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Secondary Volcanically-Induced Lunar Atmosphere and Lunar Volatiles: 3-D modeling and Analysis

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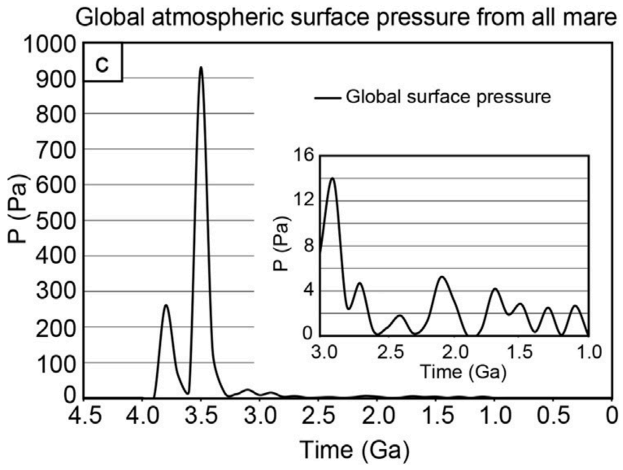
Motivation



- Needham & Kring, 2017 : ~3.5 Gya Moon could have a transient collisional atmosphere up to 10 mb due to volcanic outgassing from the maria
- Wilson, Head & Deutsch, 2019: the thickness of such an atmosphere would depend on intervals between the eruptions, and may not exceed a microbar scale
- Such an Atmosphere would determine transport and deposition of volatiles

Methods

- ROCKE-3D - planetary General Circulation Model (GCM) (Way et al. 2017)
  - https://simplex.giss.nasa.gov/gcm/ROCKE-3D
- 1-D chemistry model determines composition of atmosphere

Atmospheric composition depends on:

Volcanic outgassing (Needham & Kring, 2017)

CO	- can convert to CO_2 in H_2O presence	(80-750 ppm)
H_2O	- can escape or condense[1]	(1.8-9 ppm)
H_2	- can easily escape[2]	(0.007-45 ppm)
S	- condenses quickly at the surface[2]	(180-540 ppm)

Atmospheric chemistry

CO ←→ CO_2 (for T > 175 K : CO_2 – dominated)[1]

Atmospheric escape

Less than 30 kg/s for most species (see Aleinov et al., 2019 for details)

[1]green – greenhouse gas [2]gray – not included in current research

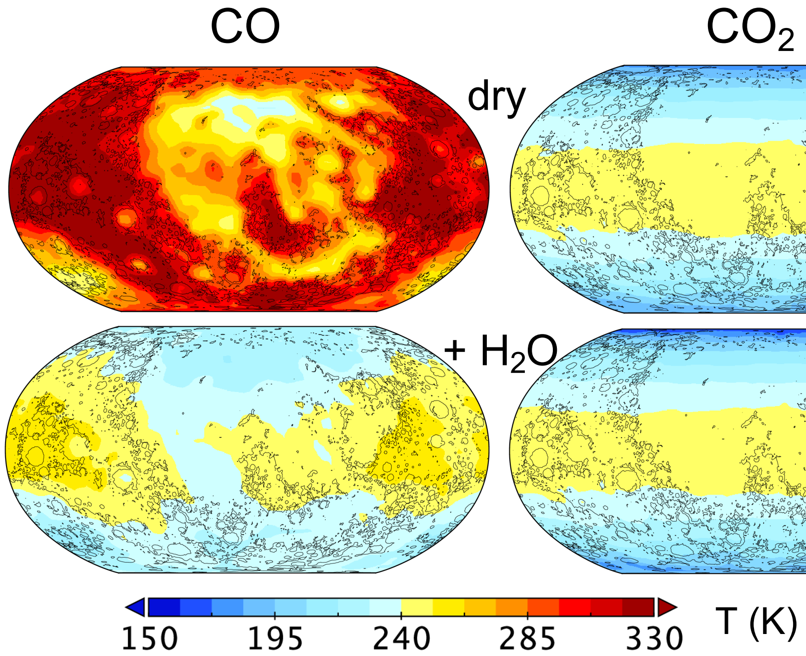
Experiments

- Atmospheric pressure: 10 mb, 2.5 mb and 1 mb
- Atmospheric composition:
    - Main components: 100% CO or 100% CO_2
    - Presence of water: dry or 0.005 kg/kg H_2O
- Obliquity with respect to Sun: 0º, 8º, 25º, 40º
- Rotation period: 17.8 days (45 Earth radii orbit)
- Solar radiation: solar constant: 0.75 of modern value, spectrum: 2.9 Gya
- Current observed topography, albedo & distribution of PSRs (assume lunar topographic features unchanged last 3.5 Gy)

