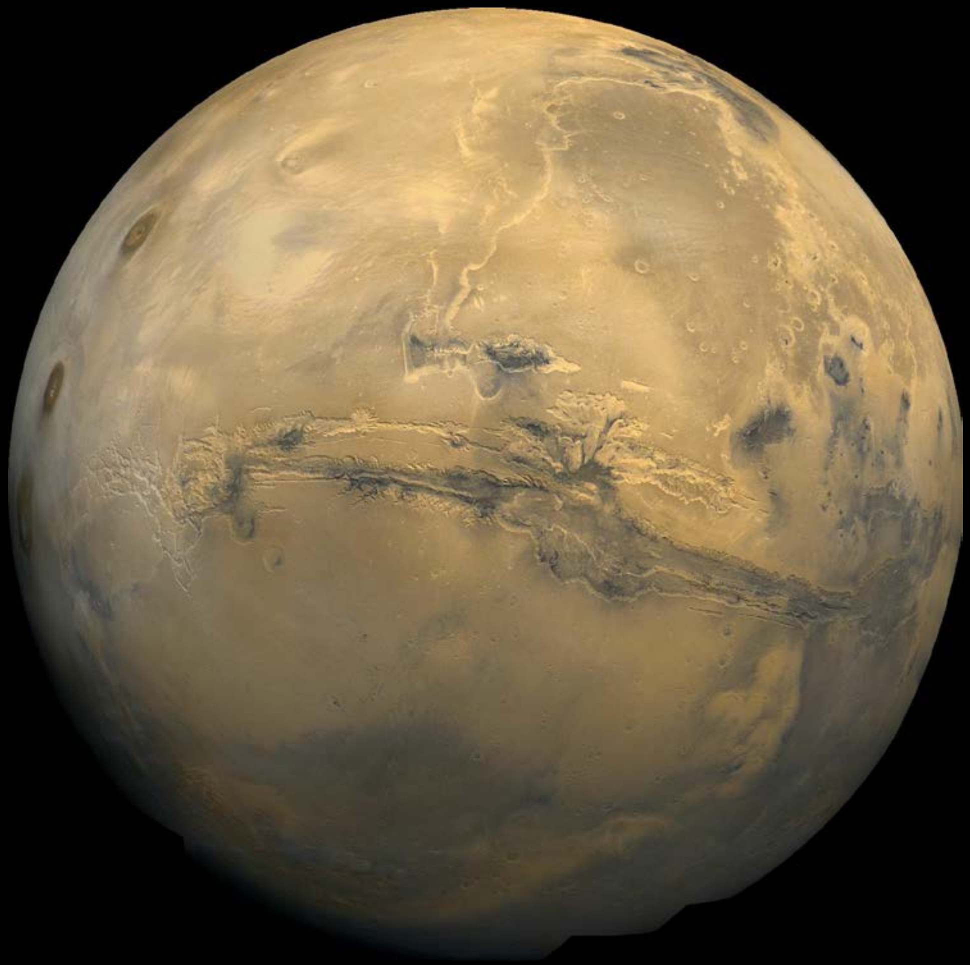
ICME effects at Mars:
energy deposition and feedback from enhanced thermosphere



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Eslab Symposium, ESTEC, May 16, 2018

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ICMEs at Mars

- Why do we care?
  - ICMEs increase the ionospheric escape.
  - ICMEs were more common in the early solar system (Jakosky et al. 2015).
- The interaction with the solar wind changes significantly during the passage of the disturbed solar wind (e.g. Jakosky et al. 2015, Dong et al. 2015, Curry et al. 2015, Ma et al. 2018, Harada et al. 2018).
- Since the arrival of MAVEN in September 2014, two big events have been recorded by the spacecraft instrumentation.

Effect on thermosphere

- Fang et al. (2013): effect of enhanced precipitation of O+ pickup ions in the thermosphere (MTGCM + MCPIT).
- Three cases:
  - Quiet: 4 cm-3, 400 km/s, 3 nT Parker spiral.
  - Active: 4 cm-3, 1200 km/s, 3 nT (By only).
  - Extreme: 20 cm-3, 1000 km/s , 20 nT (By only).
- Thermospheric heating: ~9 K (quiet), ~15 K (active), ~60 K (extreme).

