Atmospheric Distribution of Methane on Mars

Sébastien Viscardy

Frank Daerden

Lori Neary

“Methane on Mars” KISS Workshop, Pasadena (USA) – June 14th, 2016

sebastien.viscardy@oma.be

Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

aeronomie.be

Plan of the presentation

- Simulations of the behavior of methane in the atmosphere of Mars after surface release
- Implications on previous and future observations
- Perspectives: simulating source and sink processes

General context

- Mumma *et al.*, Science (2009): detection of a plume of methane
- Mischna *et al.*, PSS (2011): model study of the behavior of this plume (Mischna *et al.*, PSS, 2011)
- Other GCM studies also focused on the horizontal spreading of methane (Lefèvre and Forget, Nature, 2009; Holmes *et al.*, Icarus, 2015)

- NOMAD onboard the ExoMars Trace Gas Orbiter (TGO) mission will provide the first vertical profiles of methane

Purpose of our model study

<u>Main question:</u> how does the methane evolve *<u>vertically</u>* in the atmosphere during the first weeks after surface release?

We focus on:

- the *vertical* distribution
- a short period after release (20 sols)

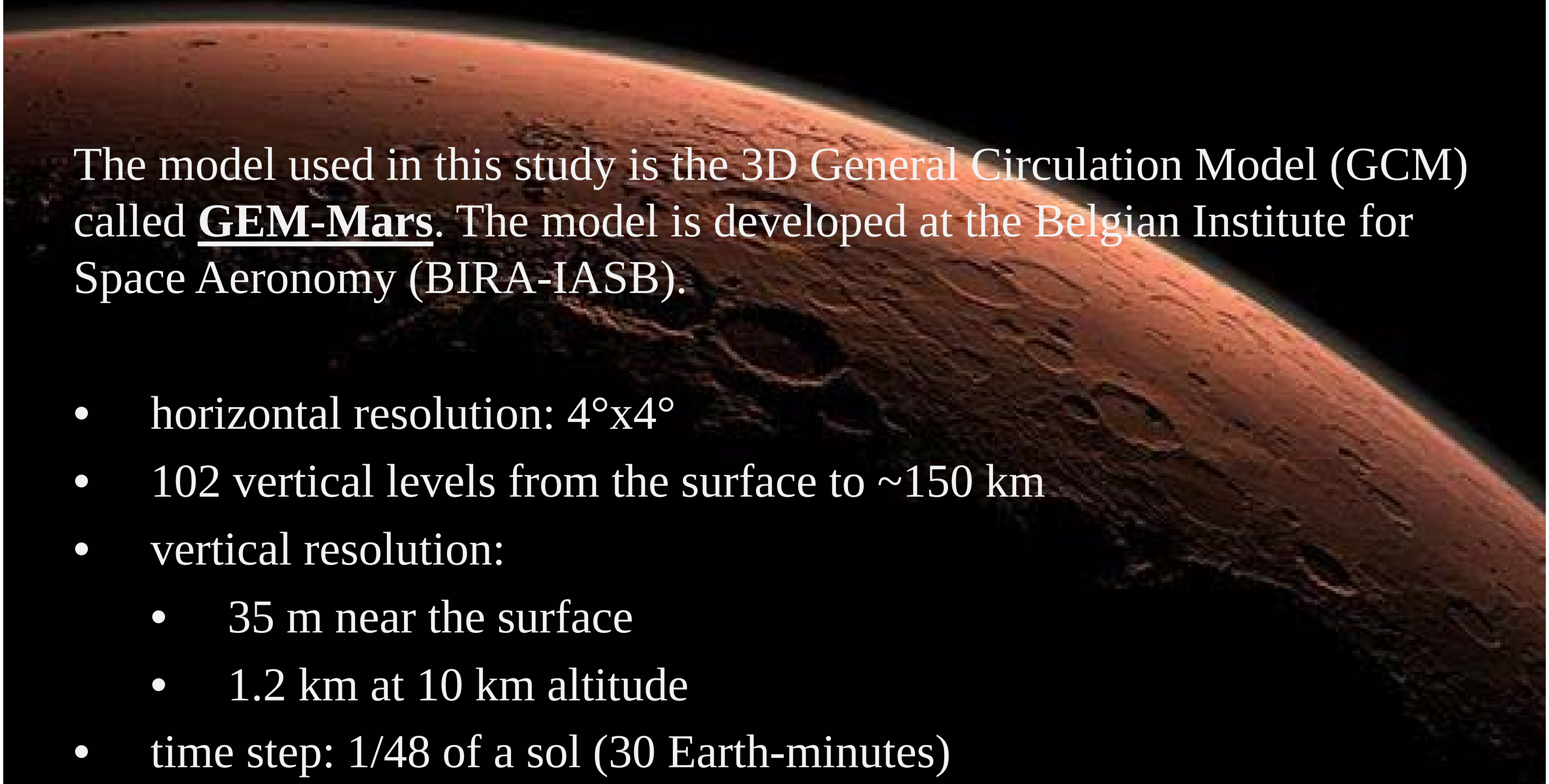
Short period (20 sols) vs. estimated lifetime of CH_4 (~300 years):

➔Methane is considered as an inactive tracer

➔ **No loss processes (neither chemistry nor other sink processes)**

Ref.: Viscardy *et al.*, “Formation of layers of methane in the atmosphere of Mars after surface release”, Geophys. Rev. Lett., 43 (2016)

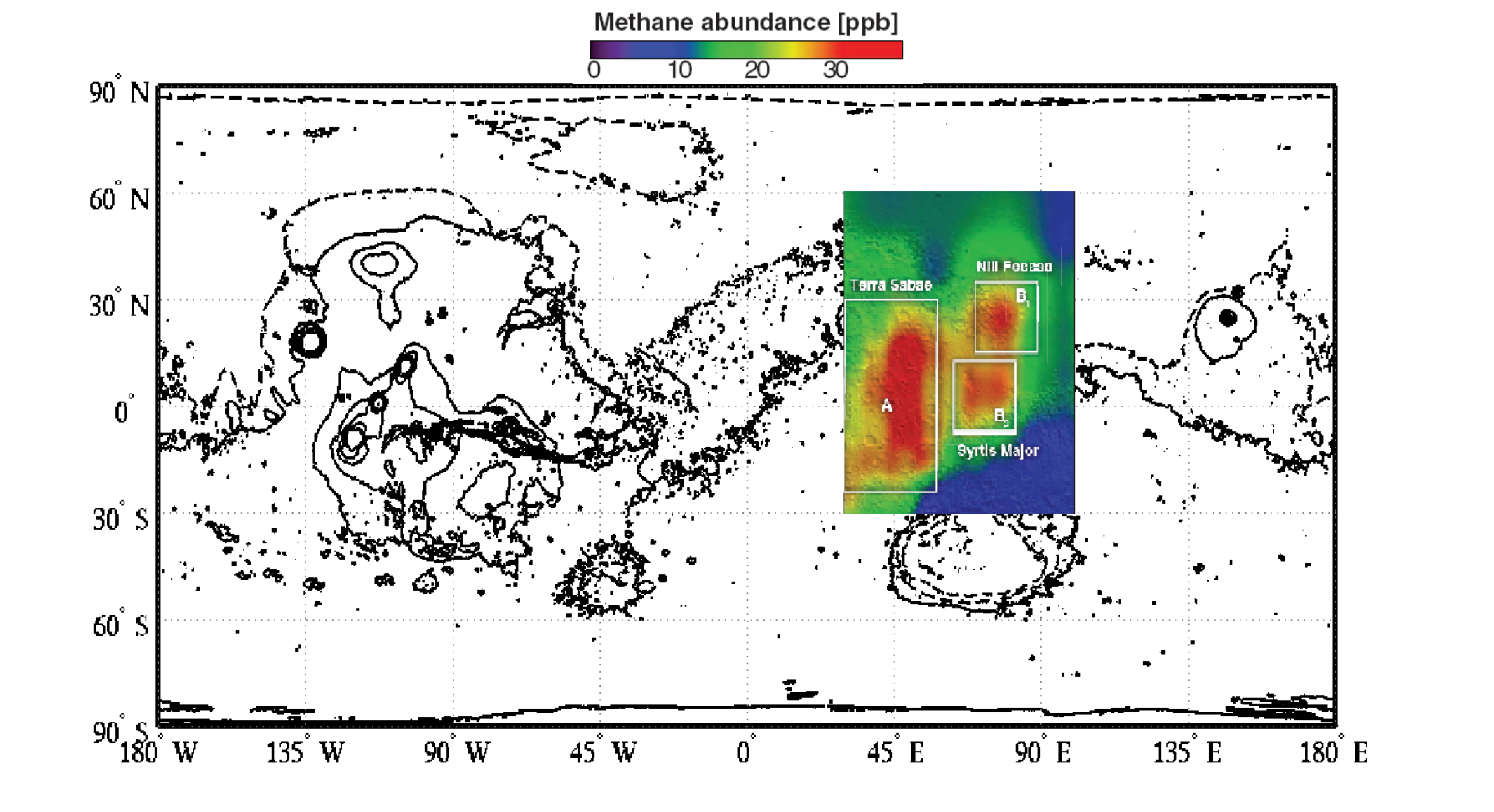
3D GCM (GEM-Mars)



The model used in this study is the 3D General Circulation Model (GCM) called **GEM-Mars**. The model is developed at the Belgian Institute for Space Aeronomy (BIRA-IASB).

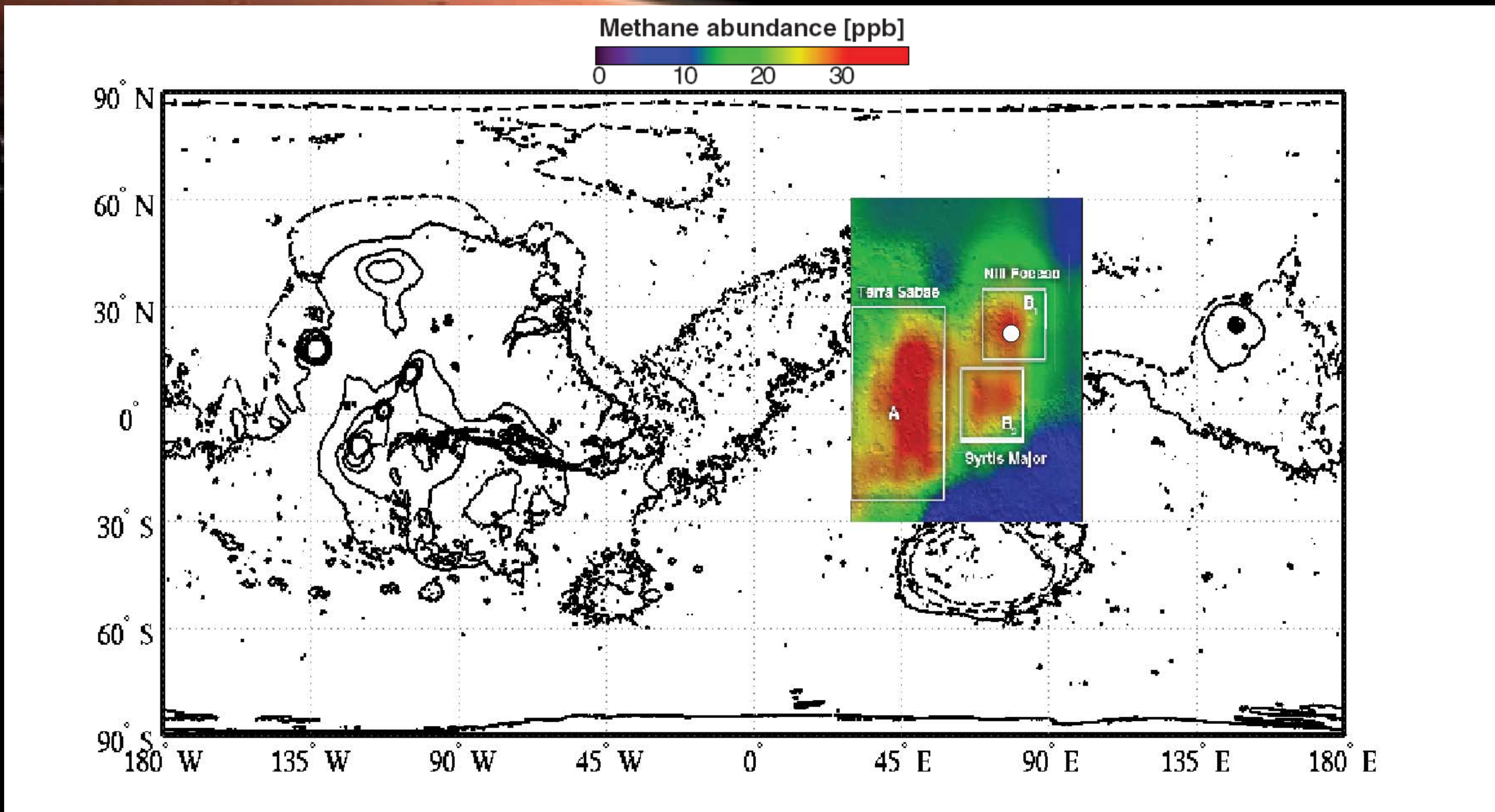
- horizontal resolution: 4°x4°
- 102 vertical levels from the surface to ~150 km
- vertical resolution:
  - 35 m near the surface
  - 1.2 km at 10 km altitude
- time step: 1/48 of a sol (30 Earth-minutes)
- amount of methane released: 5×10^6 kg

