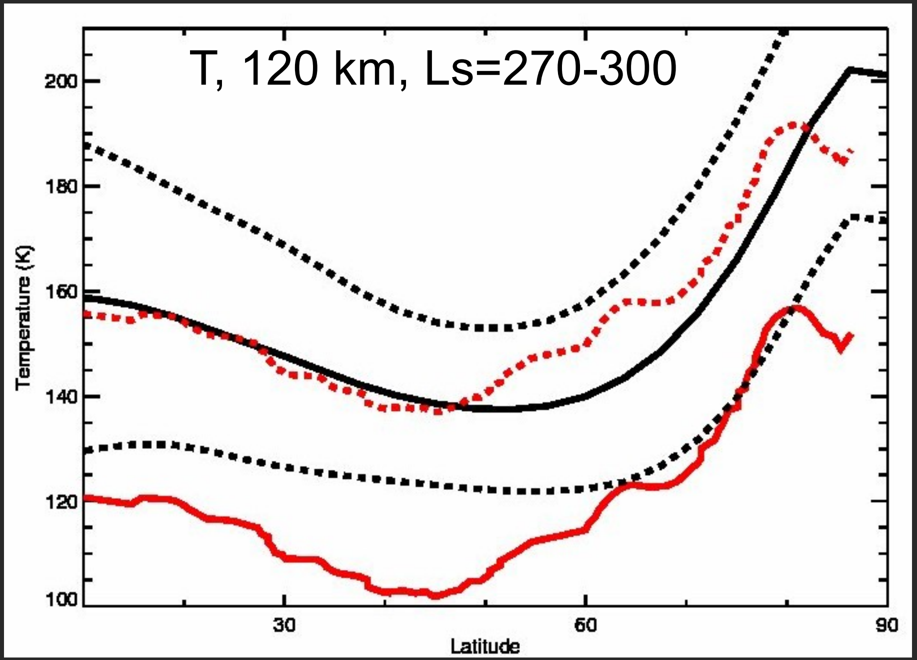


- GCM overestimates ρ and T_{meso}, underestimates z_{meso}
  - Problems in the IR radiative transfer ?

Validation (II): TPW

- MO aerobraking: ρ, T, ≈120 km, perihelion
  - Increase of T towards the winter pole observed





- GCM overestimates T(120 km) but reproduces intensity and distribution of TPW

Validation (III): MGS ER density

- Electron Reflectrometry on MGS allows to infer ρ_{185} (Lillis et al., 2005, 2008)
  - Only where important crustal magnetic field
- LMD-MGCM does generally a good job, but:
  - Problems with latitudinal variation
  - LMD-MGCM tends to overestimate ρ_{185} at mid-high lat.

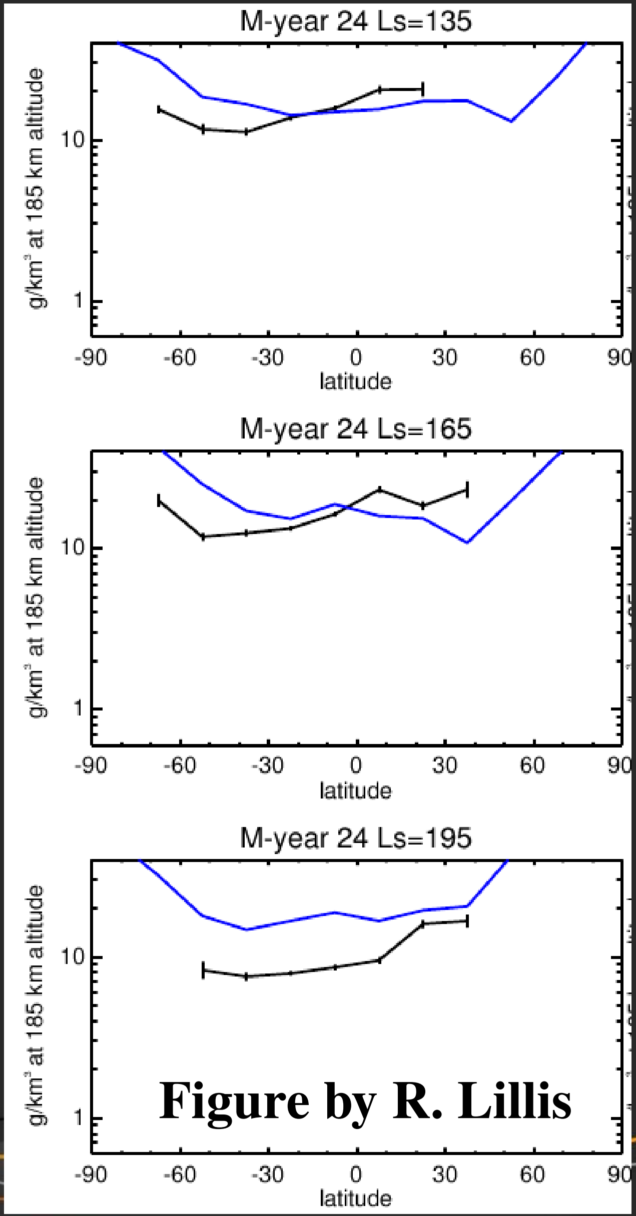
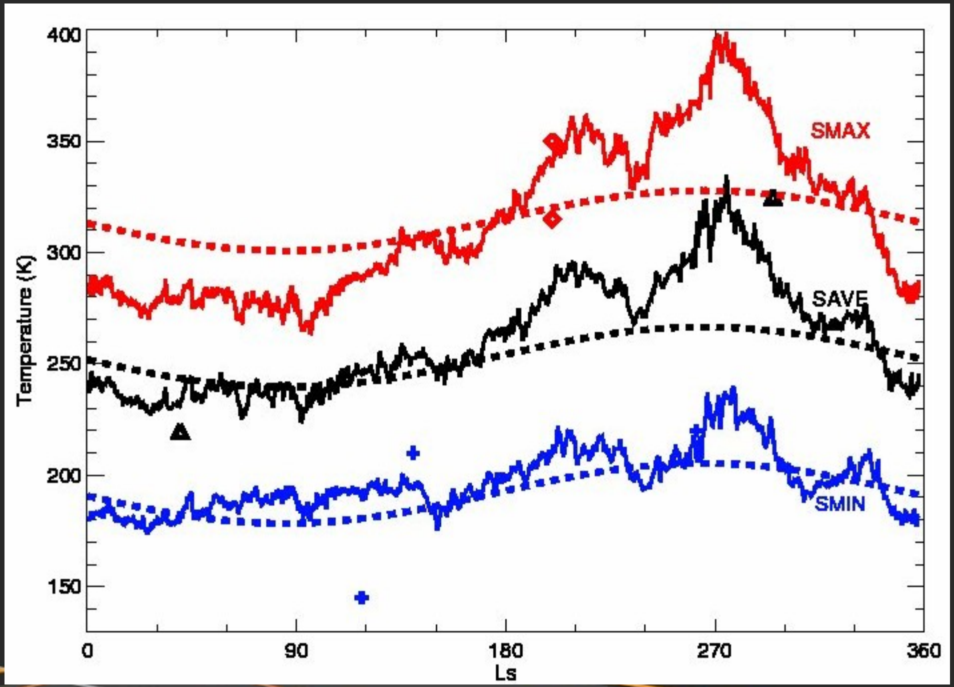


