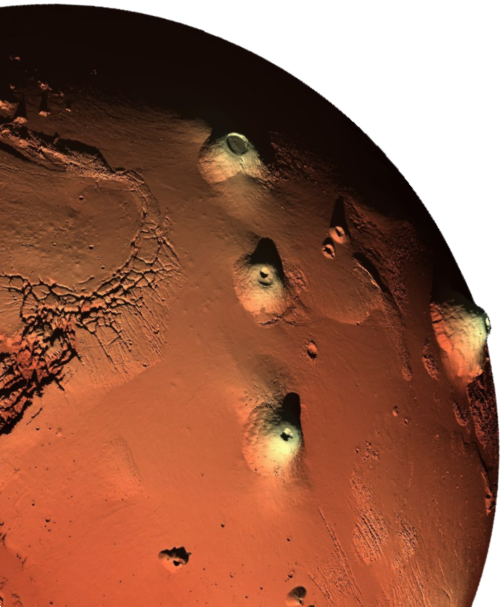
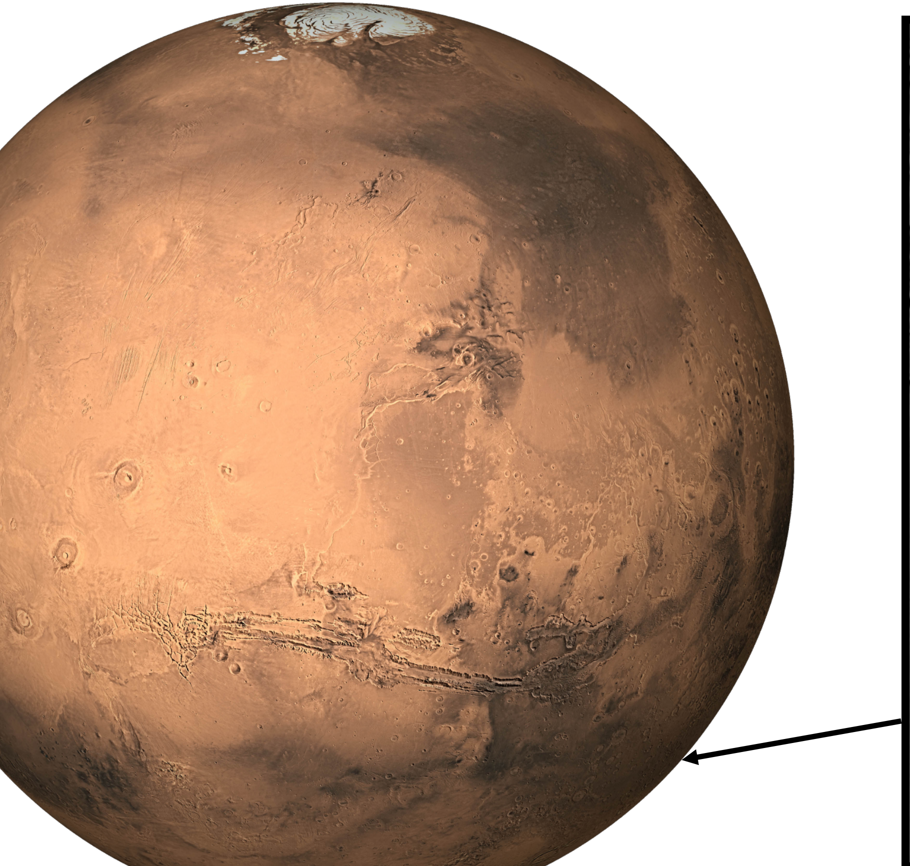
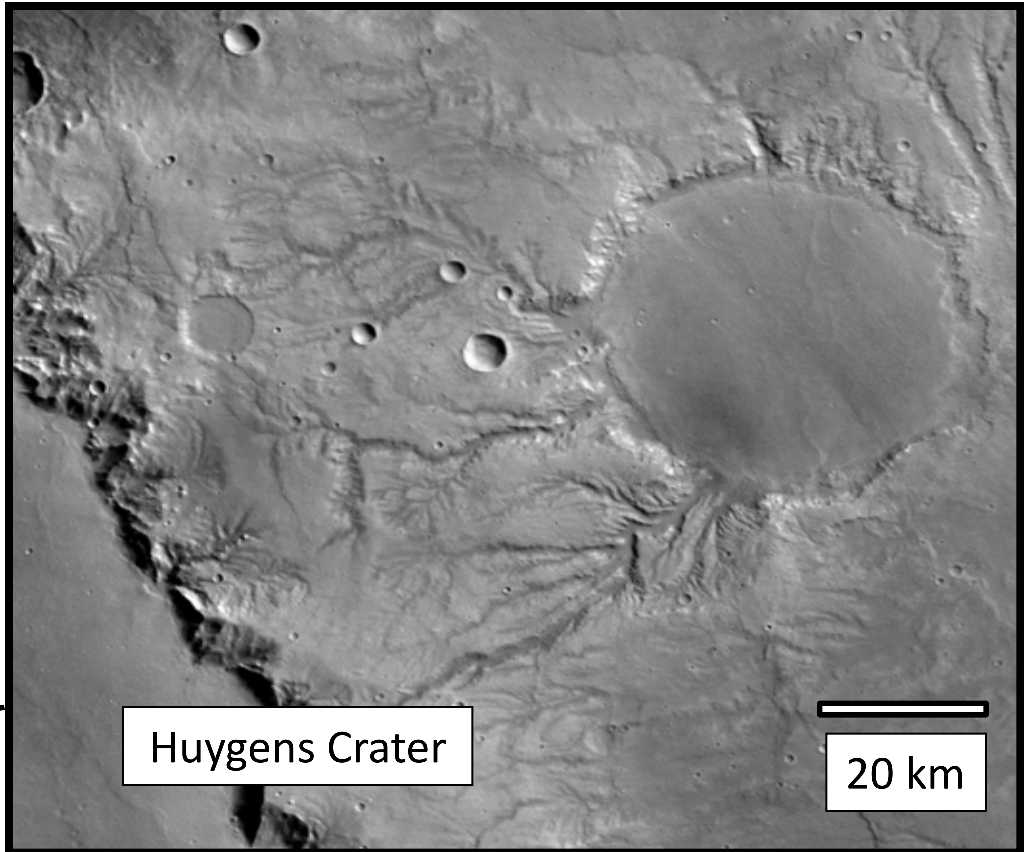
ON THE CHALLENGES OF SIMULATING THE EARLY MARS ENVIRONMENT(S) WITH CLIMATE MODELS AND LAB EXPERIMENTS

Martin Turbet, Jean-Michel Hartmann, Ha Tran, Christian Boulet, Tijs Karman, Didier Mondelain, Alain Campargue, François Forget, Ehouarn Millour, Edwin Kite, Olivier Pirali, Cédric Gillmann, Baptiste Baudin, Vladimir Svetsov



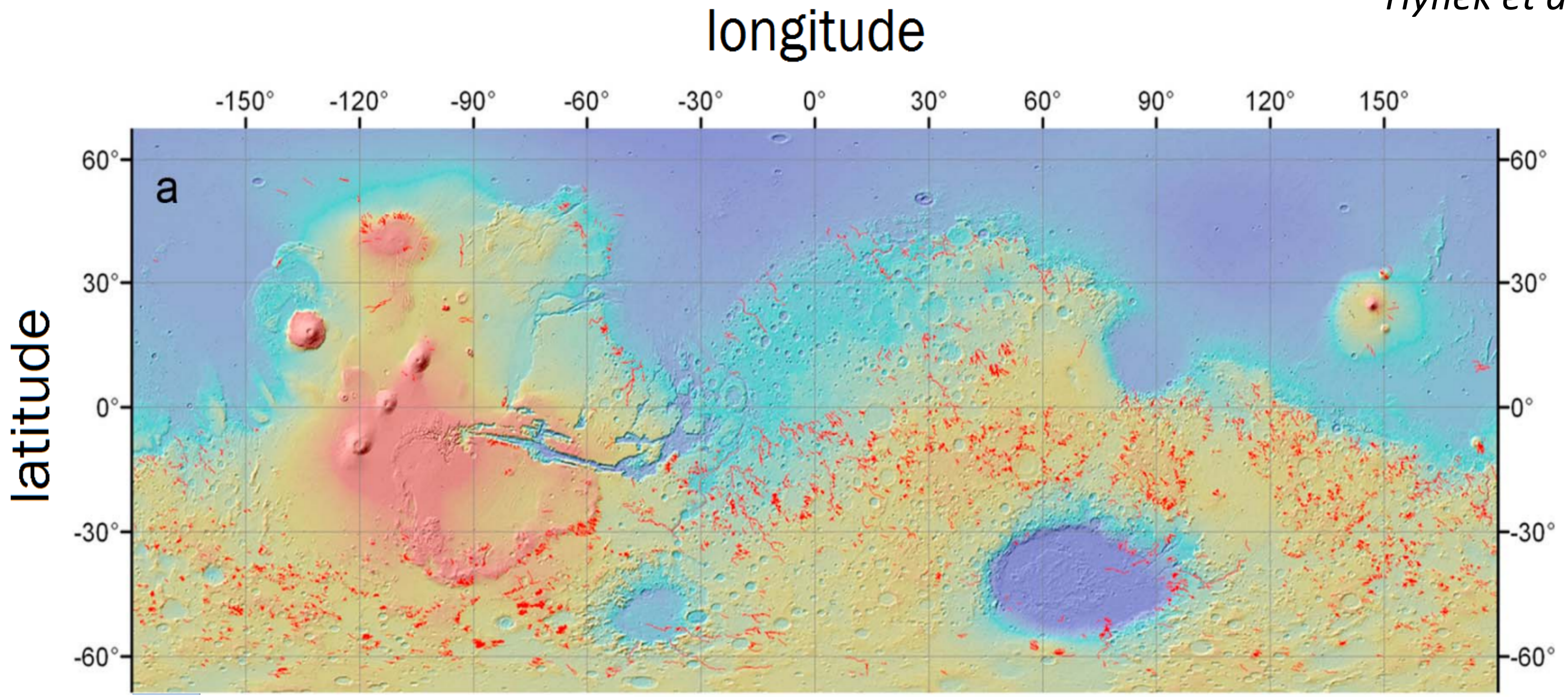
THE EARLY MARS ENIGMA





MAP OF KNOWN VALLEY NETWORKS

Hynek et al. 2010



- ➢ Formed 3.5-3.8 billion years ago
- ➢ Likely required > 10^5 years to form

OVERWHELMING NUMBER OF PIECES OF EVIDENCE FOR THE PRESENCE OF LIQUID WATER

1) Valley Networks

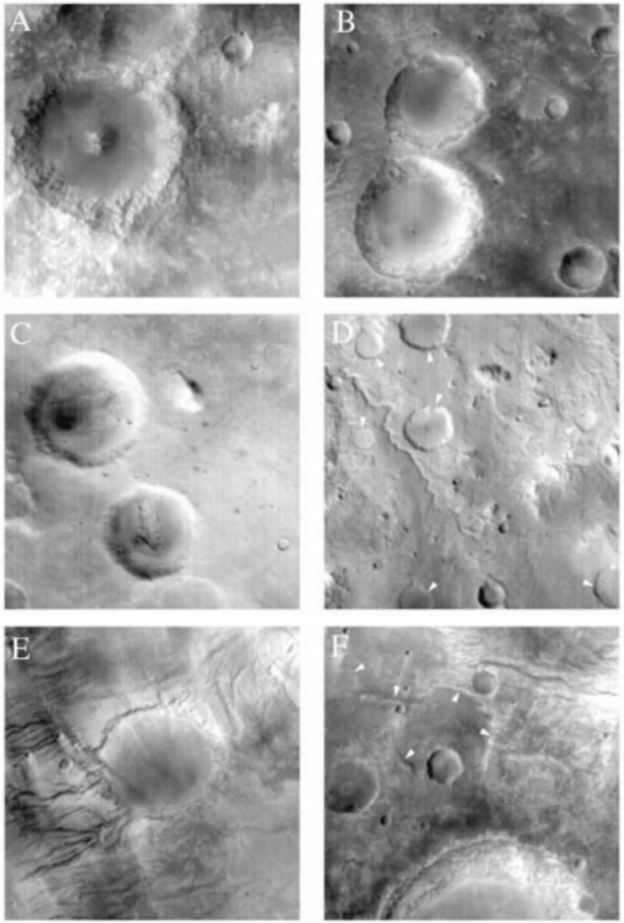
OVERWHELMING NUMBER OF PIECES OF EVIDENCE FOR THE PRESENCE OF LIQUID WATER

1) Valley Networks
2) **High erosion rates**

HIGH EROSION RATES OF OLD CRATERS (3.5-4Gyo)

Craddock & Howard 2002
Mangold et al. 2012

Crater infilling + rim erosion

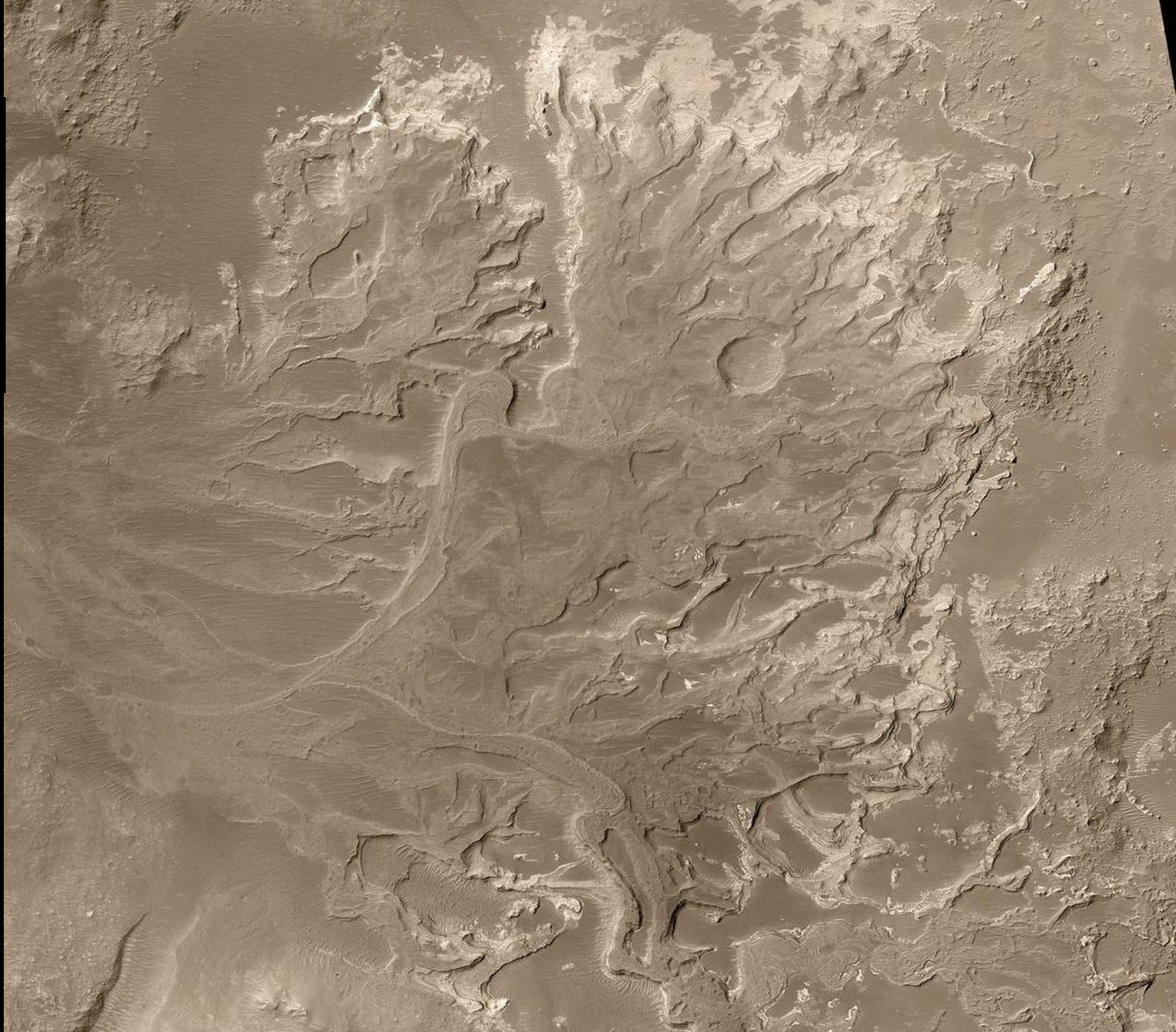


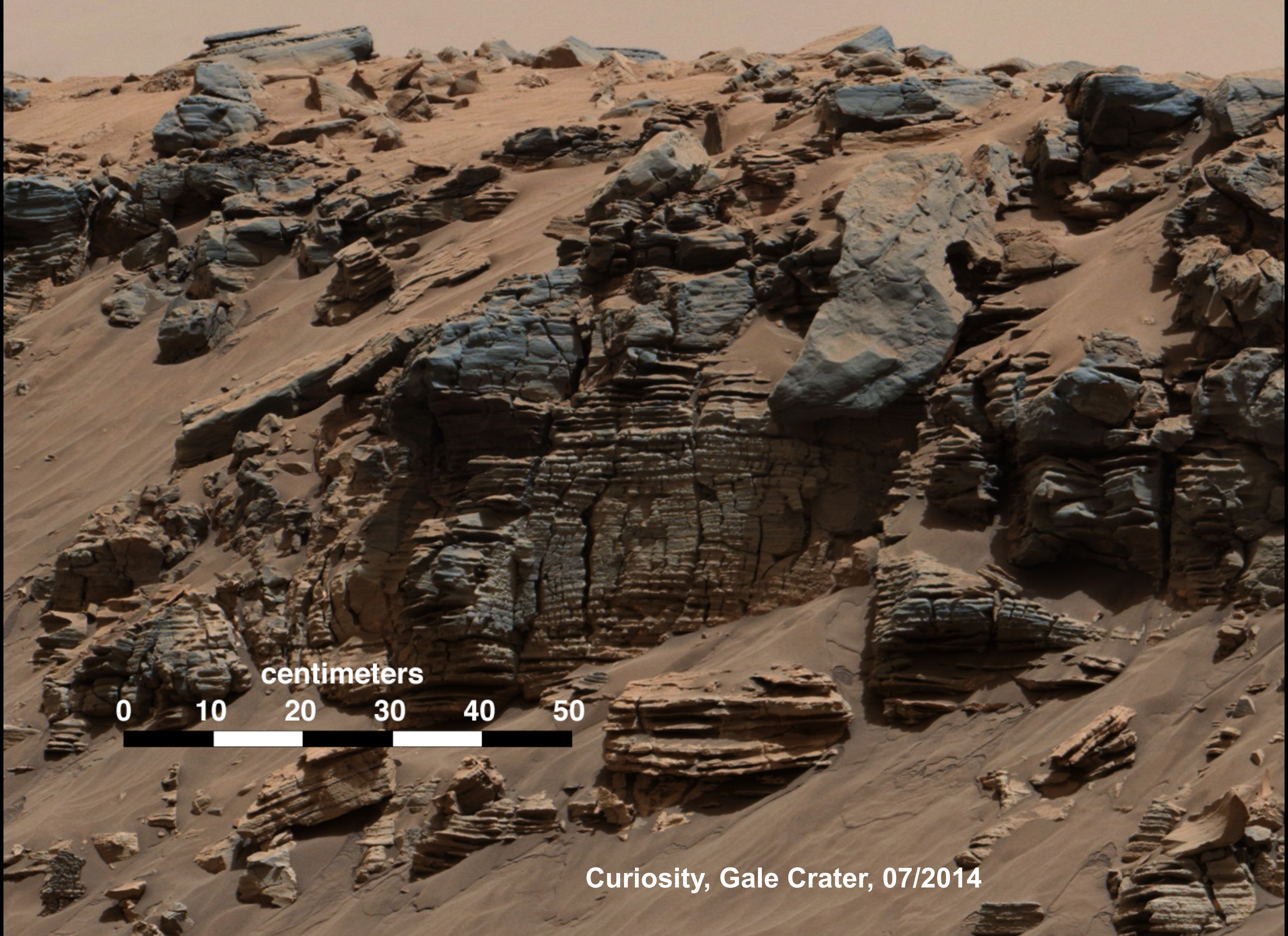
OVERWHELMING NUMBER OF PIECES OF EVIDENCE FOR THE PRESENCE OF LIQUID WATER

1) Valley Networks
2) High erosion rates
3) **Presence of sediments**

Malin and Edget 2003
Moore et al. 2003

See also
Mangold and Ansan 2006




centimeters
0 10 20 30 40 50
Curiosity, Gale Crater, 07/2014

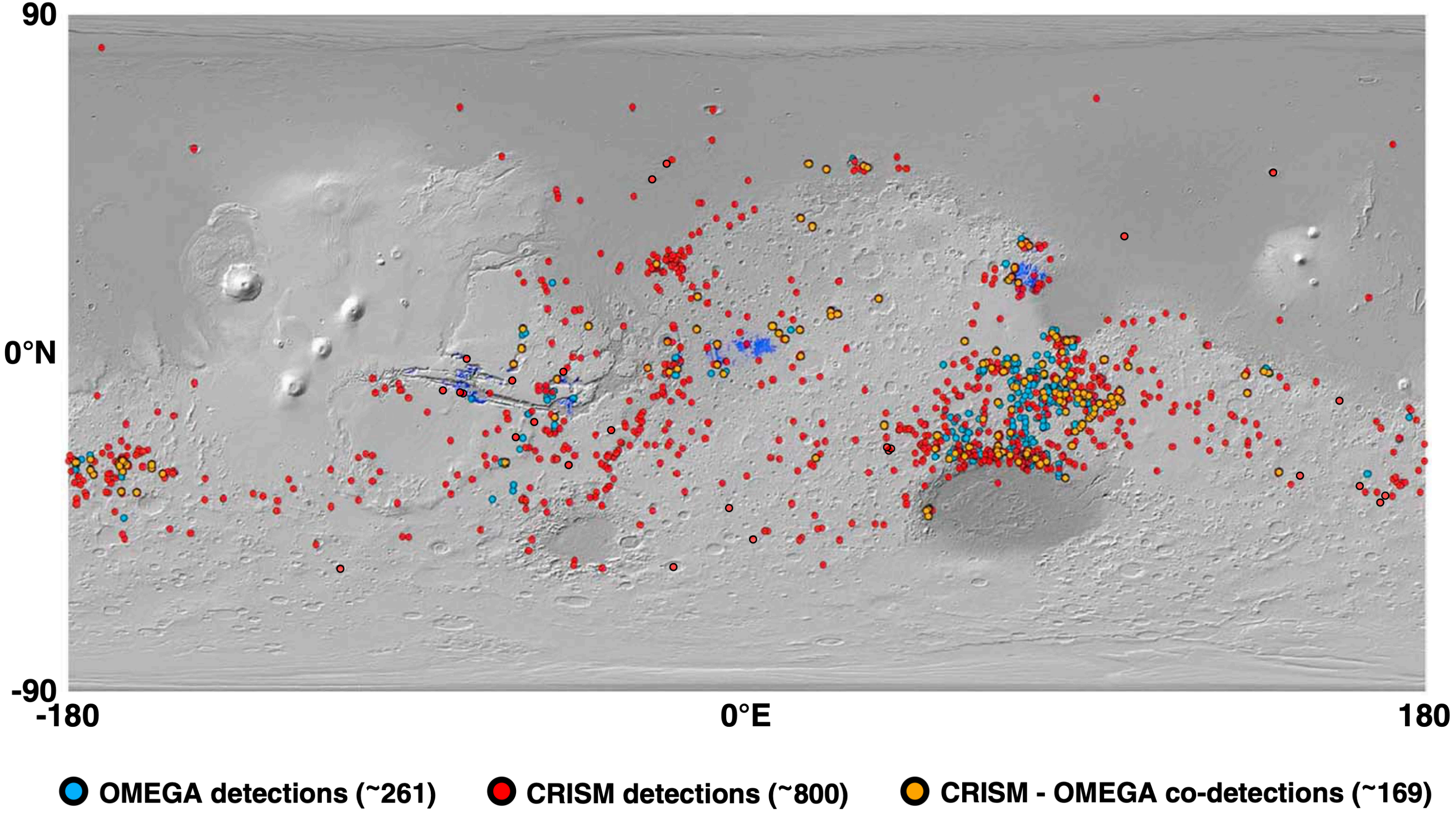
OVERWHELMING NUMBER OF PIECES OF EVIDENCE FOR THE PRESENCE OF LIQUID WATER

1) Valley Networks
2) High erosion rates
3) Presence of sediments
4) **Widespread hydrated minerals**

MAP OF HYDROUS MINERAL DETECTIONS

Carter et al. 2011

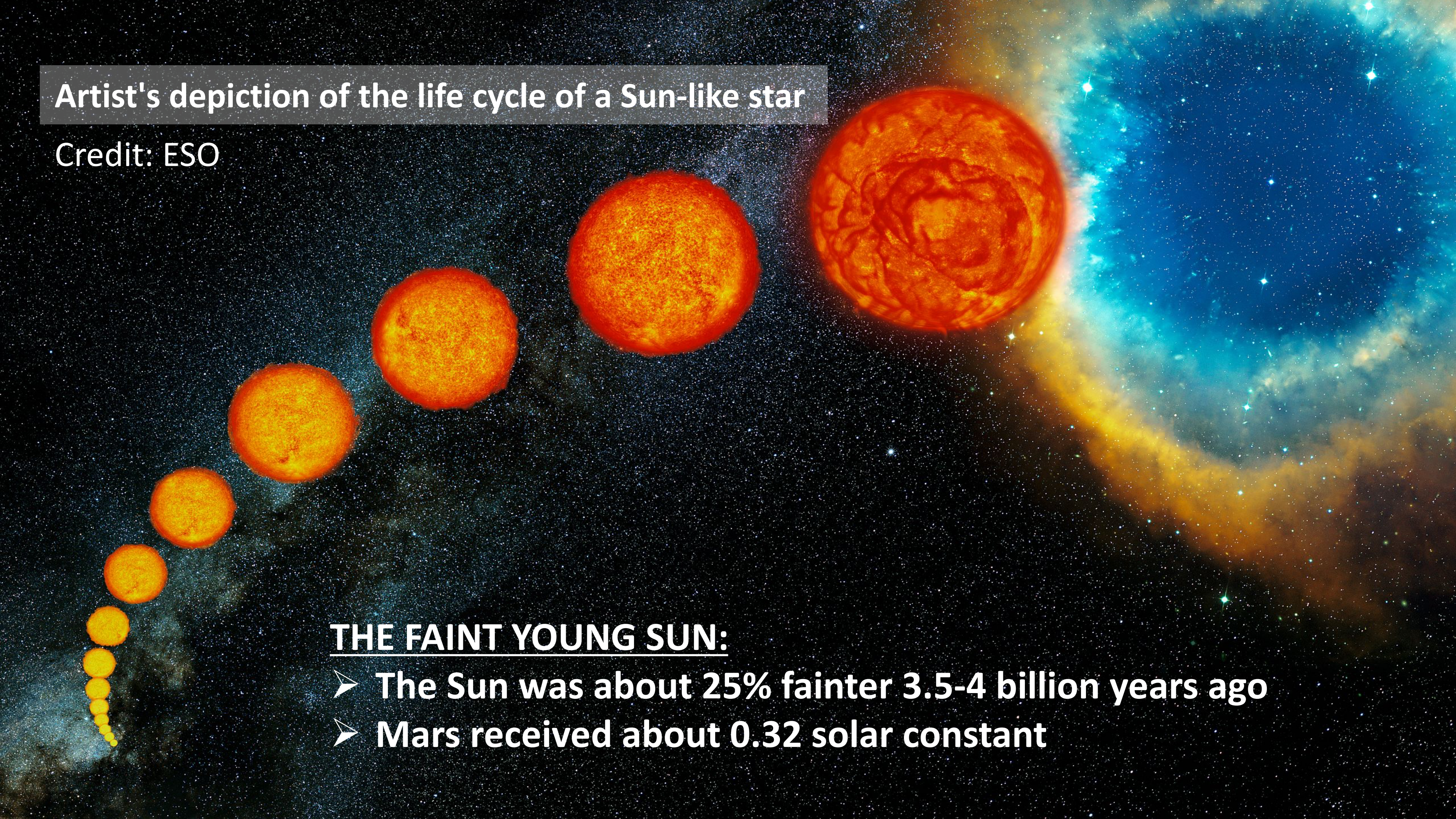
See most recent map in *Carter et al. 2019, 2020*