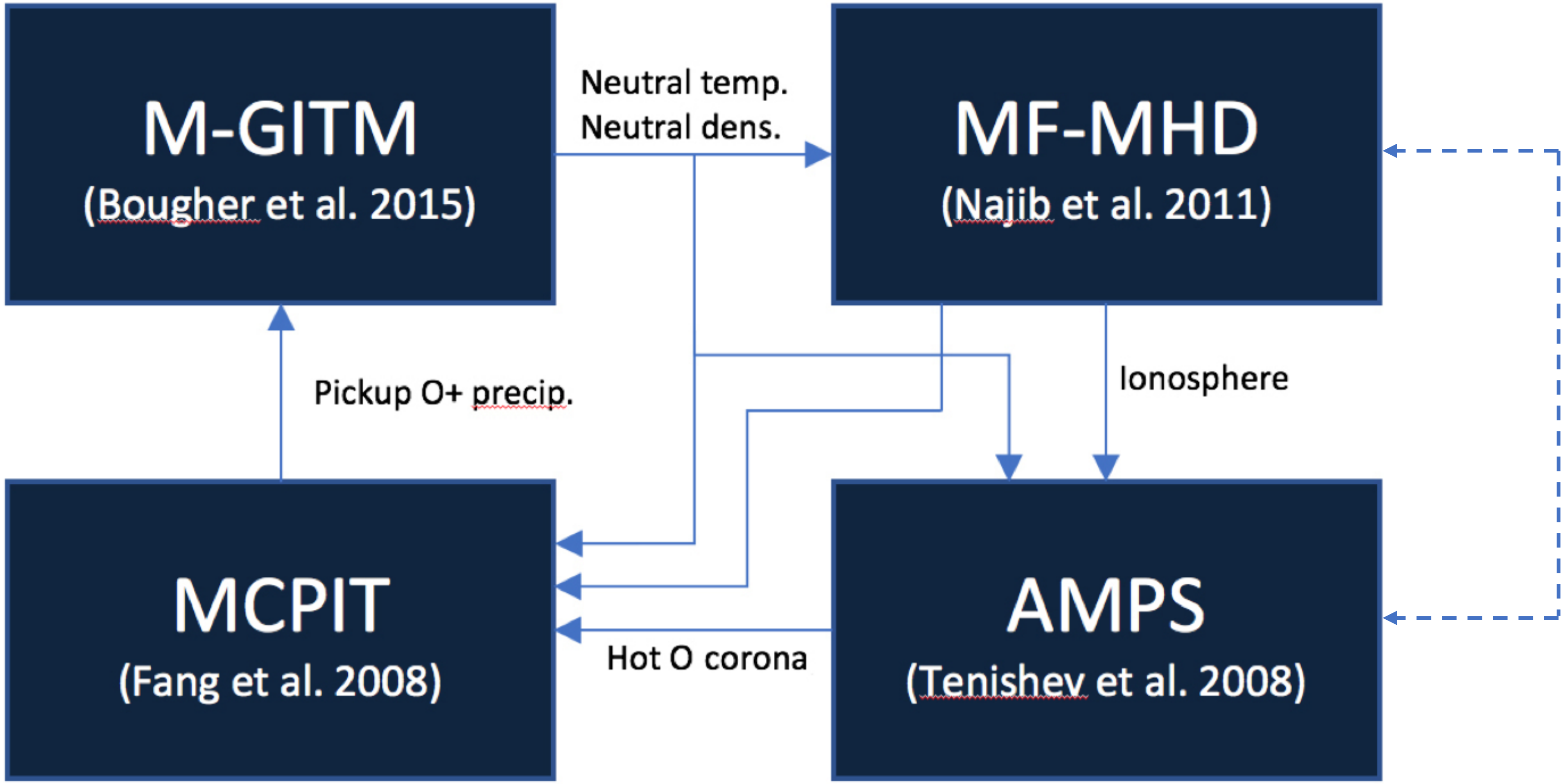
Effect of heating on escape?

- Enhanced pickup ion precipitation affects sputtering (e.g. Wang et al. 2015).
- What role does it play in the ion escape through the thermospheric heating?

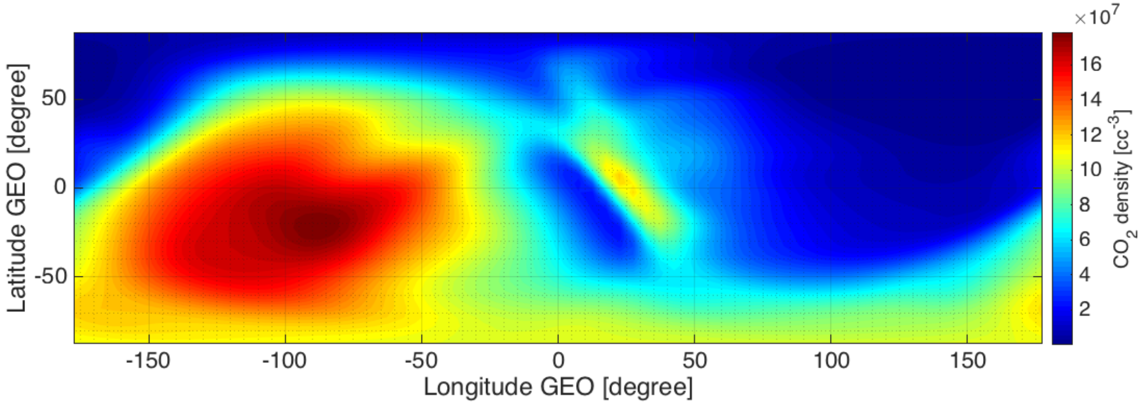
The models

- M-GITM: produces neutral densities and temperatures based on season and solar fluxes (run for March 08, 2015).
- MF-MHD: produces electromagnetic fields and ion densities based on neutral atmosphere and solar input.
- AMPS: produces hot oxygen corona based on neutral and ion densities and solar flux.
- MCPIT: produces map of heat flux from precipitation oxygen ions from hot corona.