Figure by R. Lillis

Validation (IV): MGS POD

- Exospheric temperature measured using POD with MGS (Forbes et al., 2008)
  - 4 MY of observations, seasonal and solar cycle variability



Solid lines: GCM T; lat=-45, LT=15, , lon. average, exobase

Dashed lines: exospheric T from MGS POD, lat=40S-60S, LT=14, lon. average

- Solar cycle variation well represented by GCM
- Seasonal variation stronger than observed

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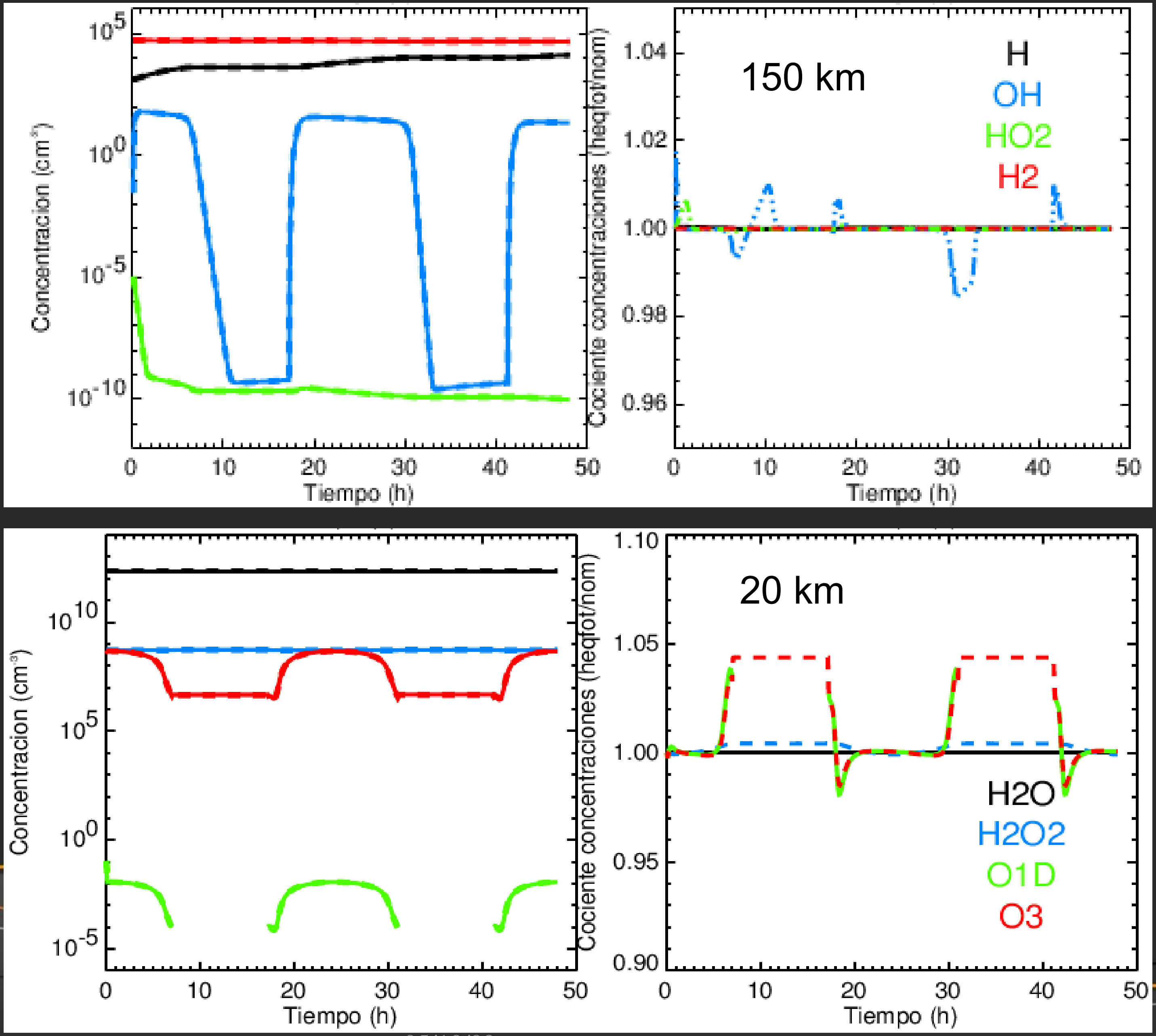
Photochemical model: numerical scheme

- Continuity equation: $\partial n_i/\partial t = P_i - l_i n_i$
- Discretization using implicit scheme
- Timestep $\Delta t < \tau$
  - Serious constrain to computation efficiency
- Photochemical equilibrium used for fastest species
  - $n_i = P_i/l_i$
  - $\tau \ll \Delta t$
  - Good accuracy, important CPU time saving