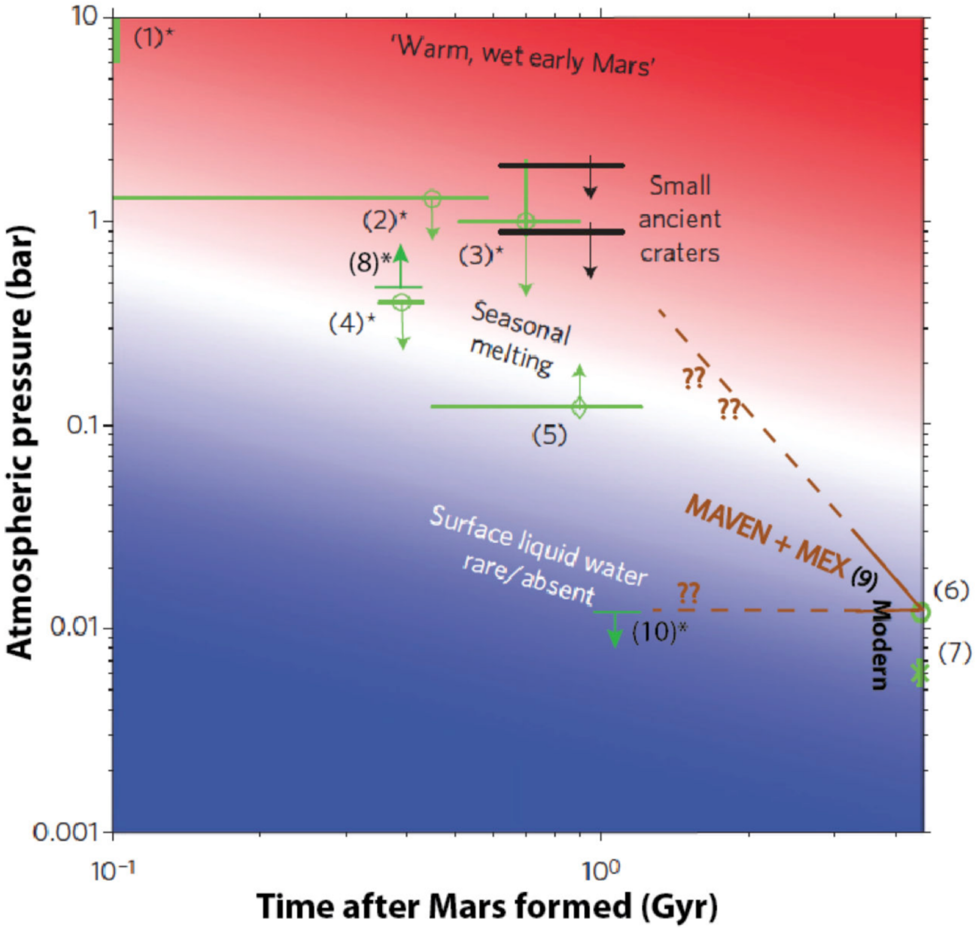
OVERWHELMING NUMBER OF PIECES OF EVIDENCE FOR THE PRESENCE OF LIQUID WATER

1) Valley Networks
2) High erosion rates
3) Presence of sediments
4) Widespread hydrated minerals
5) **Shorelines*, evidence for tsunami events***

***controversial**


Artist's depiction of the life cycle of a Sun-like star
Credit: ESO
THE FAINT YOUNG SUN:
➢ The Sun was about 25% fainter 3.5-4 billion years ago
➢ Mars received about 0.32 solar constant

WHAT ATMOSPHERE FOR EARLY MARS?



See review in *Kite (2019)*

Icarus
Volume 315, 15 November 2018, Pages 146-157

Loss of the Martian atmosphere to space: Present-day loss rates determined from *MAVEN* observations and integrated loss through time

B.M. Jakosky [a], D. Brain [a], M. Chaffin [a], S. Curry [l], J. Deighan [a], J. Grebowsky [f], J. Halekas [r], F. Leblanc [i], R. Lillis [l], J.G. Luhmann [l], L. Andersson [a], N. Andre [b], D. Andrews [c], D. Baird [d], D. Baker [a], J. Bell [e], M. Benna [f], D. Bhattacharyya [g] … R. Zurek [B]

Show more

https://doi.org/10.1016/j.icarus.2018.05.030

Highlights

- MAVEN has observed the Martian upper atmosphere for a full Martian year, and has determined the rate of loss of gas to space and the driving processes; 1–2kg/s of gas are being lost.
- The loss rate extrapolated back in time gives an estimate of the total loss of gas to space and its impact on Martian climate history; an estimated 0.8 bars or more of CO_2 likely has been lost.
- Loss to space has been the major process driving climate change on Mars.

CAN A PURE CO_2 ATMOSPHERE WARM EARLY MARS?

CAN A PURE CO_2 ATMOSPHERE WARM EARLY MARS?

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ELSEVIER

Icarus

Volume 71, Issue 2, August 1987, Pages 203-224

The case for a wet, warm climate on early Mars

J.B. Pollack, J.F. Kasting, S.M. Richardson, K. Poliakoff

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https://doi.org/10.1016/0019-1035(87)90147-3

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Abstract

Theoretical arguments are presented in support of the idea that Mars possessed a dense CO_2 atmosphere and a wet, warm climate early in its history. Calculations with a one-dimensional radiative-convective climate model indicate that CO_2 pressures between 1 and 5 bars would have been required to keep the surface temperature above the freezing point of water early in the planet's history. The higher value corresponds to globally and orbitally averaged conditions and a 30% reduction in solar luminosity; the lower value corresponds to conditions at the equator during perihelion at times of high orbital eccentricity and the same reduced solar luminosity.

Also

Kasting, 1991

Forget and Pierrehumbert, 1997

Haberle, 1998

Mischna et al, 2000

CAN A PURE CO_2 ATMOS... W...M EARLY MARS?

Icarus
Volume 210, Issue 2, December 2010, Pages 992-997

ELSEVIER

Infrared collision-induced and far-line absorption in dense CO_2 atmospheres

R. Wordsworth [a], F. Forget [a], V. Eymet [b]

Show more

https://doi.org/10.1016/j.icarus.2010.06.010

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Abstract

Collision-induced absorption is of great importance to the overall radiative budget in dense CO_2-rich atmospheres, but its representation in climate models remains uncertain, mainly due to a lack of accurate experimental and theoretical data. Here we compare several parameterisations of the effect, including a new one that makes use of previously unused measurements in the 1200–1800 cm^{-1} spectral range. We find that a widely used parameterisation strongly overestimates absorption in pure ...ospheres compared to later results, and propose a new approach that we ...urate possible given currently available data.

...1991

...nd Pierrehumbert, 1997

...1998

...t al, 2000

CAN A PURE CO … M EARLY MARS?

JGR Planets

Research Article | Free Access

Radiative transfer in CO_2-rich atmospheres: 1. Collisional line mixing implies a colder early Mars

N. Ozak, O. Aharonson, I. Halevy

First published: 11 May 2016 | https://doi.org/10.1002/2015JE004871 | Citations: 6

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SECTIONS

Abstract

Fast and accurate radiative transfer methods are essential for modeling CO_2-rich atmospheres, relevant to the climate of early Earth and Mars, present-day Venus, and some exoplanets. Although such models already exist, their accuracy may be improved as better theoretical and experimental constraints become available. Here we develop a unidimensional radiative transfer code for CO_2-rich atmospheres, using the correlated *k* approach and with a focus on modeling early Mars. Our model differs from existing models in that it includes the effects of CO_2 collisional line mixing in the calculation of the line-by-line absorption coefficients. Inclusion of these effects results in model atmospheres that are more transparent to infrared radiation and, therefore, in colder surface temperatures at radiative-convective equilibrium, compared with results of previous studies. Inclusion of water vapor in the model atmosphere results in negligible warming due to the low atmospheric temperatures under a weaker early Sun, which translate into climatically unimportant concentrations of water vapor. Overall, the results imply that sustained warmth on early Mars would not have been possible with an atmosphere containing only CO_2 and water vapor, suggesting that other components of the … climate system are missing from current models or that warm

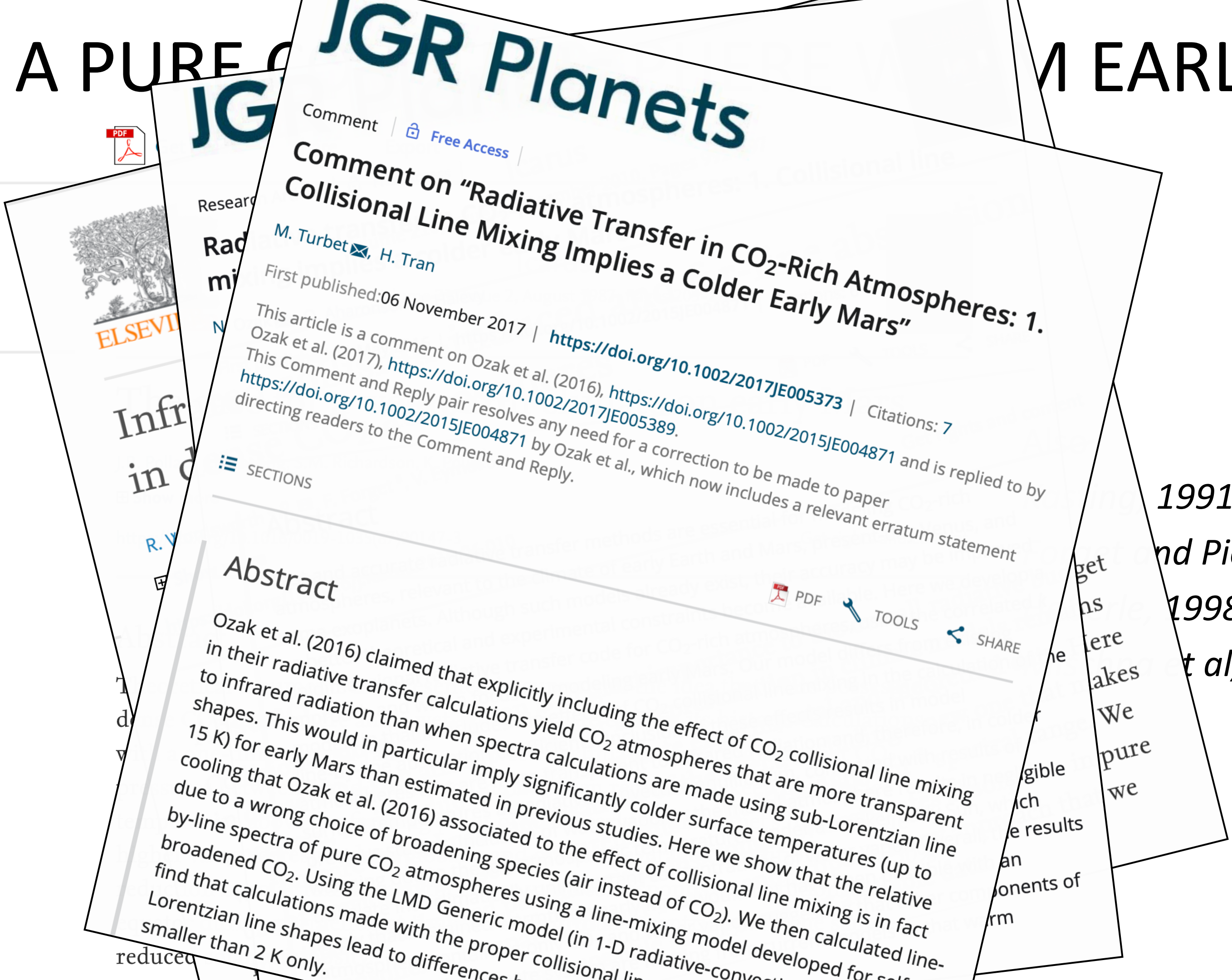
… 1991

…nd Pierrehumbert, 1997

… 1998

…t al, 2000

CAN A PURE C … M EARLY MARS?


JGR Planets

Comment | Free Access |

Comment on "Radiative Transfer in CO_2-Rich Atmospheres: 1. Collisional Line Mixing Implies a Colder Early Mars"

M. Turbet, H. Tran

First published: 06 November 2017 | https://doi.org/10.1002/2017JE005373 | Citations: 7

This article is a comment on Ozak et al. (2016), https://doi.org/10.1002/2015JE004871 and is replied to by Ozak et al. (2017), https://doi.org/10.1002/2017JE005389.
This Comment and Reply pair resolves any need for a correction to be made to paper https://doi.org/10.1002/2015JE004871 by Ozak et al., which now includes a relevant erratum statement directing readers to the Comment and Reply.

SECTIONS

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Abstract

Ozak et al. (2016) claimed that explicitly including the effect of CO_2 collisional line mixing in their radiative transfer calculations yield CO_2 atmospheres that are more transparent to infrared radiation than when spectra calculations are made using sub-Lorentzian line shapes. This would in particular imply significantly colder surface temperatures (up to 15 K) for early Mars than estimated in previous studies. Here we show that the relative cooling that Ozak et al. (2016) associated to the effect of collisional line mixing is in fact due to a wrong choice of broadening species (air instead of CO_2). We then calculated line-by-line spectra of pure CO_2 atmospheres using a line-mixing model developed for self-broadened CO_2. Using the LMD Generic model (in 1-D radiative-convecti… find that calculations made with the proper collisional lin… Lorentzian line shapes lead to differences … smaller than 2 K only.

1991
nd Pierrehumbert, 1997
1998
t al, 2000

CAN A PURE ... M EARLY MARS?

...1991

...nd Pierrehumbert, 1997

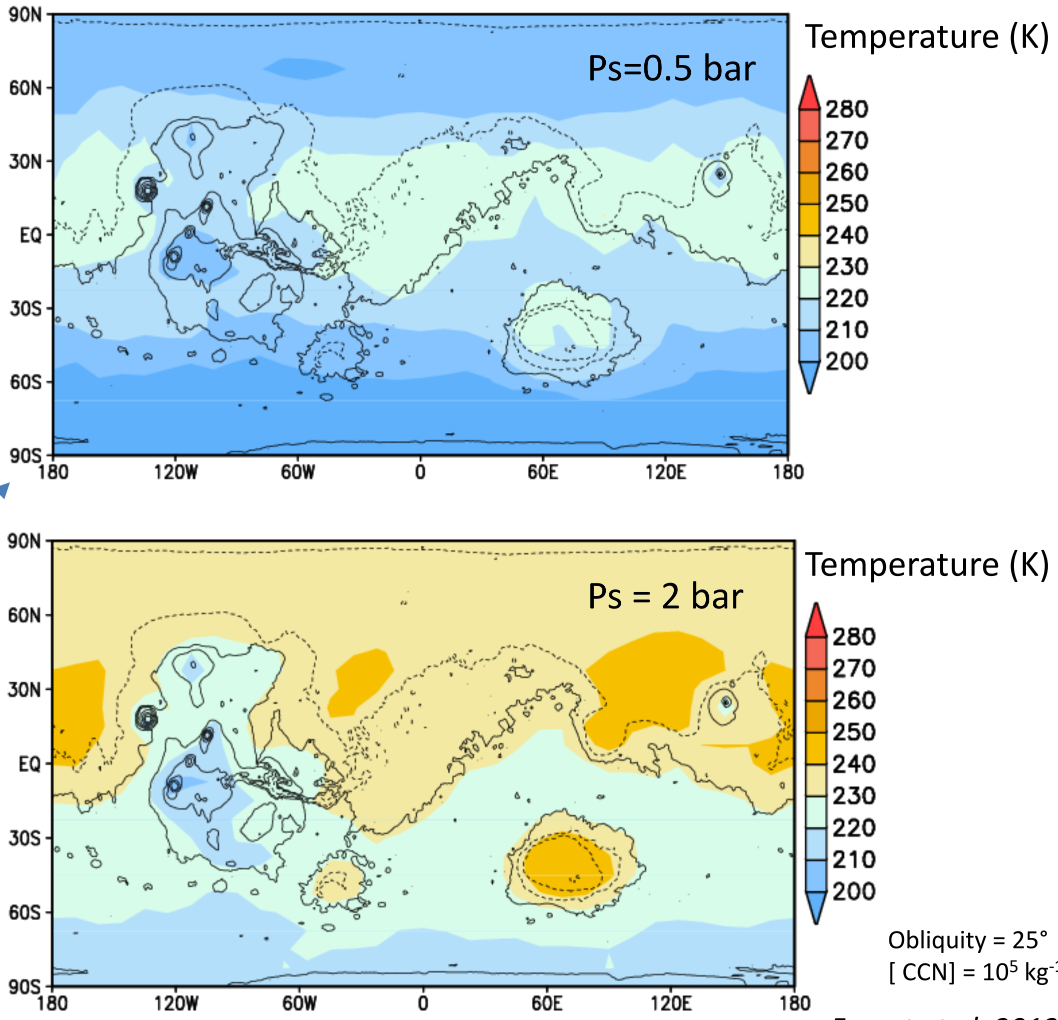
...1998

...t al, 2000

THE EARLY MARS ENIGMA

Early Mars with
$CO_2/N_2/H_2O$ should be cold

CO_2 atmosphere:
Annual mean surface temperature

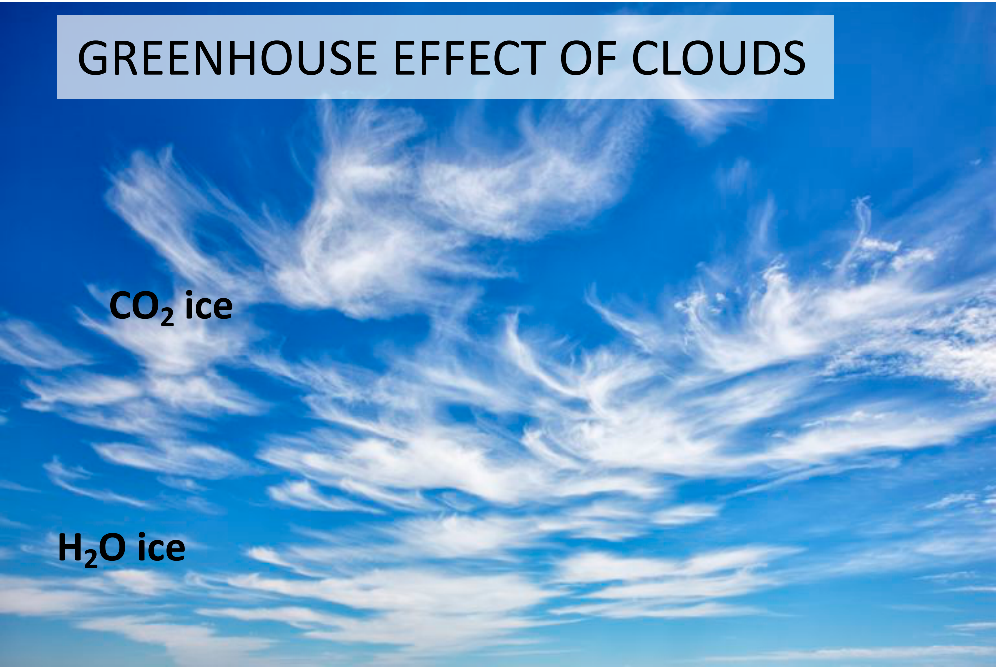


Obliquity = 25°
[CCN] = 10^5 kg^{-1}

Forget et al. 2013

For a review, see:
Wordsworth 2016, AREPS
Haberle et al. 2017, Cambridge Univ. Press

SCENARIOS FOR THE WARMING OF EARLY MARS



Follow the debate

CO_2 ice clouds

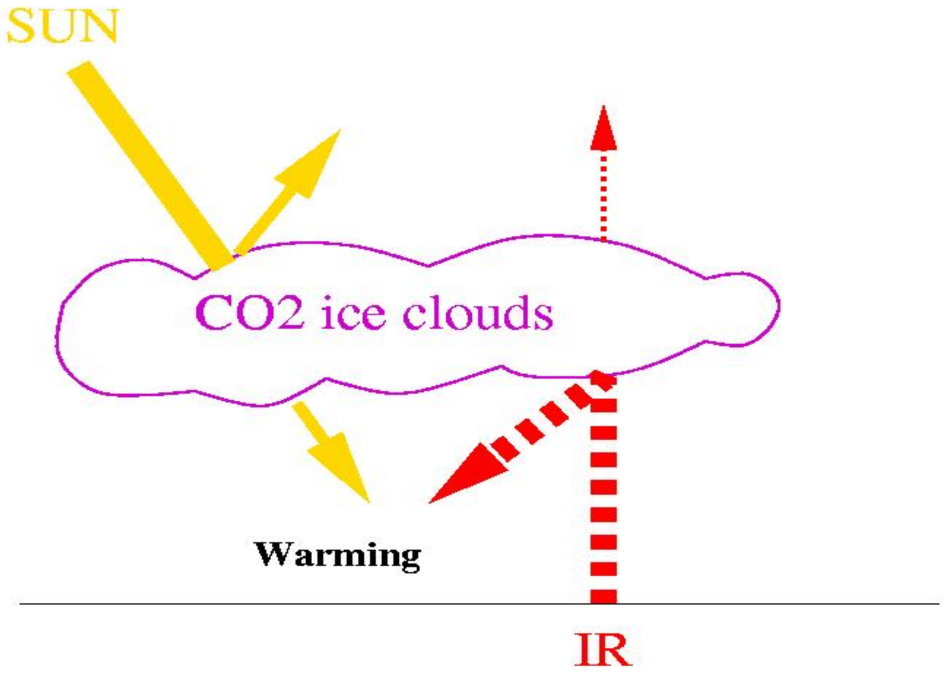
Forget & Pierrehumbert 1997
Forget et al. 2013
Kitzmann et al. 2013, 2016, 2017

H_2O ice clouds

Urata & Toon 2013
Wordsworth et al. 2013
Ramirez & Kasting 2017
Turbet et al. 2020a

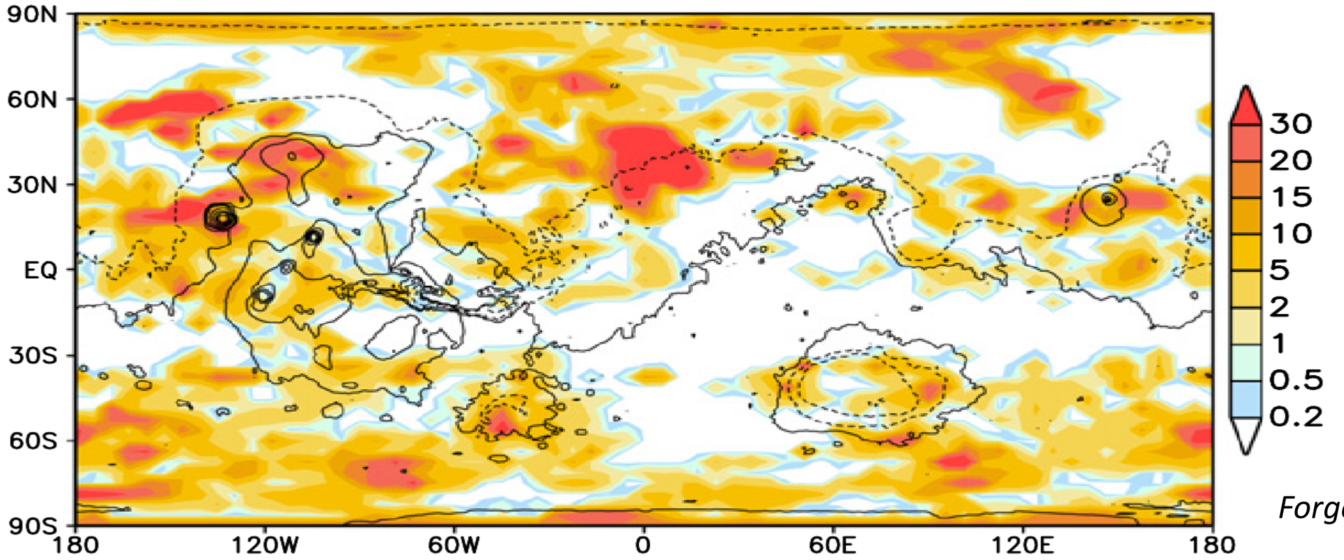
WARMING BY CO_2 ICE CLOUDS BACK-SCATTERING

Forget & Pierrehumbert 1997



WARMING BY CO_2 ICE CLOUDS BACK-SCATTERING

CO_2 ice clouds coverage



Forget et al. 2013

<u>Main caveats:</u>

1) Partial CO_2 cloud coverage (*Forget et al. 2013*)

2) Scattering effect overestimated (*Kitzmann 2016*)

WARMING BY H_2O ICE CLOUDS

Urata & Toon 2013
Wordsworth et al. 2013
Ramirez & Kasting 2017
Turbet et al. 2020a

<u>Main caveats:</u>

1) Cloud coverage must be very high
2) Size of H_2O ice particles must be tuned
3) Altitude of clouds must be tuned
4) Precipitations must be artificially suppressed