Plume of methane observed in 2003



Mumma *et al.*, Science (2009)

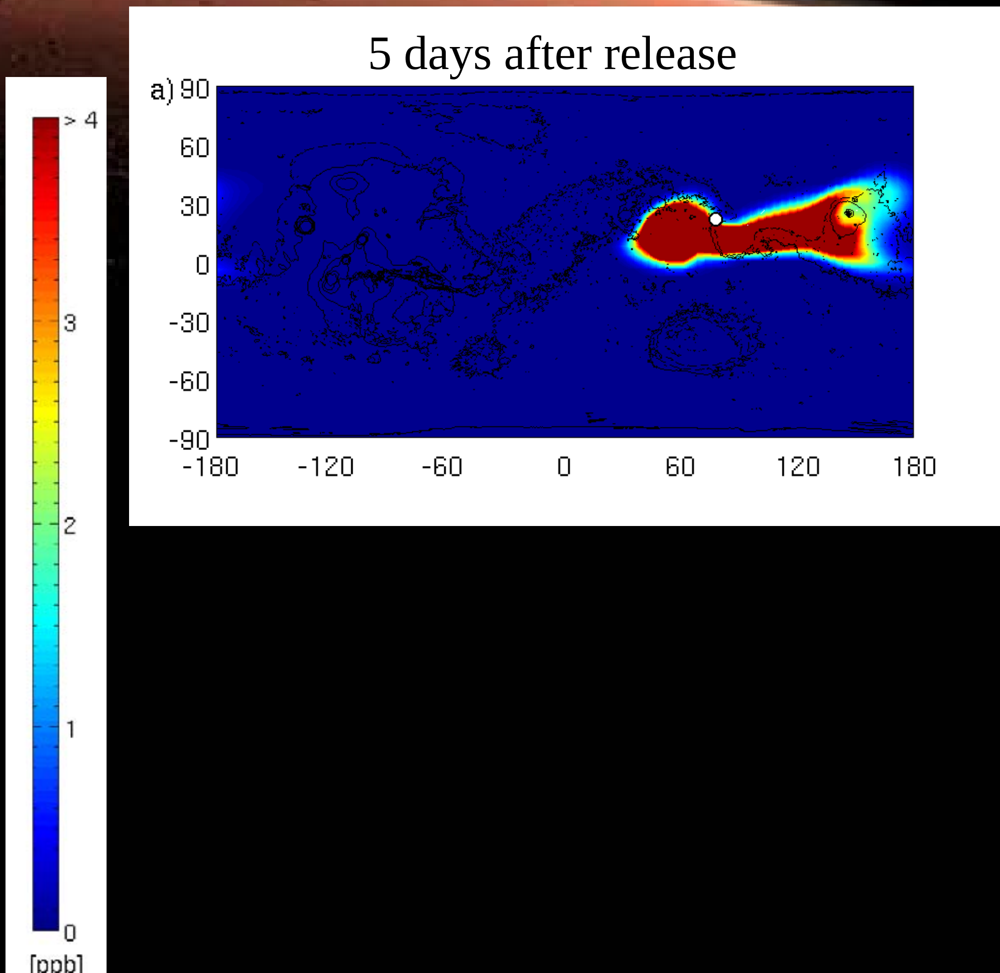
Plume of methane observed in 2003



Mumma *et al.*, Science (2009)