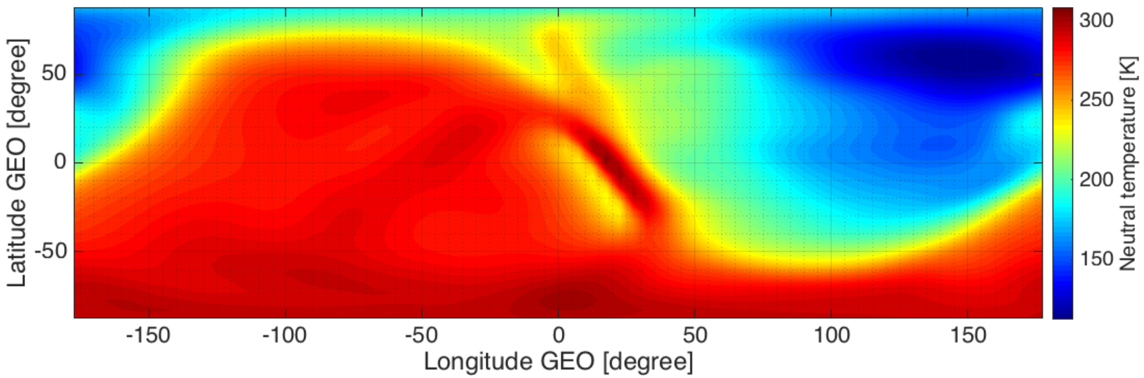
The models


M-GITM
(Bougher et al. 2015)
Neutral temp.
Neutral dens.
MF-MHD
(Najib et al. 2011)
Pickup O+ precip.
Ionosphere
MCPIT
(Fang et al. 2008)
Hot O corona
AMPS
(Tenishev et al. 2008)

The models: M-GITM (neutral atmosphere)

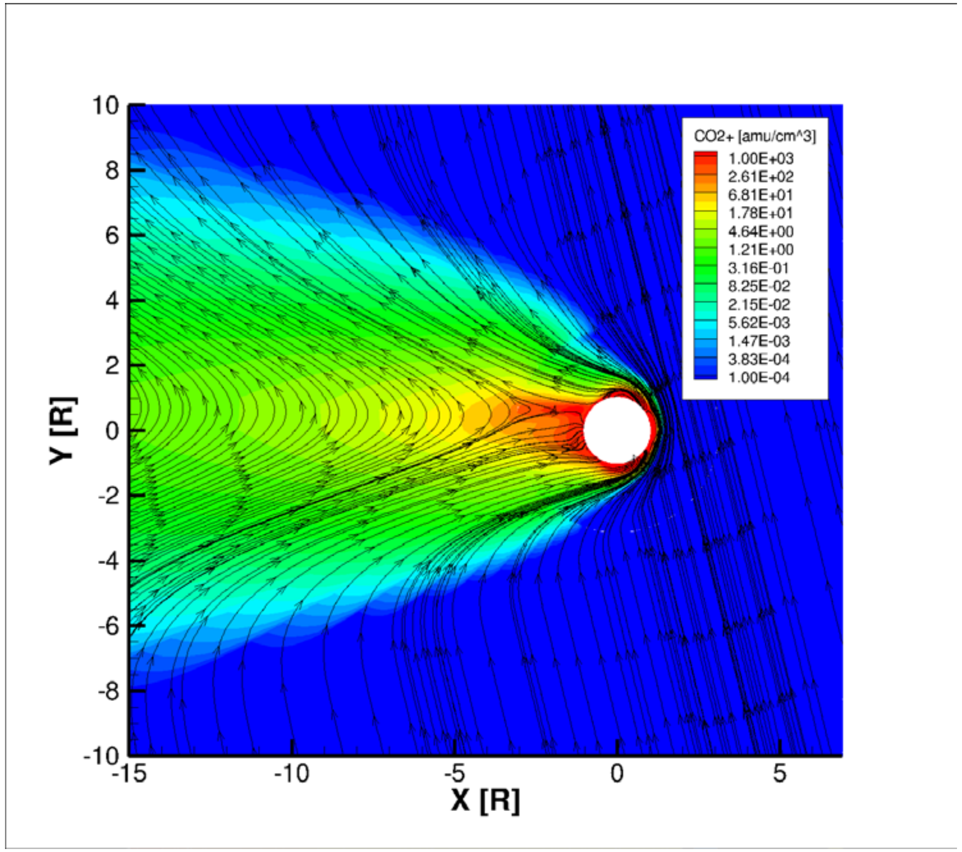


CO_2 density at exobase (198 km)