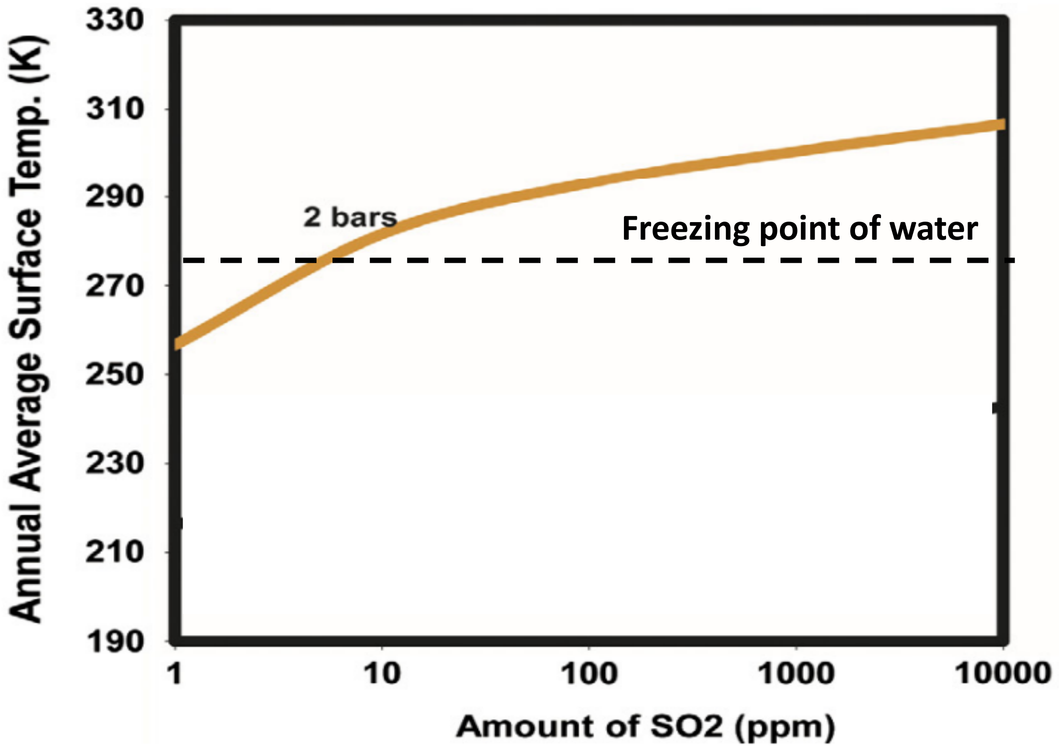
☛ *Ramirez & Kasting 2017*
Turbet et al. 2020

SCENARIOS FOR THE WARMING OF EARLY MARS

Follow the debate

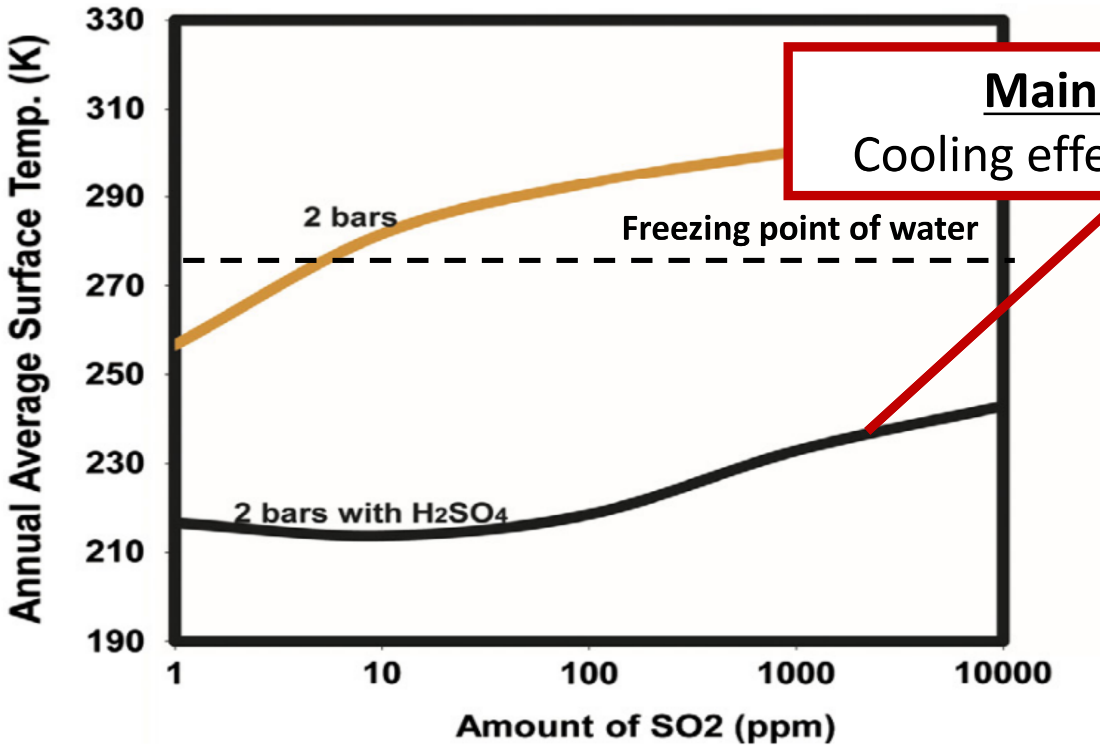
Johnson et al. 2008
Tian et al. 2010
Mischna et al. 2013
Halevy & Head 2014
Kerber et al. 2015

WARMING BY VOLCANIC GASES (SO_2, H_2S)



Kerber et al. 2015

WARMING BY VOLCANIC GASES (SO_2, H_2S)

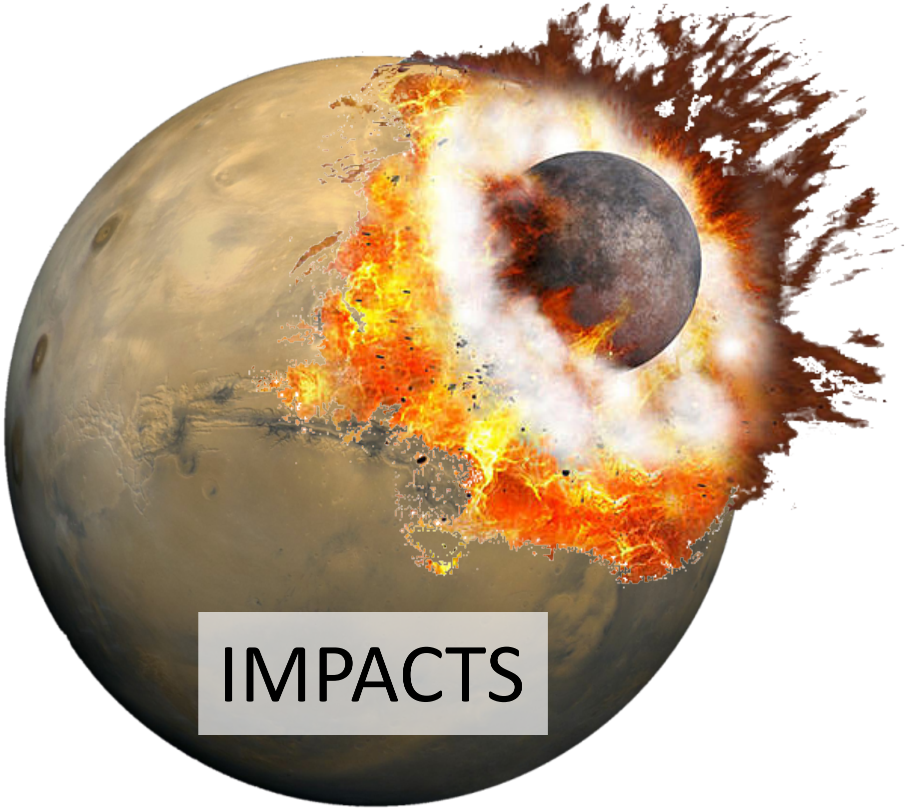


Main caveat:

Cooling effect of aerosols

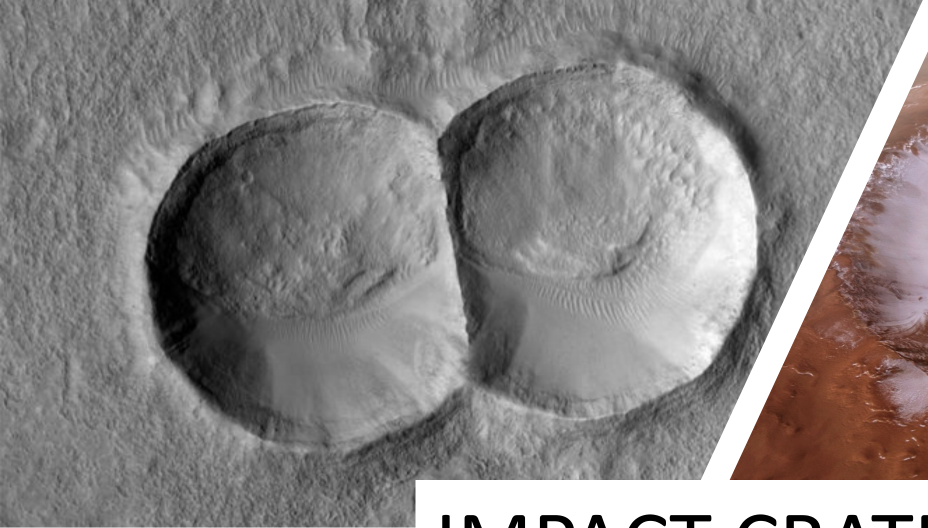
Kerber et al. 2015

SCENARIOS FOR THE WARMING OF EARLY MARS

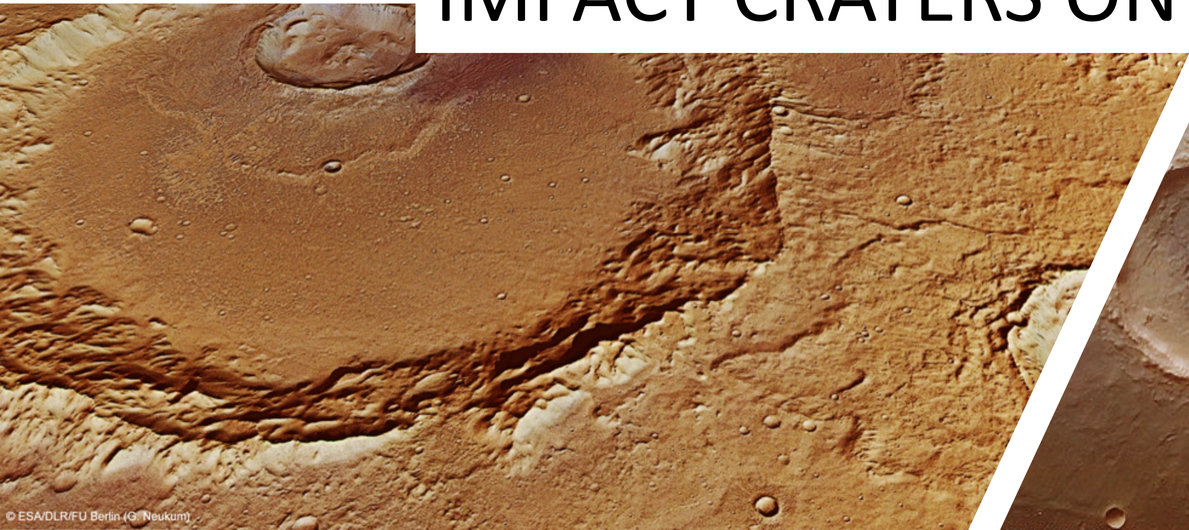


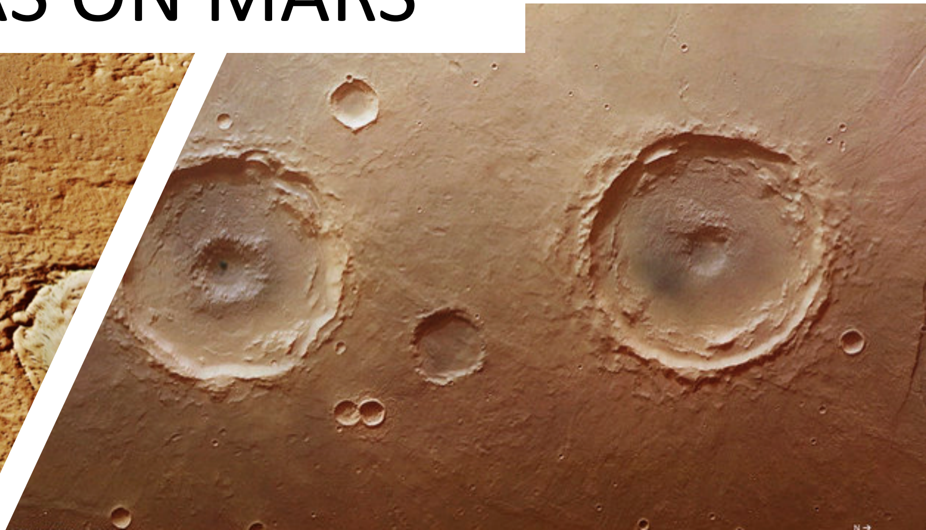
☛ Follow the debate

Segura et al. 2002, 2008, 2012
Turbet 2018
Steakley et al. 2019
Turbet et al. 2020a

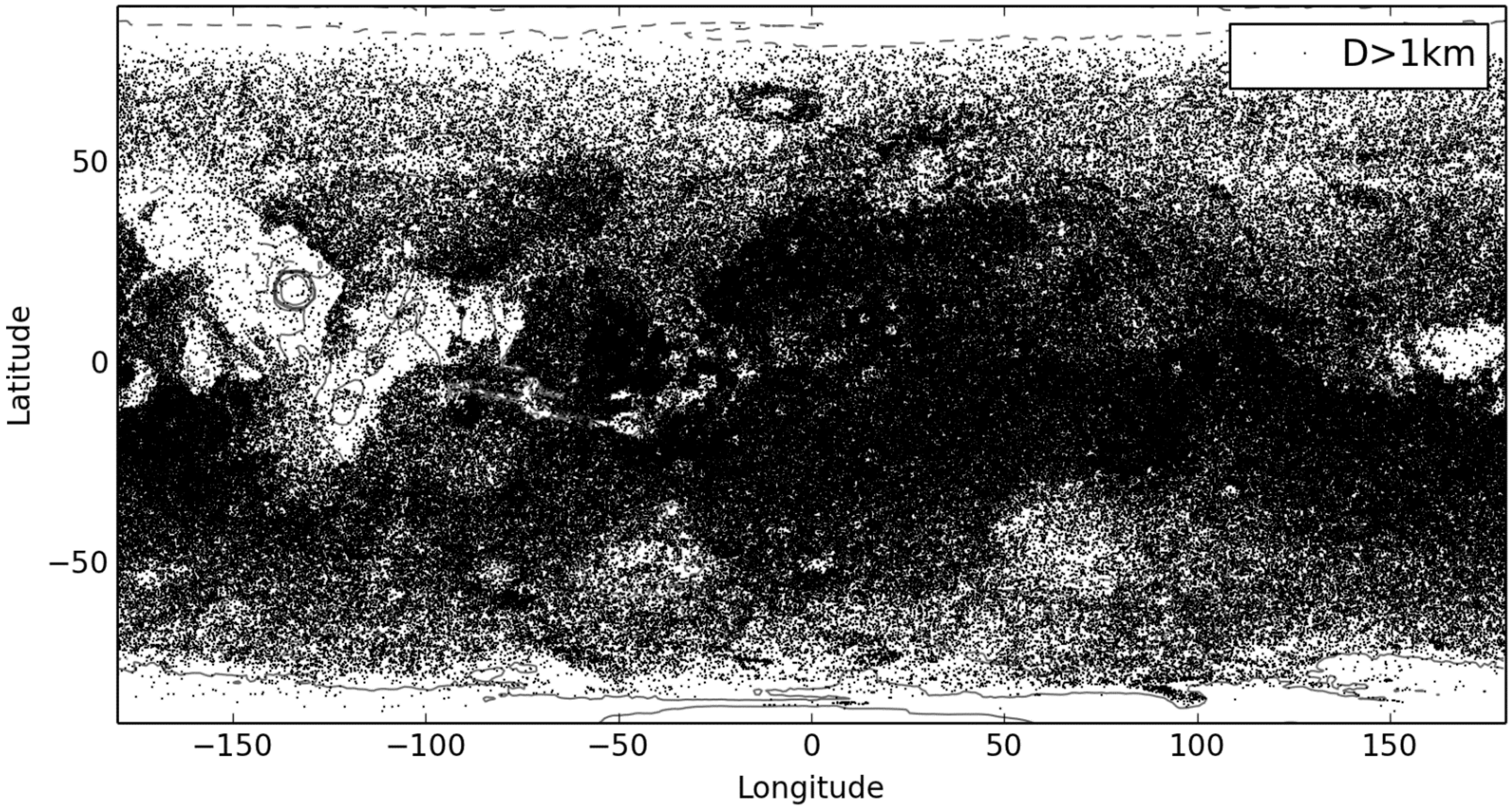


IMPACT CRATERS ON MARS



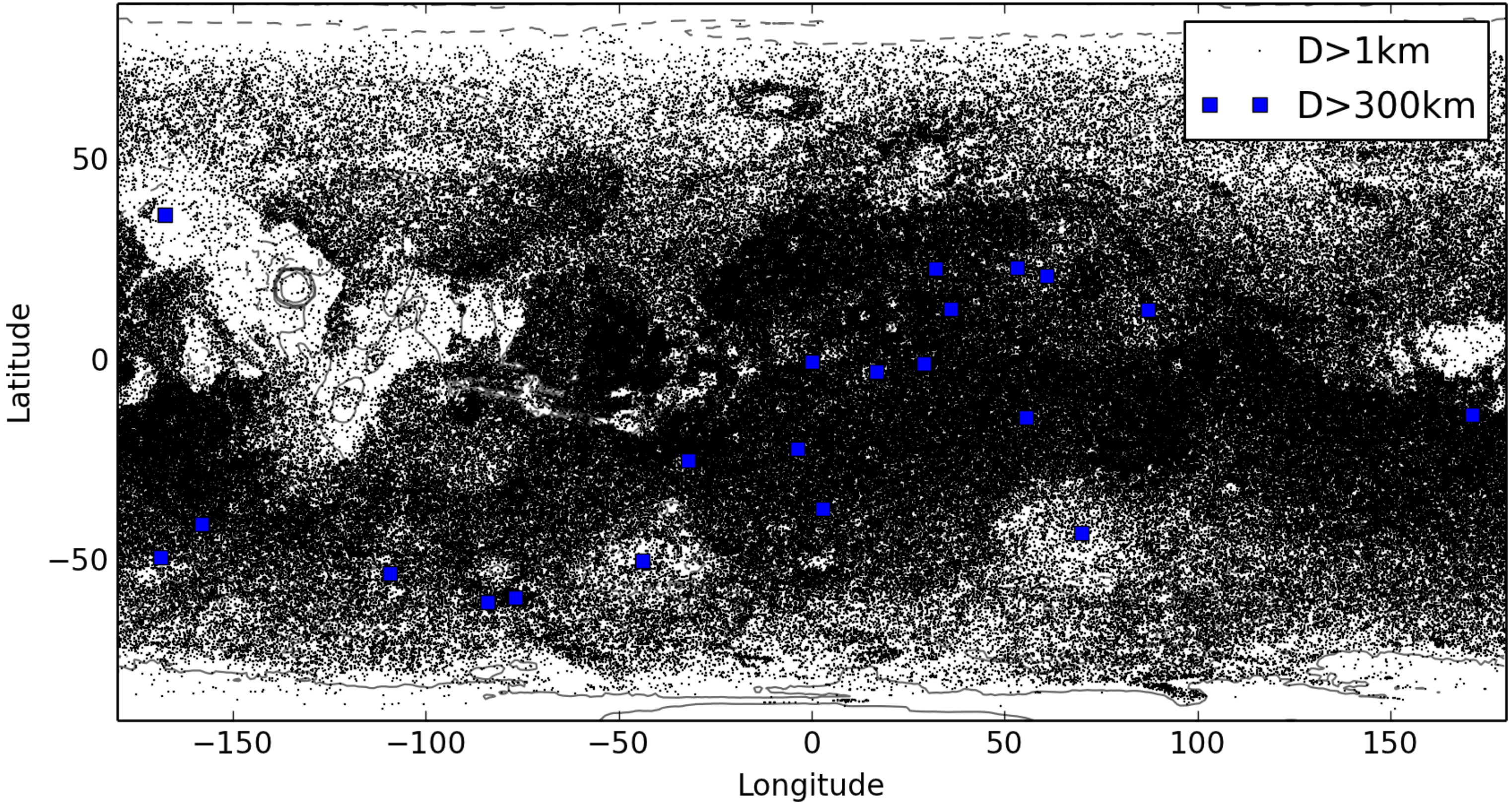


Map of impact craters on Mars



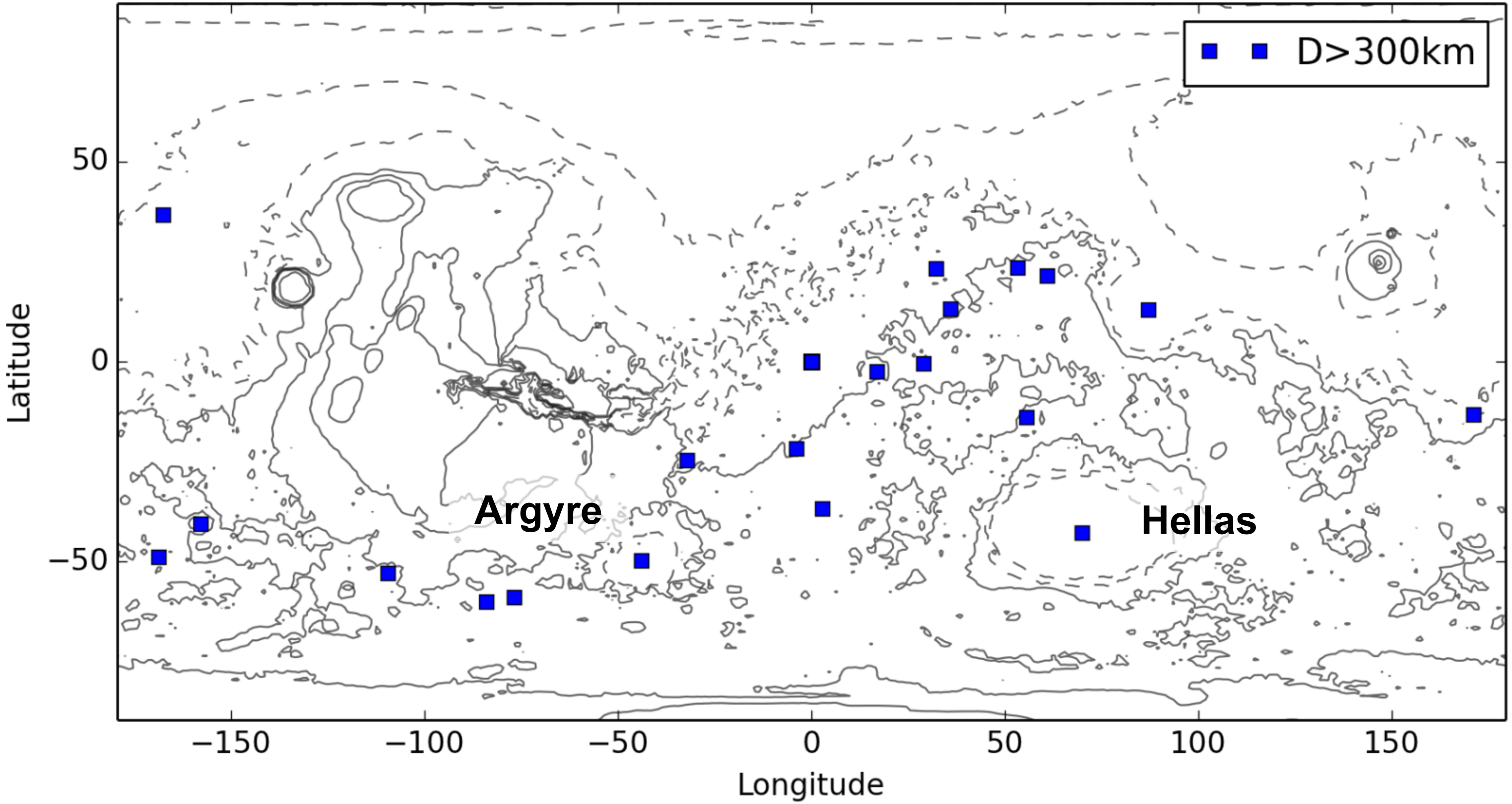
Made with the Robbins crater database

Map of impact craters on Mars



Made with the Robbins crater database

Map of impact craters on Mars



Made with the Robbins crater database

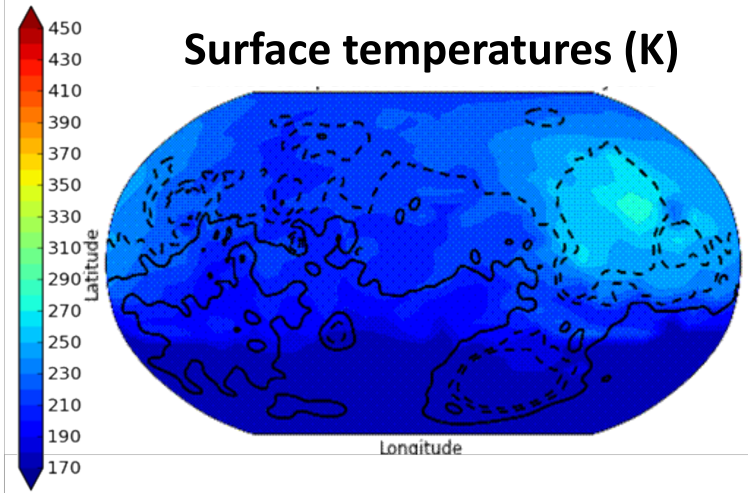
VERY BIG IMPACT EVENTS

Turbet et al. 2020a

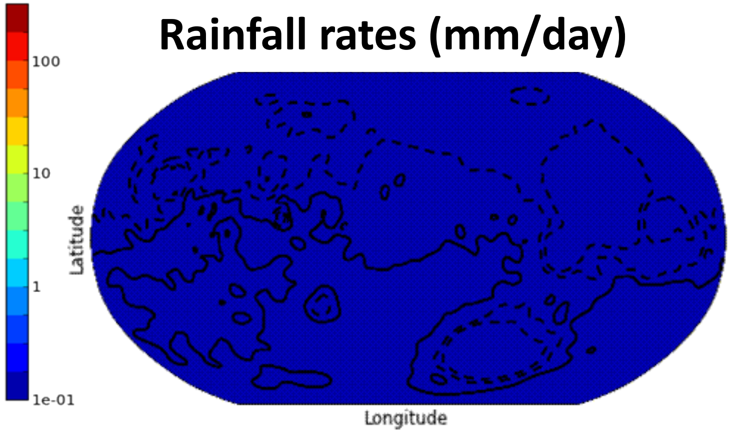
100km diameter meteorite impacting a 1bar CO_2 atmosphere

- Atmosphere + Subsurface = 500 Kelvins
- Vaporization of 1bar of H_2O (30m GEL)