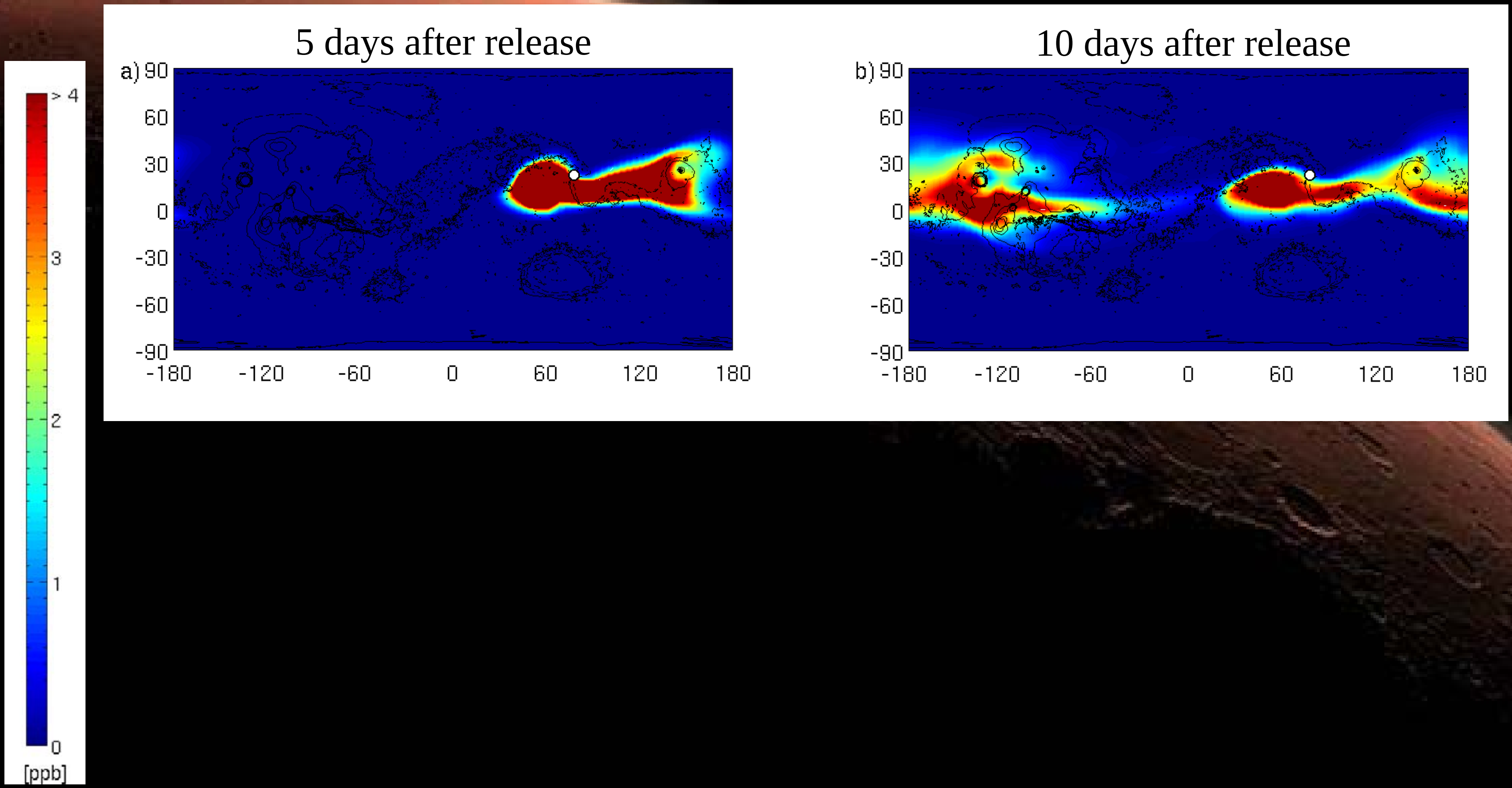
Horizontal evolution of methane

Column averaged mixing ratio



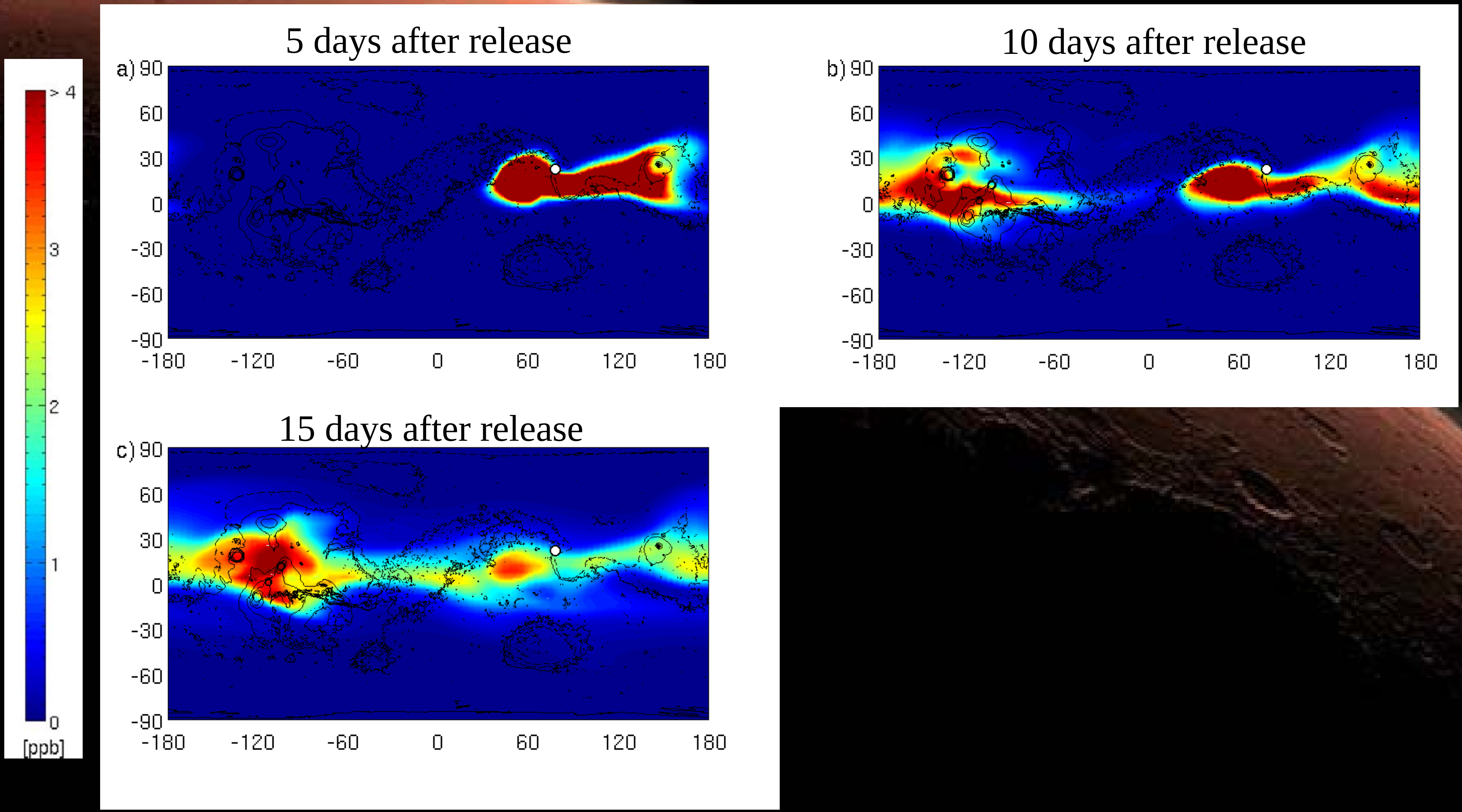
Horizontal evolution of methane

Column averaged mixing ratio



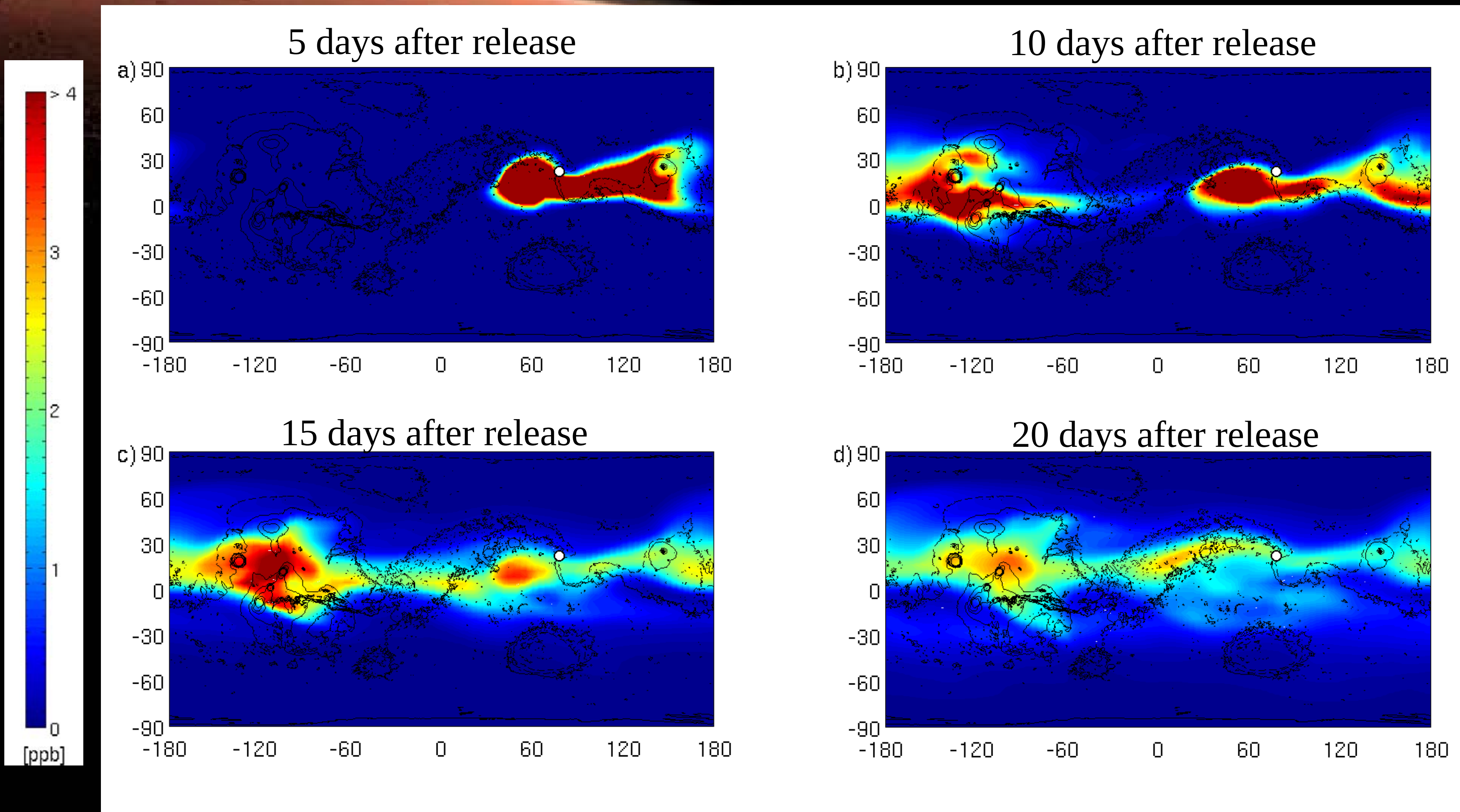
Horizontal evolution of methane

Column averaged mixing ratio

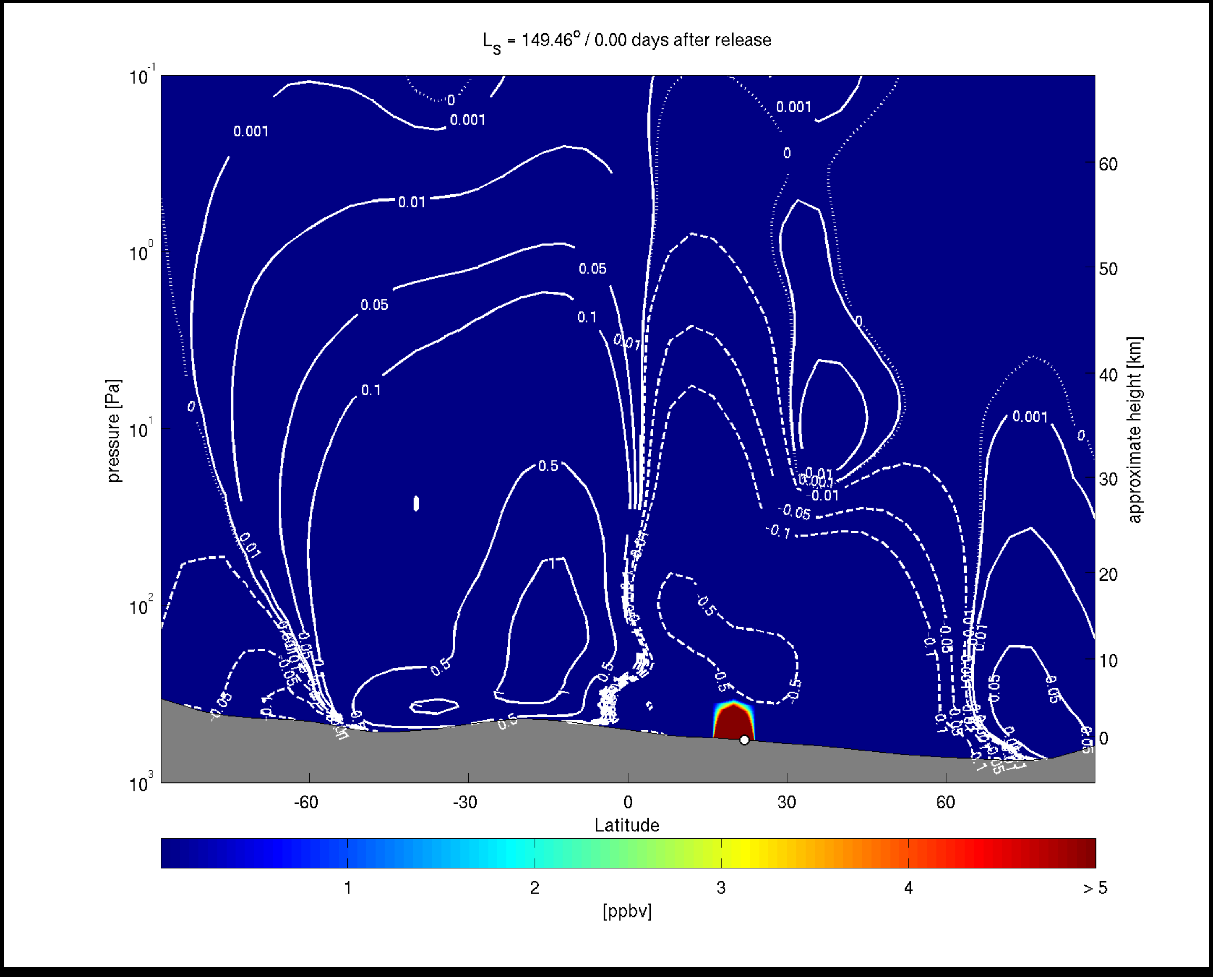


Horizontal evolution of methane

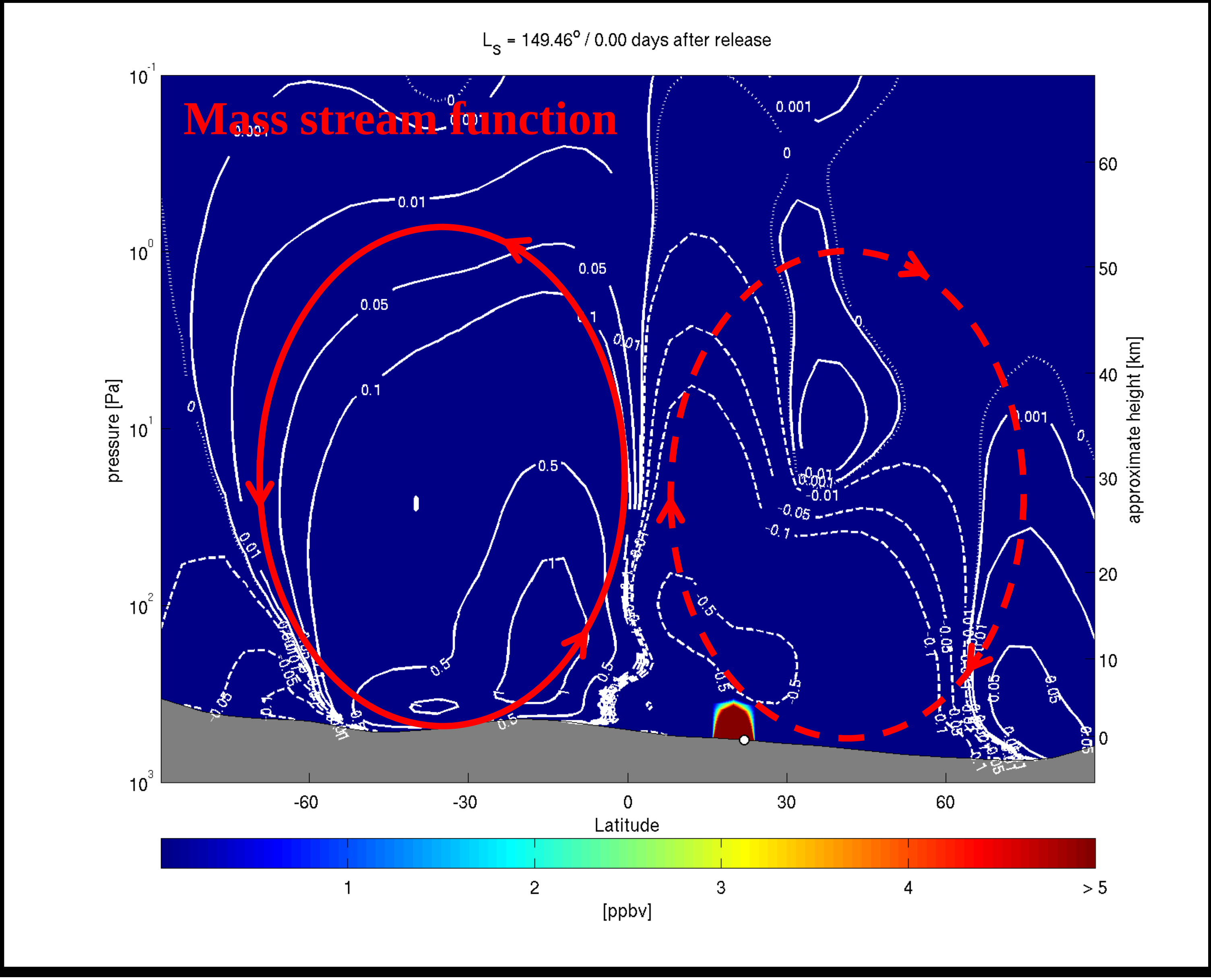