Photochemical equilibrium accuracy



Photochemical model

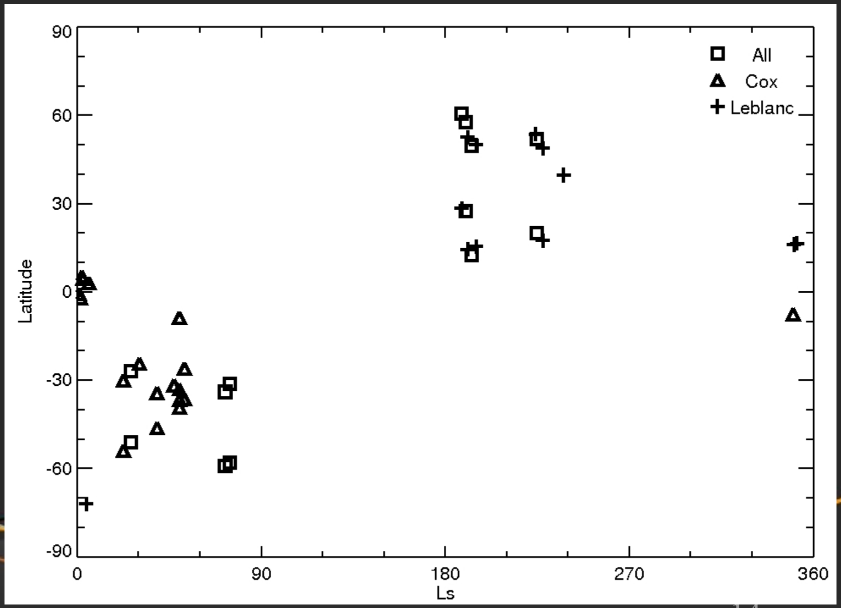
- 12 species:
  - CO_2, CO, $O(^3P)$, $O(^1D)$, O_2, O_3, H, OH, HO_2, H_2, H_2O, H_2O_2
  - PE for $O(^1D)$, OH, HO_2 and O_3
- 27 reactions, including 9 photodissociations
  - Reaction rates from JPL compilation
  - Photodissociation coefficients calculated
- Later extension: Nitrogen chemistry
  - 5 new species: N, $N(^2D)$, NO, NO_2, N_2
  - 17 new reactions (3 photodissociations)

Photochemical model: implementation in the LMD-MGCM

- Development and testing using 1-D model
  - Collaboration with IAA (Granada, Spain)
- Included in the thermospheric module of LMD-MGCM (Angelats i Coll et al., 2005; González-Galindo et al., 2005)
- Another chemical scheme is used for the lower atmosphere
  - More sophisticated chemistry needed there
  - Similar results obtained in the transition region

Photochemistry: NO nightglow

- $N + O \Rightarrow NO^*$
- N and O atoms formed in the dayside thermosphere, transported to nightside
  - Good tracer of circulation
- Observed by SPICAM (60 orbits)
  - Sampling far from complete
  - Strong variability observed



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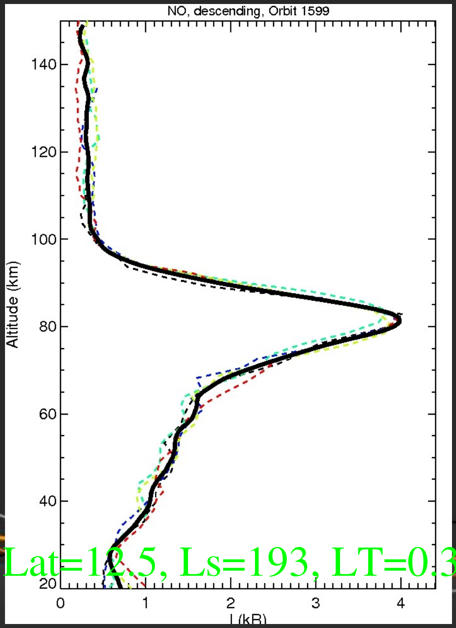
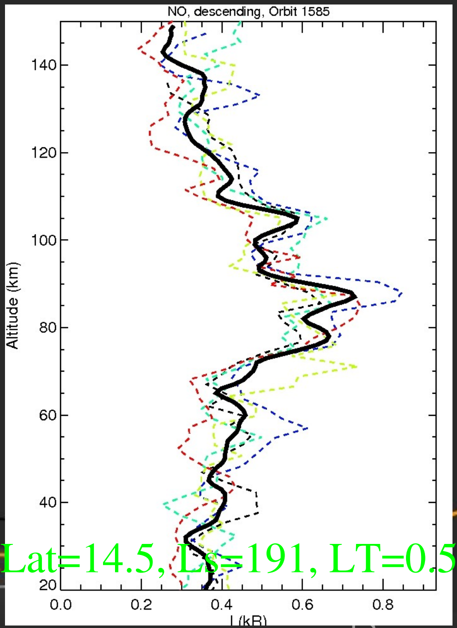
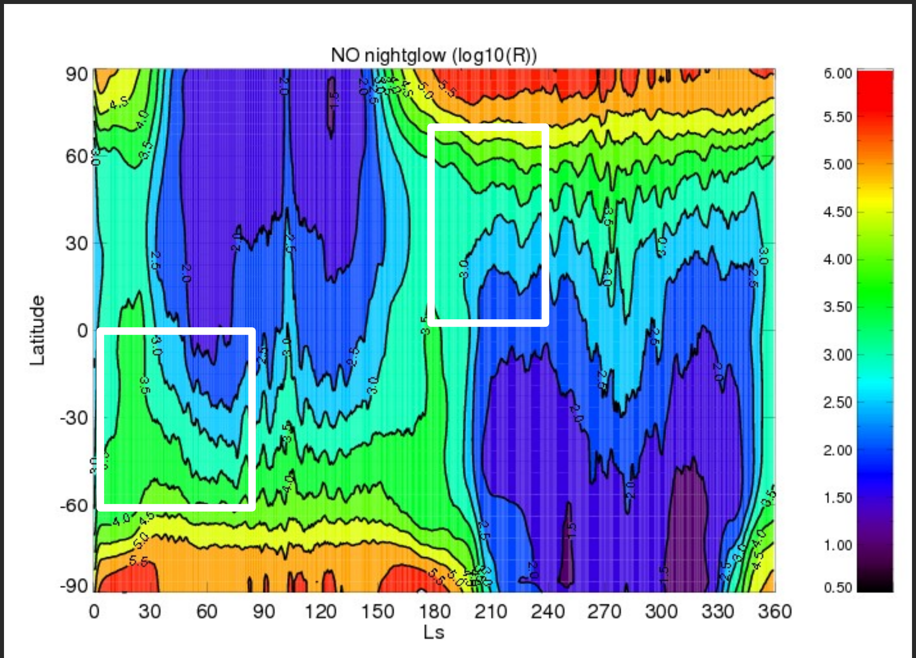
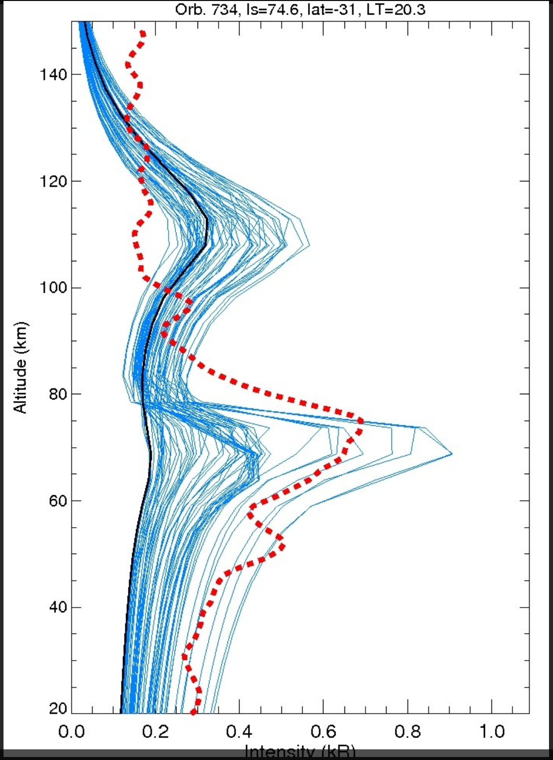