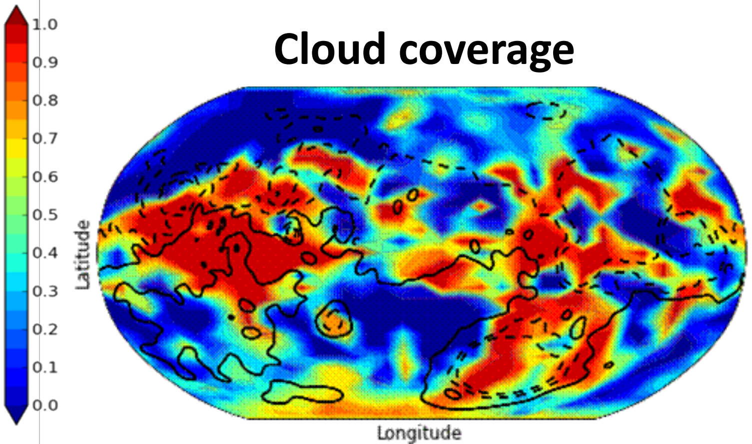
Surface temperatures (K)



Rainfall rates (mm/day)

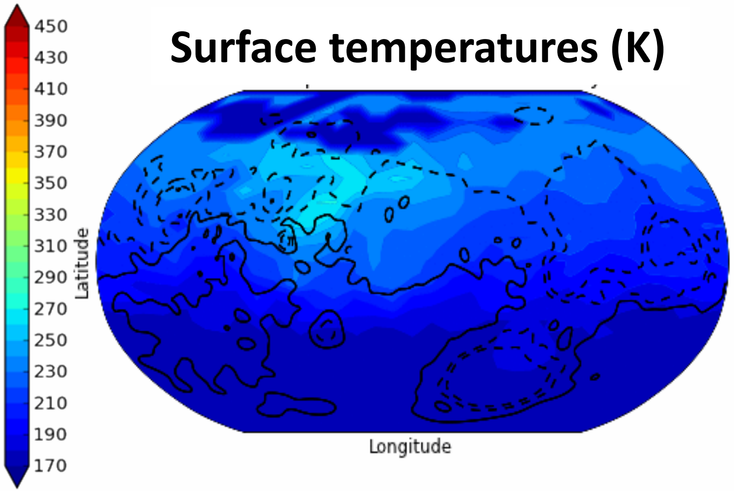


Cloud coverage



VERY BIG IMPACT EVENTS

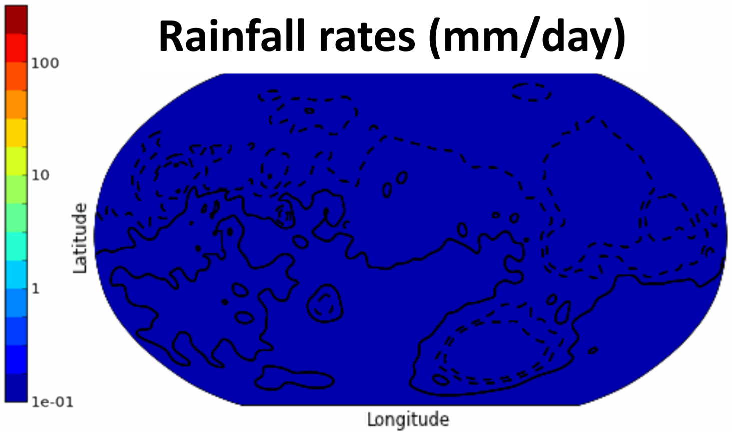
Turbet et al. 2020a

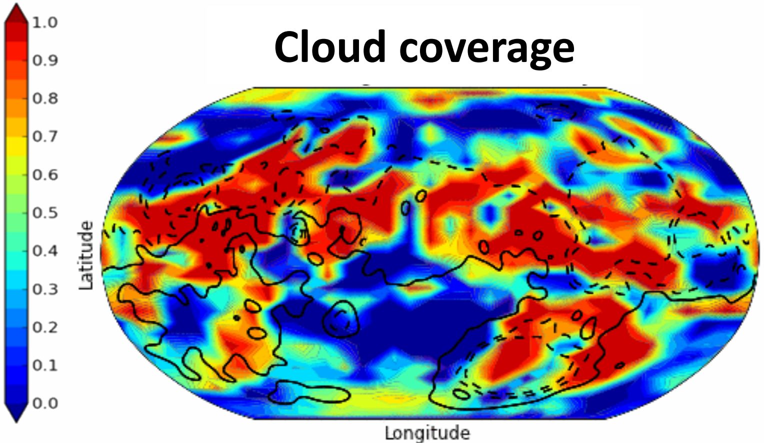


100km diameter meteorite impacting a 1bar CO_2 atmosphere

- Atmosphere + Subsurface = 500 Kelvins
- Vaporization of 1bar of H_2O (30m GEL)

after 0.1 martian years

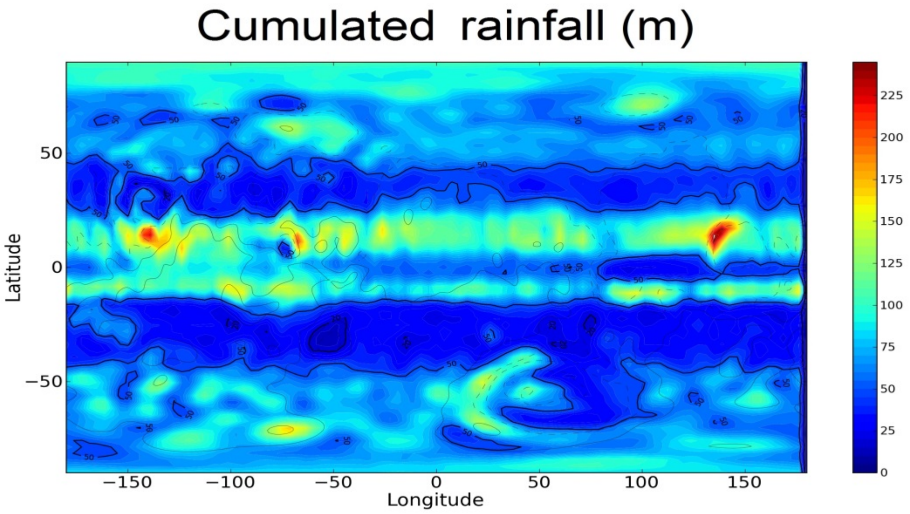




VERY LARGE IMPACT EVENTS

Turbet et al. 2020a

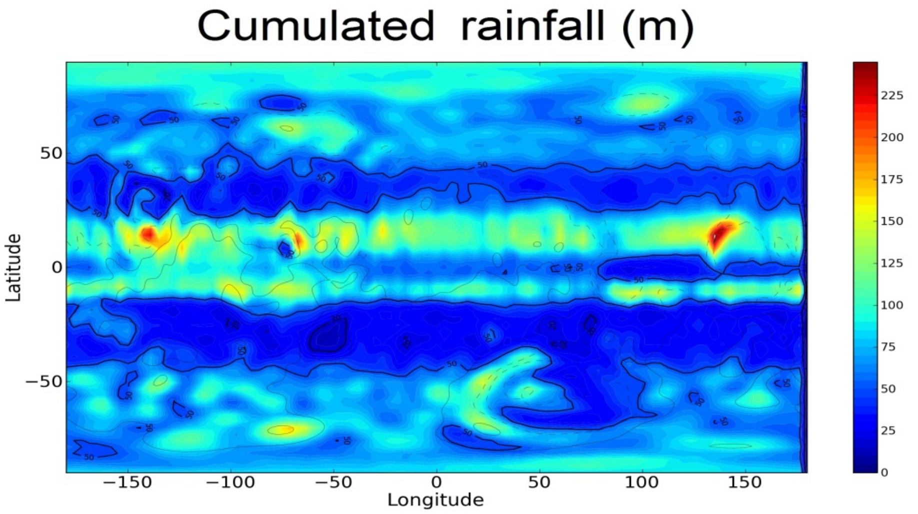
Cumulated rainfall in 3D climate simulation



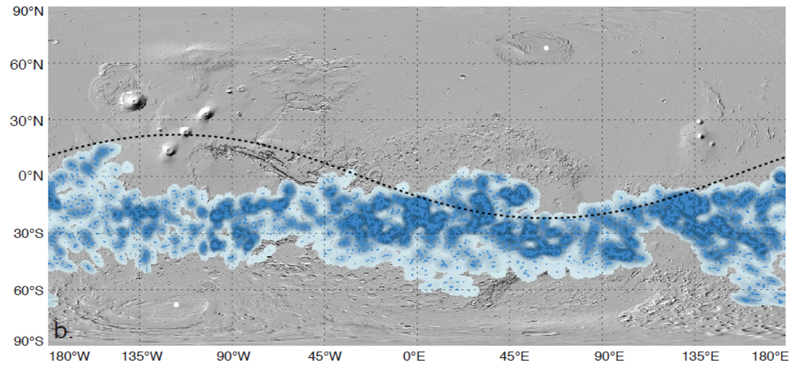
VERY LARGE IMPACT EVENTS

Turbet et al. 2020a

Cumulated rainfall in 3D climate simulation

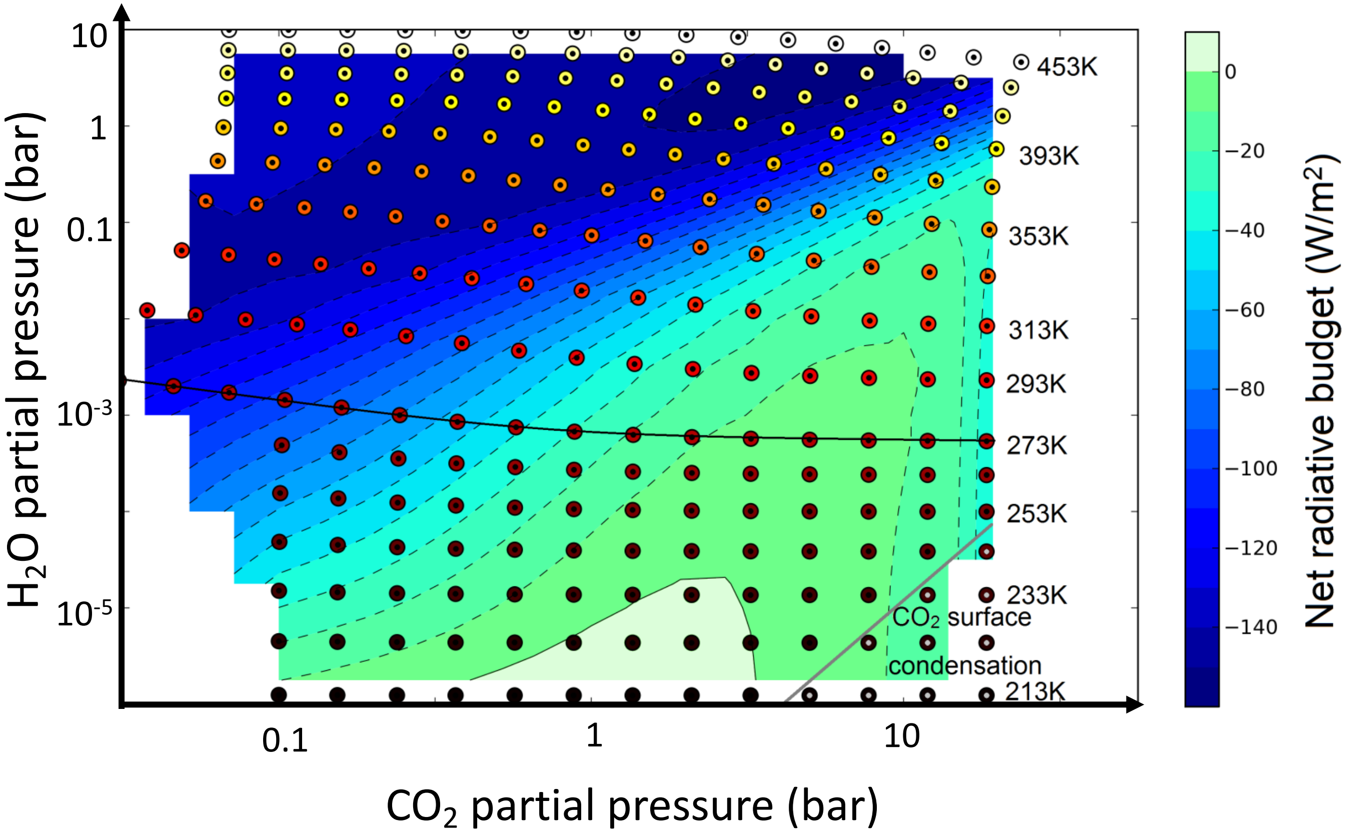


Positions of valley networks



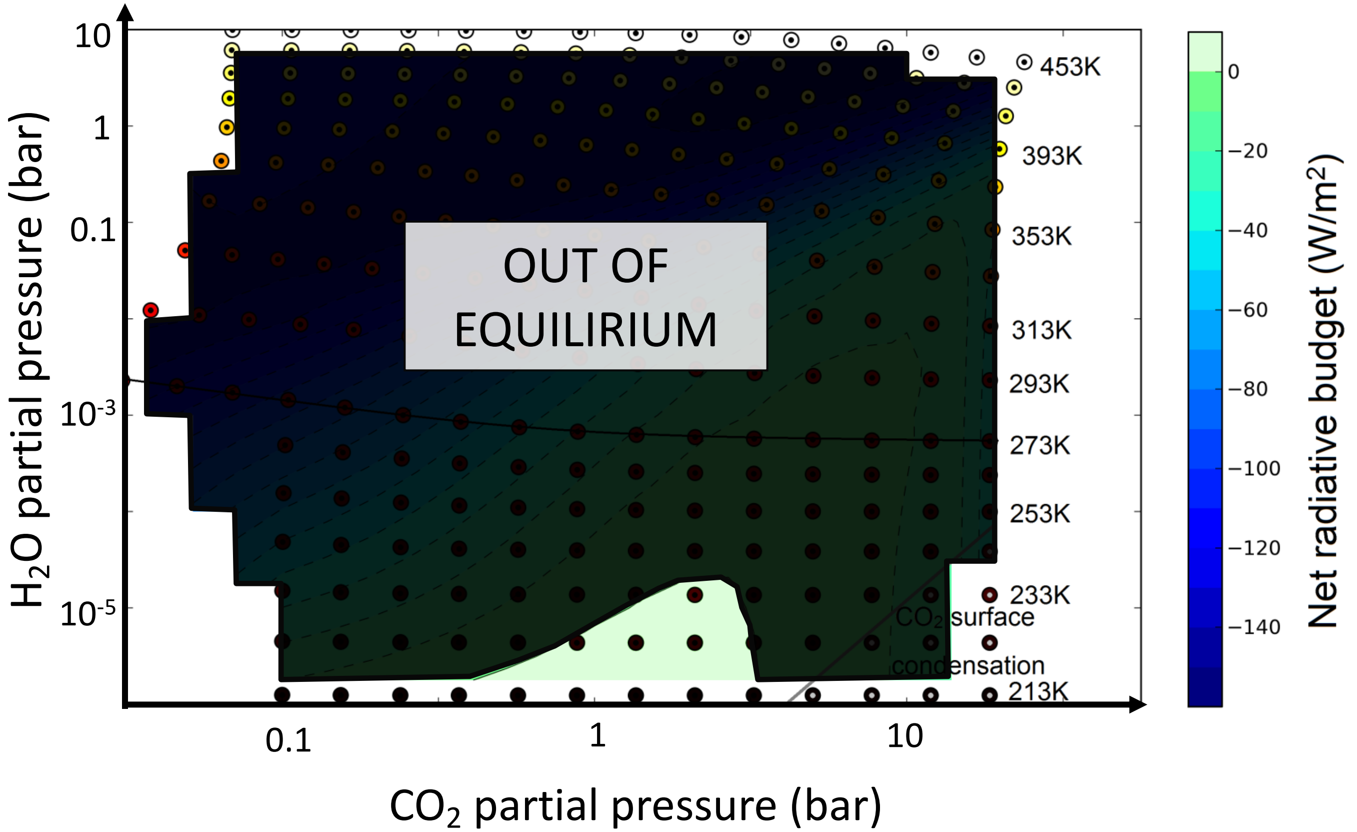
LARGE IMPACTS WITH A 1-D **CLOUD-FREE** CLIMATE MODEL

Turbet et al. 2020a



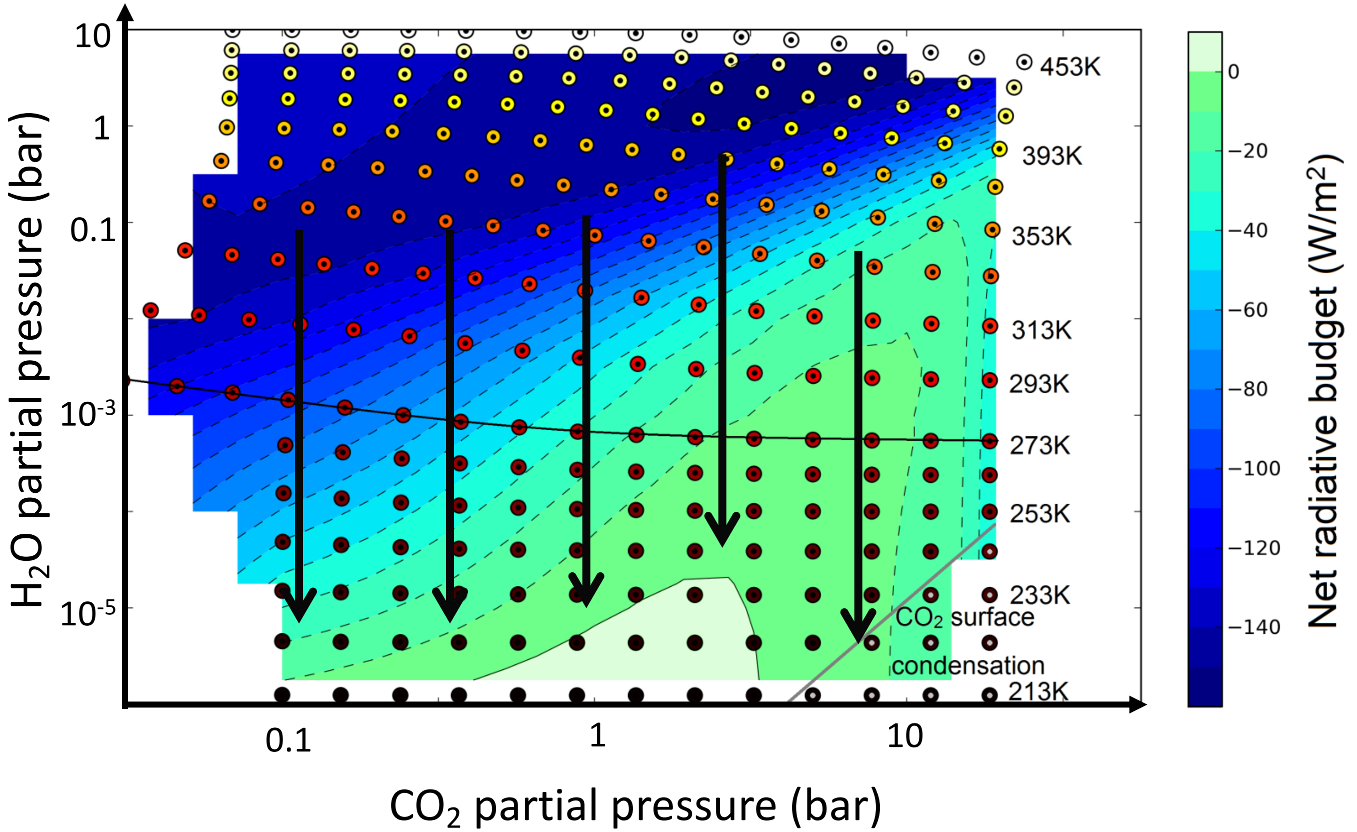
LARGE IMPACTS WITH A 1-D **CLOUD-FREE** CLIMATE MODEL

Turbet et al. 2020a



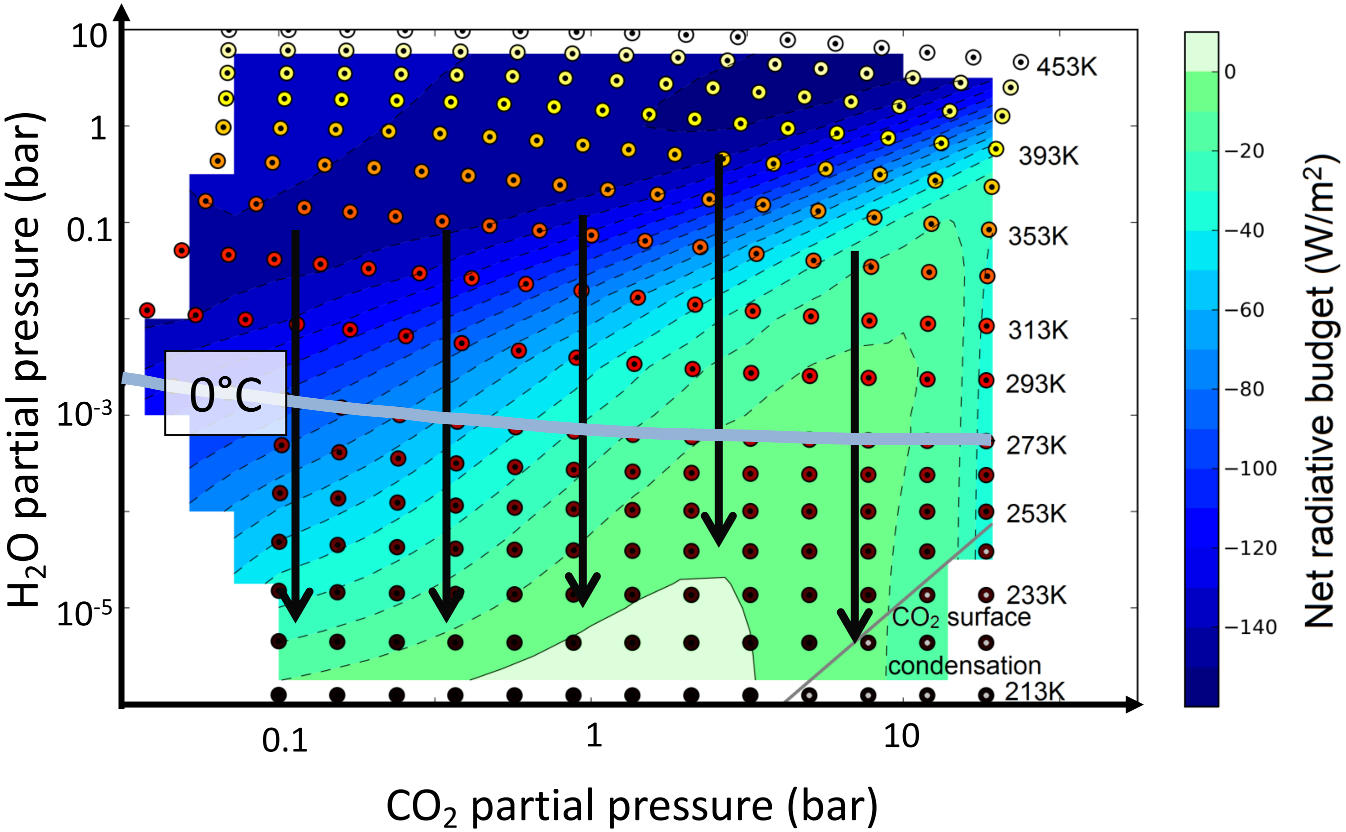
LARGE IMPACTS WITH A 1-D **CLOUD-FREE** CLIMATE MODEL

Turbet et al. 2020a



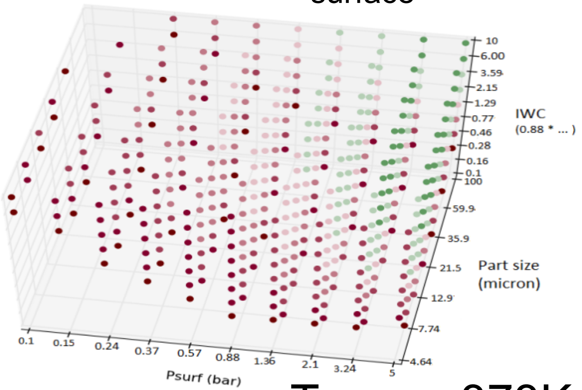
LARGE IMPACTS WITH A 1-D **CLOUD-FREE** CLIMATE MODEL

Turbet et al. 2020a

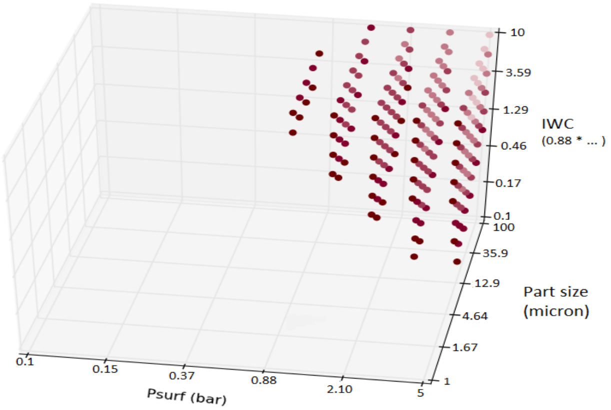


LARGE IMPACTS WITH A 1-D **CLOUDY** CLIMATE MODEL

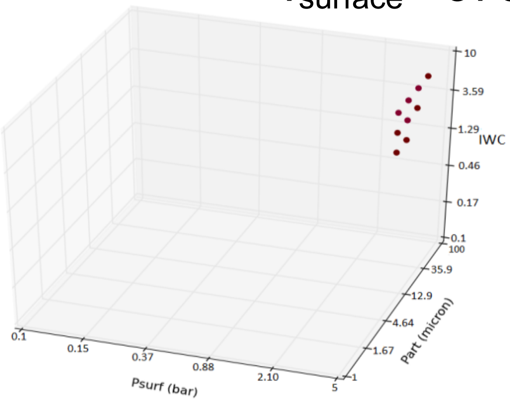
$T_{surface}$= 273K



$T_{surface}$= 323K



$T_{surface}$= 373K



Turbet et al. 2020

0% 50% 100%

Cloud coverage (in %)

VERY LARGE IMPACTS

In summary,

Turbet et al. 2020a

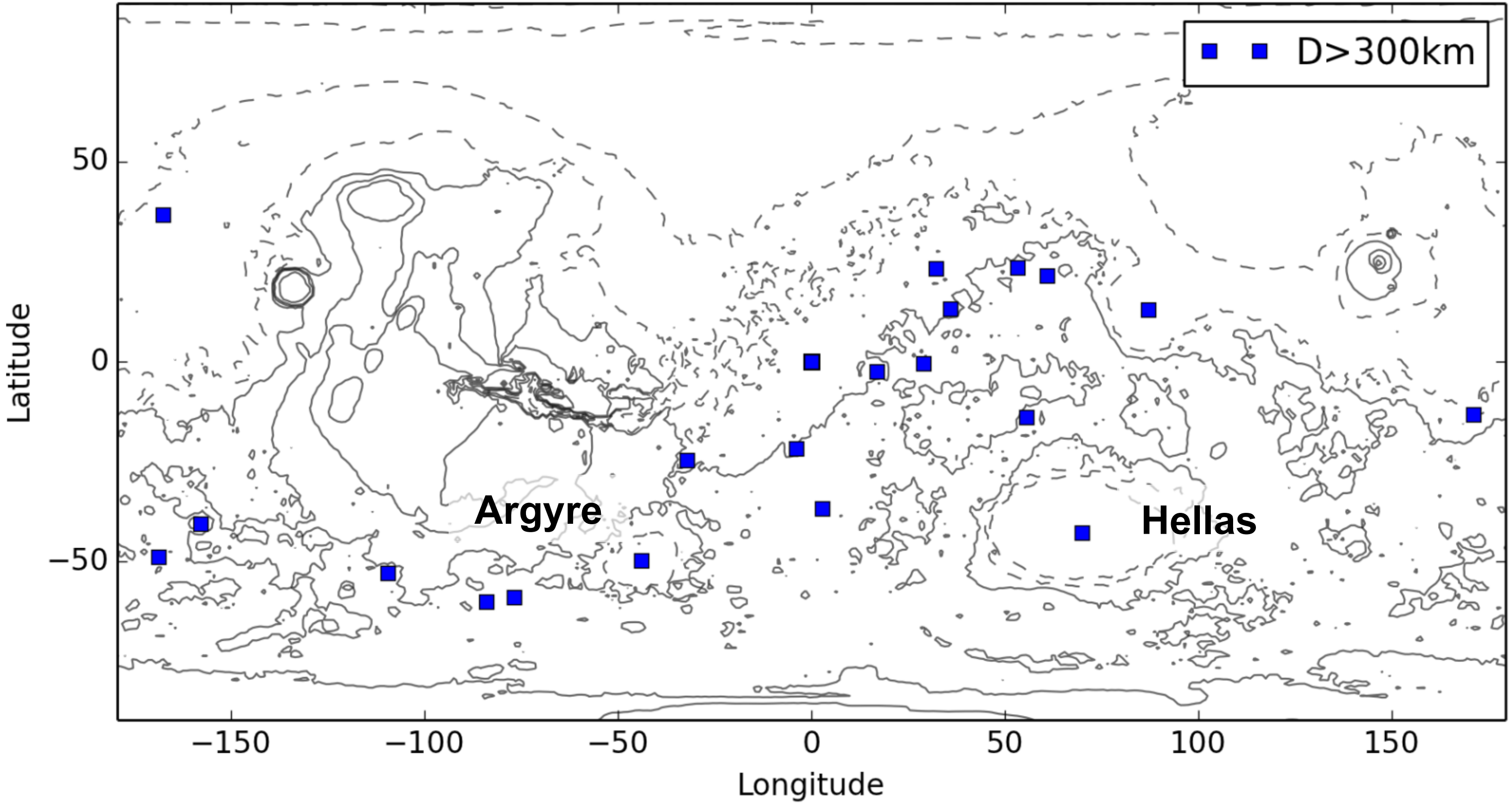
- ➢ No self-sustained 'RUNAWAY CLIMATE'
- ➢ Warming is instead SHORT-LIVED

($O(10^1)$ martian years for the largest impact events).

