Ames Research Center

Amazonian Climate Modeling

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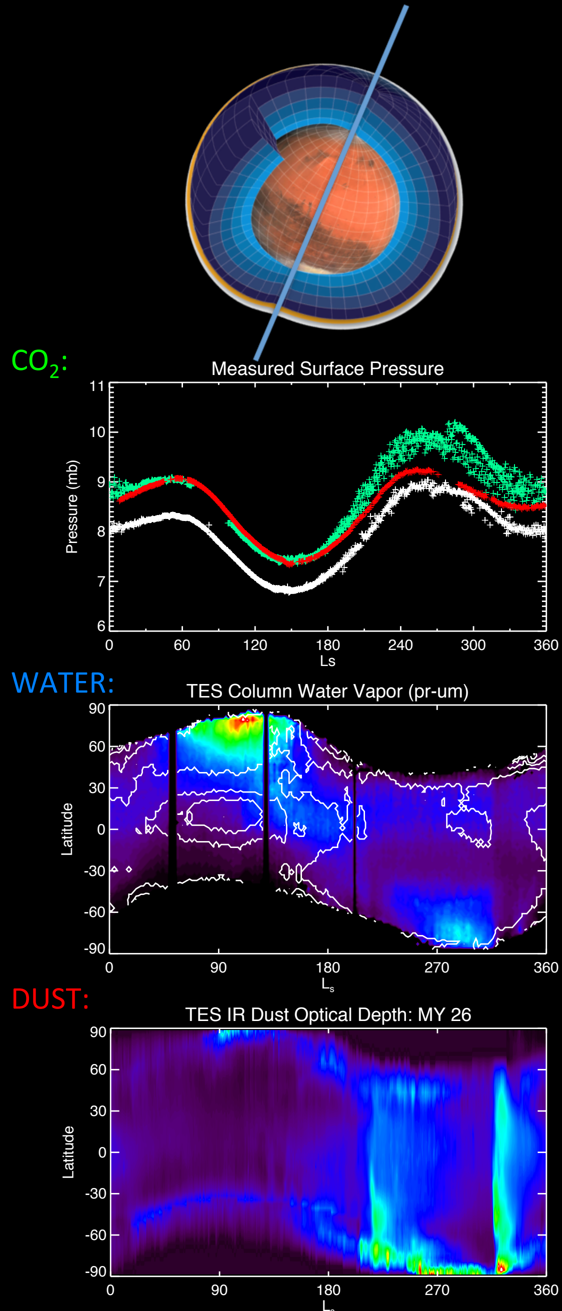
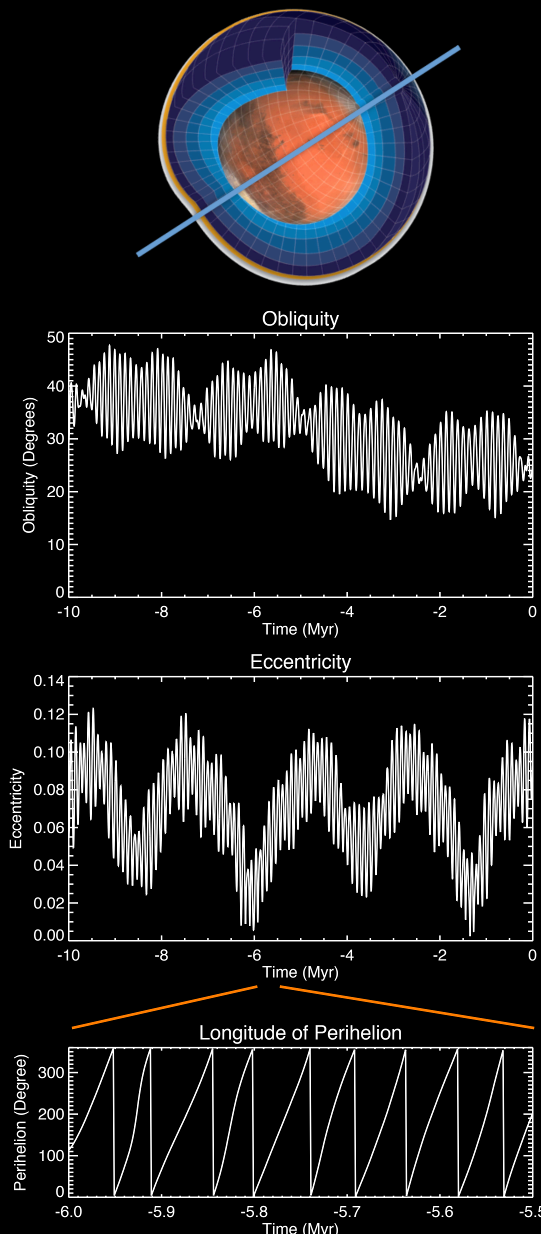
NASA Ames Research Center