Photochemistry: NO nightglow

- 1 Mars Year simulation with the LMD-MGCM
- Nightglow traced by N and O recombinations

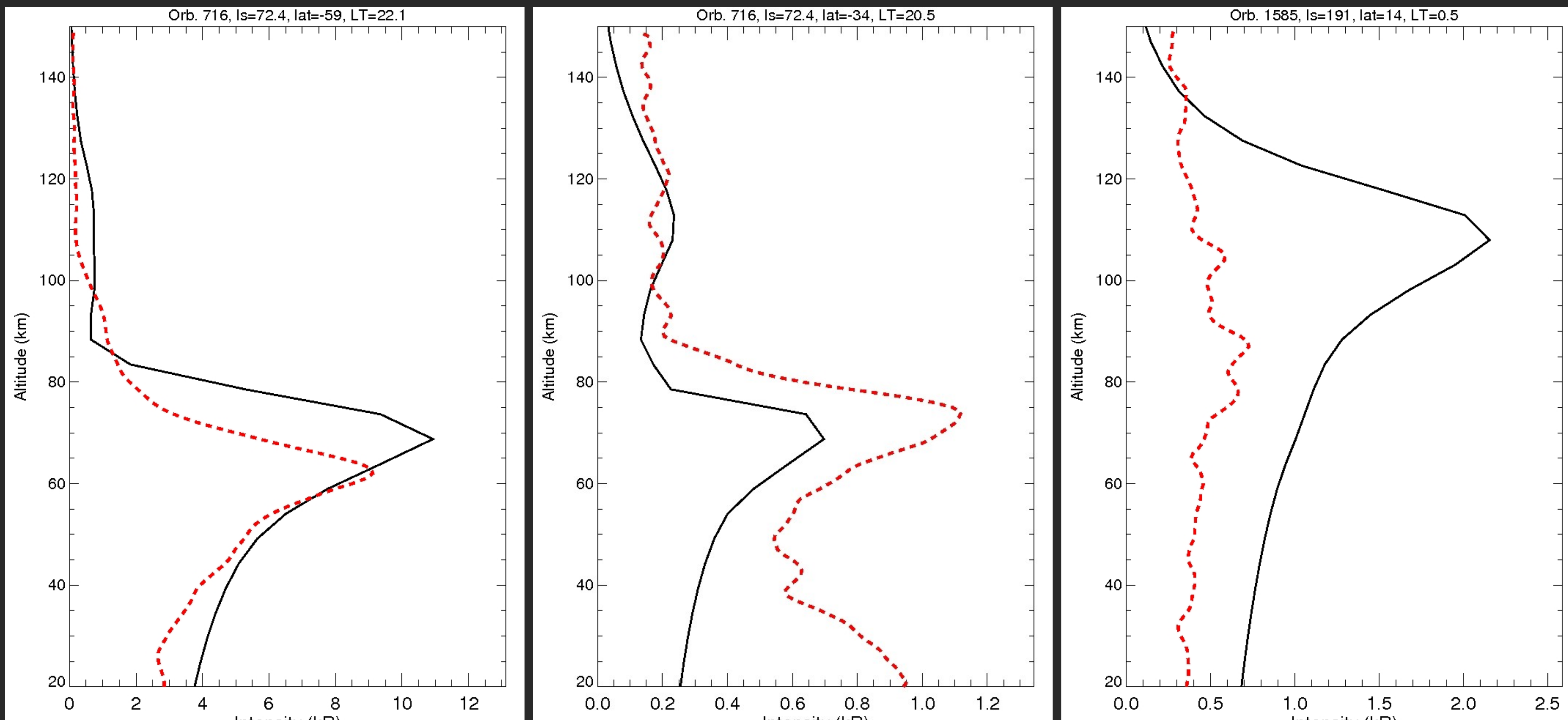




- Higher intensity at poles during autumn/winter
- Strong longitudinal variability predicted