- ➢ Precipitation are (1) deluge-style, (2) insufficient and (3) uncorrelated with valley networks positions.

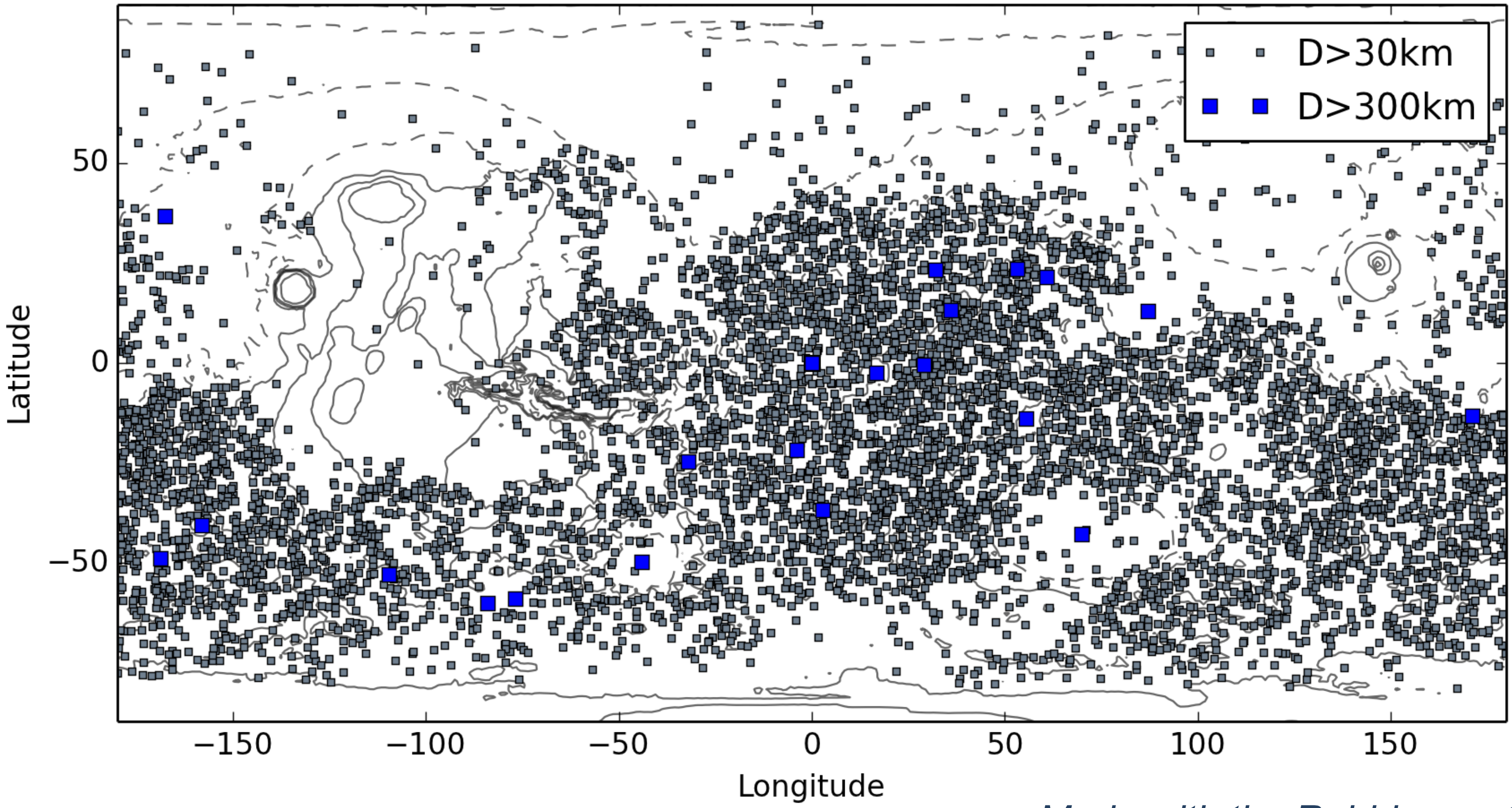
Remark: Very large impacts could have contributed to (1) mineralogy and (2) the crater rim degradation.

Map of impact craters on Mars



Made with the Robbins crater database

Map of impact craters on Mars

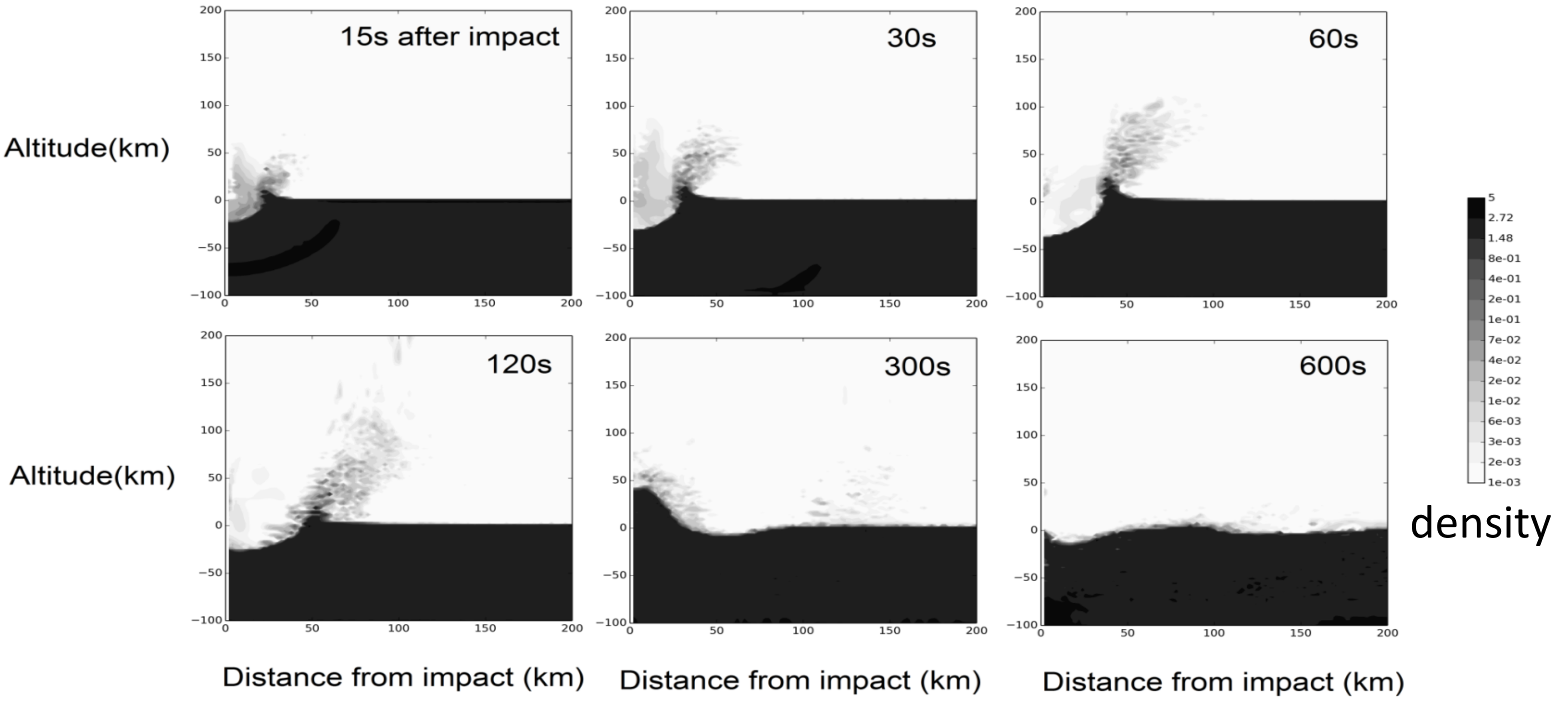


Made with the Robbins crater database

HYDROCODE SIMULATIONS

Turbet 2018, PhD thesis

15-km diameter body hitting the surface of Mars

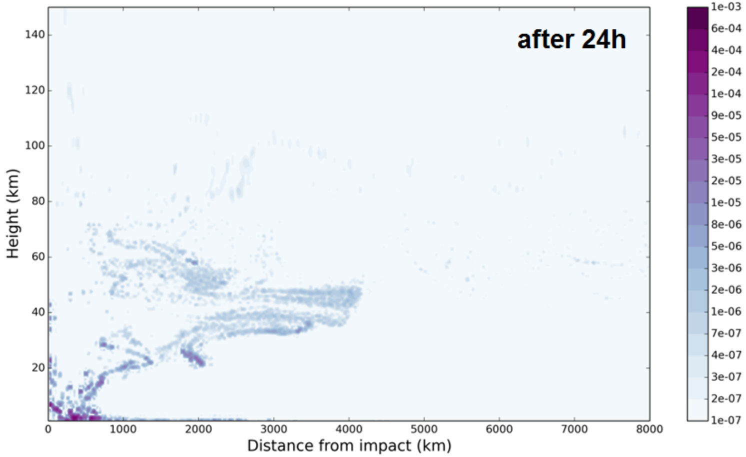


HYDROCODE SIMULATIONS

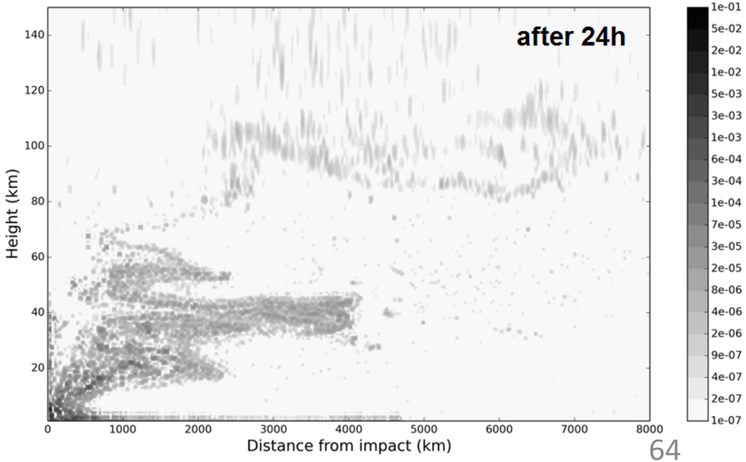
<u>Ejecta field after the impact event</u>

Turbet 2018, PhD thesis

Density of water particles (in g/cm^3)



Density of stony particles (in g/cm^3)

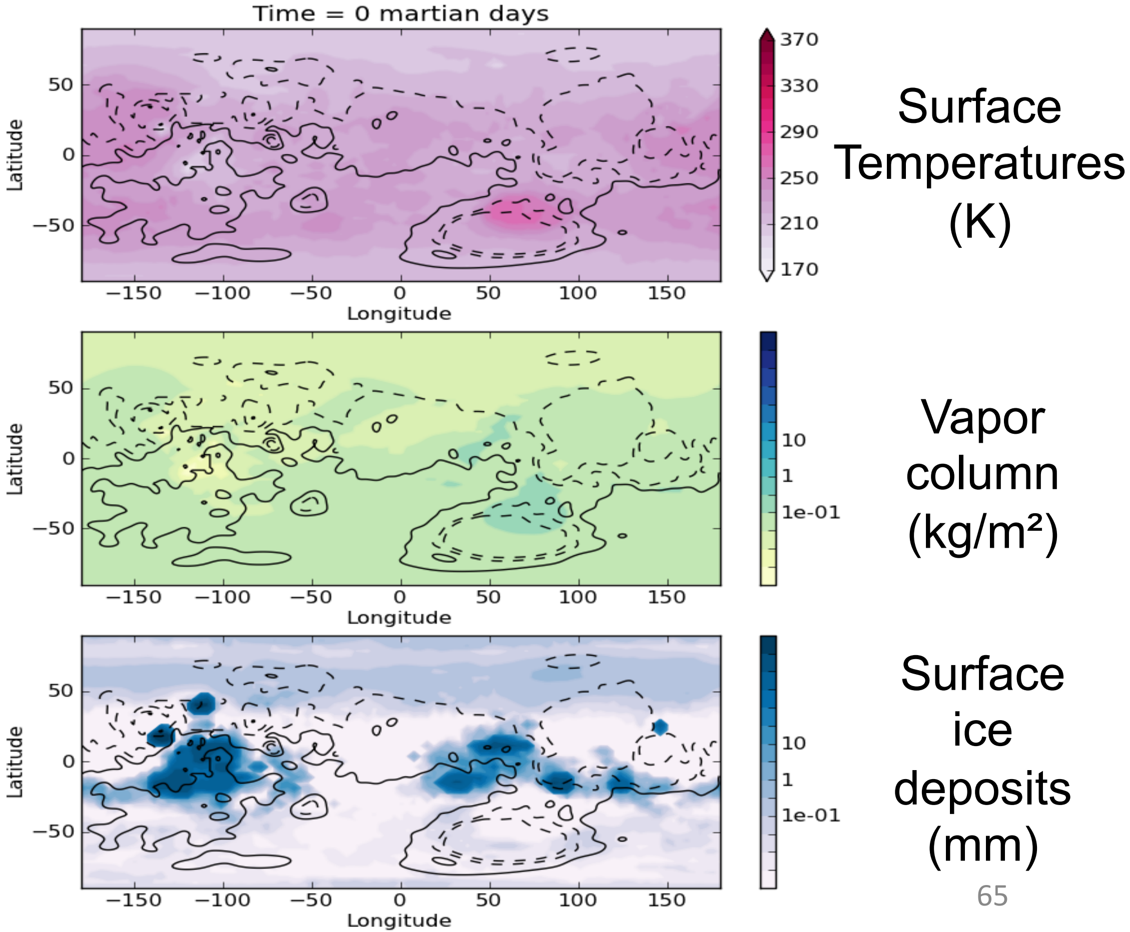


RESULTS OF 3-D GLOBAL CLIMATE MODEL

INITIAL STATE

1bar CO_2 atmosphere

Stabilized surface ice reservoirs



Turbet 2018, PhD thesis

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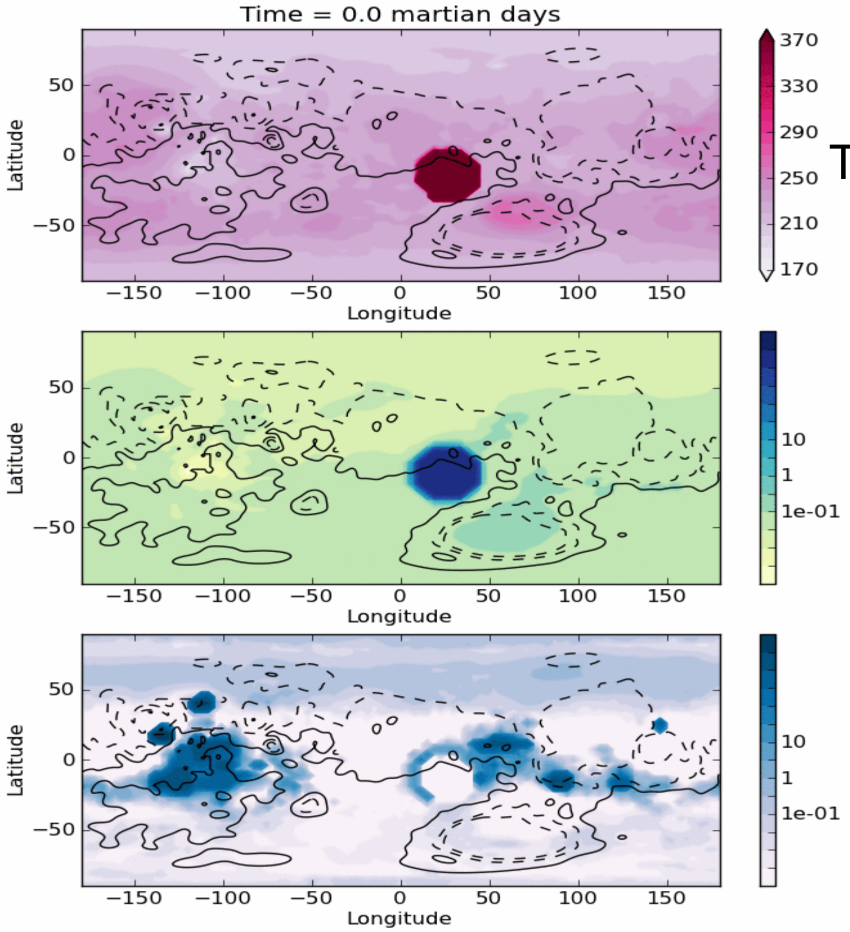


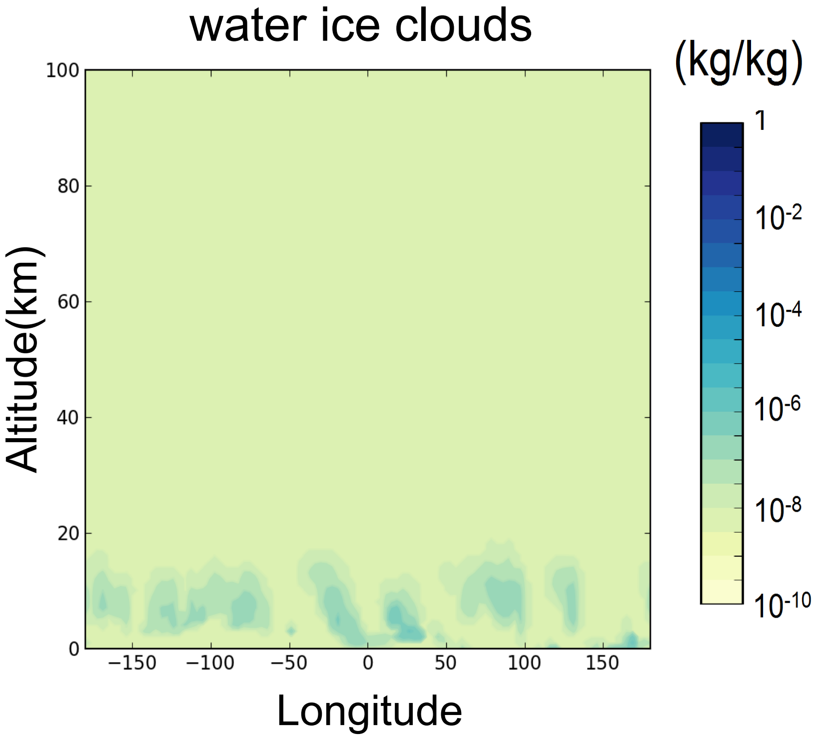
Surface Temperatures (K)

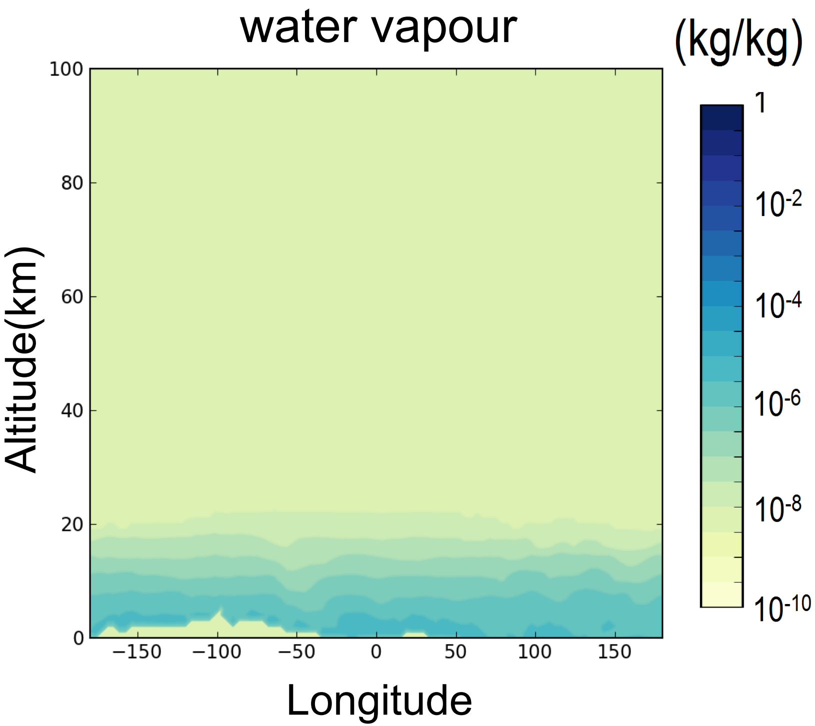
Vapor column (kg/m²)

Surface ice deposits (mm)