CURRENT MARS + MODIFIED ORBIT PARAMETERS = AMAZONIAN MARS





Laskar et al. (2004)

CO_2 CYCLE?

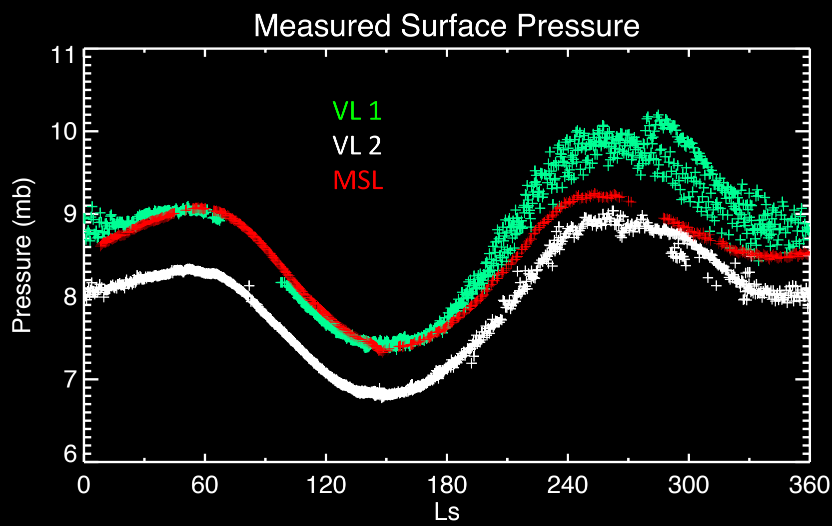
WATER CYCLE?

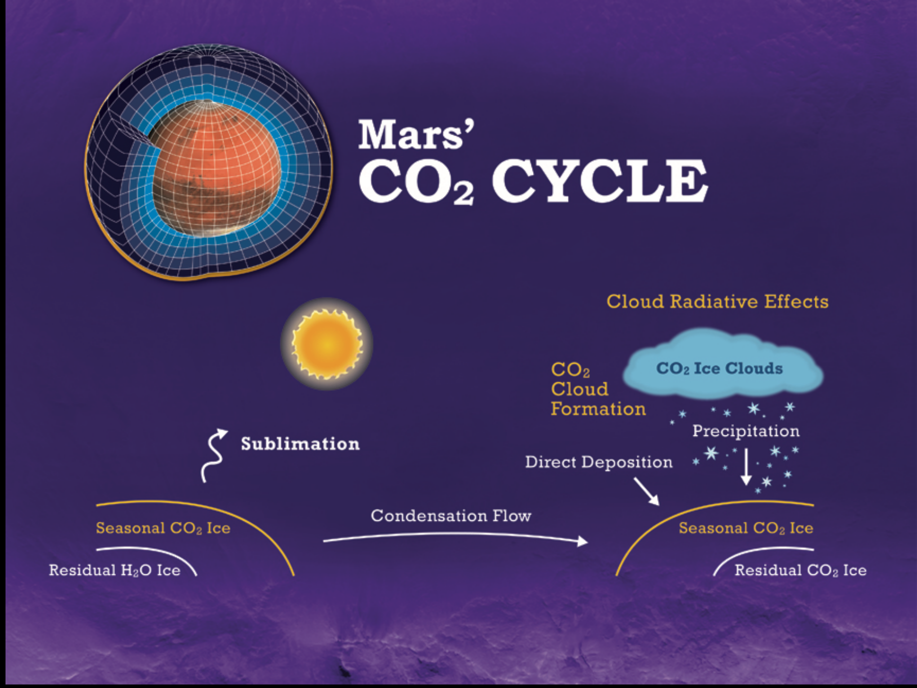
DUST CYCLE?