Column averaged mixing ratio



Vertical evolution of methane:
zonal mean

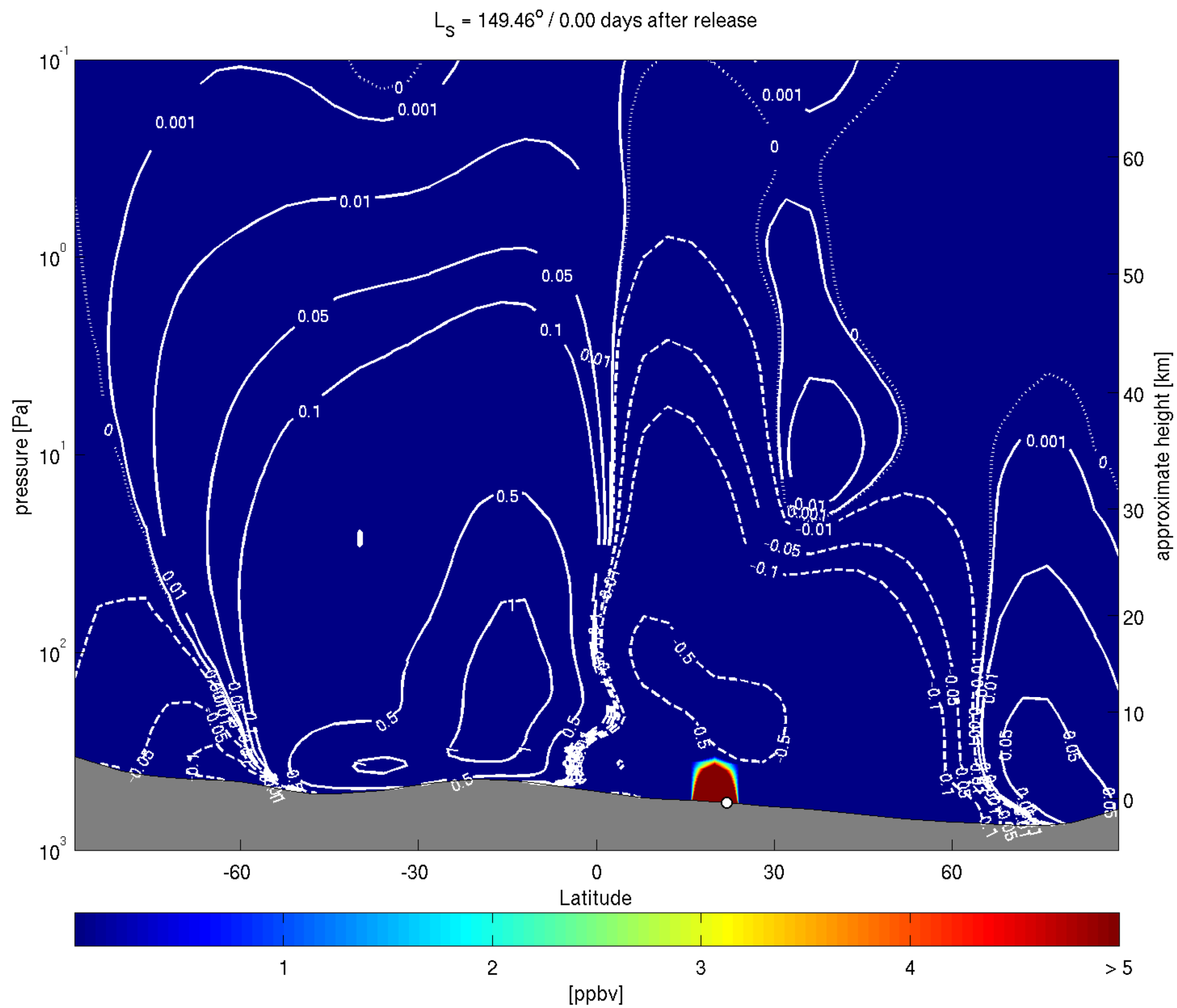


Zonal mean



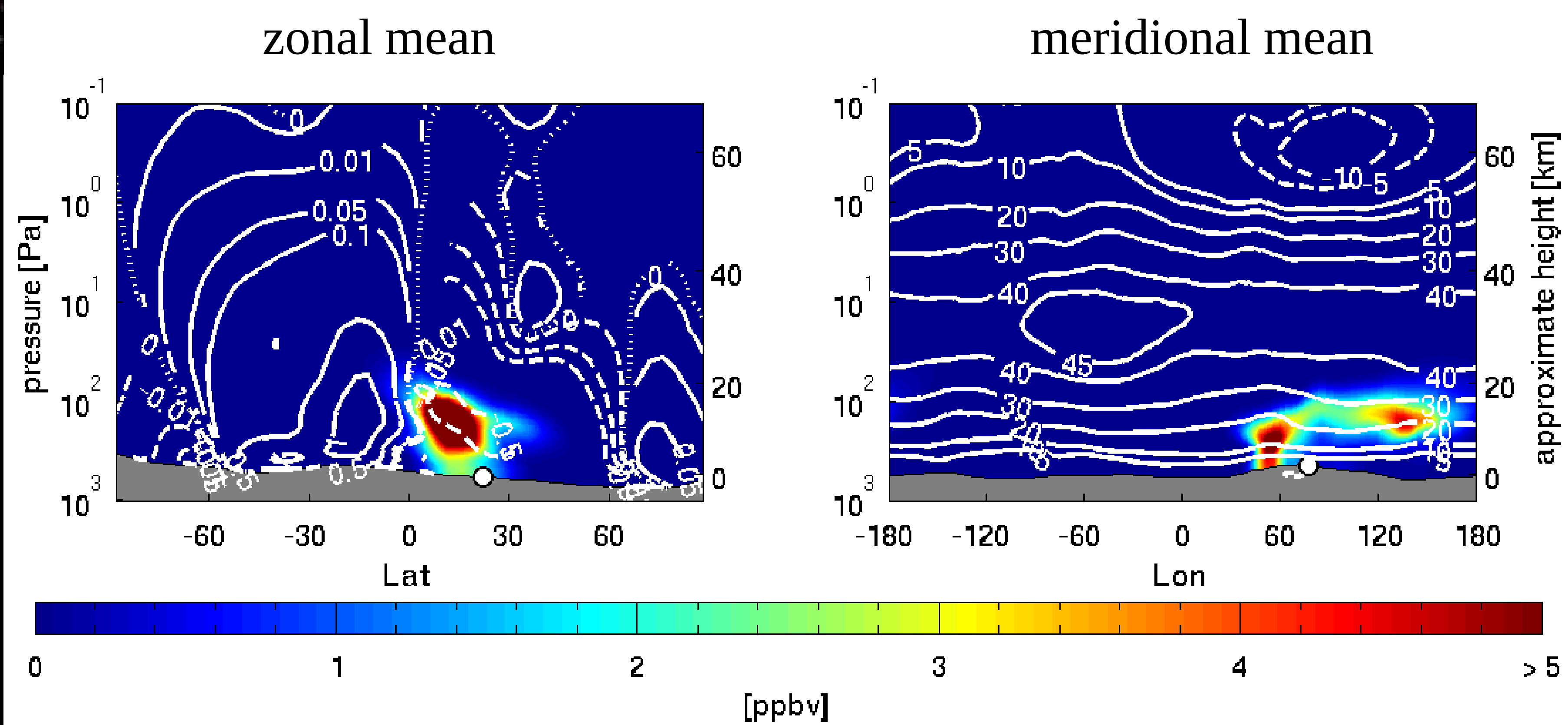
L_S = 149.46° / 0.00 days after release
Mass stream function
pressure [Pa]
approximate height [km]
Latitude
[ppbv]

Zonal mean

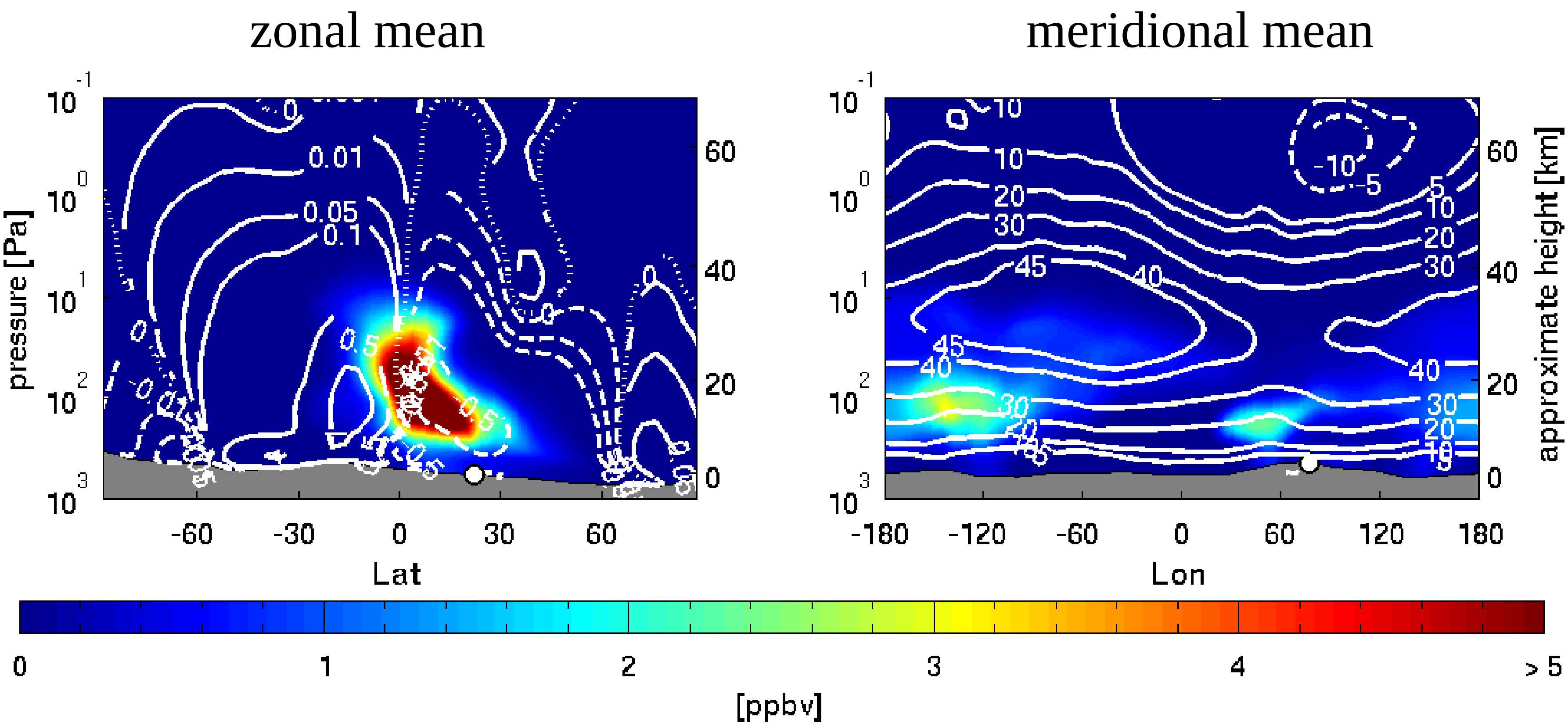


L_S = 149.46° / 0.00 days after release
pressure [Pa]
approximate height [km]
Latitude
[ppbv]
1
2
3
4
> 5