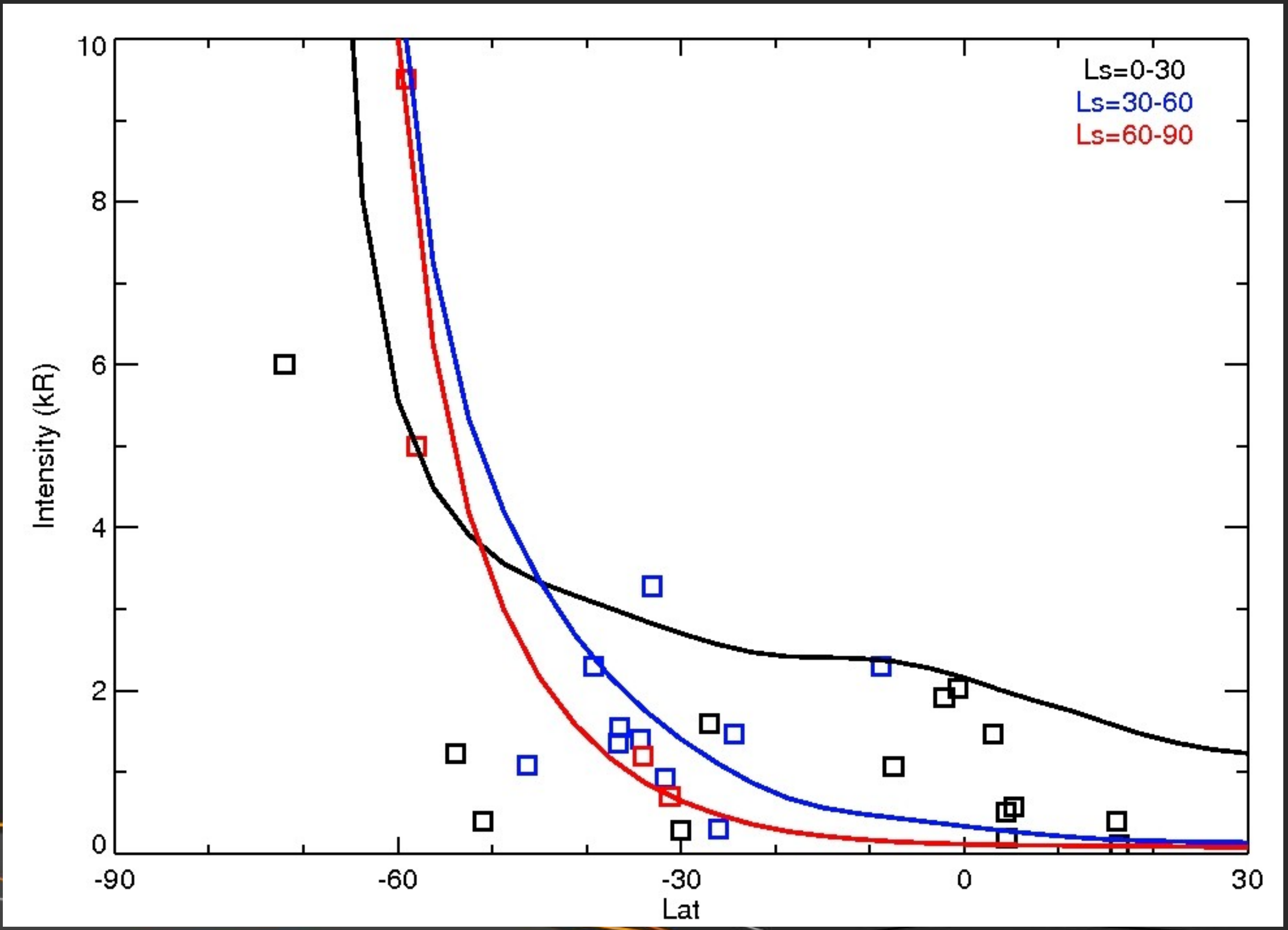
Photochemistry: NO nightglow

- Peak to peak comparison



Photochemistry: NO nightglow

Comparison of tendencies: Int vs Lat, Ls=0-90



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Comparison tendencies:
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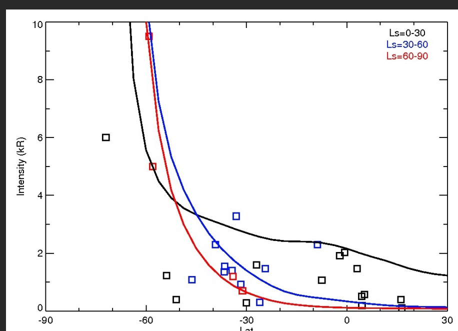