NOTE:

- Modeling the Amazonian climate is distinctly different than modeling Noachian/Early Hesperian climate.
- Early Mars GCMs generally include physics of massive atmospheres, warm water cycle physics, and simplified cloud microphysics.

CURRENT MARS: CO_2 CYCLE





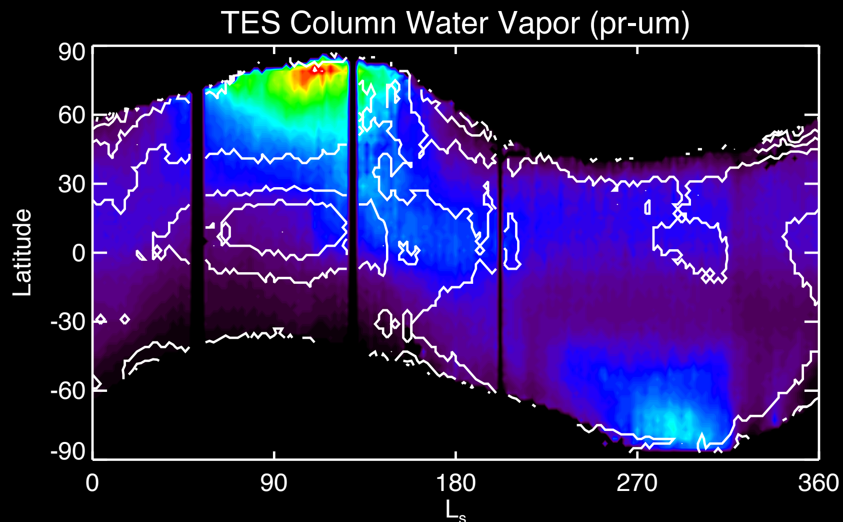
CO_2 Cycle Tuning:

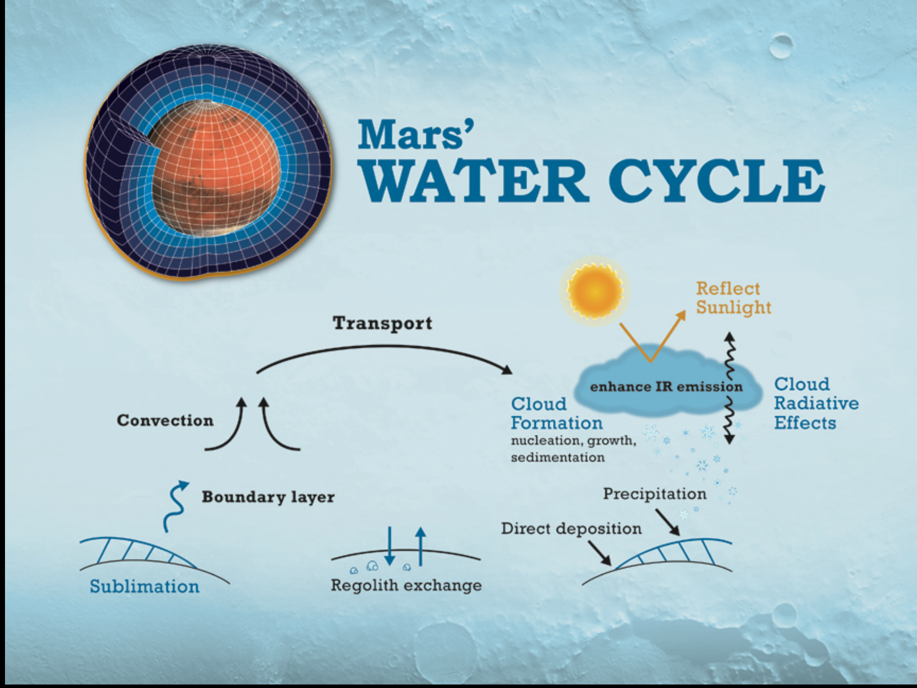
1. Change parameters to reproduce VL 1 and VL 2 observed surface pressures:
   - CO_2 ice albedo, emissivity
   - Sub-surface H_2O ice depth
2. GCMs can readily reproduce the CO_2 cycle
   Forget et al. (1999); Haberle et al. (2008); Guo et al. (2009)