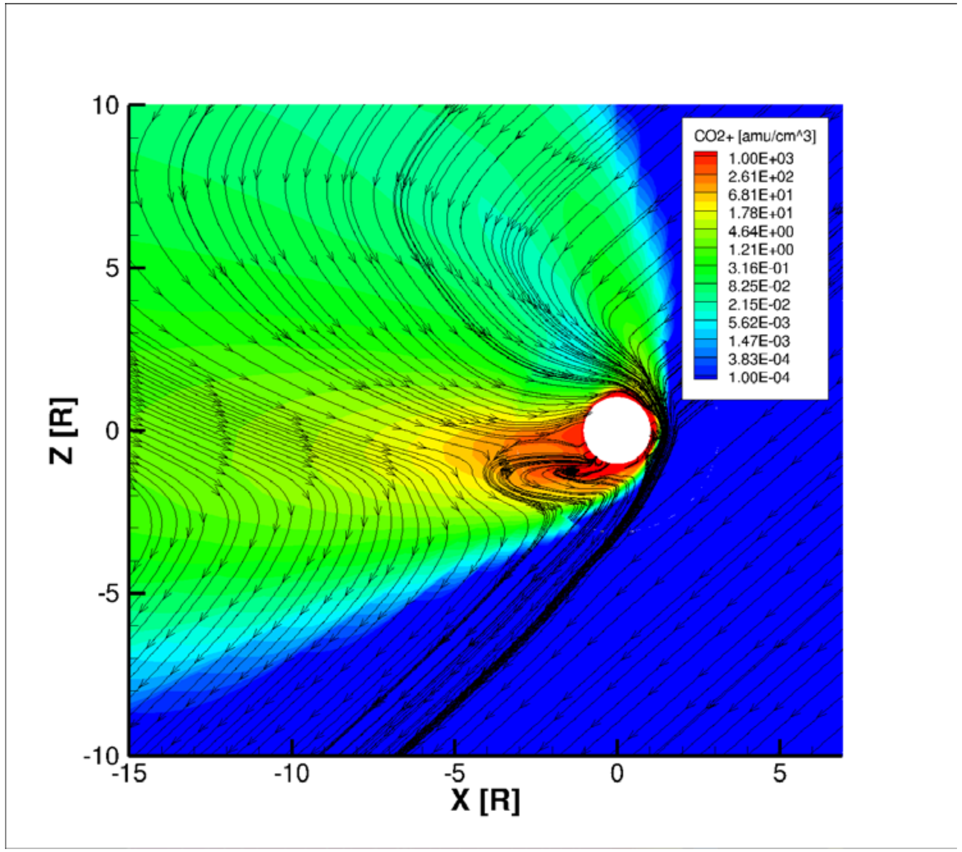


Neutral temperature at exobase (198 km)

The models: MF-MHD (EM fields and ion densities)

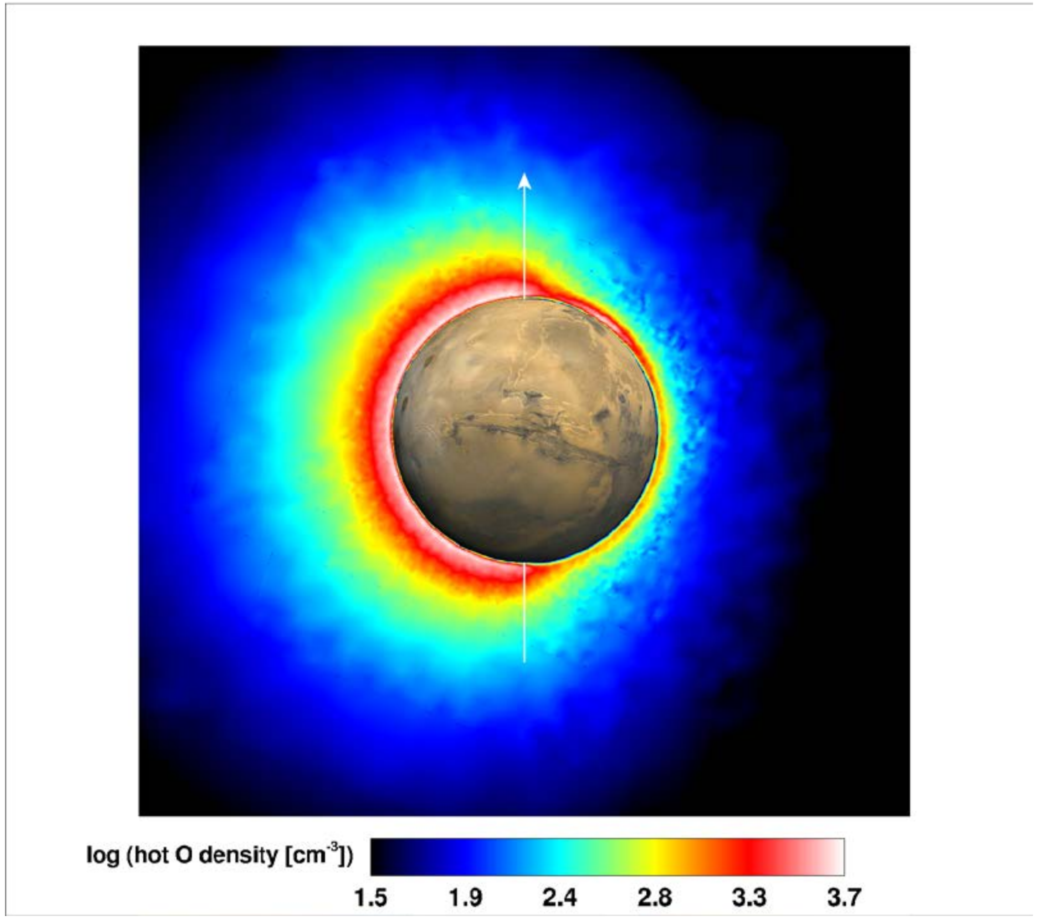


O_2^+ density and magnetic field lines (equatorial plane)