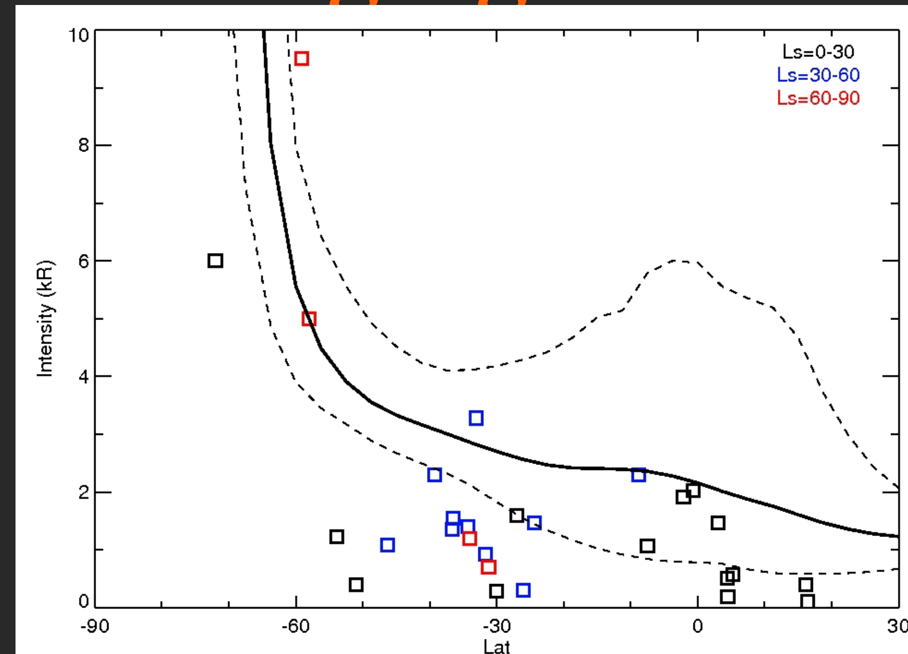

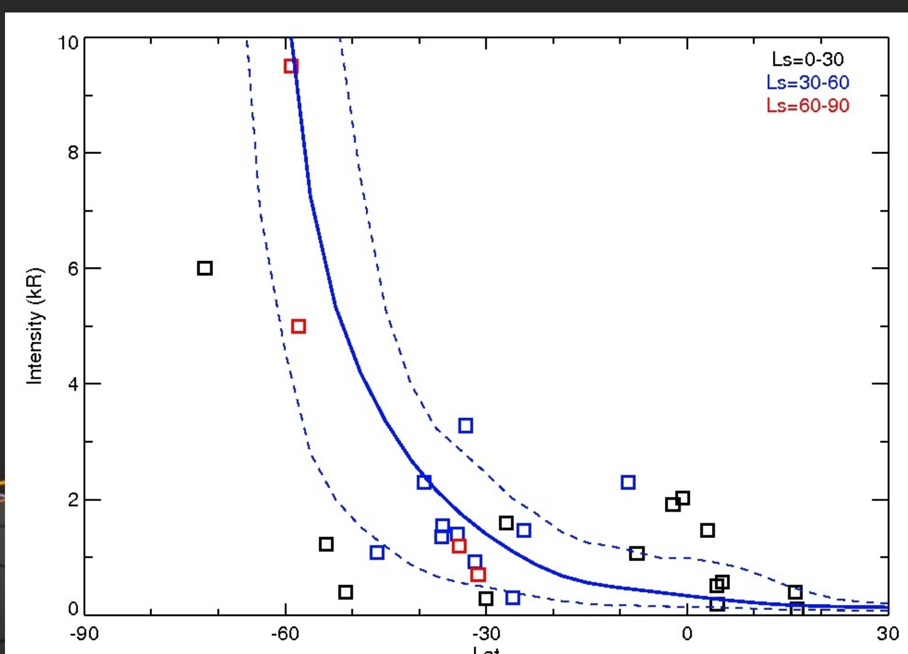

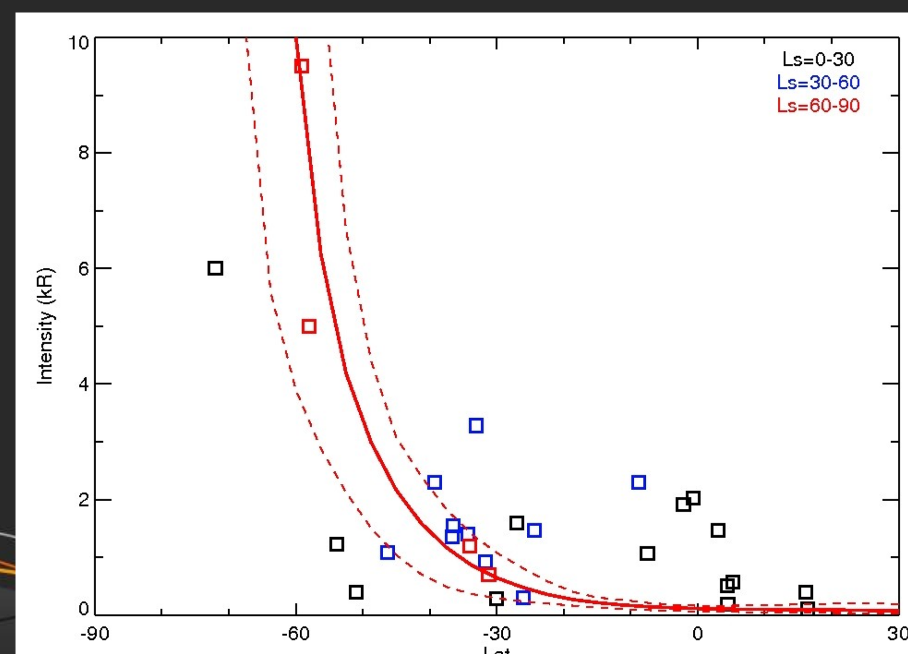

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Ionosphere

- Why studying the Martian ionosphere with a GCM?
  - Mars ionosphere sounded by different instruments
  - Valuable information can be gained about background neutral atmosphere
  - Coupling with the solar wind, escape,...
- But LMD-MGCM only included neutral chemistry
  - Extended chemical module (ions) developed; collaboration IAA (Granada, Spain)/LMD (Paris, France)

Ionosphere in the LMD-MGCM: what is in

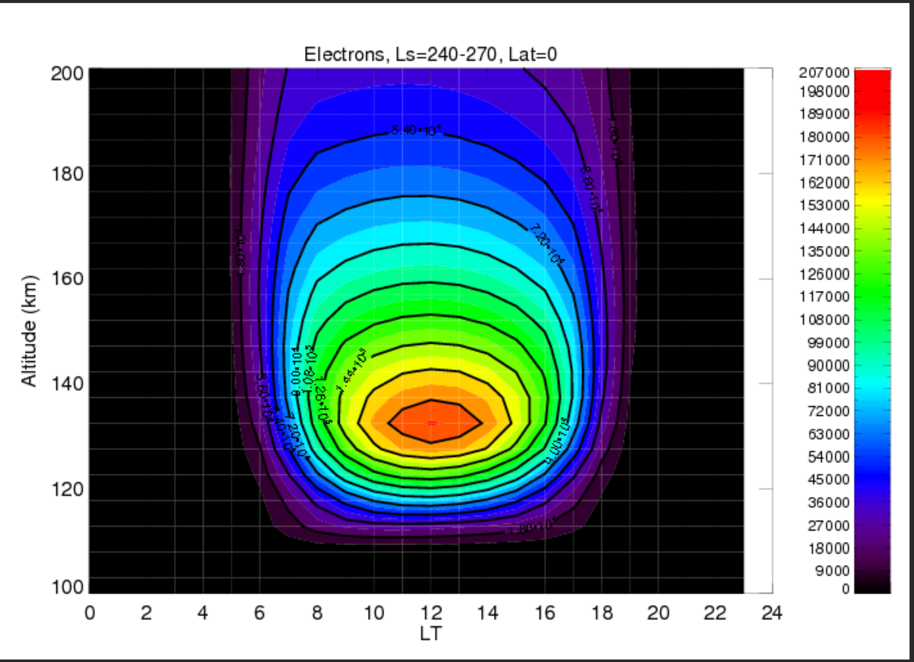
- 9 new ionospheric species (+ electrons)
  - O_2^+, O^+, CO_2^+, CO^+, N^+, NO^+, N_2^+, H^+, C^+
  - Plasma globally neutral
  - Photochemical equilibrium for most ions
- 37 new ionospheric reactions
  - Rates from JPL compilation
  - 11 photoionizations, rates calculated by the model