CO_2 Condensation & Sublimation:

1. Surface:
   - Governed by energy balance
2. Atmosphere:
   - Usually a simple scheme—no clouds!
     - CO_2 condenses when $T<T_{sat}$
     - Condensed mass either delivered to surface or can sublimate below
   - More recently: CO_2 cloud schemes

CURRENT MARS: WATER CYCLE



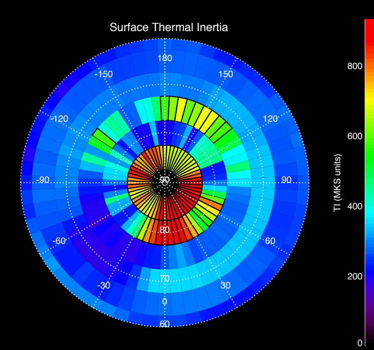


Importance of Water Ice Clouds:

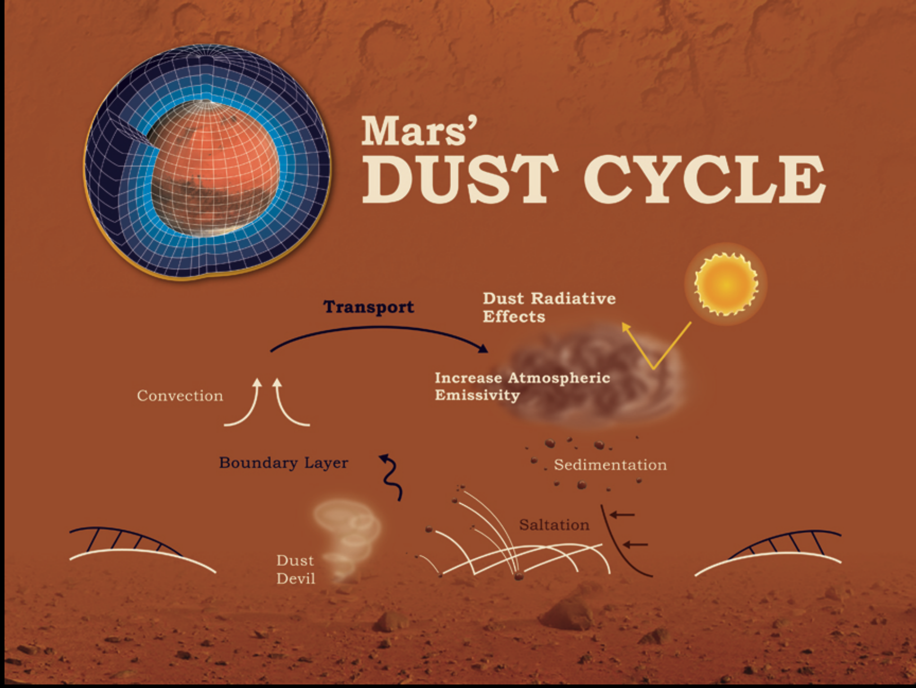
1. Radiative Influences
   - Tropical clouds warm aloft
     - Feedbacks with circulation
       → Hadley cell intensifies
2. Microphysical Processes
   - Clouds limit vertical extent of H_2O
     - N-S transport influenced: Clancy effect
   - Dust needed for nucleation!
3. GCMs now simulate H_2O cycle with R.A. Clouds
   Navarro et al., 2014; Haberle et al. (2017); Lee et al. (2016)