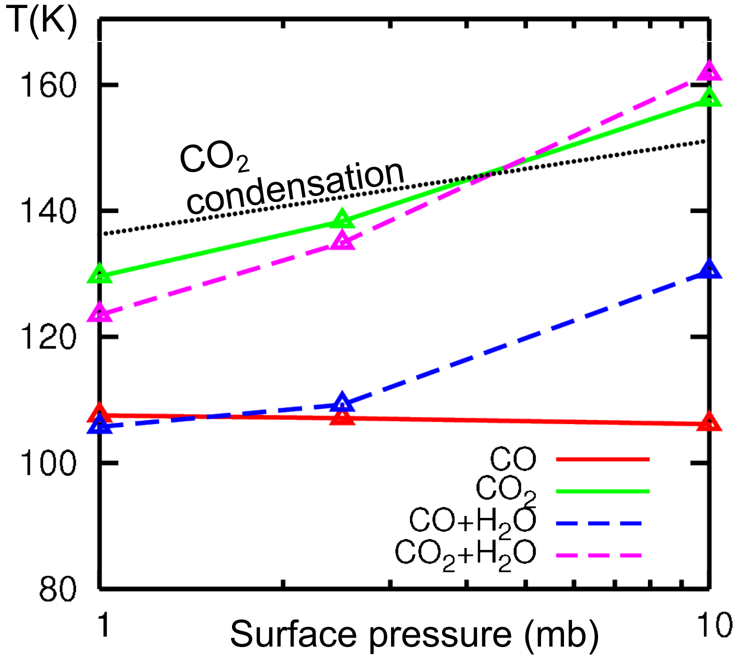
Temperature dependence on composition and mass

0-obliquity *Preliminary results in Aleinov et al. (2019) GRL, 46, 5107.*

Lower (2% mass) atmospheric temperature for 1 mb atmosphere (dry CO atmosphere is much warmer due to lack of radiative cooling)



Ground temperature at the poles (CO2 can condense for lower surface pressures)