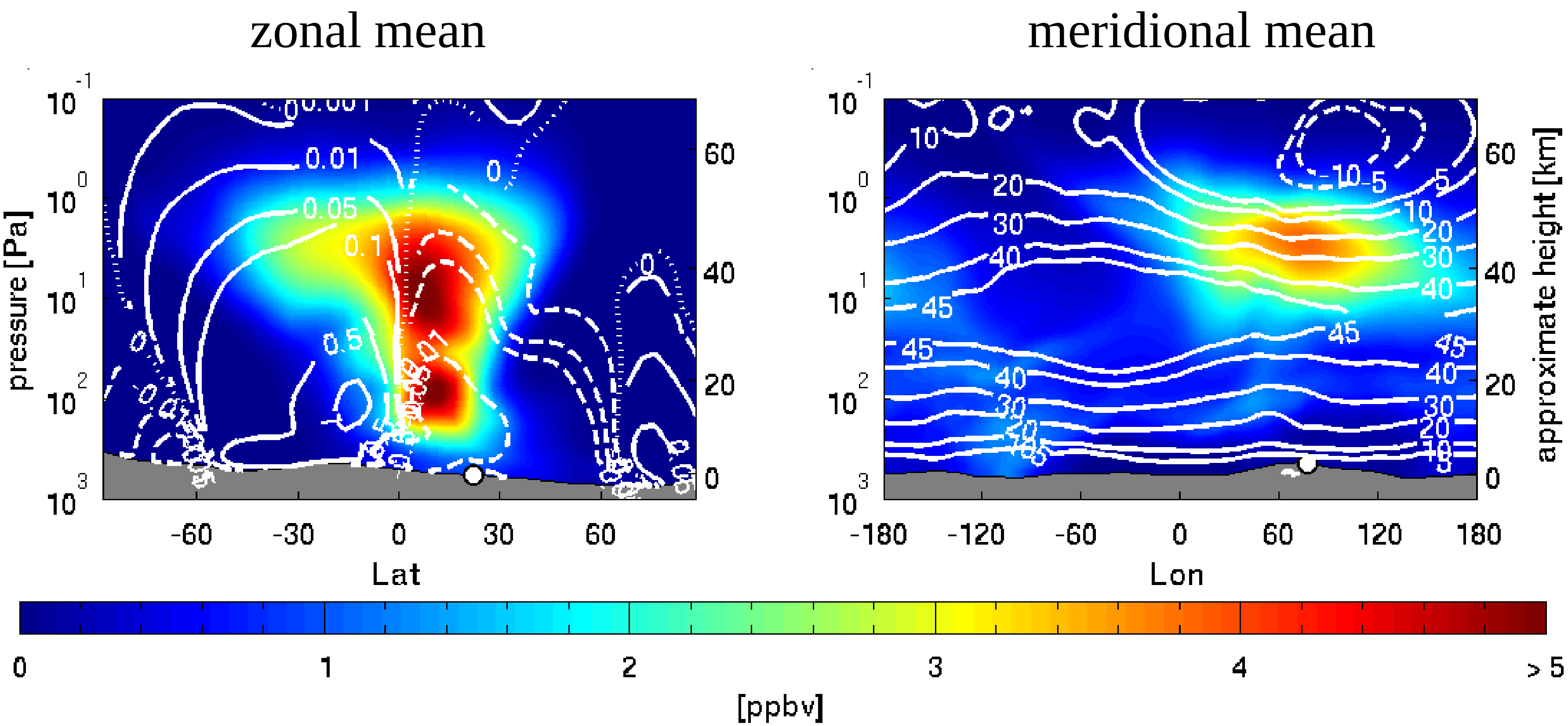
5 days after release



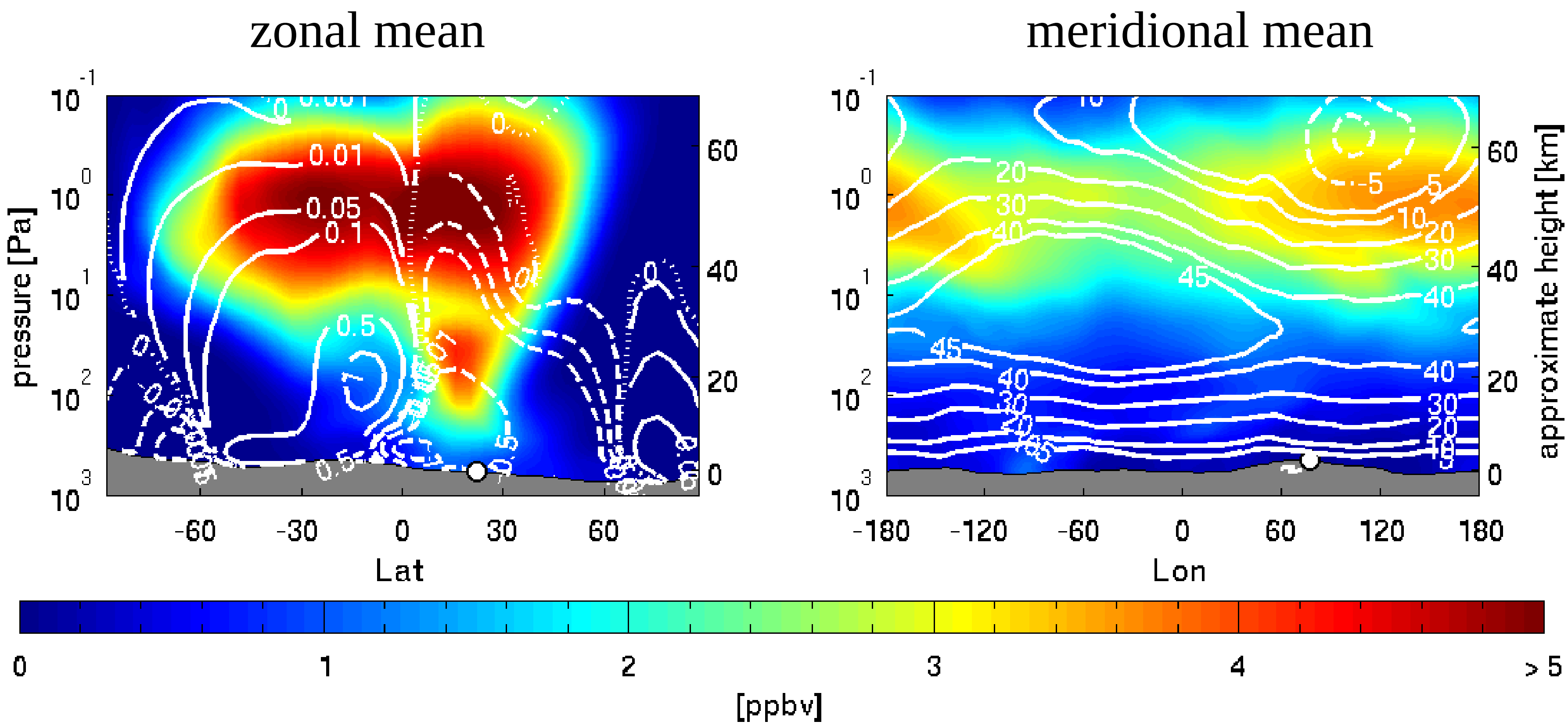
10 days after release



15 days after release

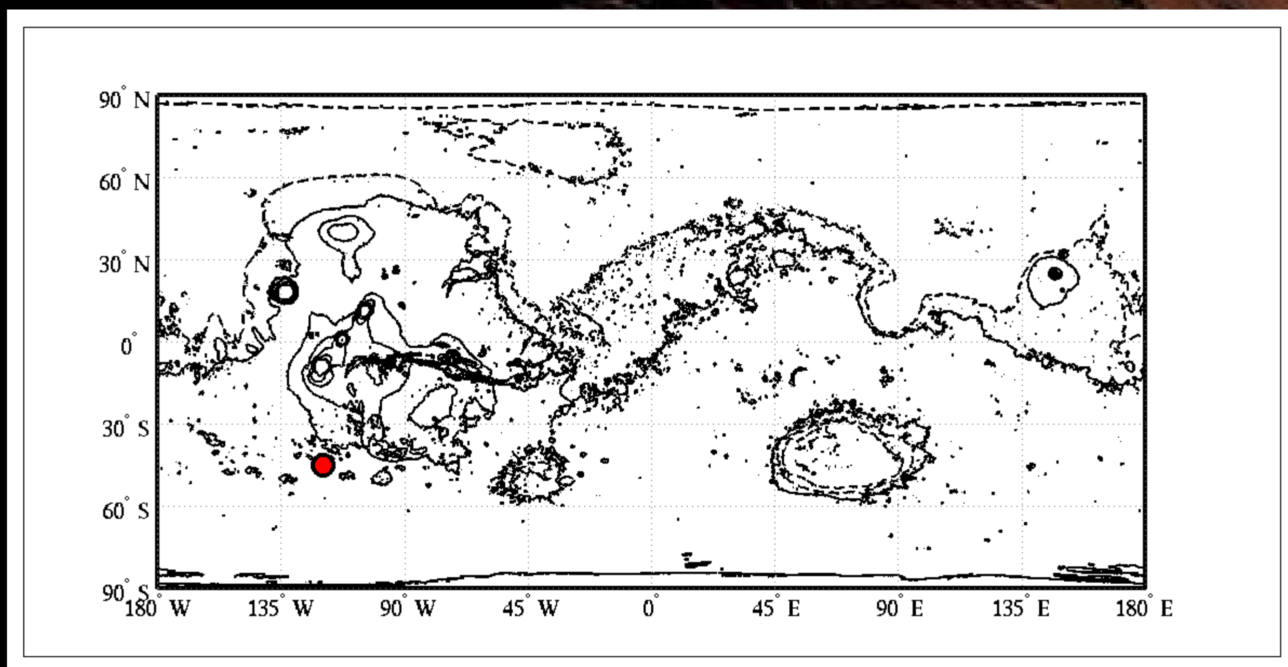


20 days after release

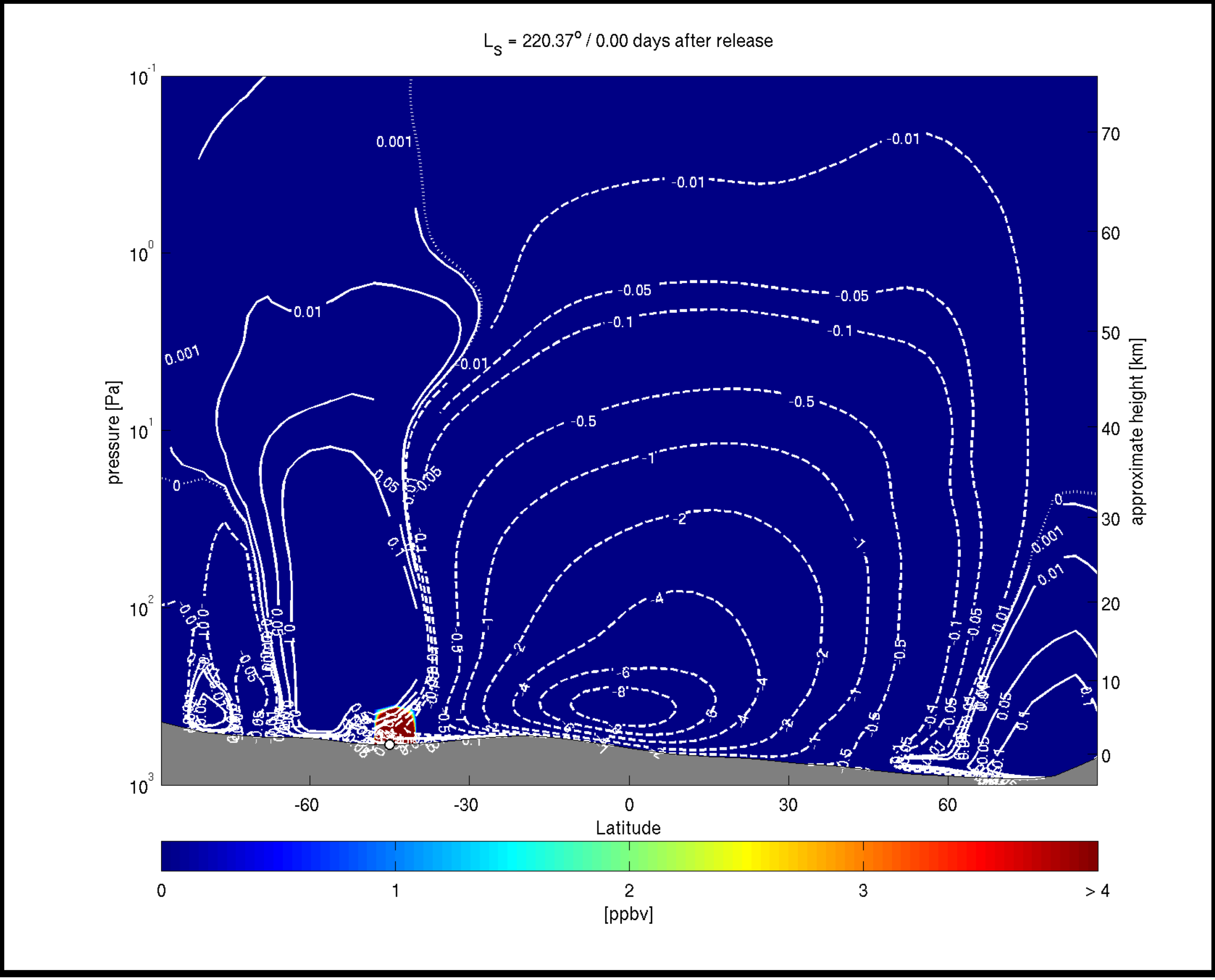


Surface release scenario:
Southern hemisphere in mid Spring

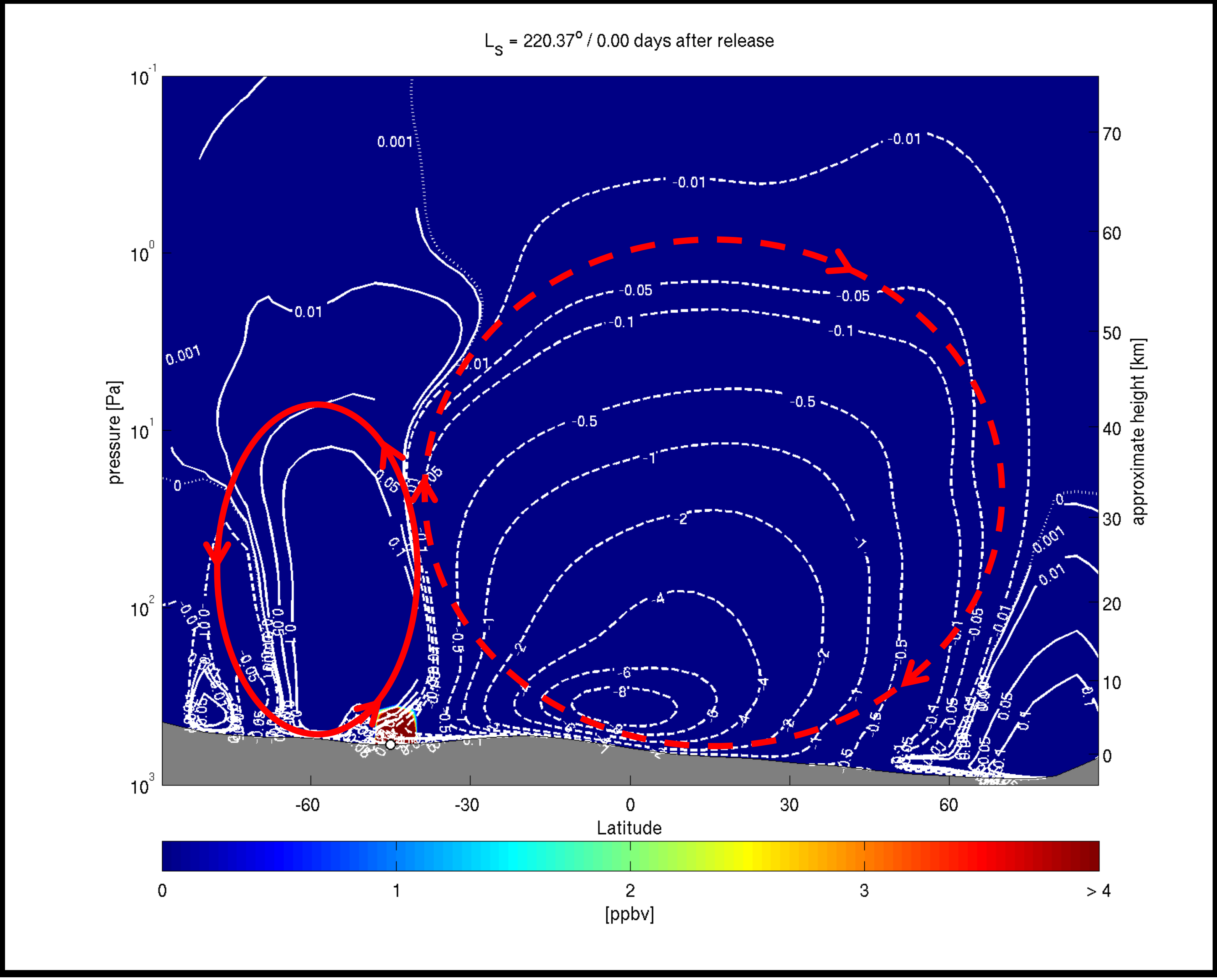
- Source location: 45°S, 240°E
- Season: $L_S = 220°$
- Instantaneous release
- Period: 20 sols after release