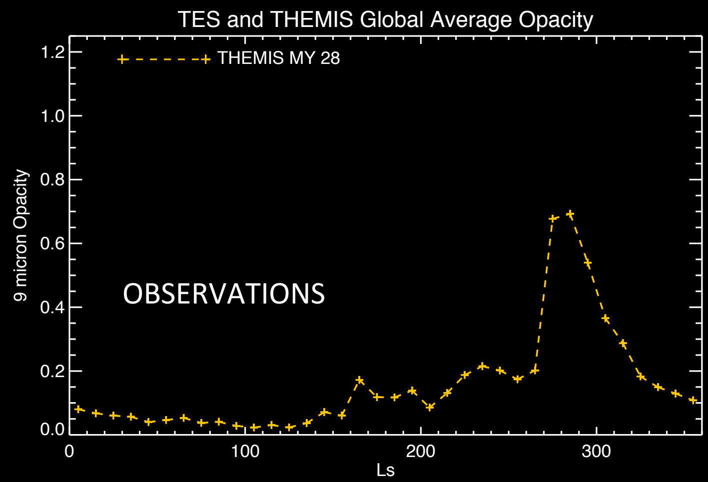
Surface Water Ice Reservoirs:

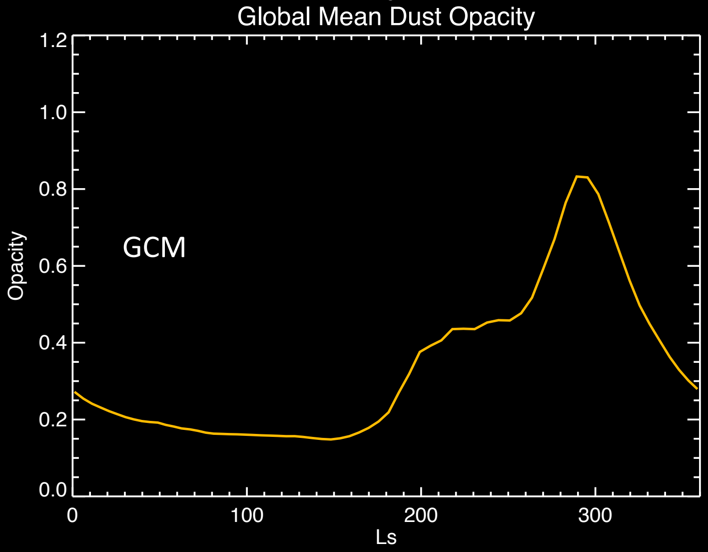
1. "Permanent" Source: North Cap
   - Defined by observed T.I. or T_g
     - Simulations show cap is not in equilibrium
       → Highest latitudes gain annually
       → Lower latitudes lose annually
2. Seasonal/Diurnal
   - Seasonal CO_2 cap
   - Nighttime frosts
3. Regolith
   - Often not included



CURRENT MARS: DUST CYCLE (Part I)







Dust Lifting Parameterizations:

1. Wind Stress (Saltation)
   - Lifting occurs when a threshold wind stress is exceeded
   - Provides localized sources and storms
2. Dust Devils
   - Lifting depends on sensible heat flux, PBL depth
   - Provides background, low-level source

GCMs predict low levels of dust during aphelion and increased dustiness during perihelion

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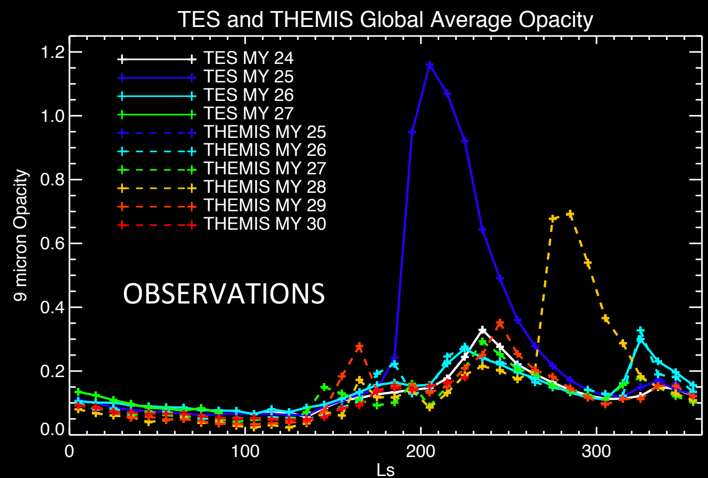