RESULTS OF 3-D GLOBAL CLIMATE MODEL

Upper atmosphere water ice clouds sediment rapidly

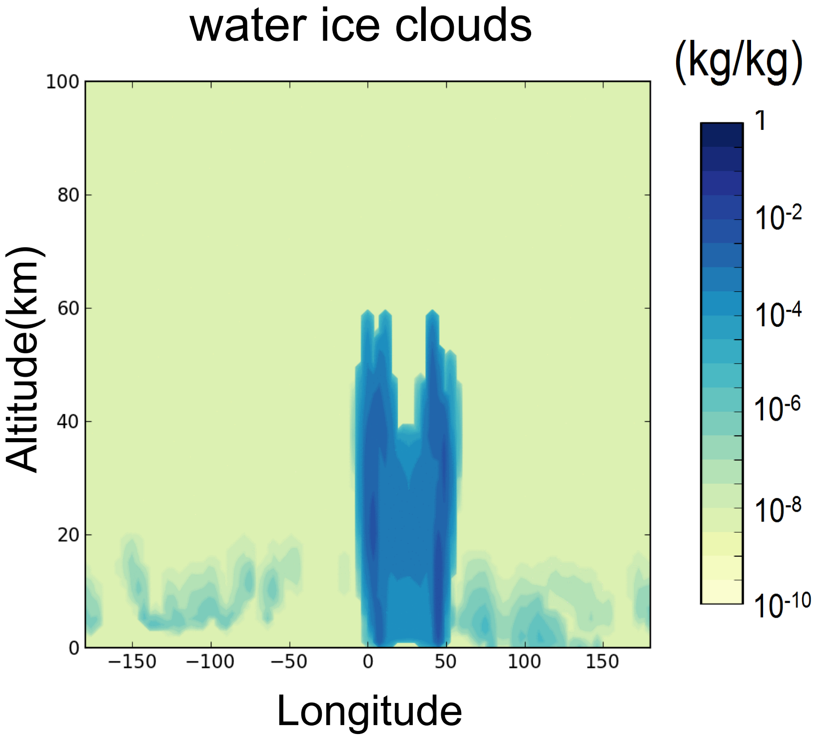


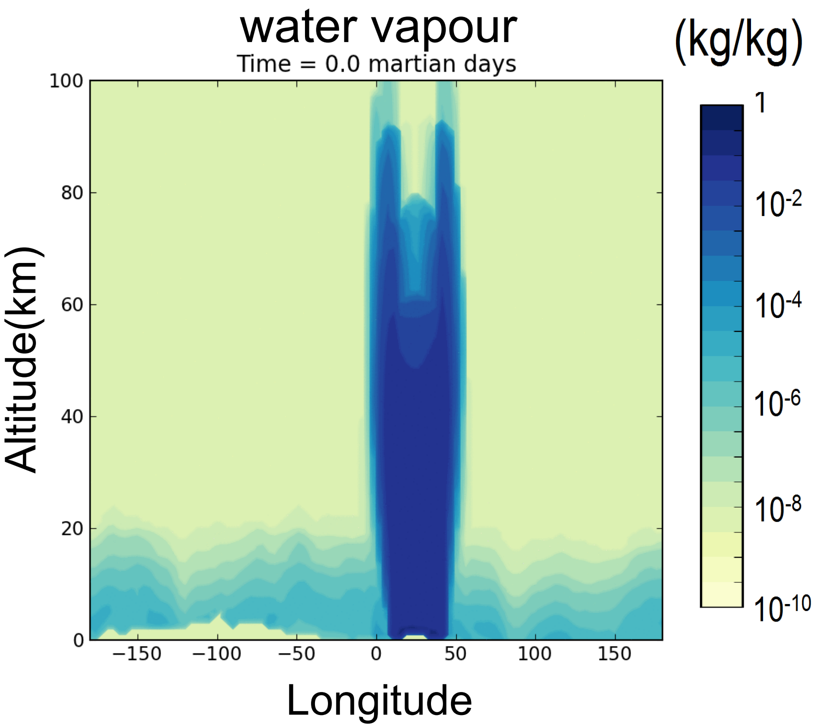


Turbet 2018, PhD thesis

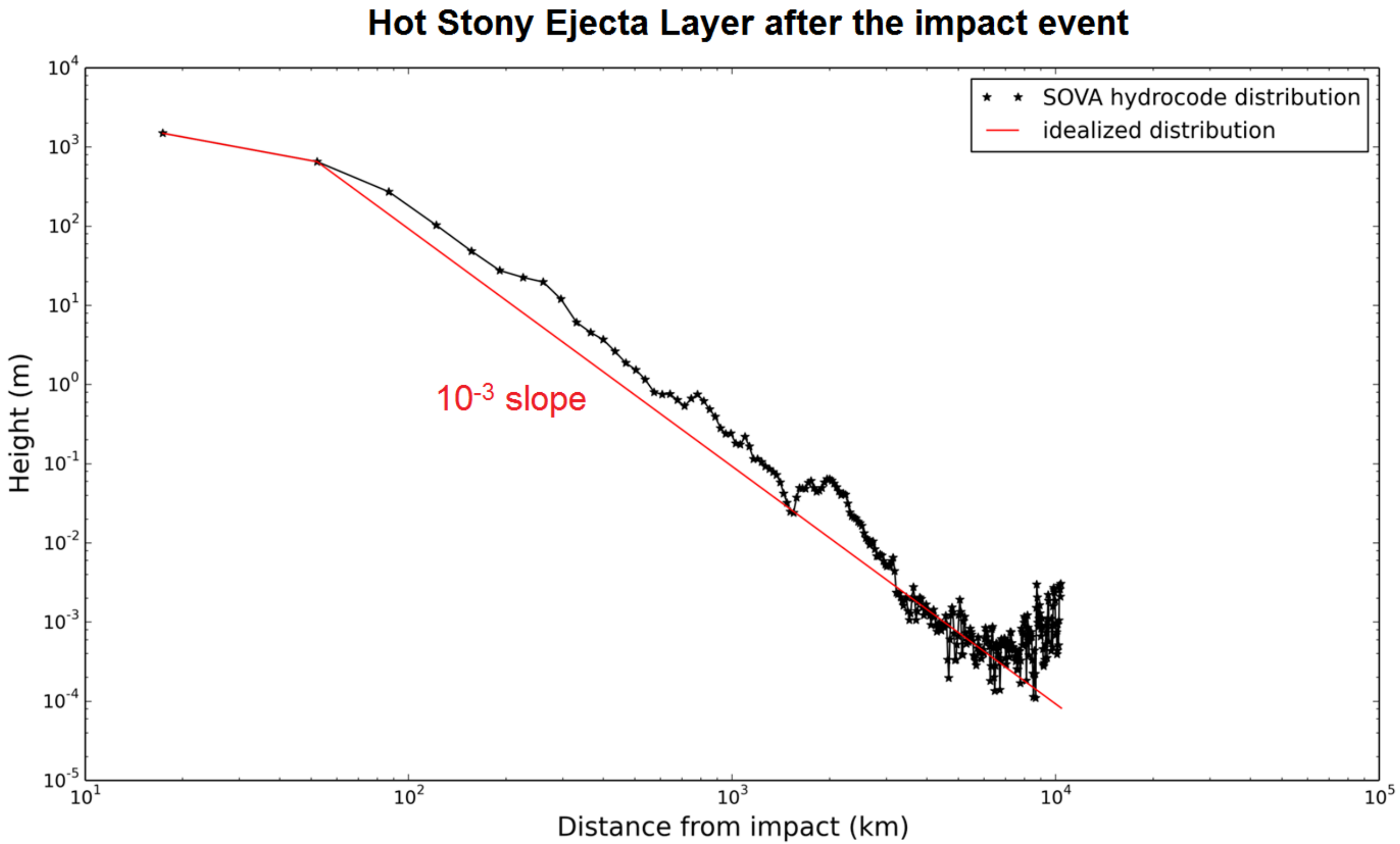
RESULTS OF 3-D GLOBAL CLIMATE MODEL

Upper atmosphere water ice clouds sediment rapidly





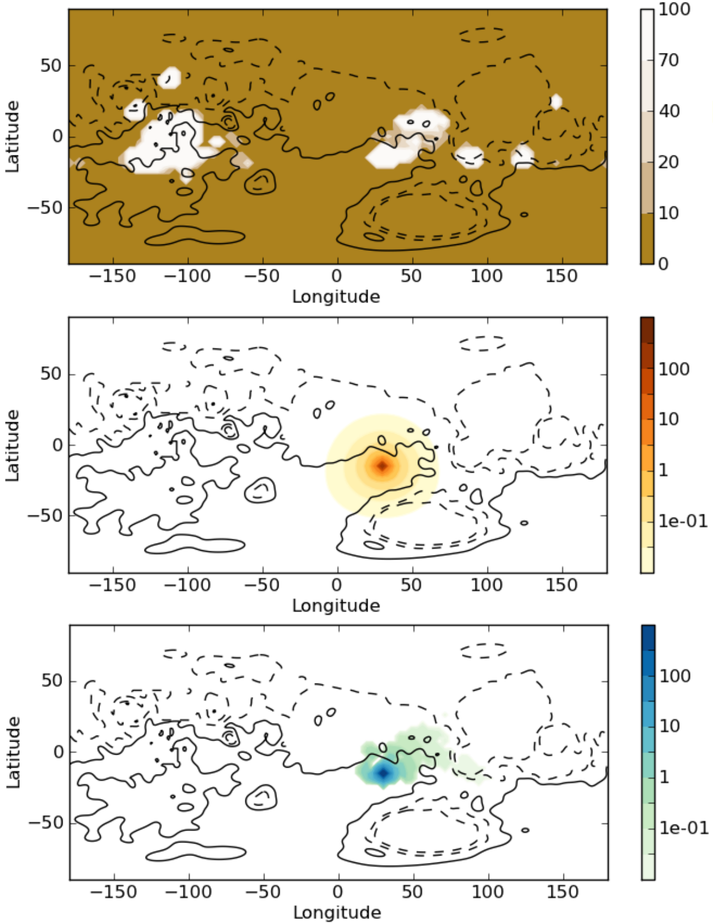
Turbet 2018, PhD thesis



Turbet 2018, PhD thesis

MELTING OF THE PERMANENT ICE RESERVOIRS

➢ **<u>Results:</u>**
Melting of a <u>85 cm</u> Global Equivalent Layer **MAXIMUM**



Permanent initial ice deposits (in mm)

Thickness of the ejecta layer (in m)

Maximum production of liquid water from melting (in m)

Turbet 2018, PhD thesis

AMOUNT OF ICE MELTING

Turbet 2018, PhD thesis

➢ Maximum cumulated melt production:

- 150m GEL for 5-50km diameter impactors
- 70m   GEL for <5 km   diameter impactors
- **220m GEL in total**

➢ Minimum total water required to carve the valley networks:

- 5000m GEL (Luo et al. 2017)
- 640m GEL (Rosenberg et al. 2018)

CONCLUSION:
MELT PRODUCTION IS NOT SUFFICIENT ENOUGH TO CARVE THE VALLEY NETWORKS

REDUCING GASES (H_2)

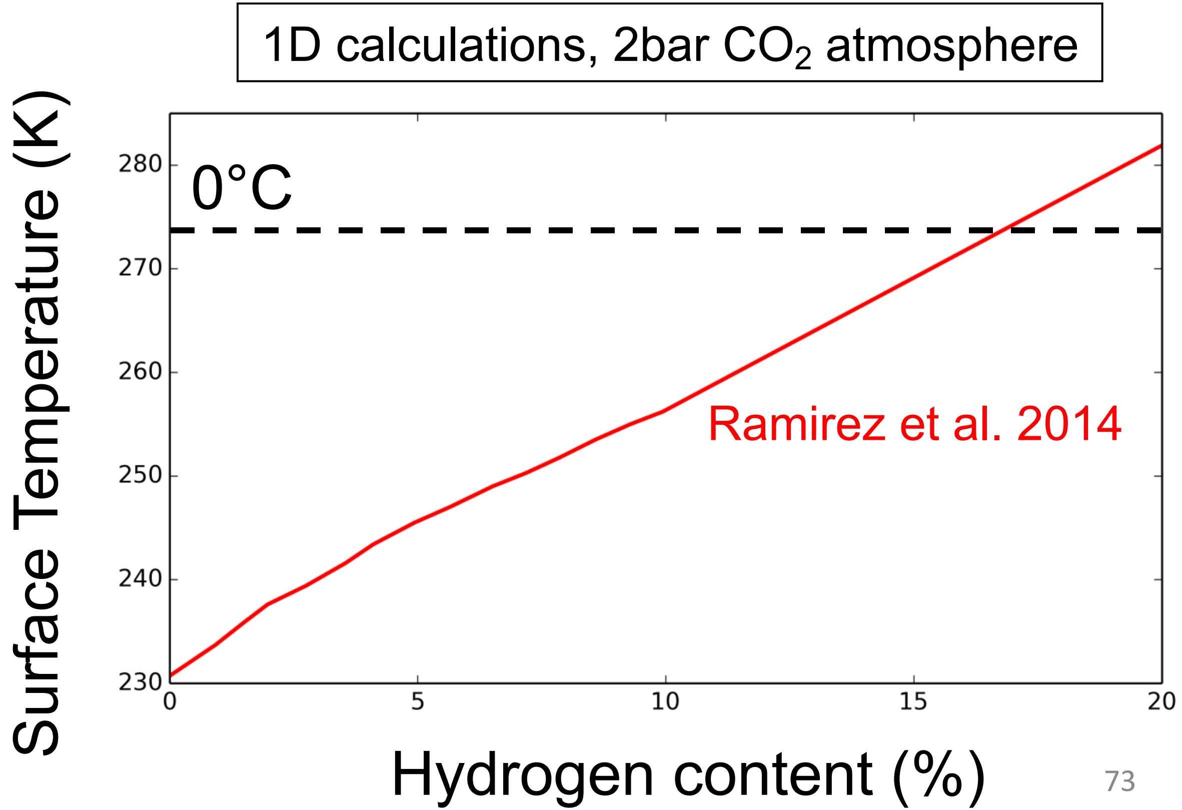
A viable alternative to warm early Mars?

Possible sources of H_2:

- Outgassing from a reduced early Martian mantle (*Ramirez et al. 2014*)
- Serpentinization (see *Chassefière et al. 2016*)
- Radiolysis (*Tarnas et al. 2018*)
- Atmospheric thermochemistry following large meteorite impacts (*Haberle et al. 2019*)

REDUCING GASES (H_2)

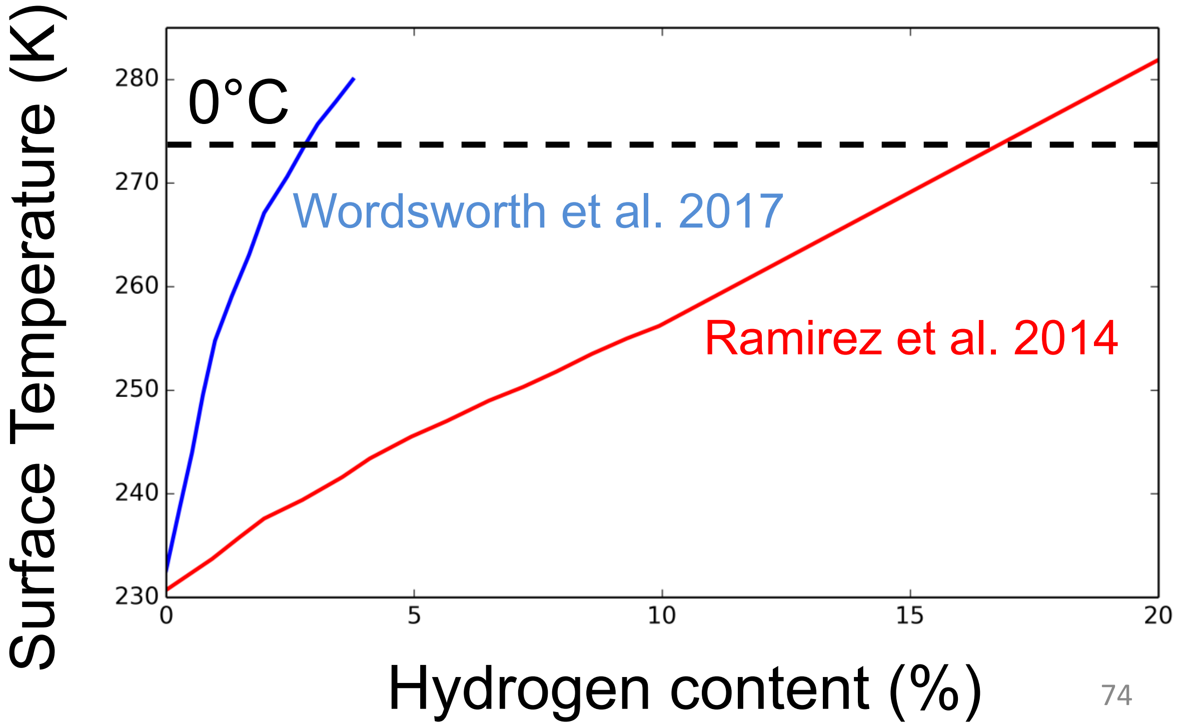
A viable alternative to warm early Mars?



REDUCING GASES (H_2)

A viable alternative to warm early Mars?

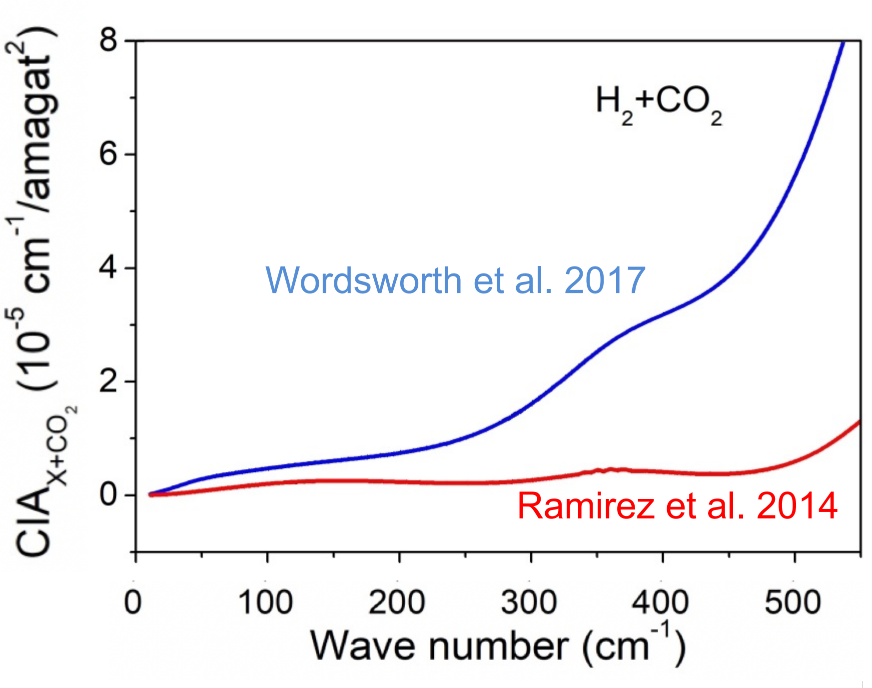
1D calculations, 2bar CO_2 atmosphere



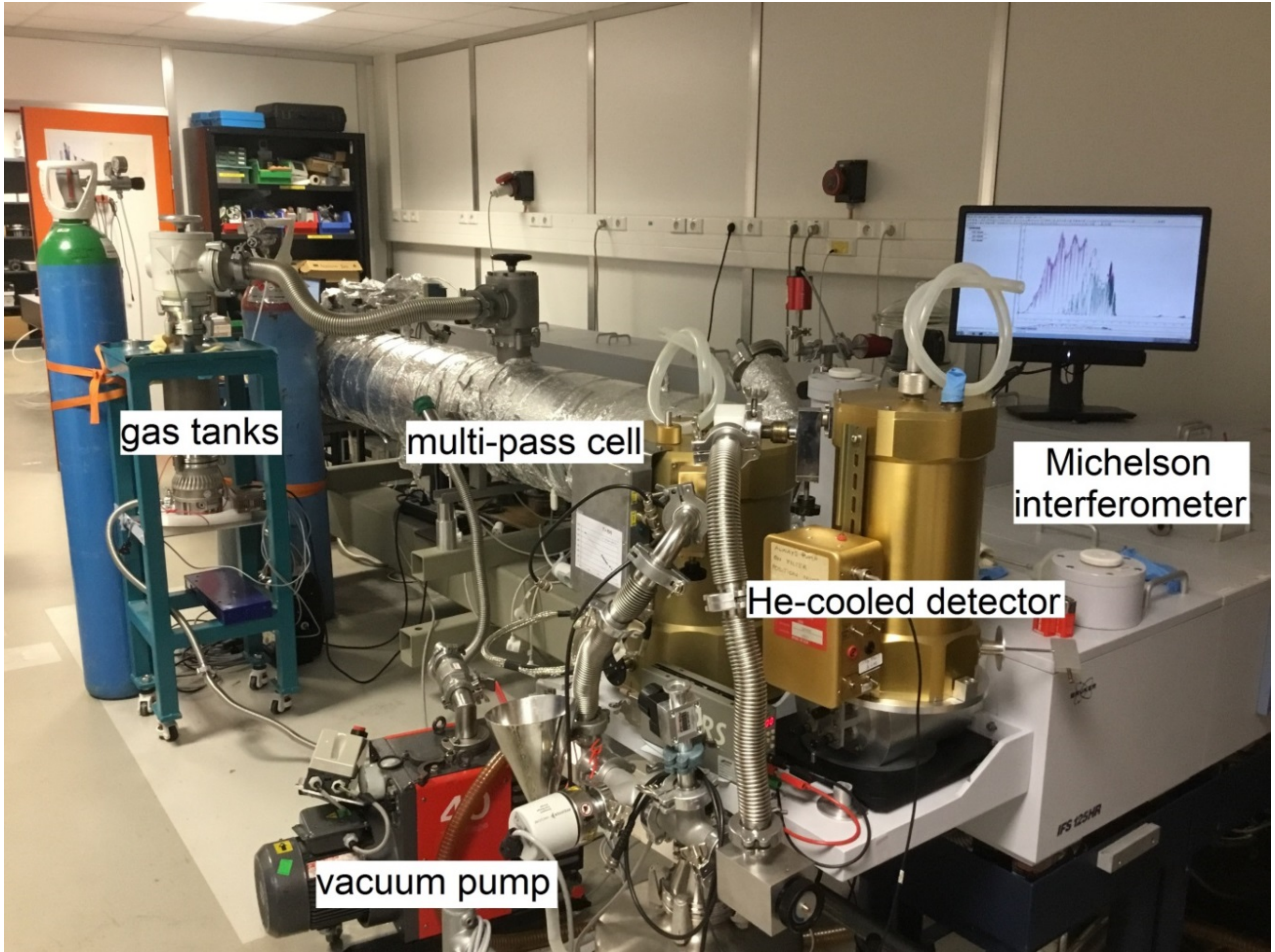
COLLISION-INDUCED ABSORPTIONS

N_2-H_2 (exp+theory)

CO_2-H_2 (theory)



EXPERIMENTS AT THE SOLEIL SYNCHROTRON / AILES LINES

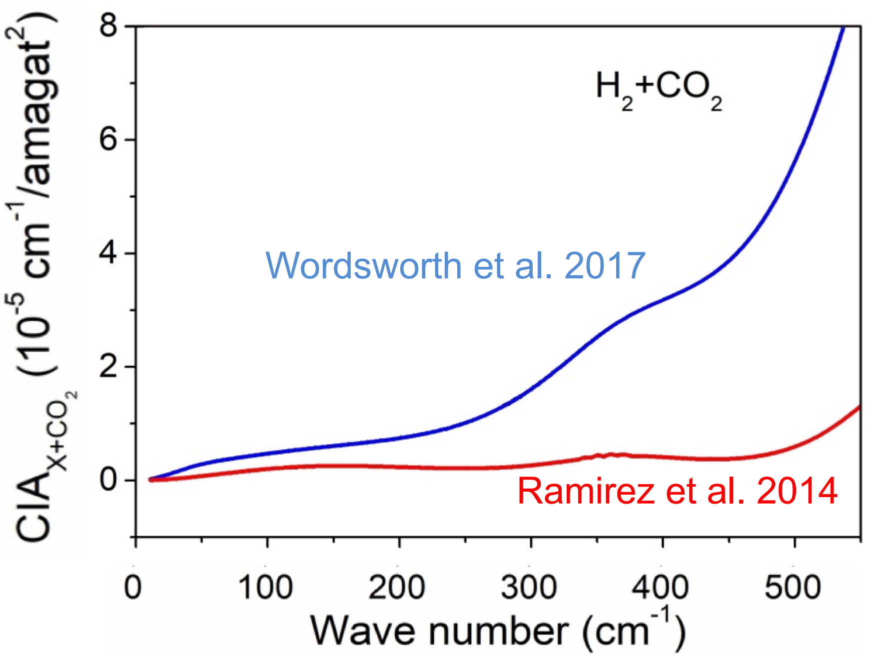


Turbet et al. 2019, Icarus

COLLISION-INDUCED ABSORPTIONS

N_2-H_2 (exp+theory)

CO_2-H_2 (theory)



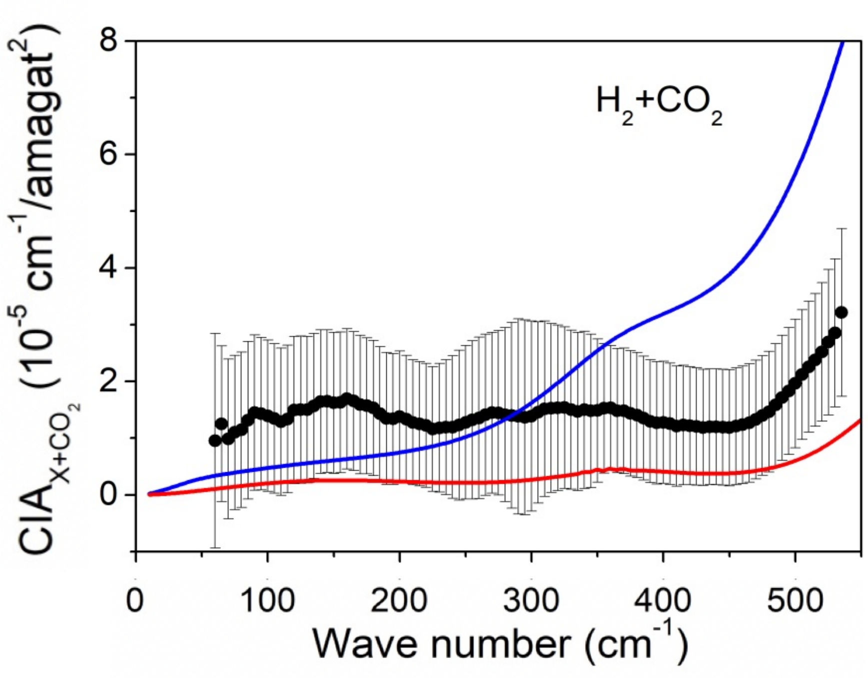
Turbet et al. 2019, Icarus

COLLISION-INDUCED ABSORPTIONS

N_2-H_2 (exp+theory)

CO_2-H_2 (theory)

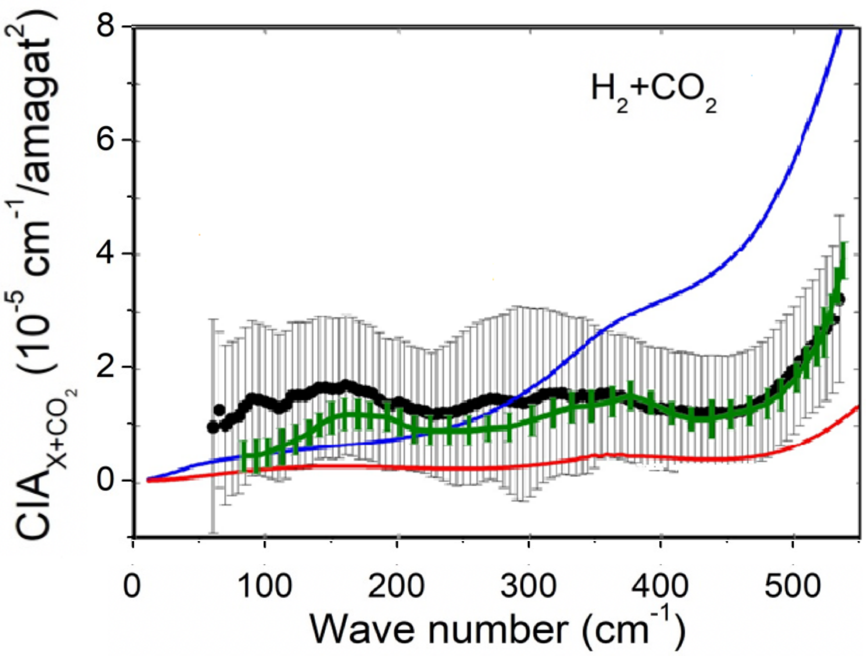
CO_2-H_2 (exp)