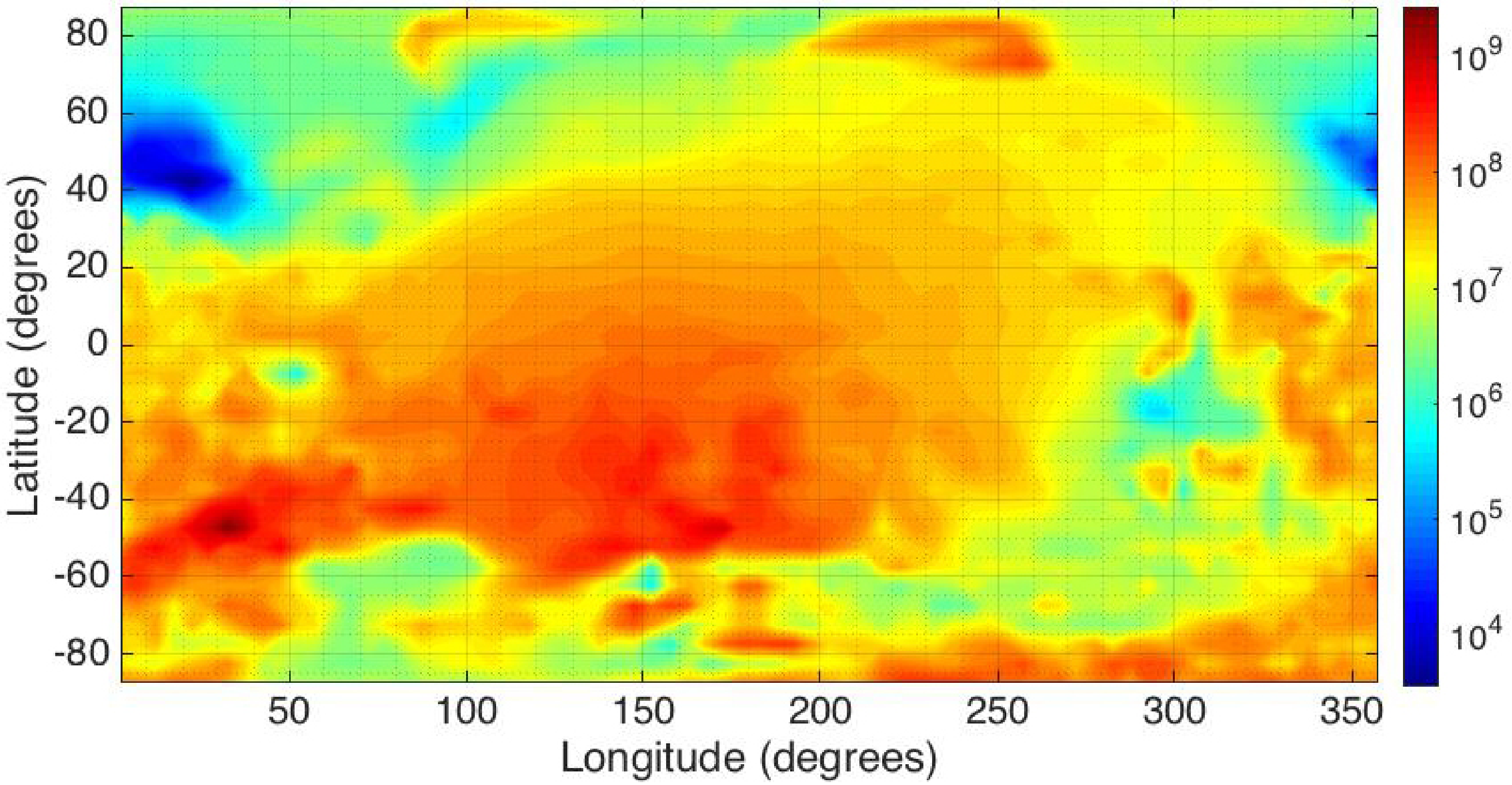
O_2^+ density and magnetic field lines (side view)

The models: AMPS (hot O corona)