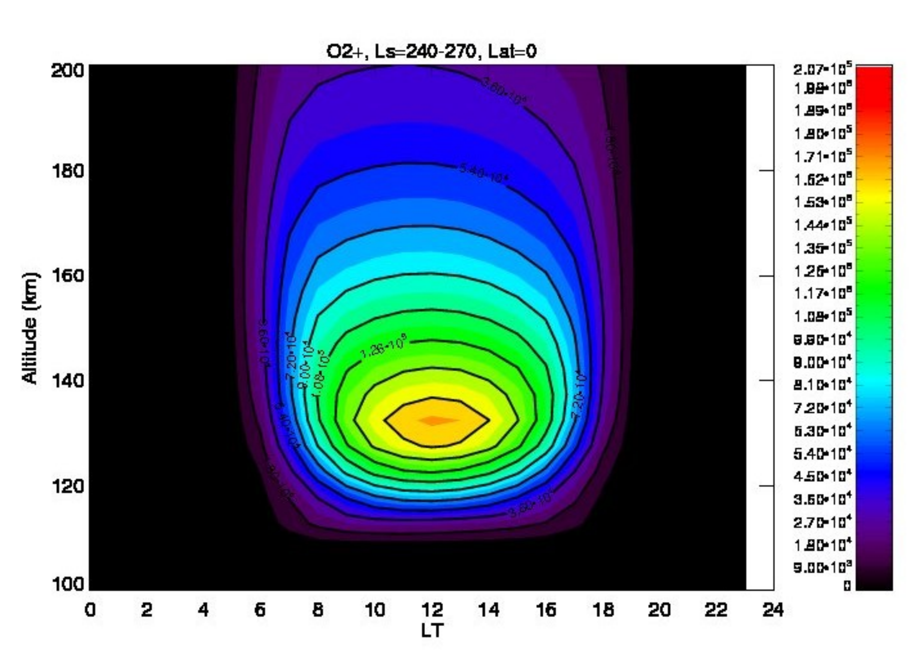
Ionosphere in the LMD-MGCM: what is NOT in

- Advection of ions/electrons by general circulation
  - Work in progress, to be finished soon
- Secondary photoionizations by photoelectrons
  - Important for the secondary ionization peak
  - Parameterization by Simon & Witasse, to be included
- Plasma transport
  - Limits the validity to the photochemical region (<180km)
- Effects of magnetic fields

Ionosphere in the LMD-MGCM: results

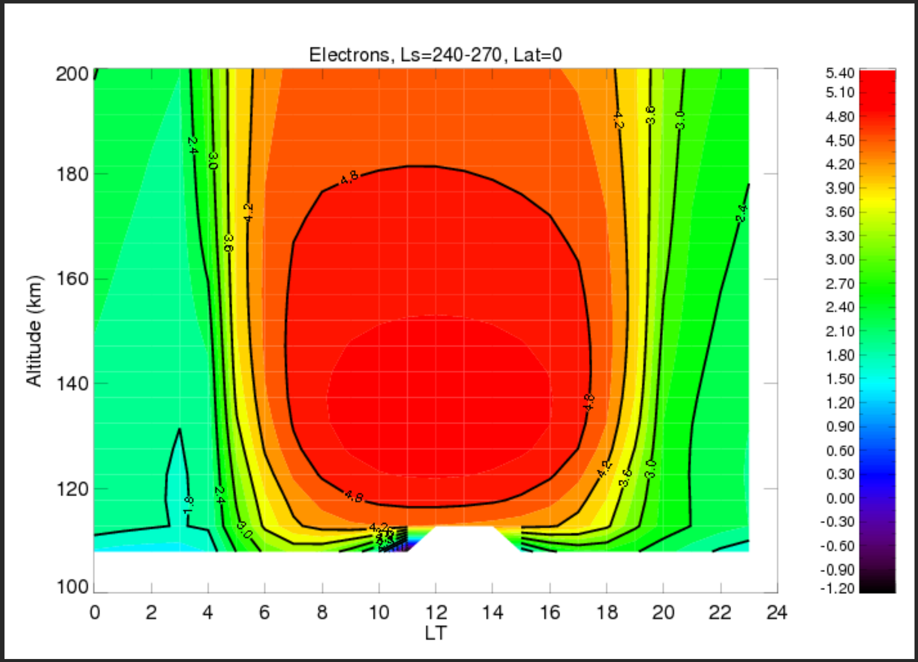
Electron concentration, Ls=240-270, equator