Turbet et al. 2019, Icarus

COLLISION-INDUCED ABSORPTIONS

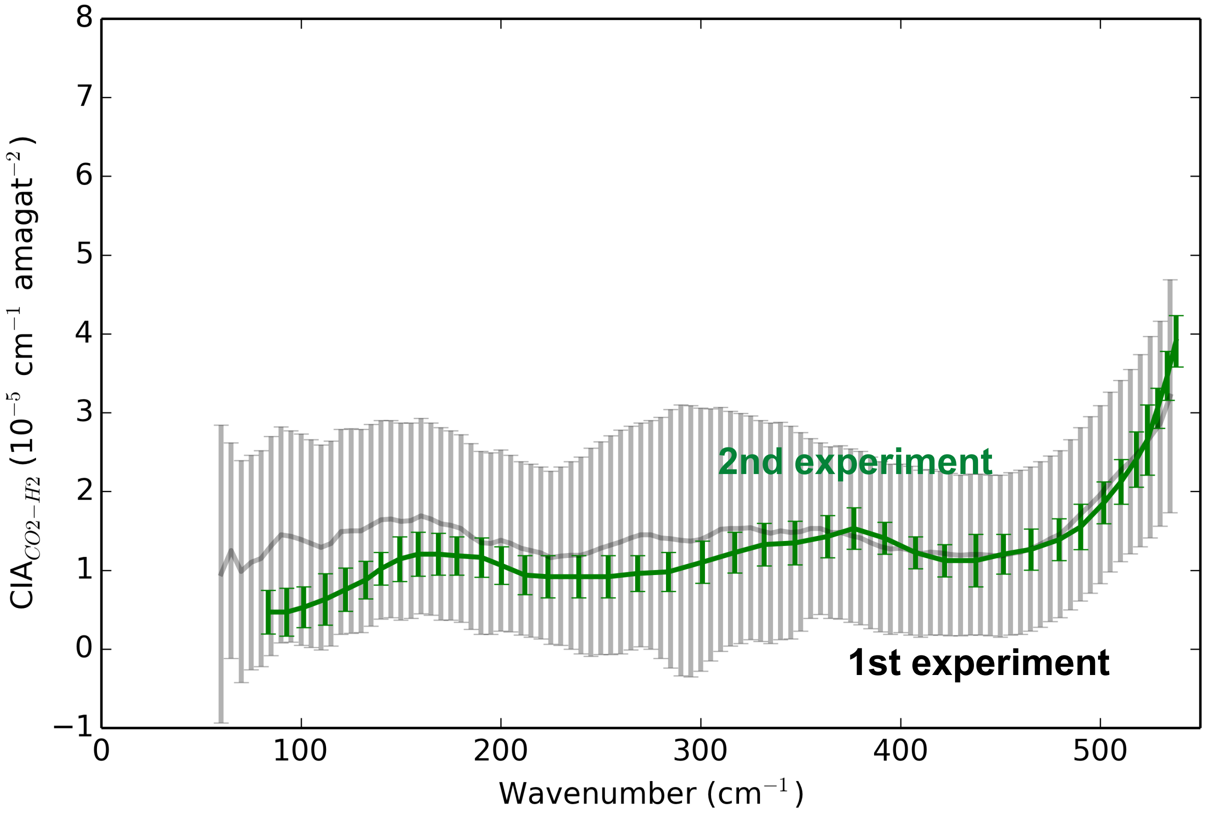
- N_2-H_2 (exp+theory)
- CO_2-H_2 (theory)
- CO_2-H_2 (exp)
- CO_2-H_2 (2^{nd} exp)



Turbet et al. 2019, Icarus
Turbet et al. 2020b (available on arXiv)

CO_2+H_2 COLLISION-INDUCED ABSORPTIONS

(1) EXPERIMENTS

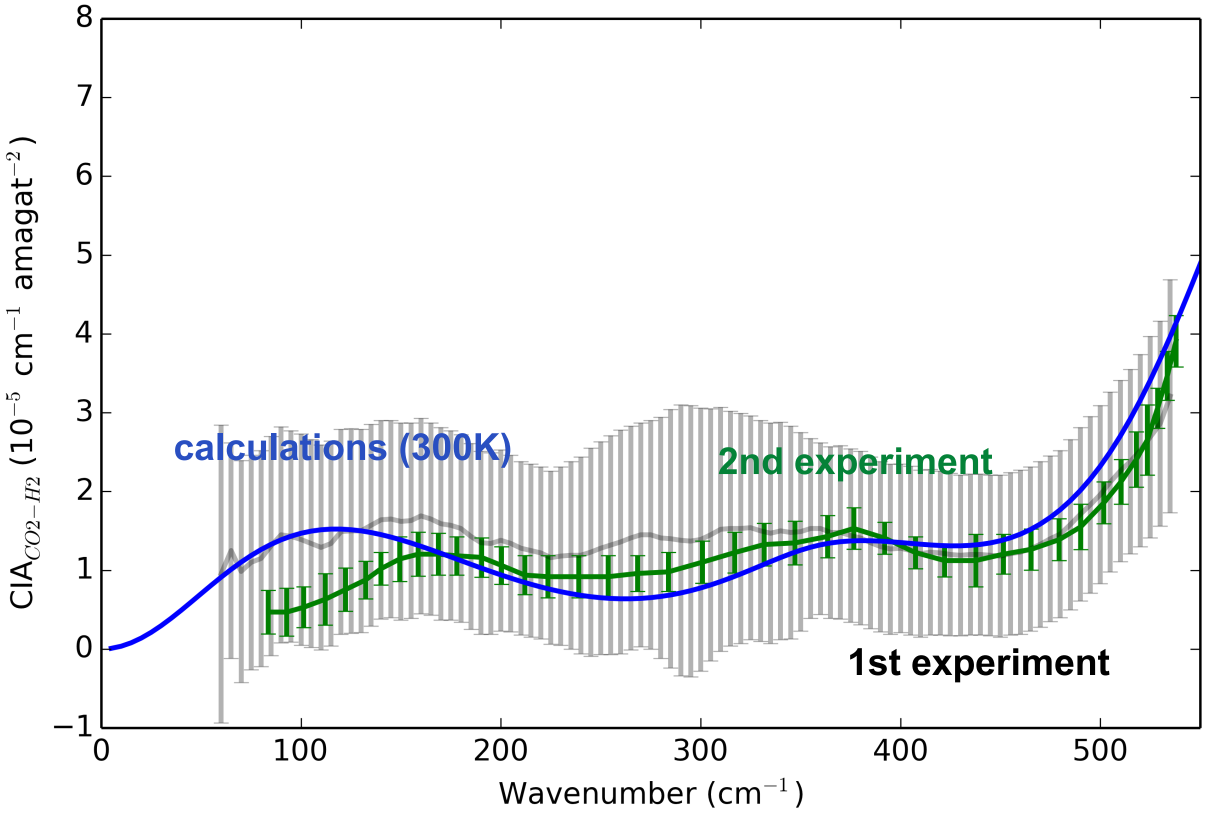


Turbet et al. 2019, Icarus

Turbet et al. 2020, sub. to Icarus (see arXiv)

CO_2+H_2 COLLISION-INDUCED ABSORPTIONS

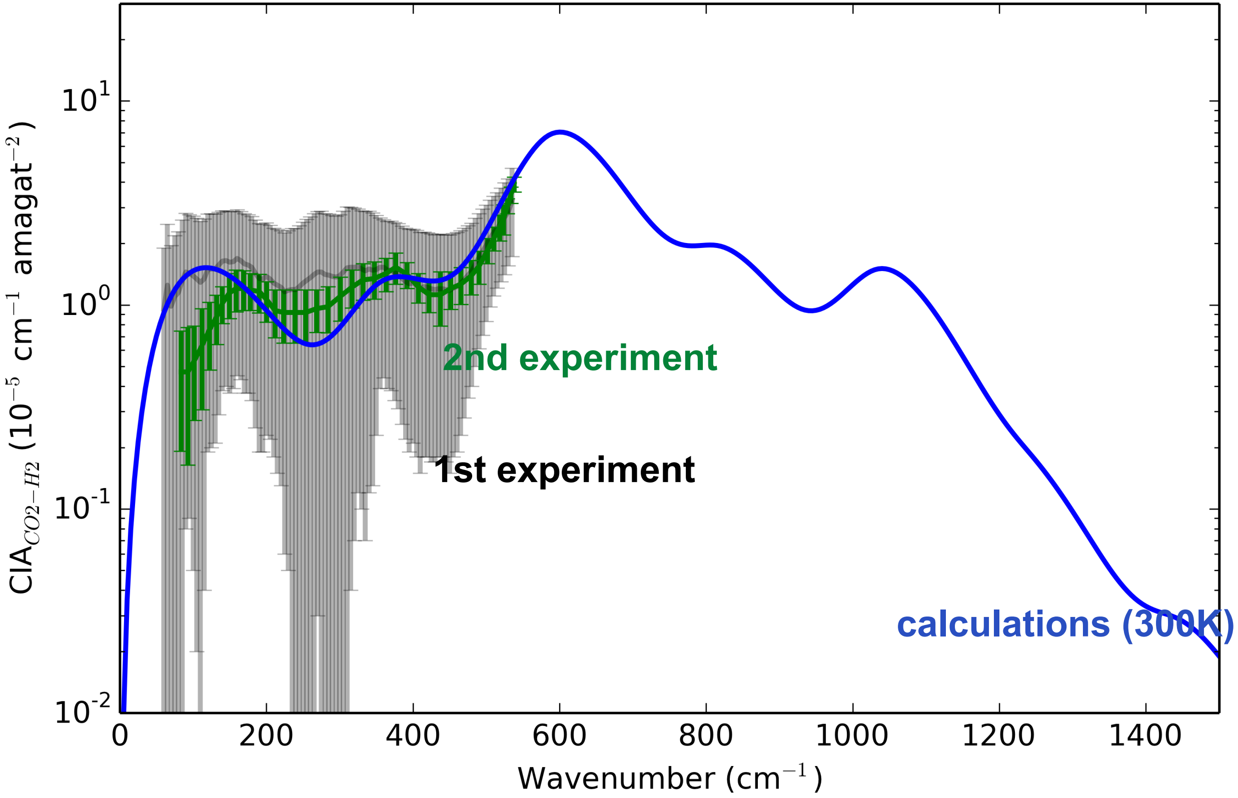
(2) CALCULS



Turbet et al. 2020, sub. to Icarus (see arXiv)

CO_2+H_2 COLLISION-INDUCED ABSORPTIONS

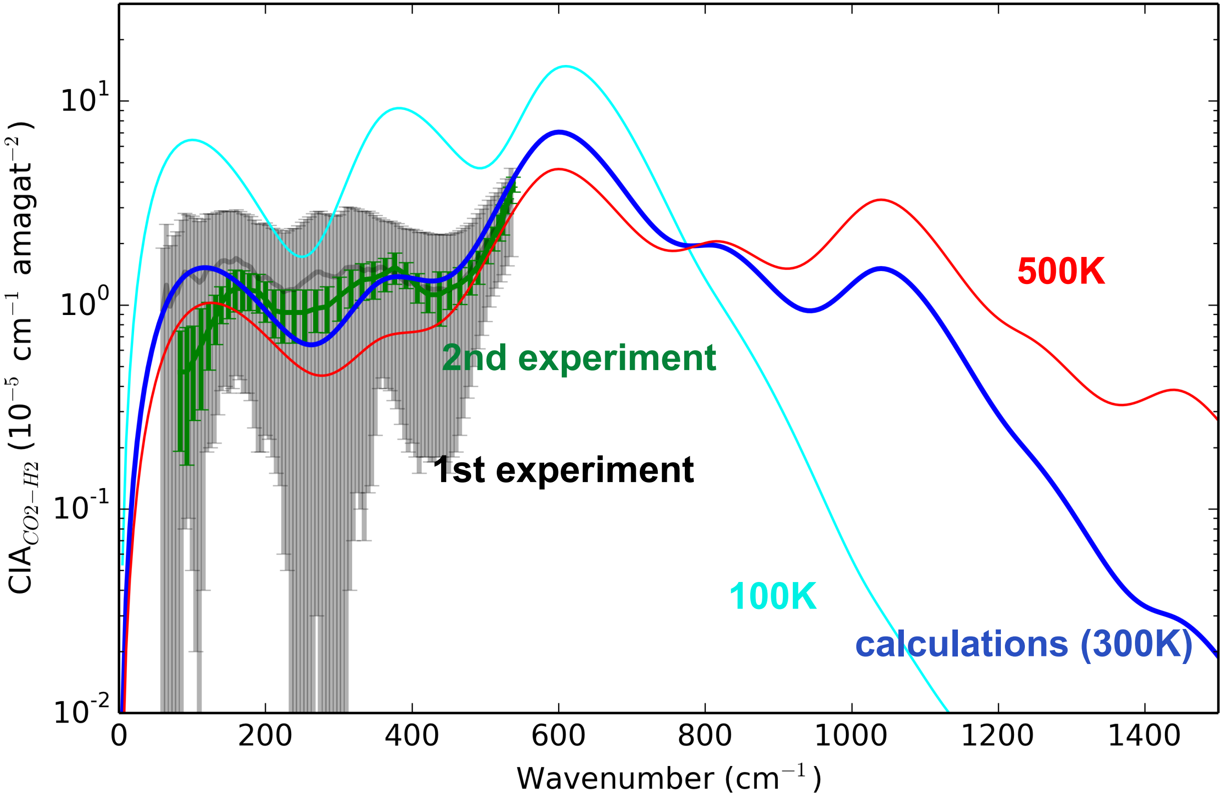
(2) CALCULS



Turbet et al. 2020, sub. to Icarus (see arXiv)

CO_2+H_2 COLLISION-INDUCED ABSORPTIONS

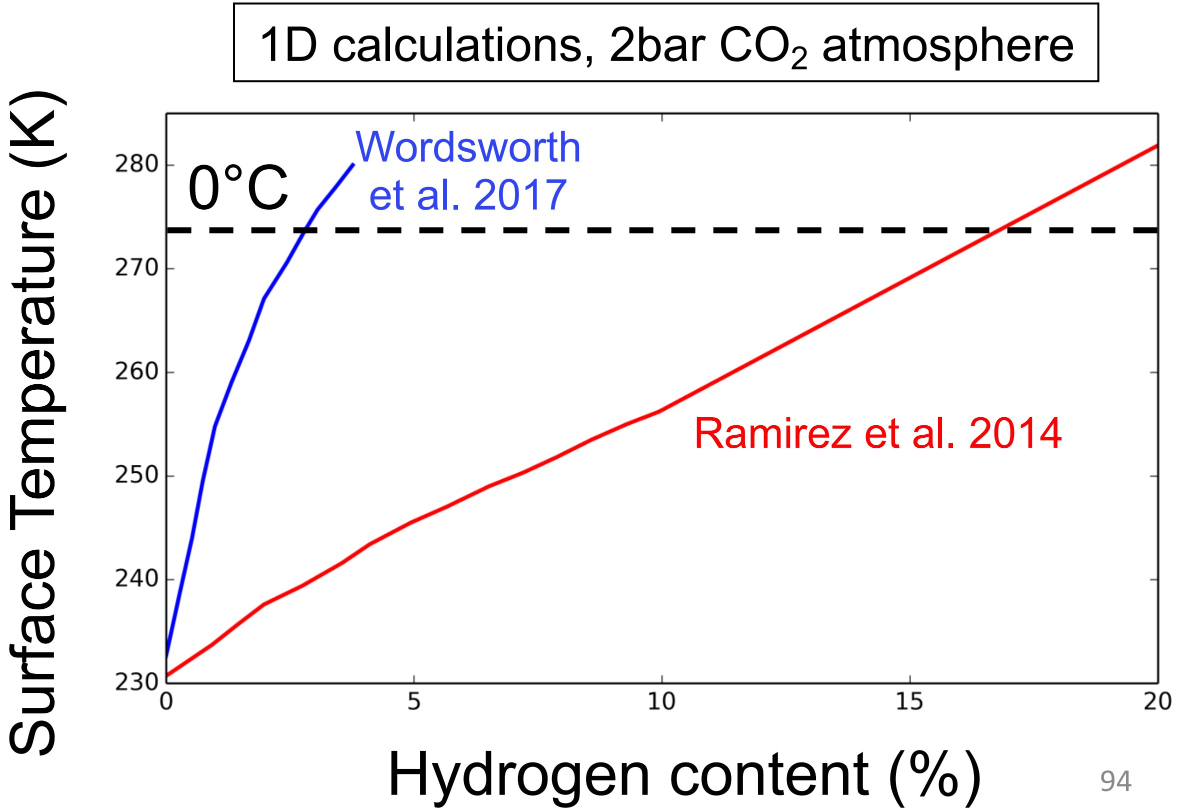
(2) CALCULS



Turbet et al. 2020, sub. to Icarus (see arXiv)

REDUCING GASES (H_2)

A viable alternative to warm early Mars?



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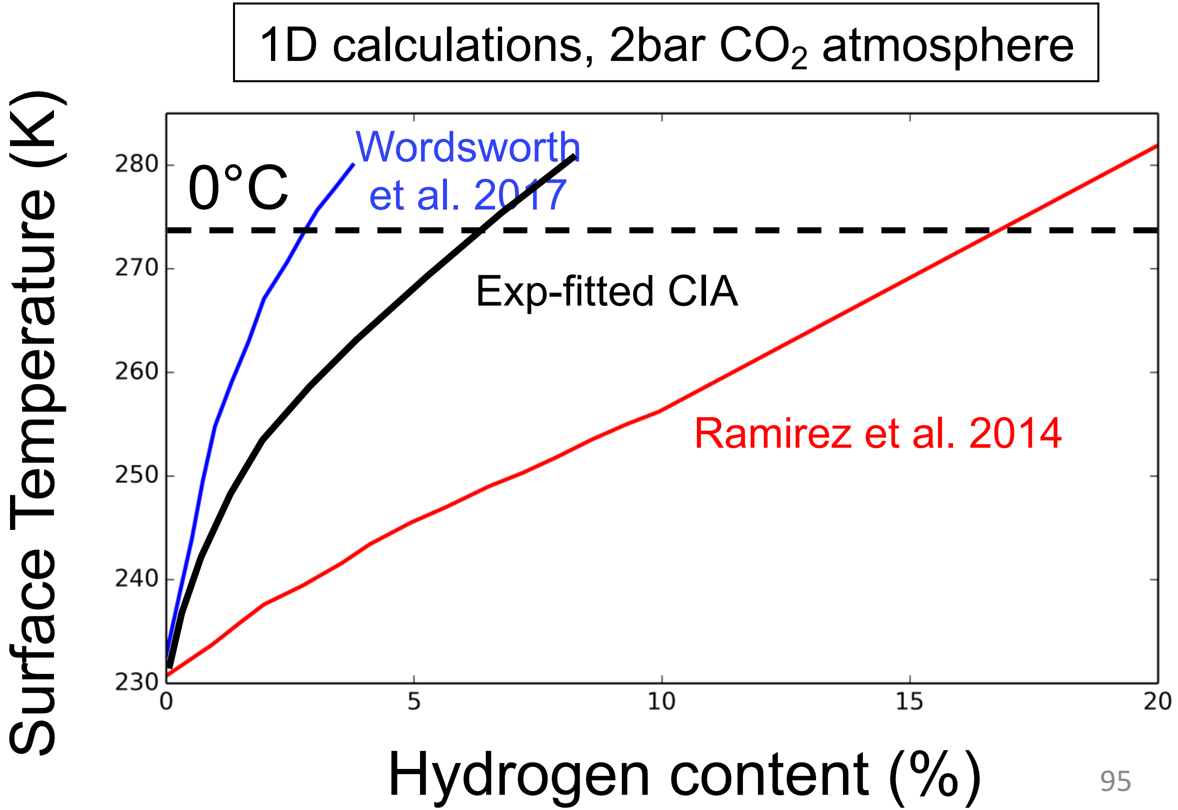
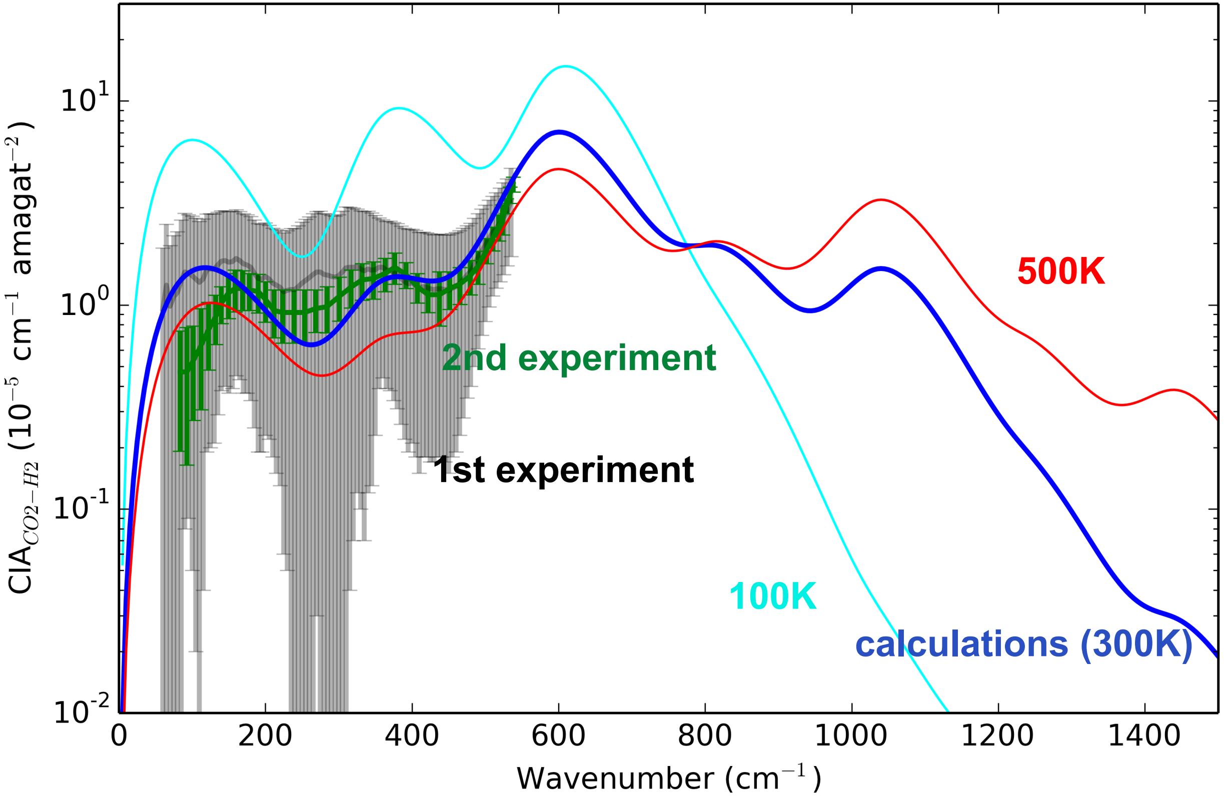


Turbet et al. 2020b (available on arXiv)

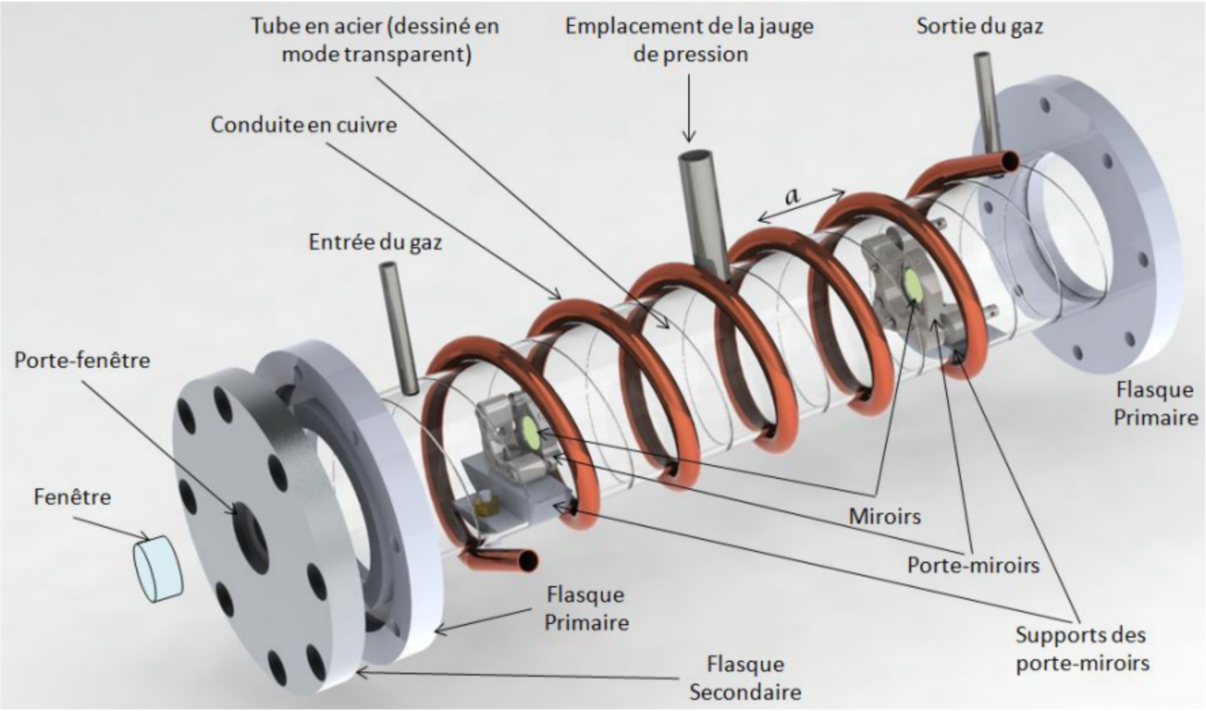
CO_2+H_2 COLLISION-INDUCED ABSORPTIONS

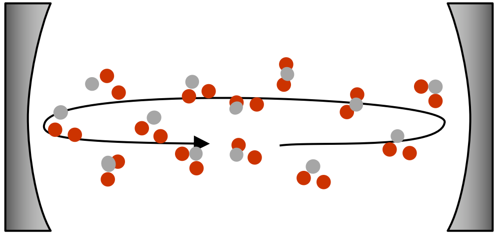
(2) CALCULS

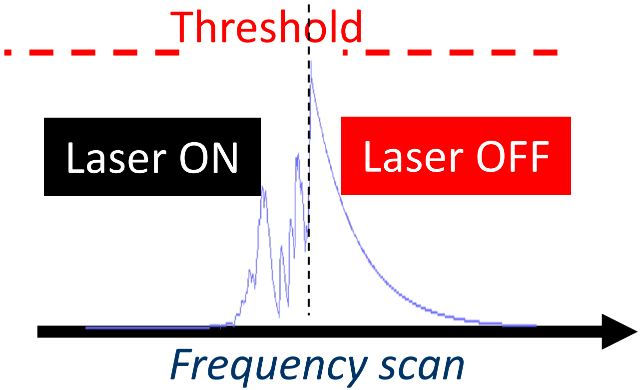


Turbet et al. 2020, sub. to Icarus (see arXiv)

THE CAVITY RING DOWN SPECTROSCOPY (CRDS) GRENOBLE EXPERIMENTAL SETUP

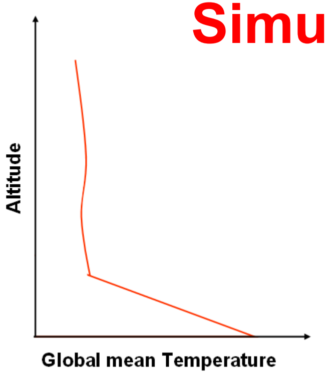






COMPLEAT Project – Credit: D. Mondelain and A. Campargue

Simulation of the Early Mars Climate : a hierarchy of models…



- 1D global radiative convective models

⇨ **To evaluate global mean surface temperature with various atmospheres**

(e.g. Kasting et al. 1991, Forget and Pollack 1997, Wordsworth et al. 2010, Ramirez et al. 2014, 2017, Turbet & Tran 2017)

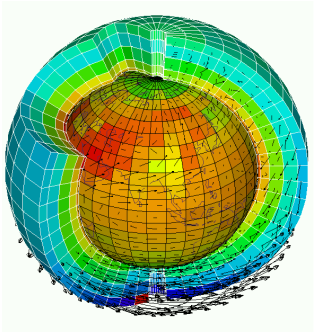
Simulation of the Early Mars Climate : a hierarchy of models…

➢ 1D global radiative convective models

⇨ To evaluate global mean surface temperature with various atmospheres

(e.g. Kasting et al. 1991, Forget and Pollack 1997, Wordsworth et al. 2010, Ramirez et al. 2014, 2017, Turbet & Tran 2017, Turbet et al. 2020ab)

➢ 3D Global Climate model with a converged water cycle



⇨ To evaluate local surface temperatures & their variations with season, obliquity, the role of clouds, etc …

(e.g. Forget et al. 2013, Mischna et al. 2013, Kerber et al. 2015, Turbet & Forget 2019)

⇨ To evaluate rain, snow melting, and long-term evolution of the full water cycle.