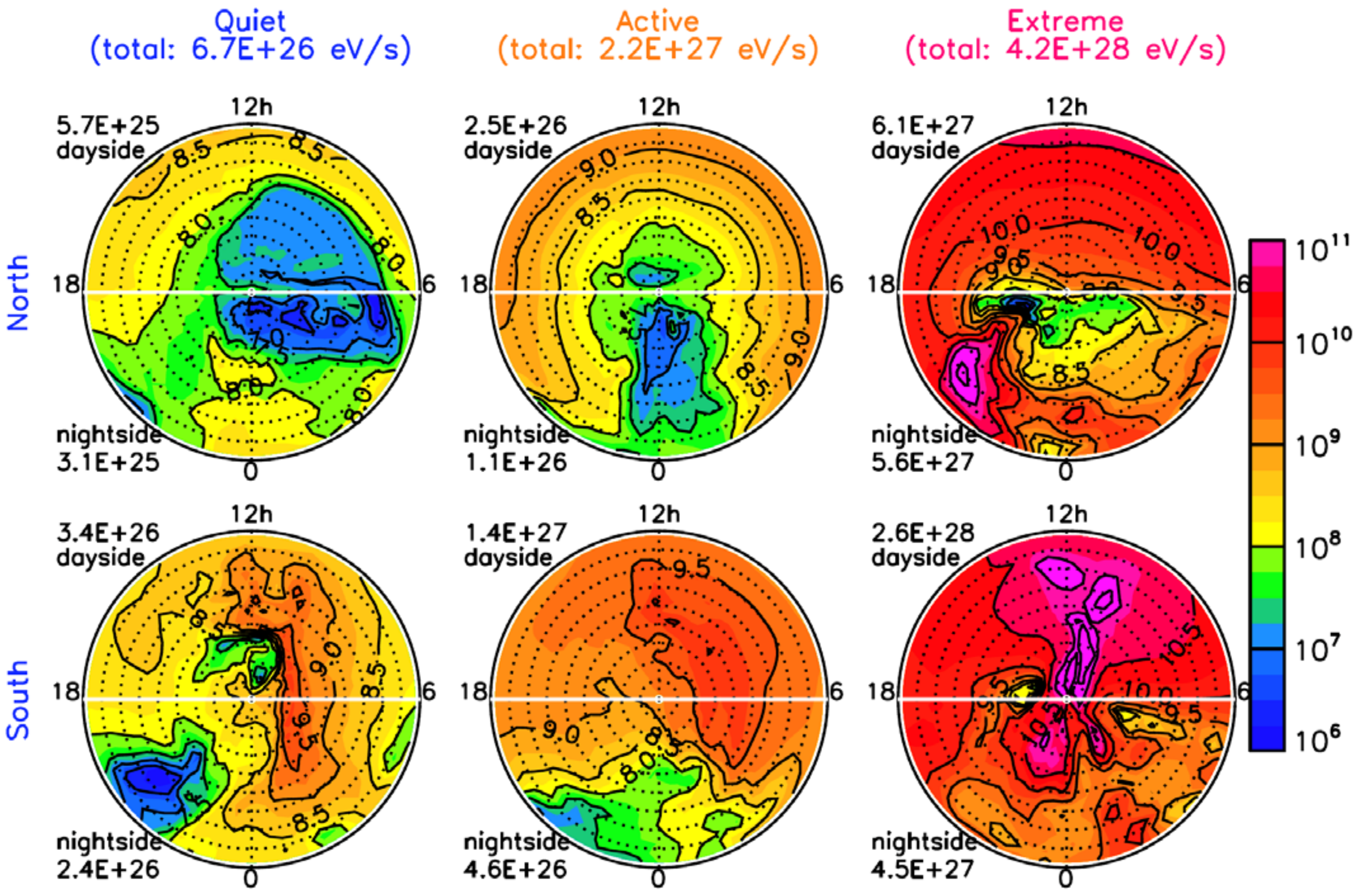
Hot O distribution around the planet
(source of pickup ions)

The models: MCPIT (O^+ precipitation and heating)