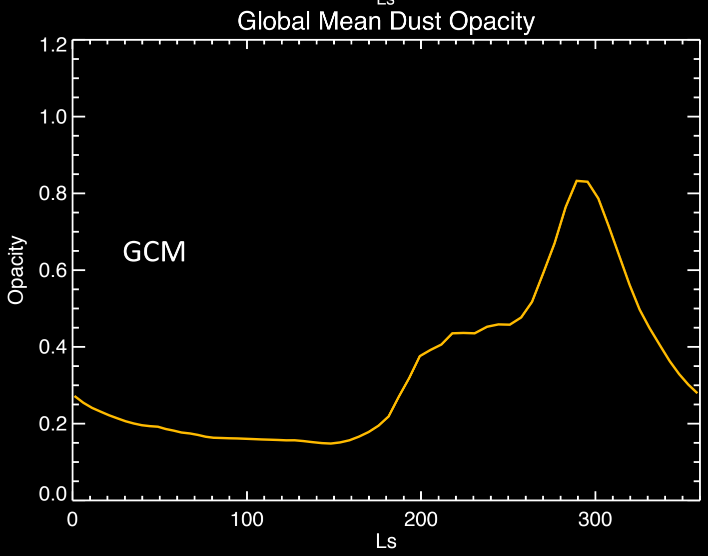

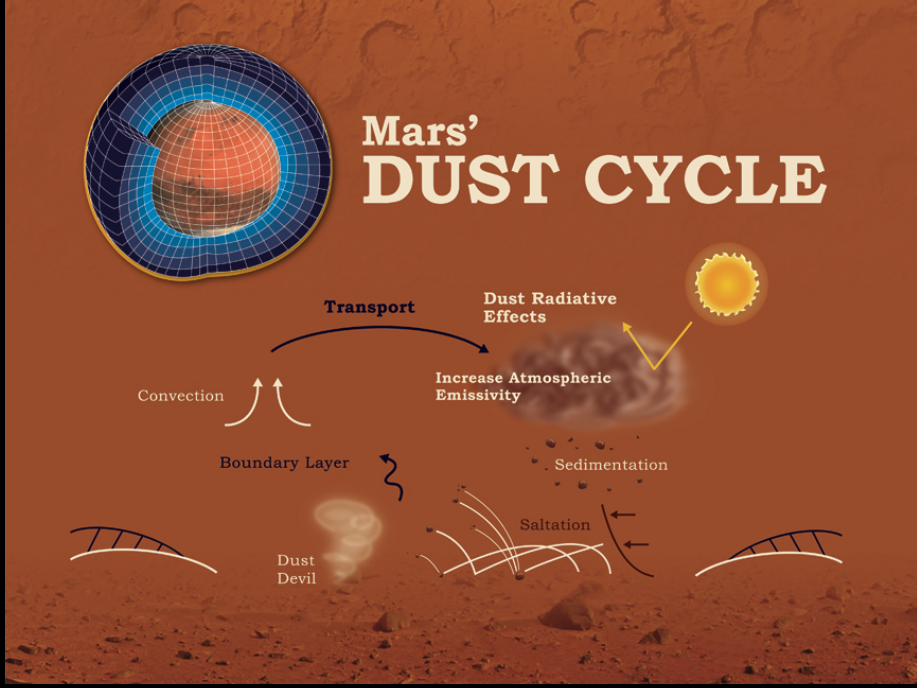

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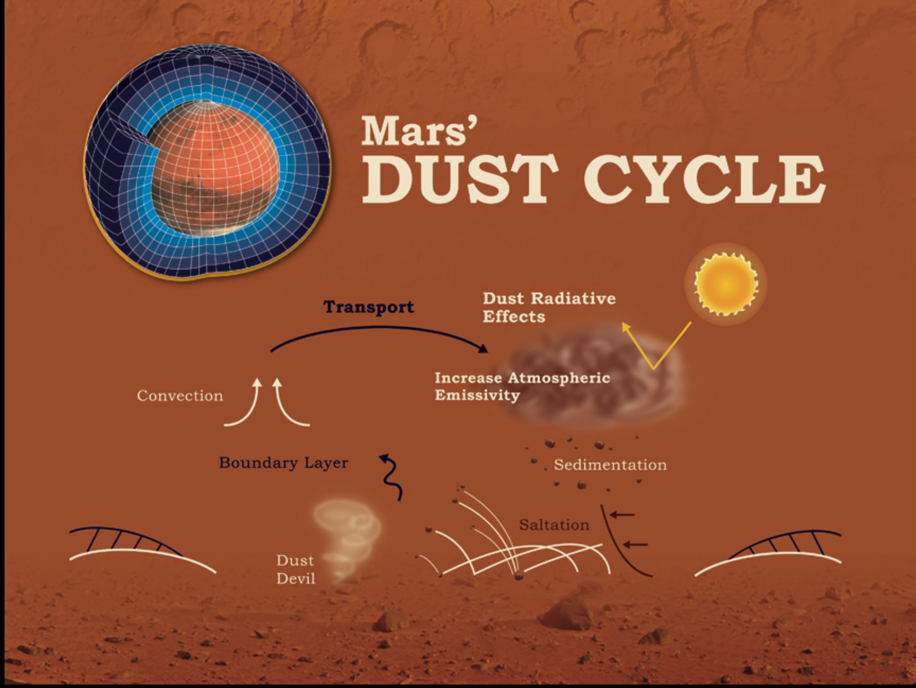