(e.g. Wordsworth et al. 2013, 2015, Turbet et al. 2017a, see also Turbet's 2018 PhD thesis, Turbet et al. 2020a)

3-D CLIMATE SIMULATIONS OF REDUCING ATMOSPHERES ON MARS

Turbet & Forget, in preparation

1) Implementation of the radiative effect of CO_2+H_2 atmospheres

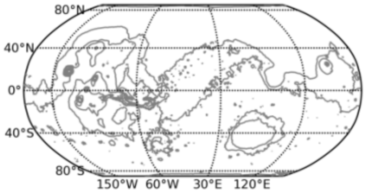
3-D CLIMATE SIMULATIONS OF REDUCING ATMOSPHERES ON MARS

Turbet & Forget, in preparation

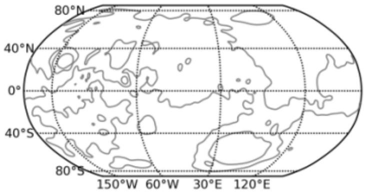
1) Implementation of the radiative effect of CO_2+H_2 atmospheres

2) Implementation of water reservoirs and their effect on topography

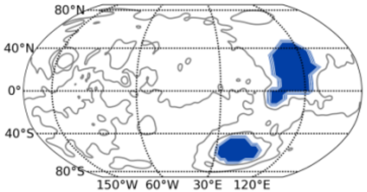
Present-day MOLA topography



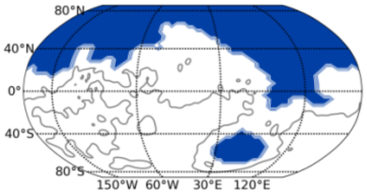
pre-TPW topography



pre-TPW topography with 100m GEL ocean (-4.26km shoreline)



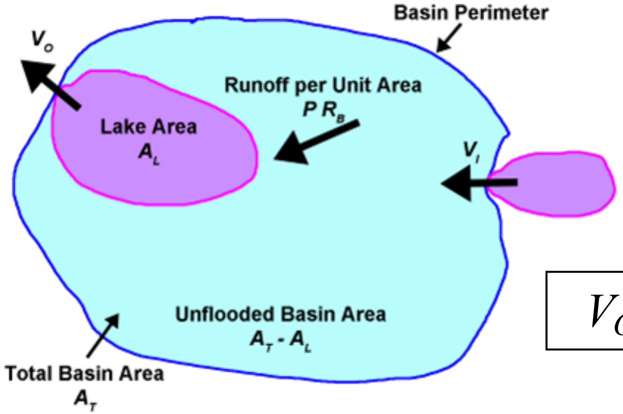
pre-TPW topography with 550m GEL ocean (-2.54km shoreline)



3-D CLIMATE SIMULATIONS OF REDUCING ATMOSPHERES ON MARS

Turbet & Forget, in preparation

1) Implementation of the radiative effect of CO_2+H_2 atmospheres
2) Implementation of water reservoirs and their effect on topography
3) **Implementation of the climatic effect of impact crater lakes and their evolution**

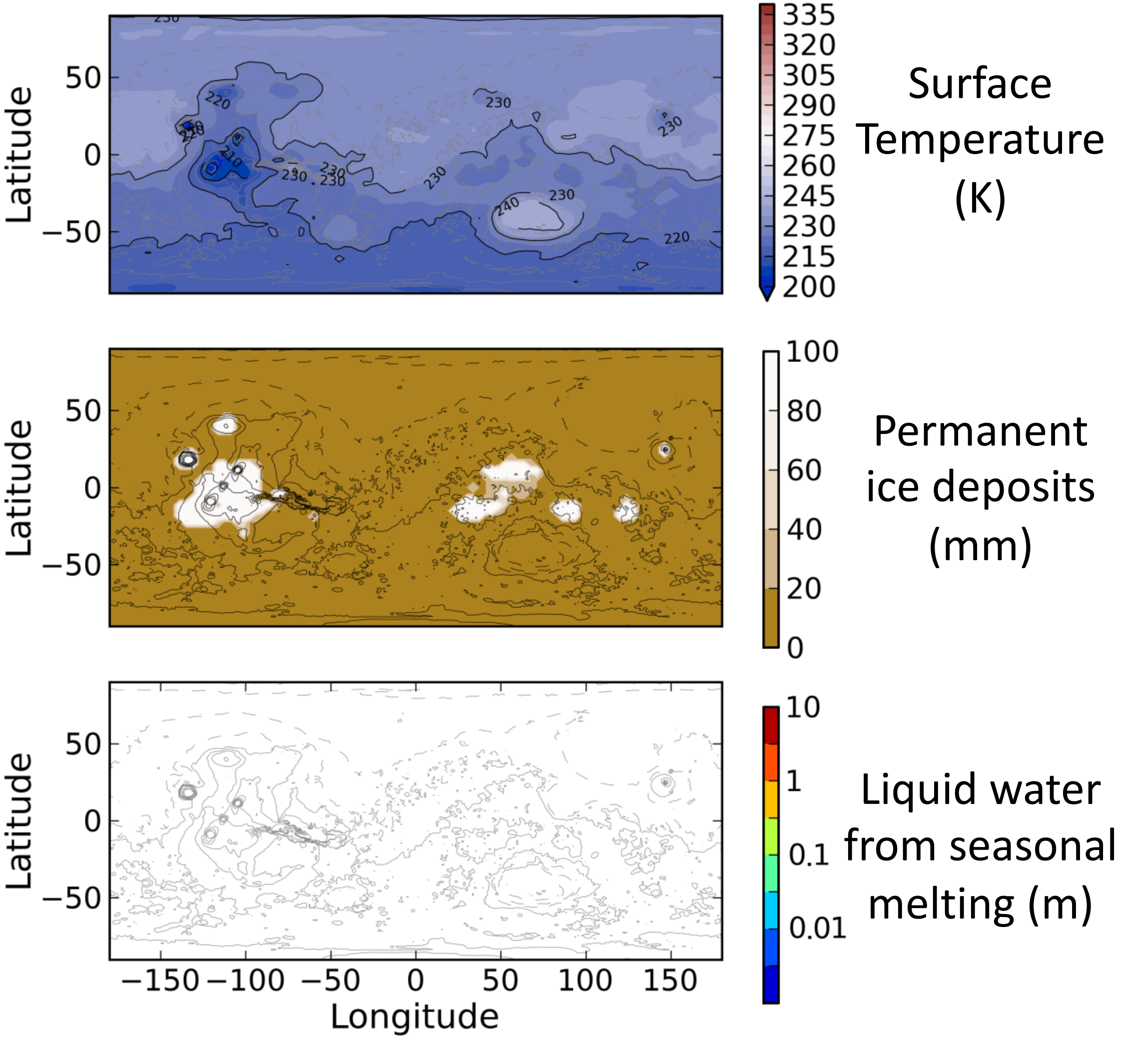


$$V_O = V_I + (A_T - A_L) P R_B + A_L P - E A_L$$

Matsubara et al. 2011

3D CLIMATE MODELING

0.8bar
pure CO_2
Atmosphere



Turbet & Forget, in preparation

3D CLIMATE MODELING

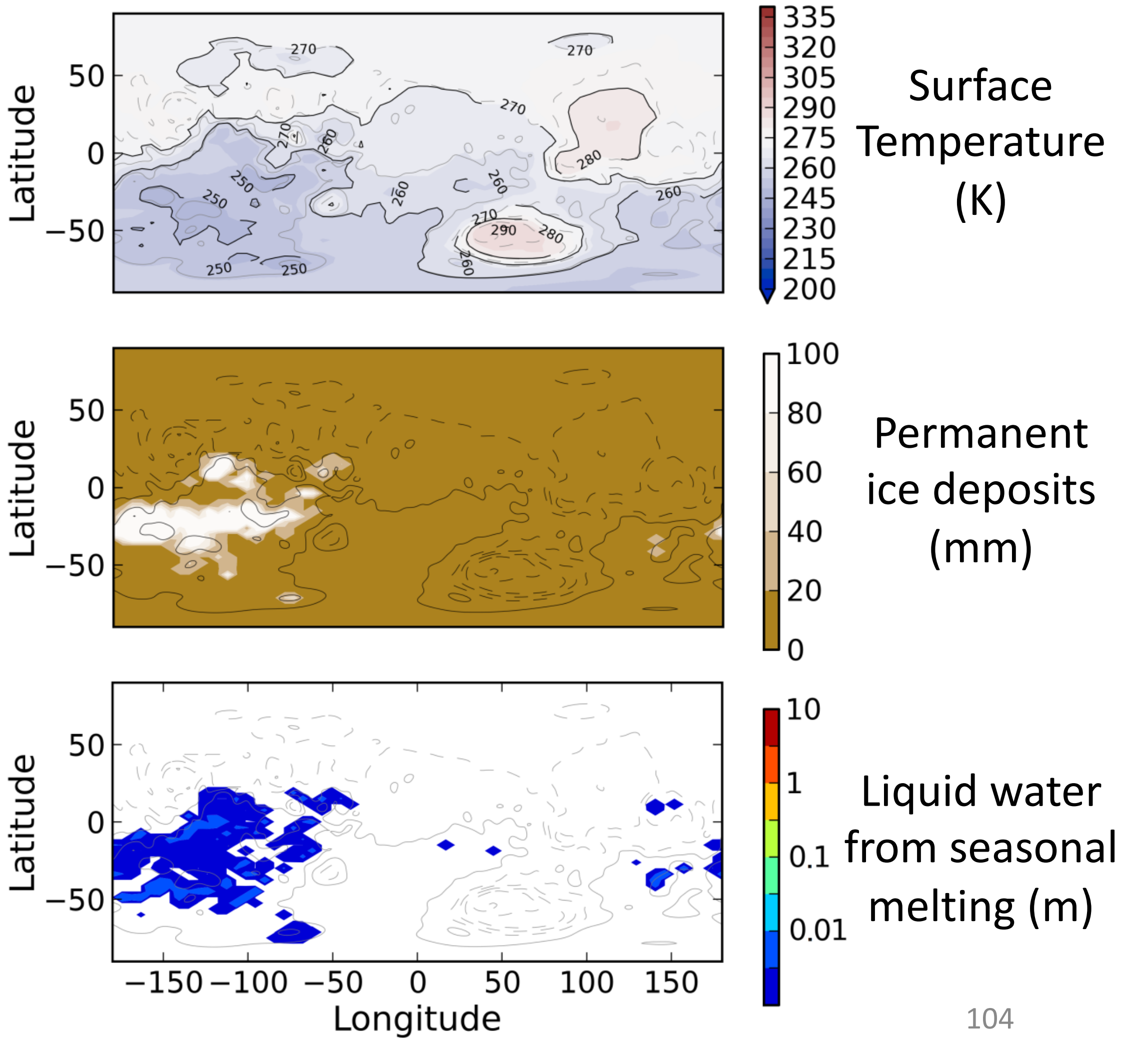
1st result –

Average Tsurf > 273K condition doesn't hold in 3D

- Water trapped in cold points
- Ice/Snow albedo feedback

Example: 0.8bar CO_2 atmosphere with 20% H_2, low water content

Turbet & Forget, in preparation



3D CLIMATE MODELING

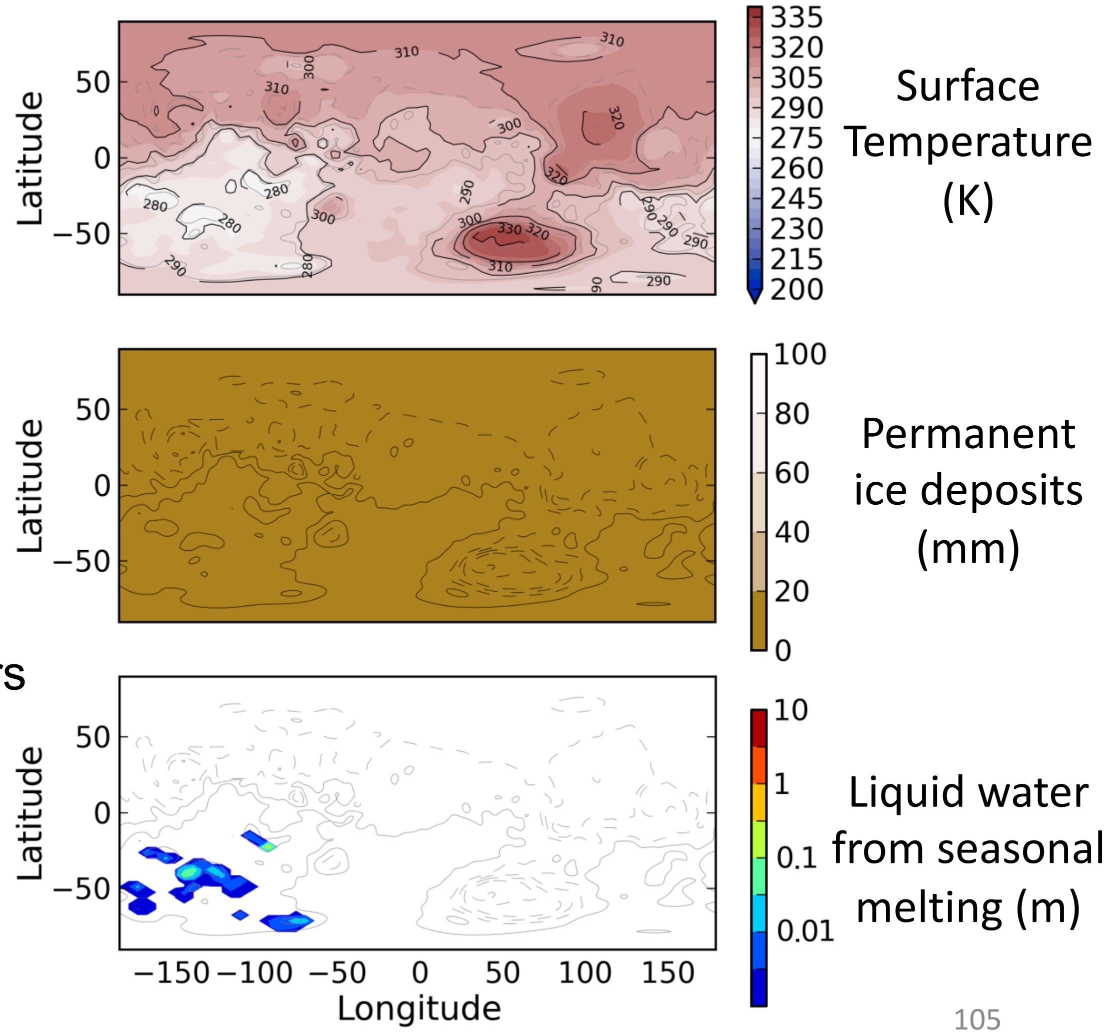
2nd result –

The temperature of the coldest point of the planet (usually the highlands for thick atmospheres) needs to be above 273K to avoid water cold trapping.

→ Need more H_2 to 'warm' early Mars

Example: 2.3bar CO_2 atmosphere with 5% H_2, low water content

Turbet & Forget, in preparation



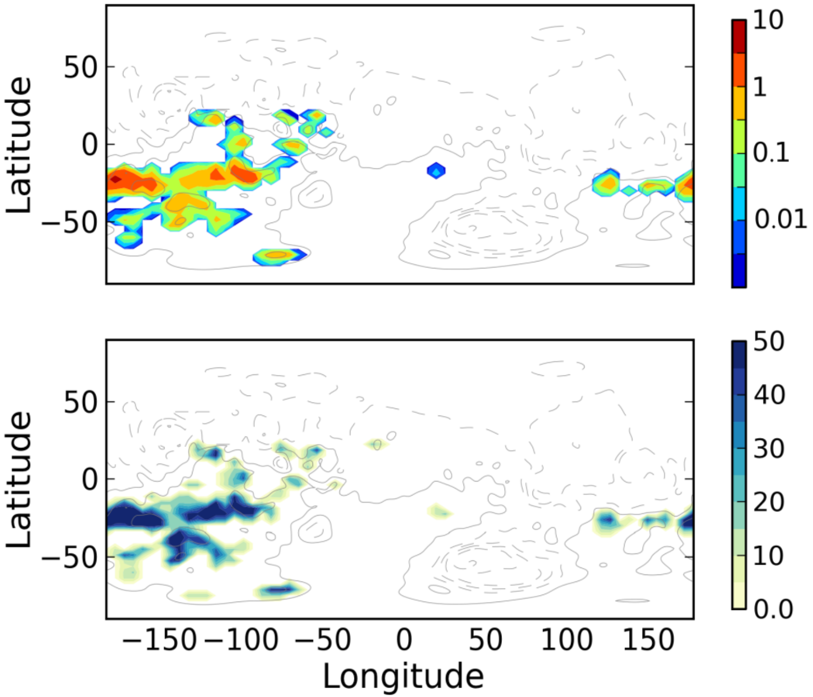
3D CLIMATE MODELING

3rd result

« Icy highland » scenario can also work in warm mode (« Wet Highlands) with water trapped in the liquid form in the southern highland lakes

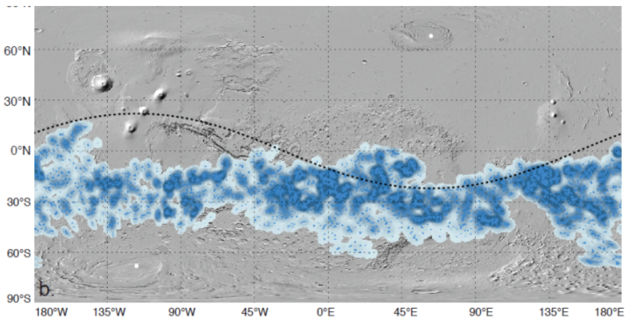
Example: 2.3bar CO_2 atmosphere with 5% H_2, low water content (~1m GEL)

Turbet & Forget, in preparation



Cumulated runoff (m/year)

Lake coverage (in %)



Valley networks positions

(pre-TPW)

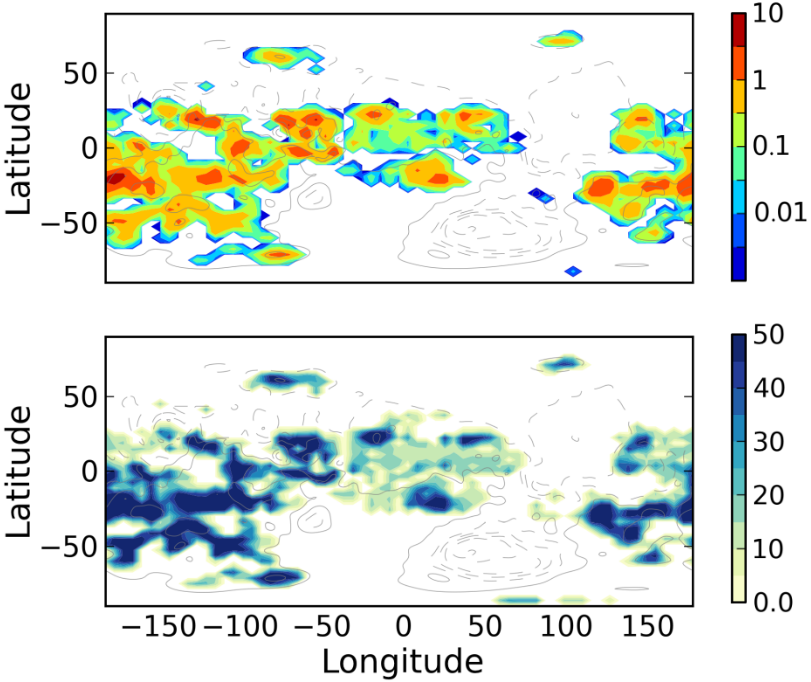
3D CLIMATE MODELING

4th result –

Position of impact-crater lakes and precipitation/runoff can be tuned assuming various water reservoir size and position

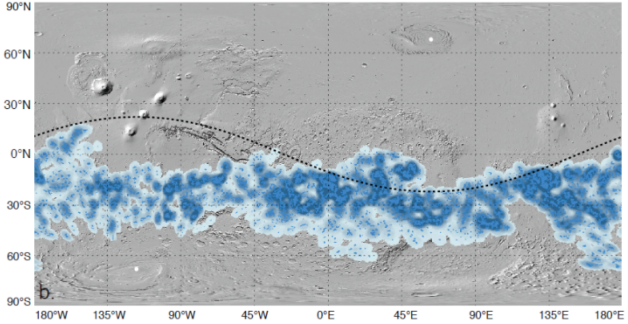
Example: 2.3bar CO_2 atmosphere with 5% H_2, low water content (~10m GEL)

Turbet & Forget, in preparation



Cumulated runoff (m/year)

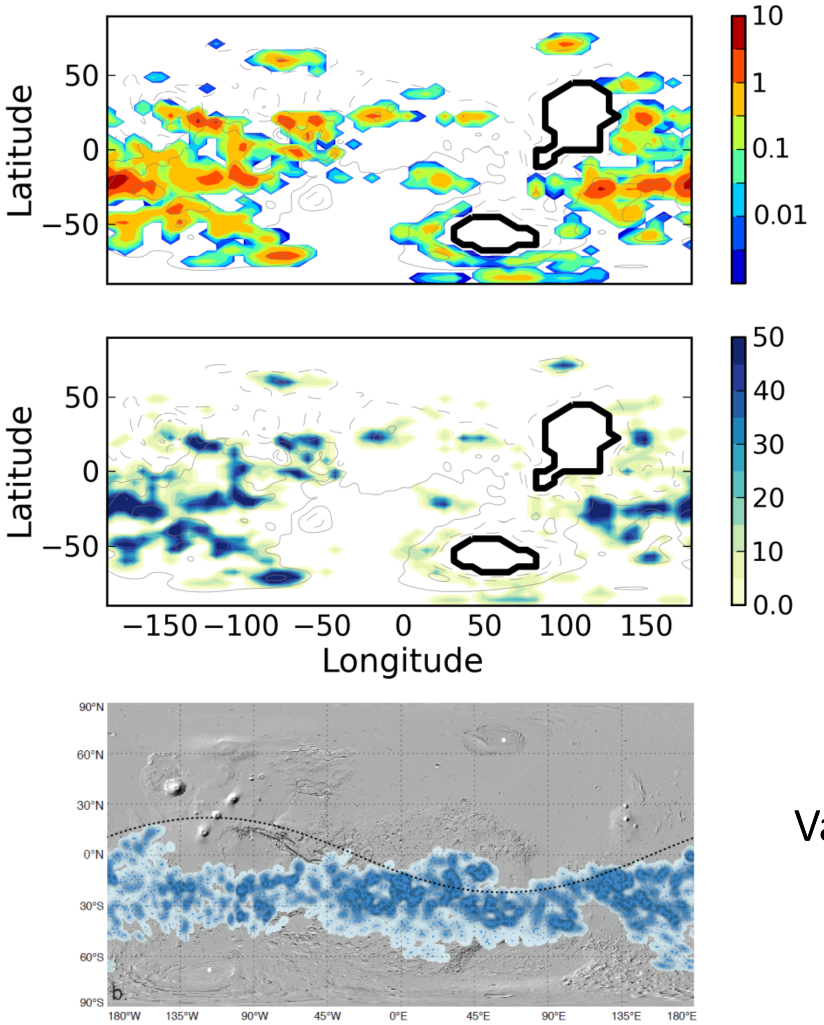
Lake coverage (in %)



Valley networks positions

(pre-TPW)

3D CLIMATE MODELING



Cumulated runoff (m/year)

Lake coverage (in %)

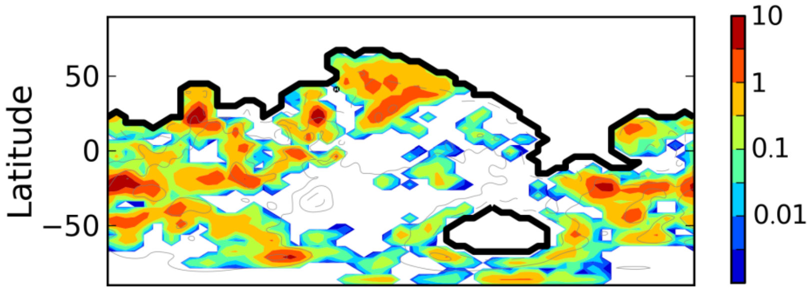
Valley networks positions

2.3bar CO_2 atmosphere with 5% H_2 with small oceans

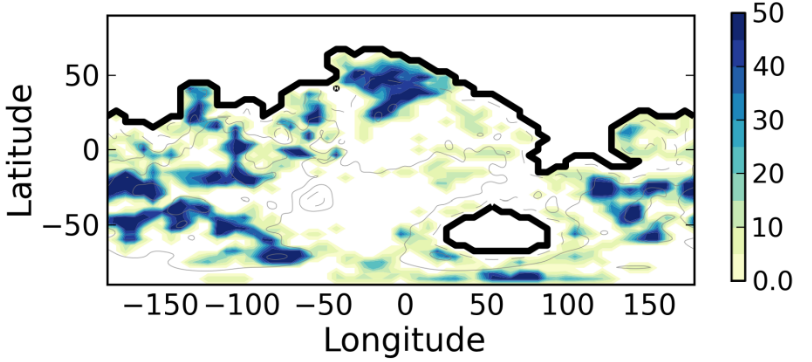
Turbet & Forget, in preparation

3D CLIMATE MODELING

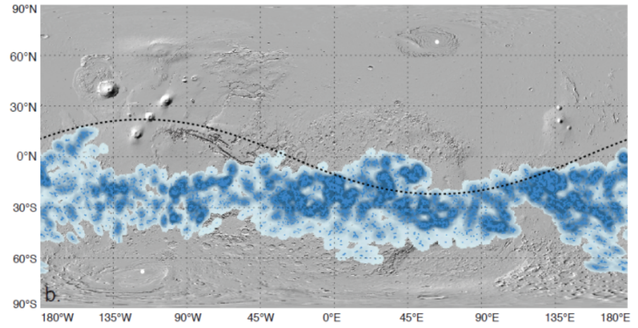
2.3bar CO_2 atmosphere with 5% H_2 with large oceans



Cumulated runoff (m/year)



Lake coverage (in %)



Valley networks positions

Turbet & Forget, in preparation

CONCLUSIONS/SUMMARY

- The « Hydrogen solution » is promising but still challenging:
  - The measured Collision-Induced Absorption (inducing greenhouse effect) not as strong as previously estimated
  - In 3D more greenhouse effect is required to avoid complete freezing of the water in cold traps (especially if one want to avoid any glaciation !)
- However, with enough greenhouse effect promising solution with realistic run-off seems possible.
- Too much greenhouse effect or too much water can provide irrealistic results (for instance with too many open-lake basin, or heavy precipitation near coastlines).
- To be continued !