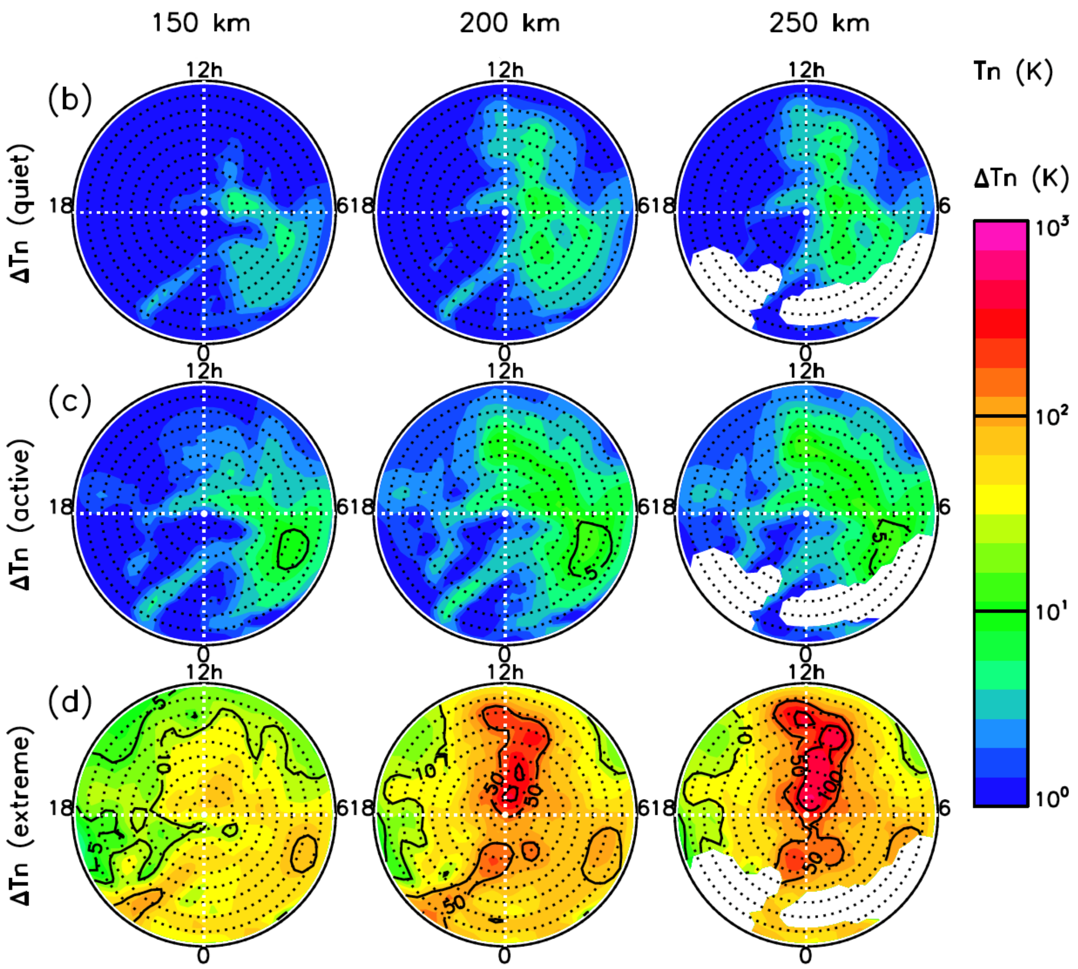
O^+ ion fluxes reaching the exobase

Initial results (active case, Fang et al. 2013)



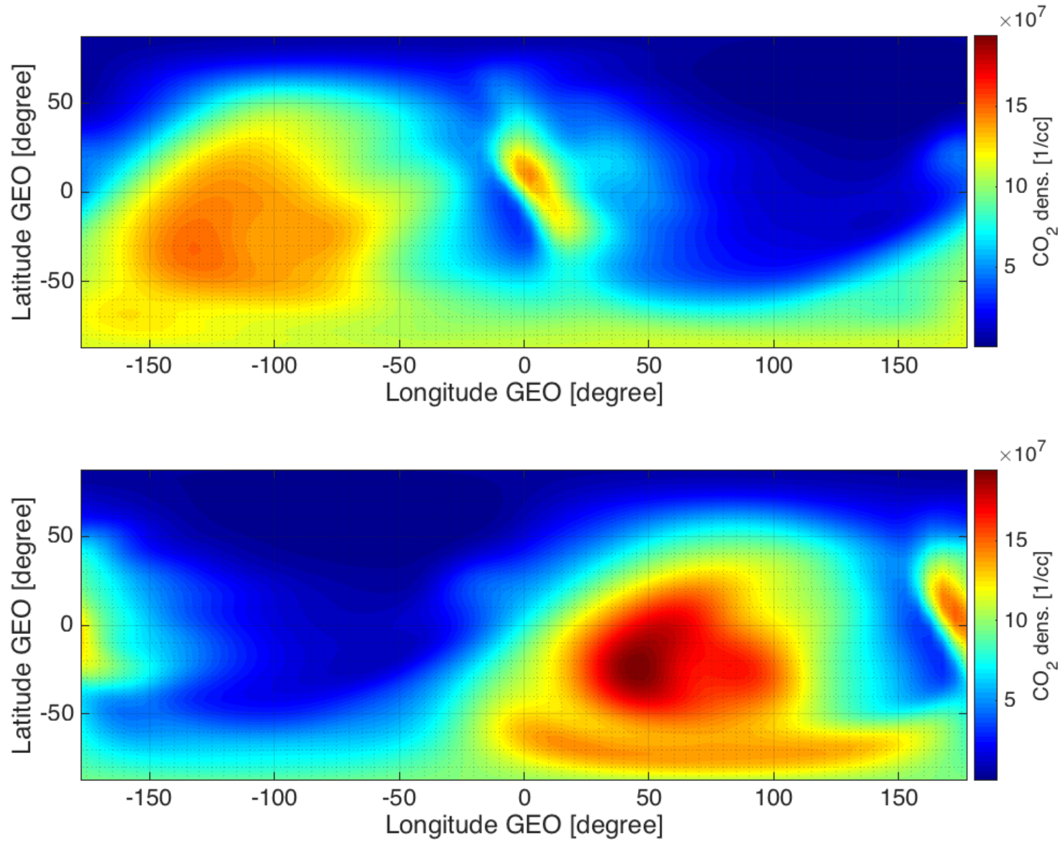
Pickup O^+ precipitation from Fang et al. (2013)

Initial results (active case, Fang et al. 2013)