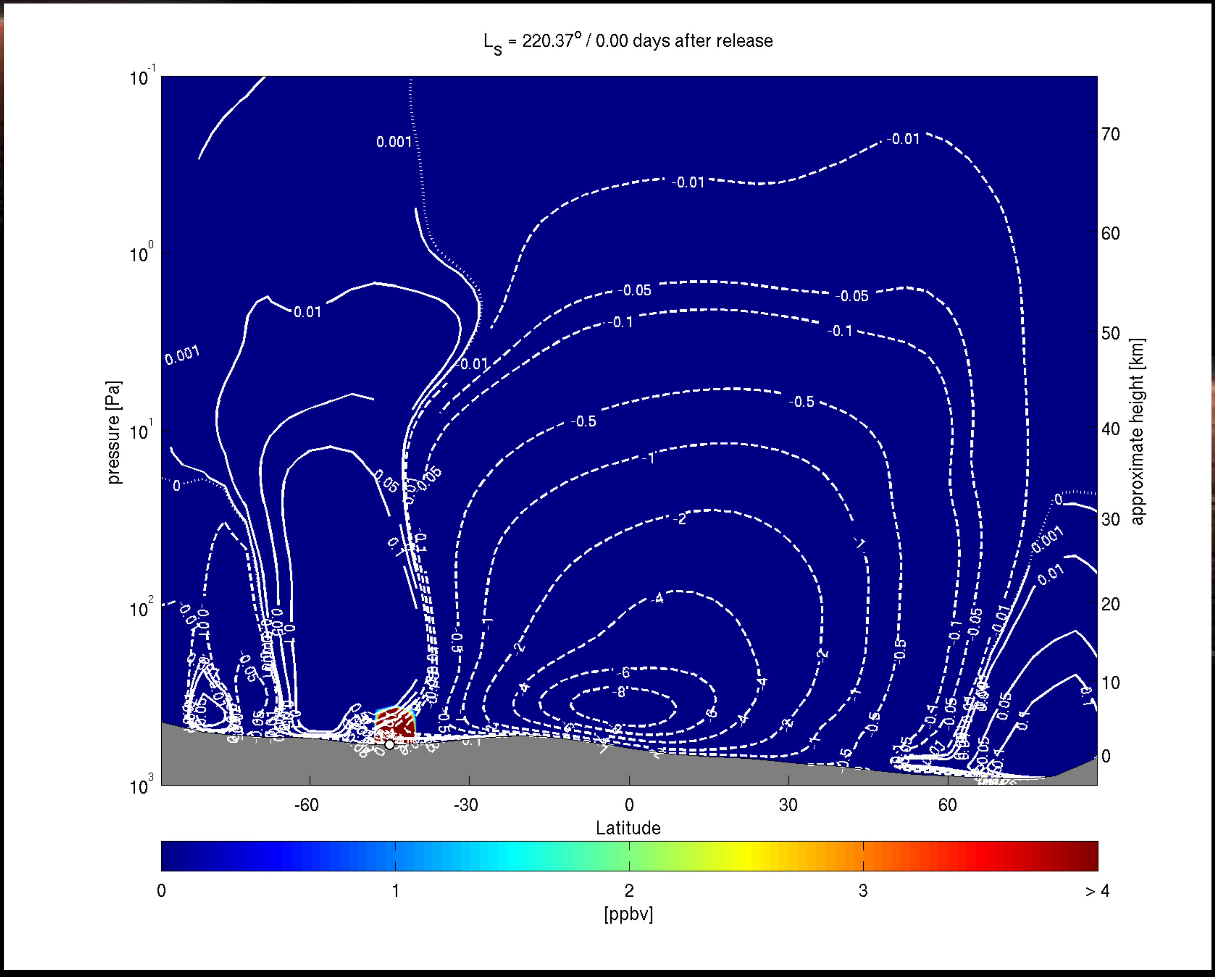
Surface release from 45°S, 240°E



Surface release from 45°S, 240°E

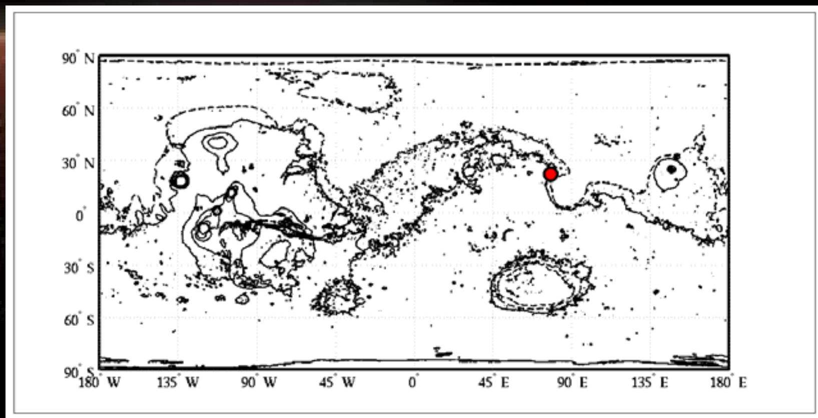


Surface release from 45°S, 240°E



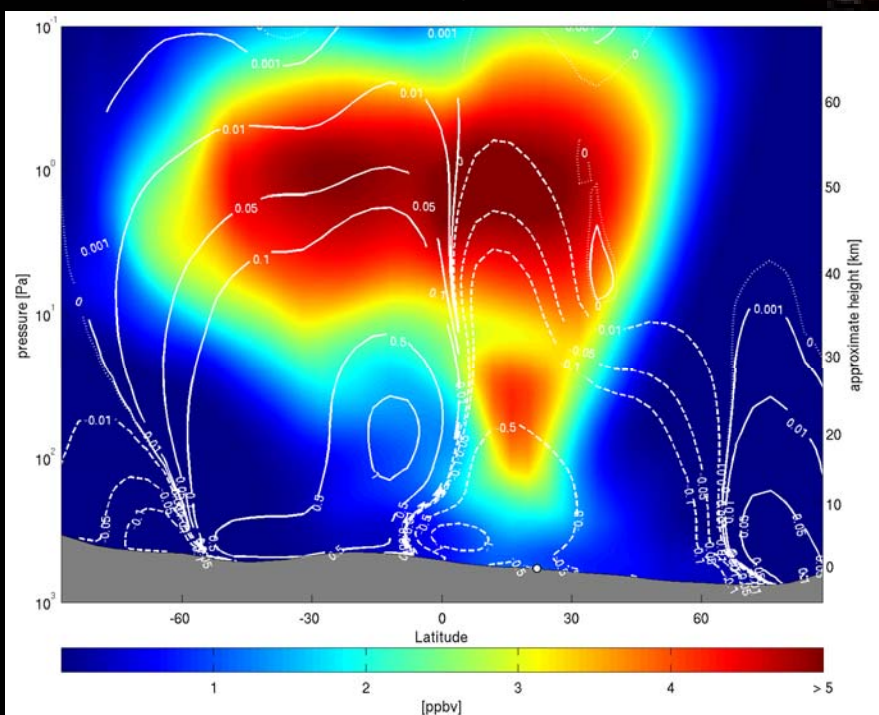
Other surface release scenarios:

I. Release in a preexistent background

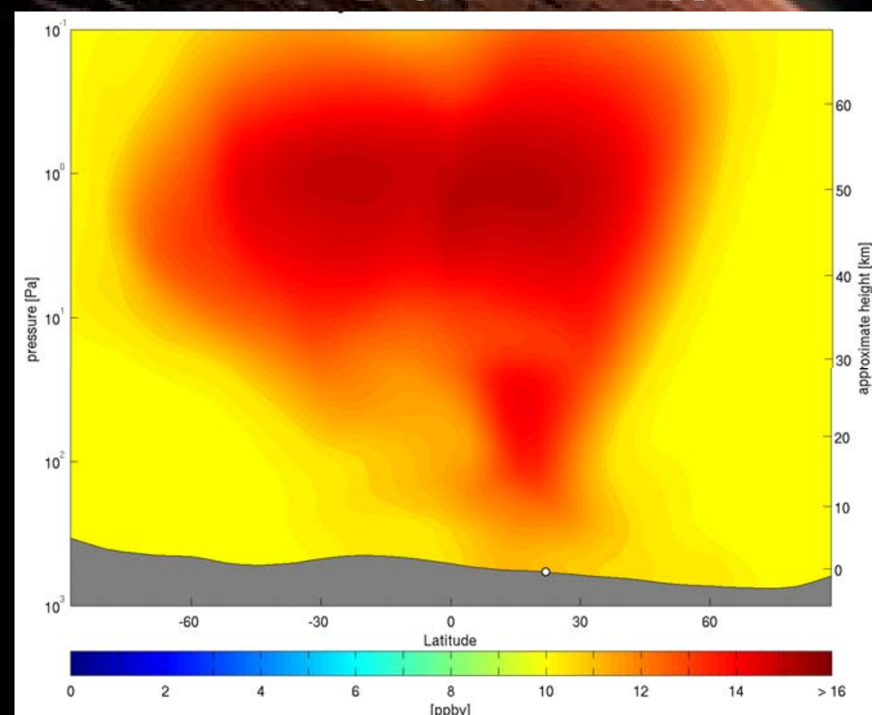


- Source location: Nili Fossae (22°N, 78°E)
- Season: L_S = 150°
- Instantaneous release
- Uniform background of 10 ppbv of CH_4