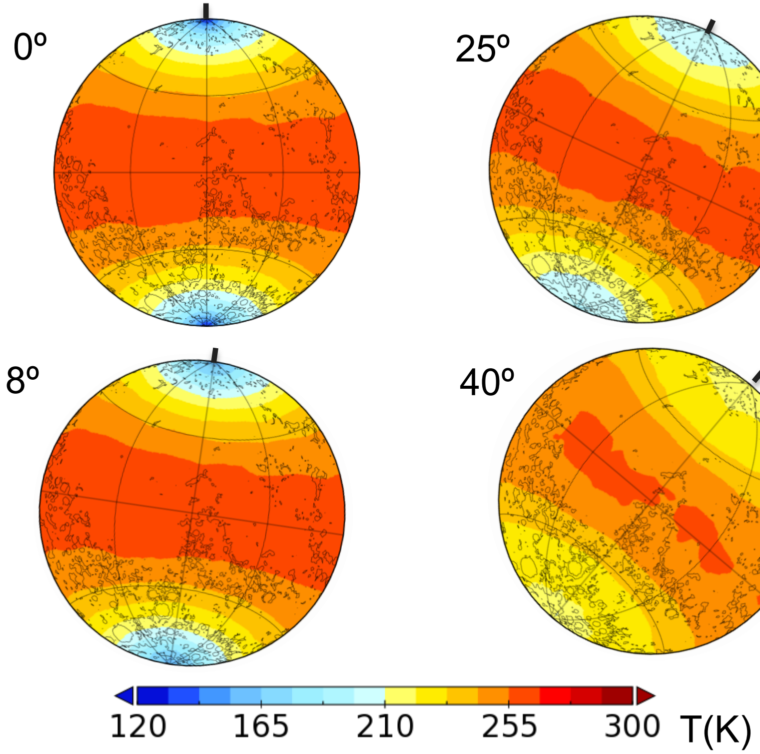


Obliquity dependence

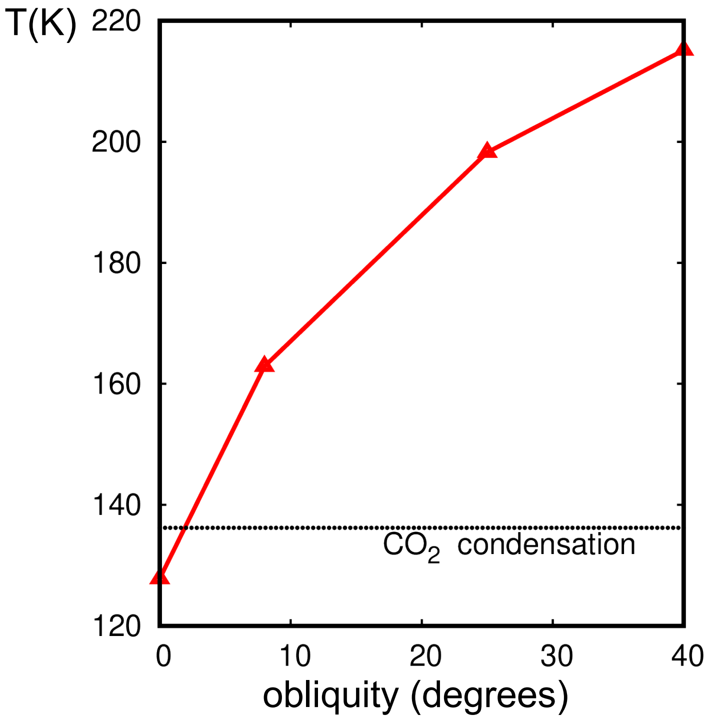
Atmosphere: 1 mb CO_2

Can non-zero obliquity prevent CO2 condensation at poles? – Yes!

Ground temperature (annual average)



Polar ground temperature



H_2O transport from a major eruption

Atmosphere: 1 mb CO2
(in equilibrium)

A major eruption in Mare Imbrium was simulated with typical parameters from Wilson & Head (2018):

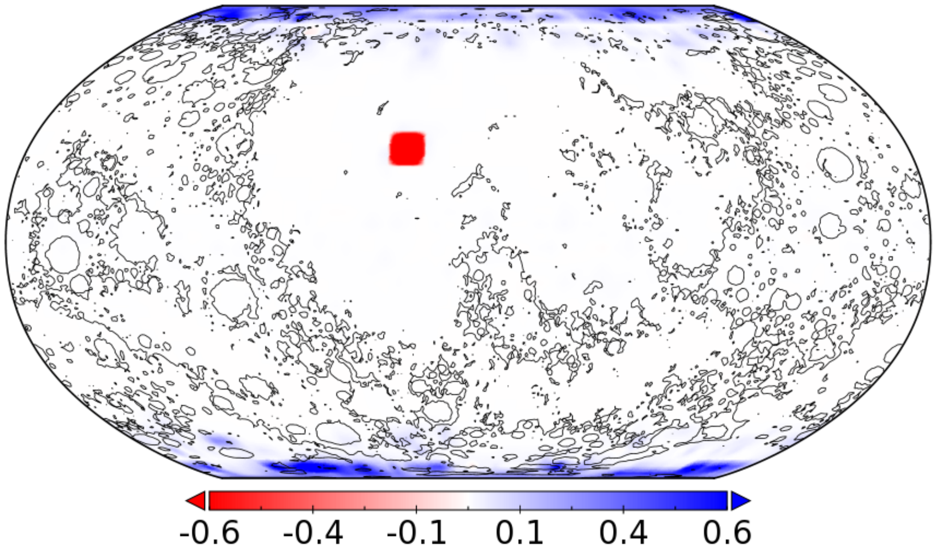
H_2O outgassing rate = $3 \cdot 10^4$ kg/s
(assuming 10^4 m^3/s magma flow and 1000 ppmw H_2O in lava)

Duration = 100 days

Outgassing region = 250 × 250 km

In 3 years 79% of outgassed H_2O was deposited in polar regions (above 68° North or below 68° South)

H_2O deposit after 3 years (kg/m^2)



Conclusions

- Atmospheric thickness determined by competition of outgassing and escape
- Composition defined by chemistry: depends on temperature and H_2O availability
- Thin (<2.5 mb) CO_2 atmosphere is less stable and is prone to collapse
- Non-zero obliquity may help with stability
- 1mb CO_2 atmosphere can effectively transport volatiles, delivering ~80% of outgassed amount from a singe major eruption to the poles in ~3 years

Acknowledgements

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