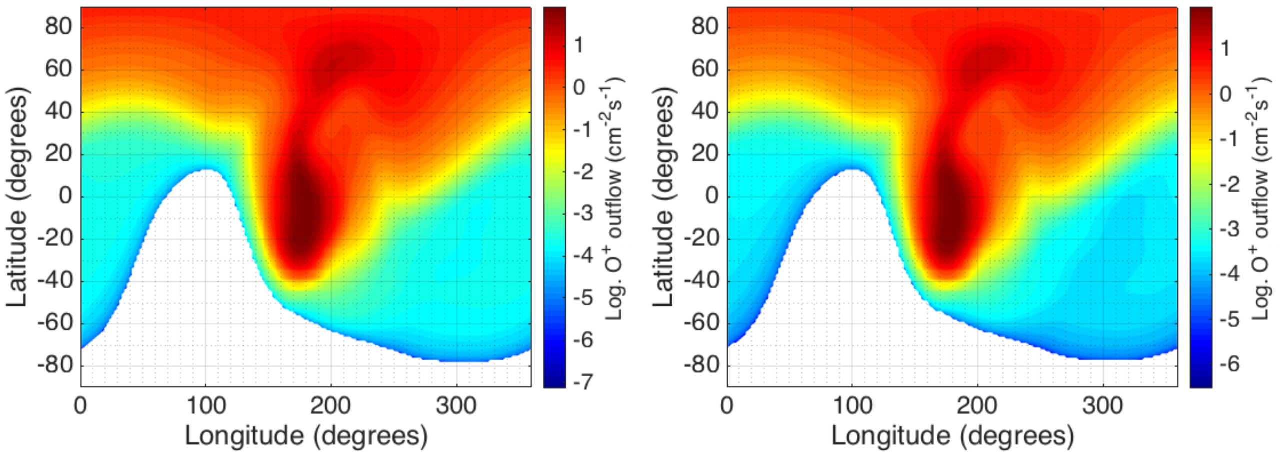
Variation in thermospheric temperatures due to precipitation of O^+ ions

Initial results (active case, Fang et al. 2013)



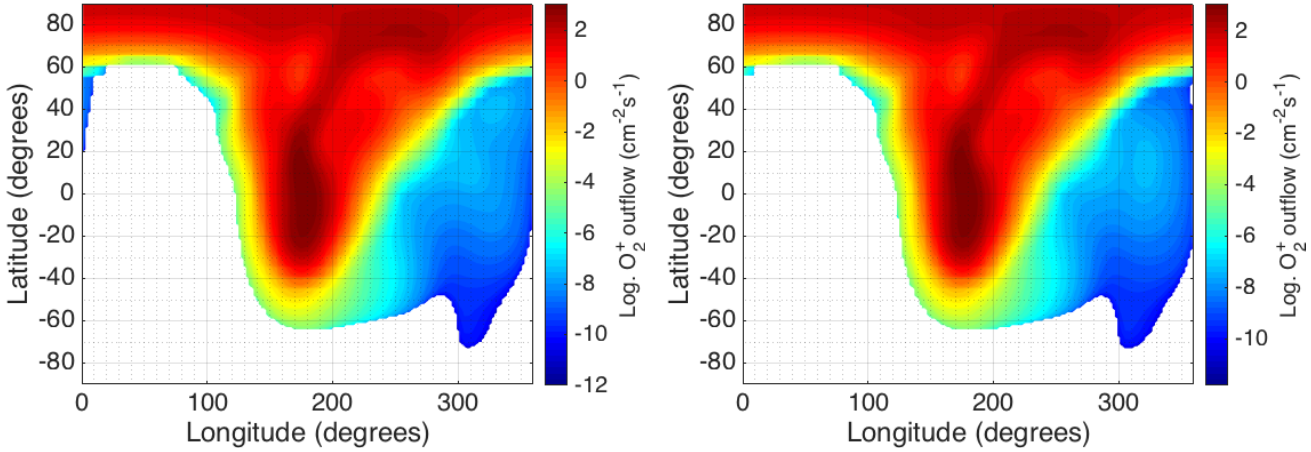
Variation in CO_2 densities at the exobase (~x2)

Initial results (active case, Fang et al. 2013)



O^+ escape at 6 R_M (3.8%)

O_2^+ escape at 6 R_M (2.5%)



Comparison with ICME events

Case	Density	Speed	Field magnitude
Quiet (Fang et al. 2013)	4	400	3
Active (Fang et al. 2013)	4	1200	3
Extreme (Fang et al. 2013)	20	1000	20
March 2015 (Dong et al. 2015)	11.9	830	~5 (~18)
September 2017 (Ma et al. 2018)	12	824	~10

Conclusions

- Extra heating source from precipitating pickup ions produces increase in thermospheric temperature of a few degrees.
- This extra heating increases the neutral density at the nominal exobase altitude.
- Heavy ion escape increases by ~2.5% (O_2^+) and ~3.8% (O^+).
- Extreme case currently collapsing due to time step issues.
- Future: simulate several steps of an ICME event (March 2015 or September 2017) to evaluate evolution of ion escape.