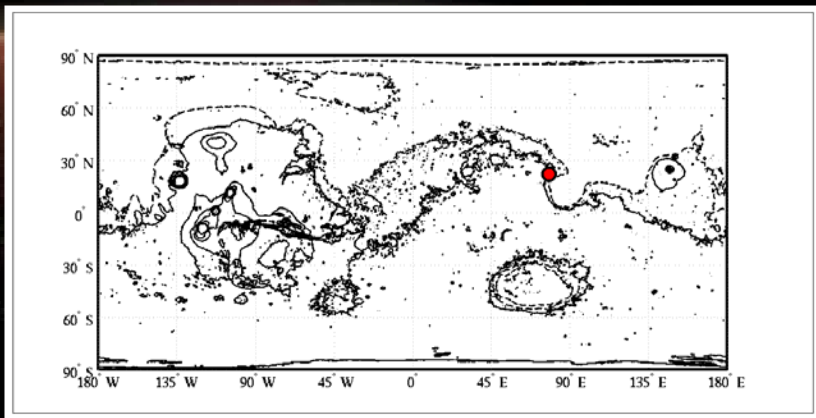
no background



uniform background of 10 ppbv

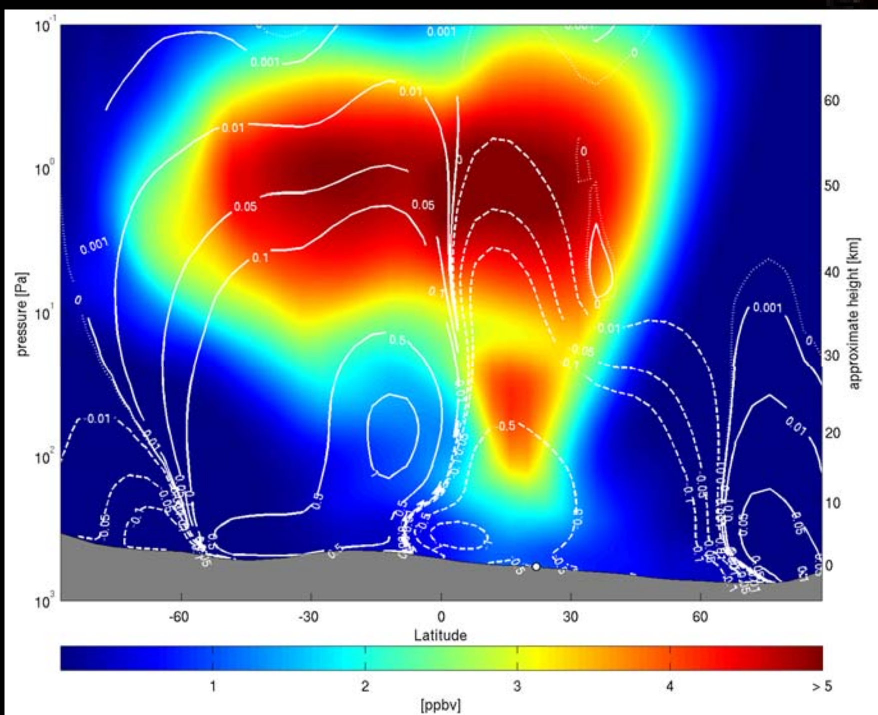


Other surface release scenarios:
II. “Pulse” vs. continuous release

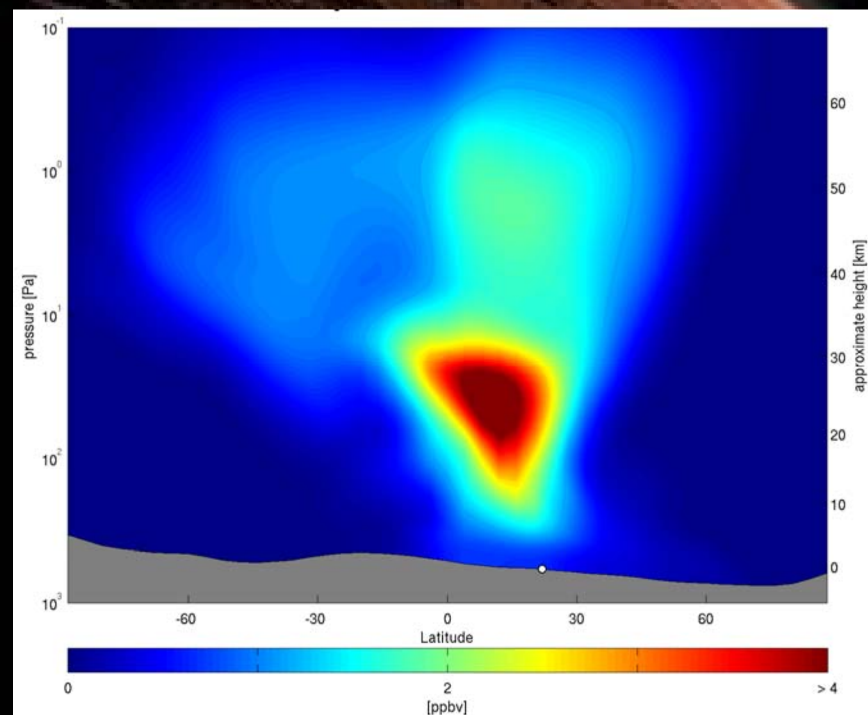


- Source location: Nili Fossae (22°N, 78°E)
- Season: L_S = 150°
- Continuous release over 10 sols

instantaneous release

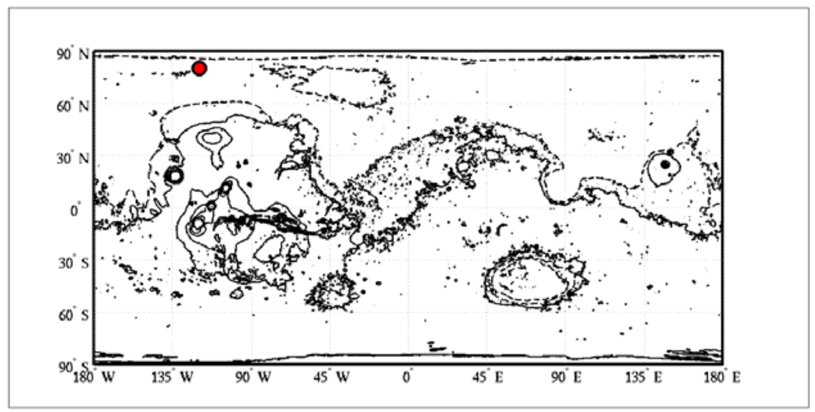


continuous release over 10 sols

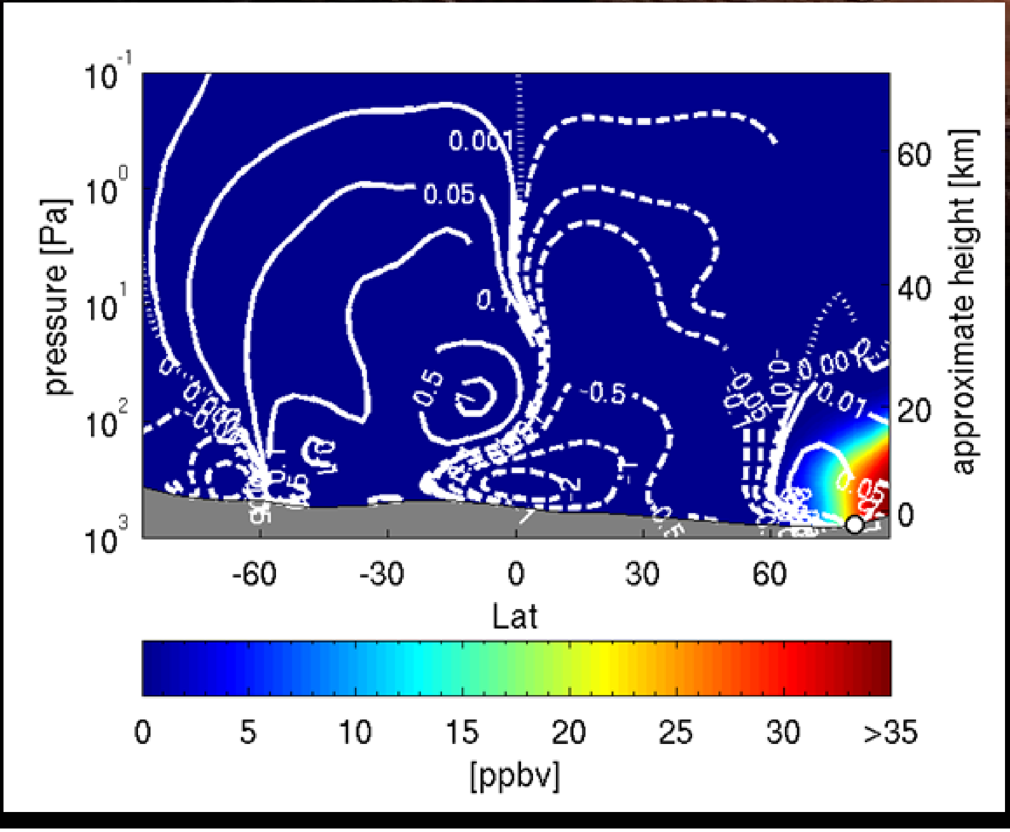


Other surface release scenarios:

III. Pulse release in northern polar region

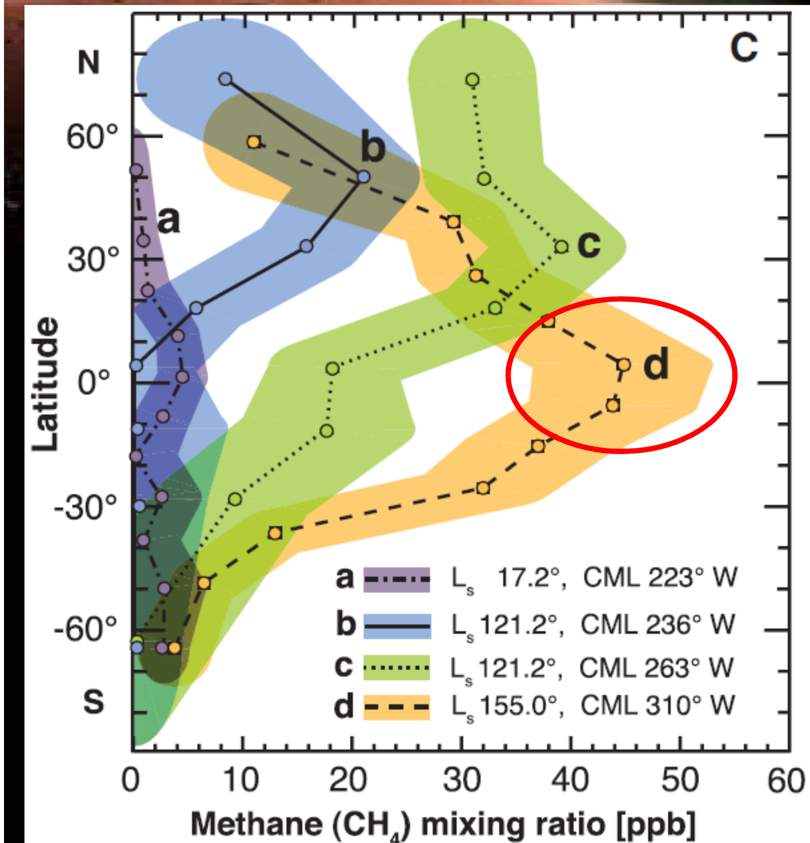


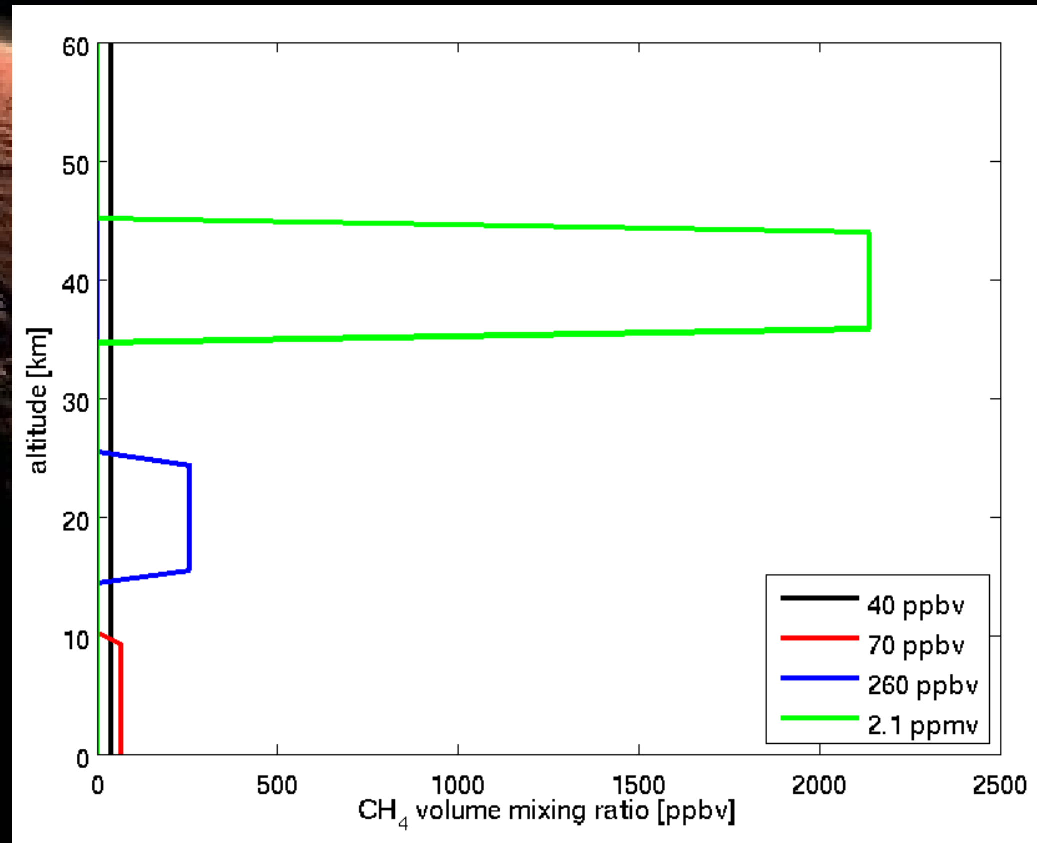
- Source location: polar region (80°N, 240°E)
- Season: L_S = 170°
- Instantaneous release



Implications:
I. vertical distribution of methane observed in the past

Mumma *et al.*, Science (2009)