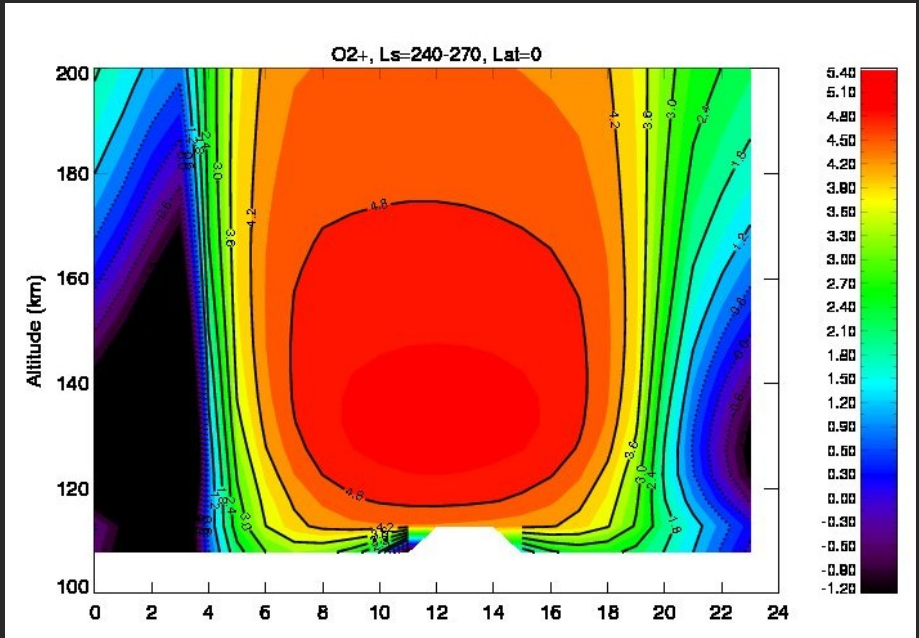


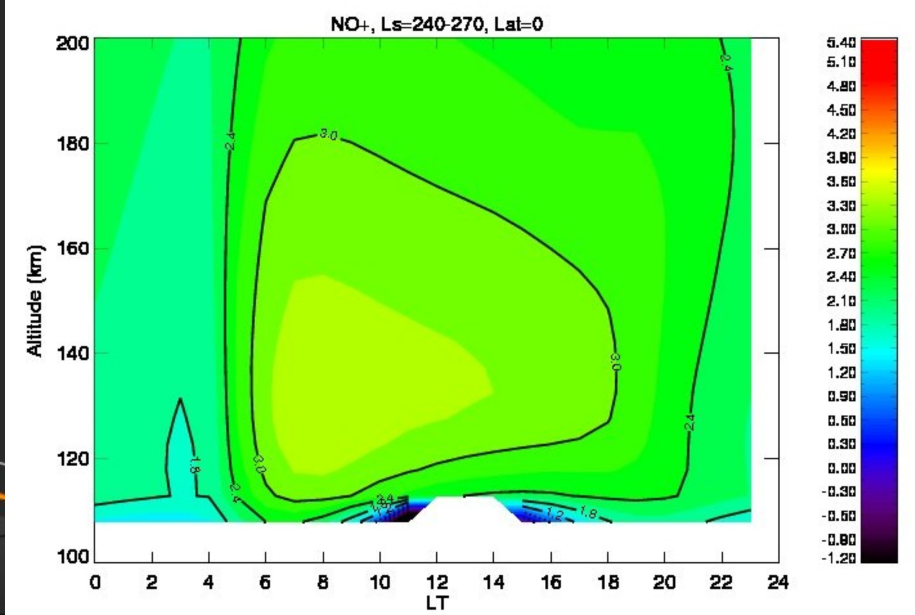


- Electron peak at ≈135 km, ≈2e5 electrons/cm3
- O2+ dominates ionosphere
  - In agreement with observations

Ionosphere in the LMD-MGCM: results



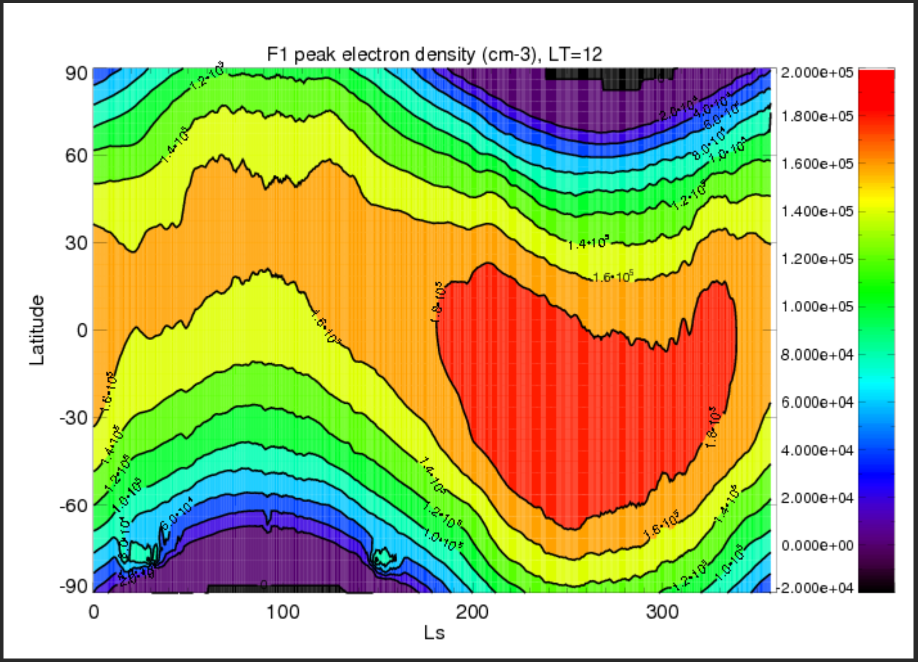


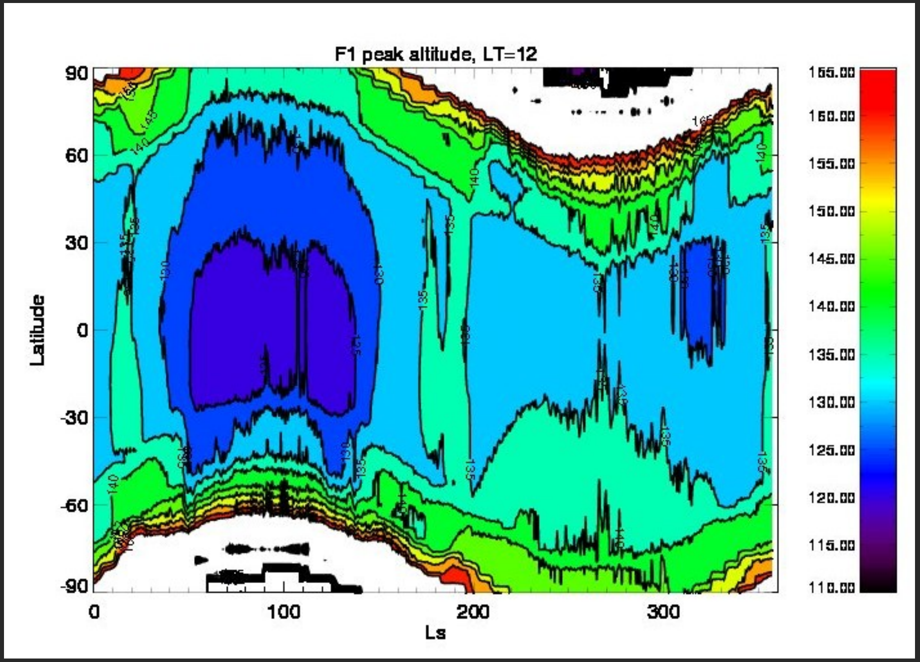


- Weak nighttime ionosphere predicted
  - Due to NO+ long lifetime
  - Result to be confirmed!

Ionosphere in the LMD-MGCM: results

1 Martian year simulation, electron peak variation





- Maximum electronic concentration in perihelion
- Peak altitude varies between 125 and 140 km
  - Qualitative agreement with observations

Summary

- Temperature/density predicted by the model validated against data
  - Temperature overestimated in the mesopause/lower thermosphere
- Chemical module included in the LMD-MGCM
  - Good agreement with NO nightglow observations
- Ionospheric now included
  - First comparisons show good qualitative agreement with observation