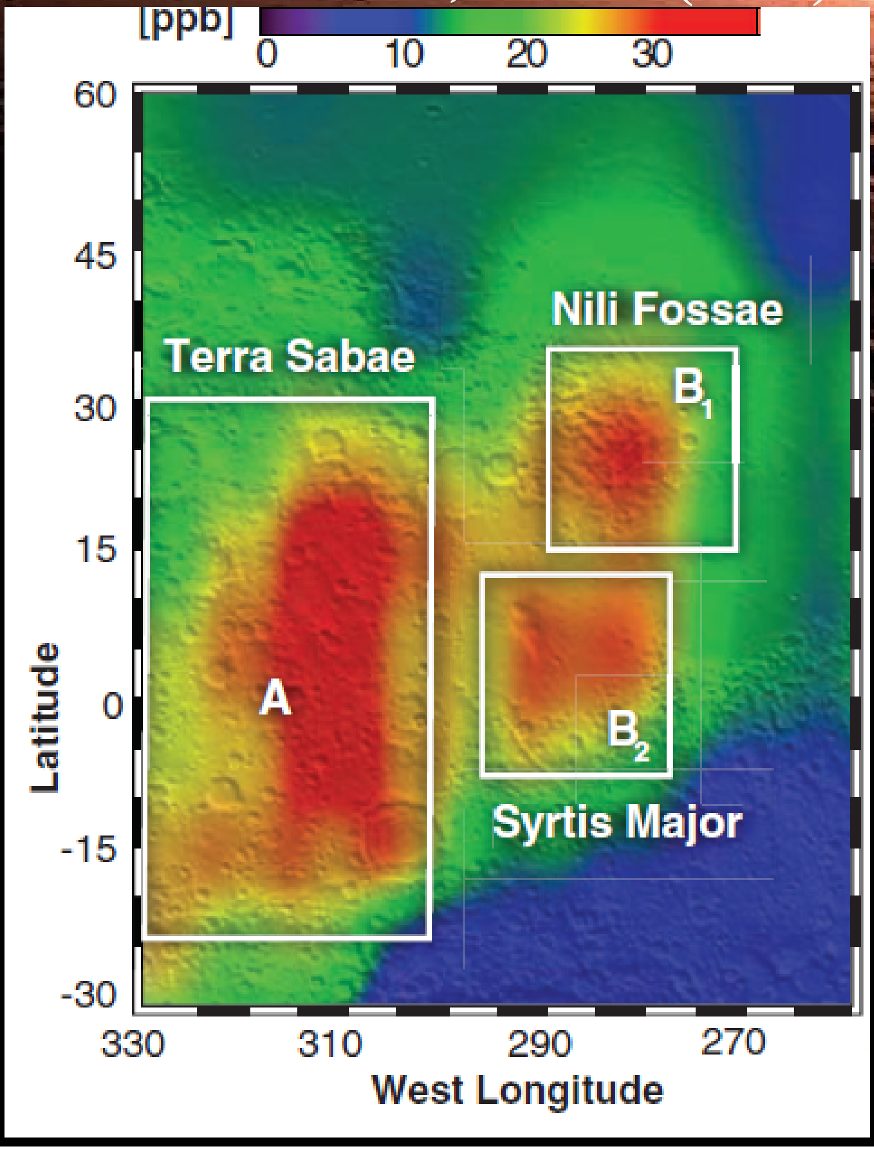
0°N lat.
50°E lon.
L_S = 155°

➔ ~40 ppbv

Implications on the retrieval of vertical profiles of methane in solar occultation ➔ NOMAD mission

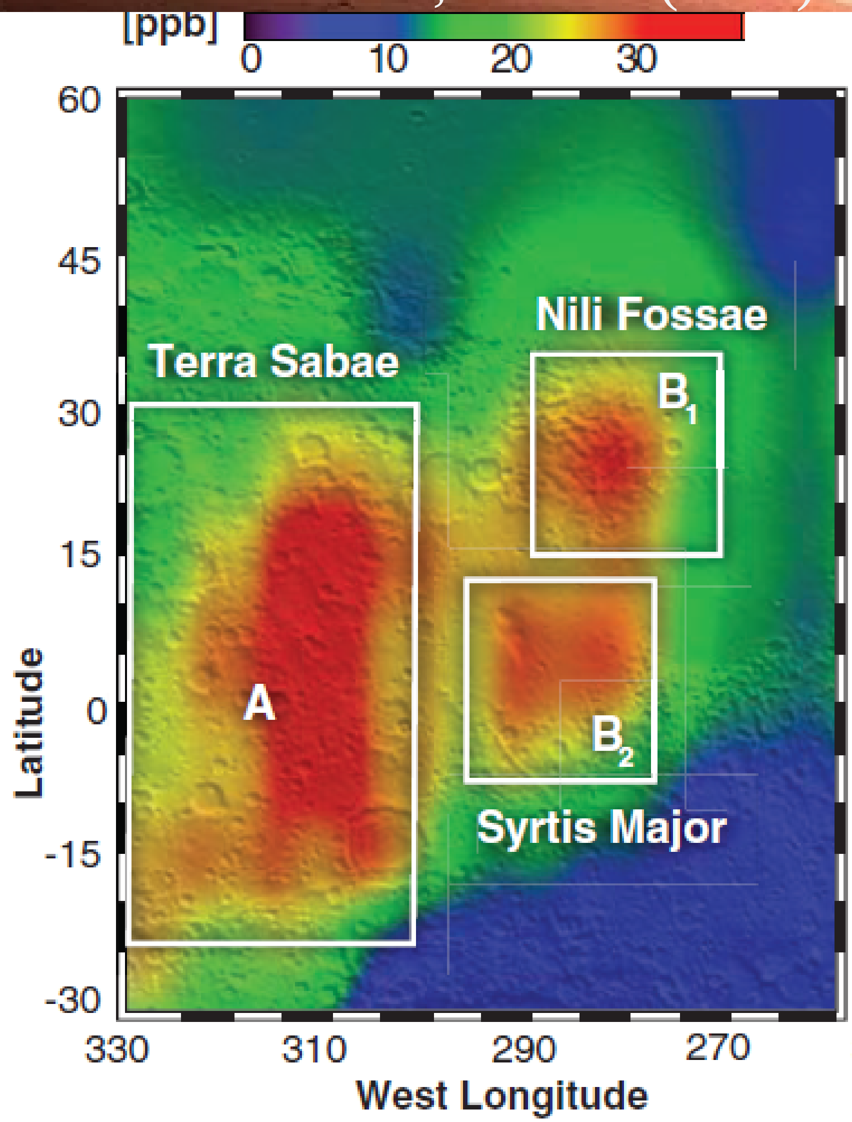
Implications:
II. Impact of dust on observations

Mumma *et al*., Science (2009)

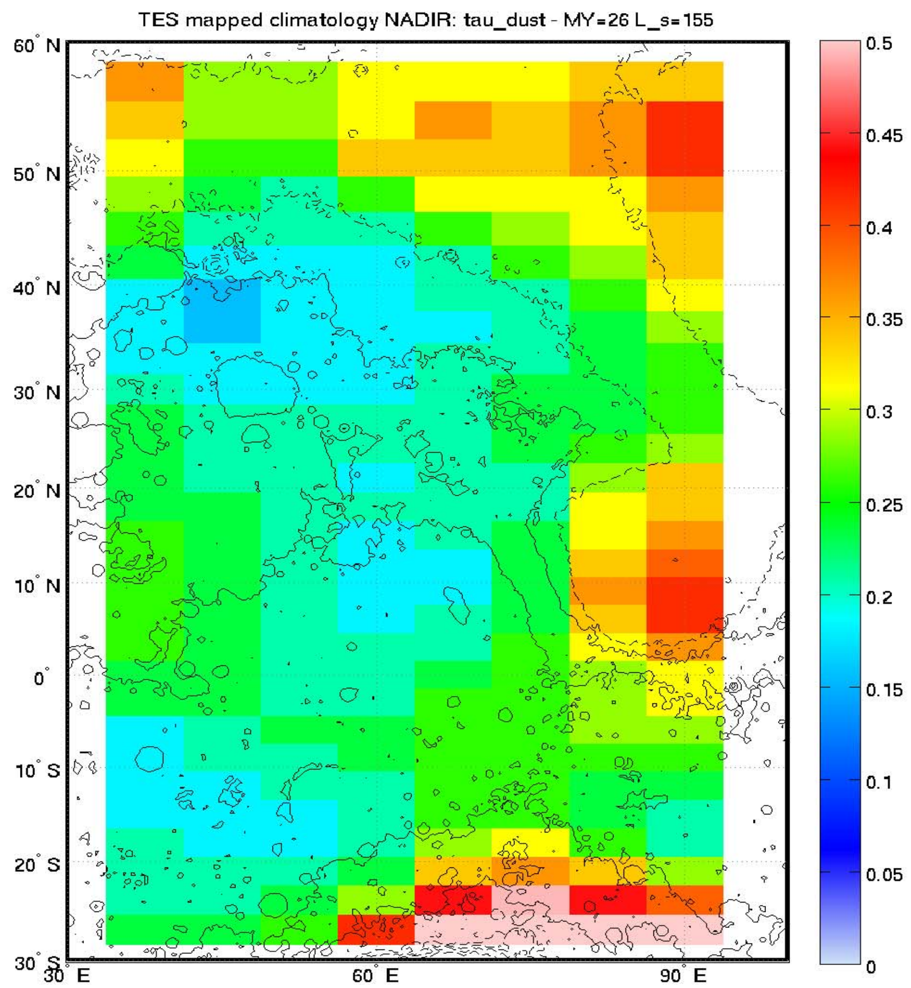


Implications:
II. Impact of dust on observations

Mumma *et al.*, Science (2009)



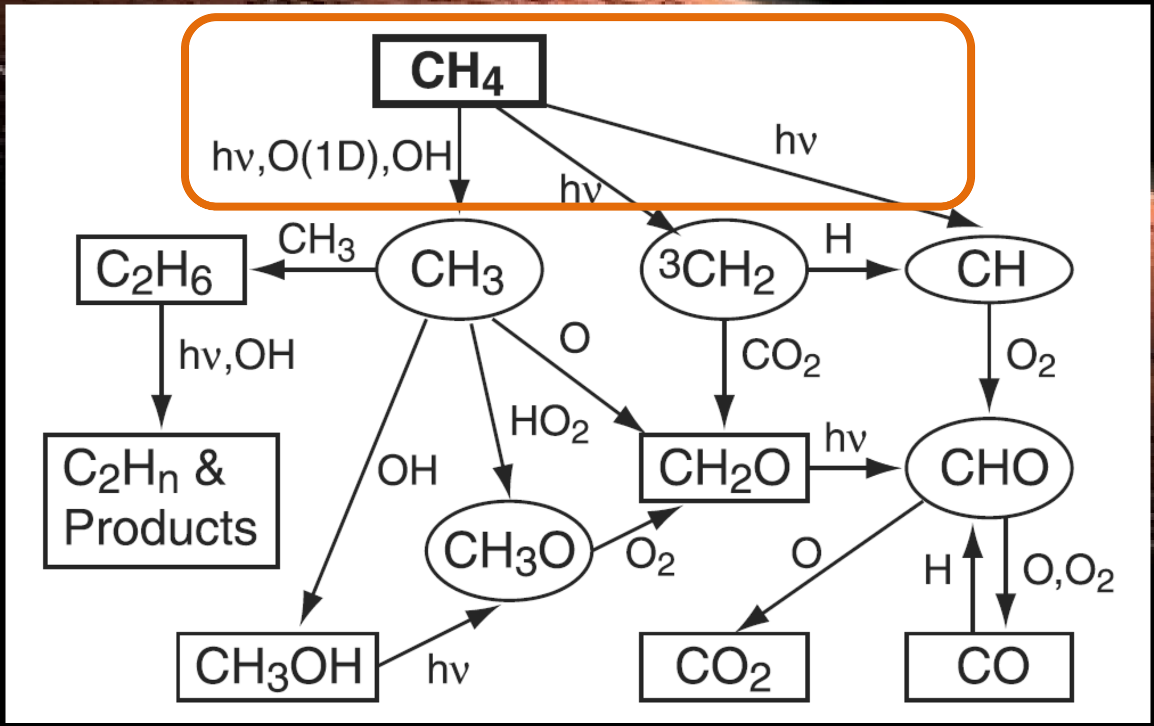
TES dust optical depth



Simulating source and sink processes of methane

I. Release of H_2O together with CH_4

Wong *et al.*, JGR (2003)



➔ Photolysis of water vapor at high altitudes might lead to the destruction of methane

Simulating source and sink processes of methane

II. Sink process: CH_4 trapped by quartz grains

Laboratory experiments by Knak Jensen *et al.*, Icarus (2014): quartz grains agitated in an atmosphere of CH_4 for 115 days

➔ wind driven erosion produces highly reactive sites on grain surfaces

➔ formation of covalent CH_3-Si bonds

➔ *"A sink for methane on Mars? The answer is blowing in the wind"*

Some issues:

- too few information available to parameterize this sink process
- what happens in presence of water vapor?

Simulating source and sink processes of methane

III. Source processes

- As little information on the source processes is available, we considered very simple surface release scenarios considered in this model study.
- Several subsurface models simulate more realistical releases of methane from the ground:
  - O. Karatekin and E. Gloesener (Royal Observatory of Belgium)
  - A. Stevens *et al.*, Icarus (2015)
  - R. Hu *et al.*, Astrobiology (2016)
- Combining subsurface models with our GCM can allow to provide clues for the origin and emission sites

Conclusions

This study focused on the 3D dispersion of methane throughout the atmosphere after the surface release

➔ Layers of methane may form during the first weeks

This result has potential implications:

- previous observations should be reinterpreted in the light of this result
  - the local mixing ratio can be higher than the column averaged mixing ratio
  - the mixing ratio higher up in the atmosphere above Gale could be much higher than those measured at the surface by MSL
- If NOMAD detect layers, this can be indicative of very recent surface emission

Perspectives:

simulating outgassing and loss of methane on Mars

- Implementation of the chemistry of methane in the GCM
- Impact of oxidizers on methane at high altitudes when CH_4 is released together with water vapor
- Investigation of recent sink processes proposed in the literature (e.g. Knak Jensen *et al.*, Icarus, 2005, etc.)
- Combination of subsurface models with the GCM:
  - simulation of more realistic release scenarios
  - clues for the emission sites and the origin of methane
- Support to the measurements of the first vertical profiles of methane by NOMAD