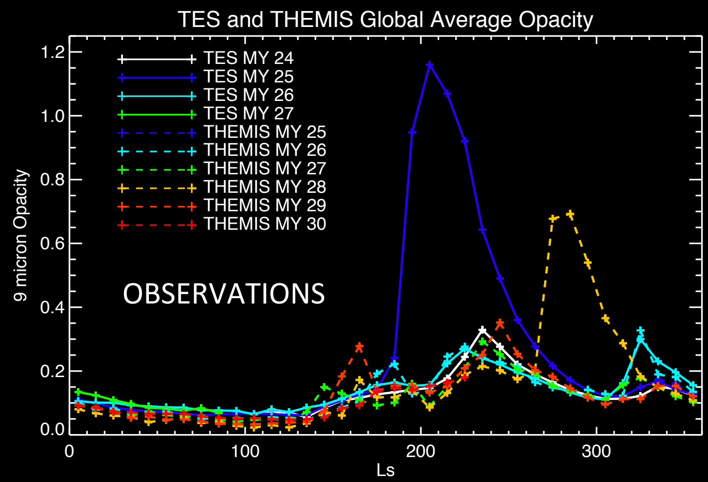

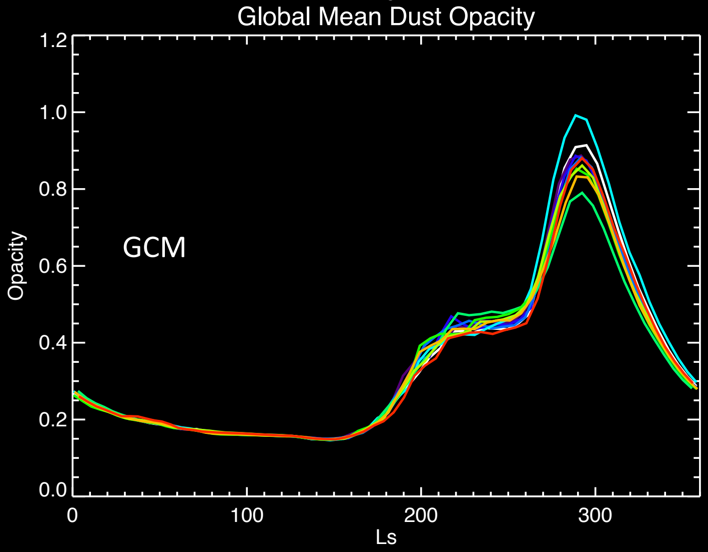

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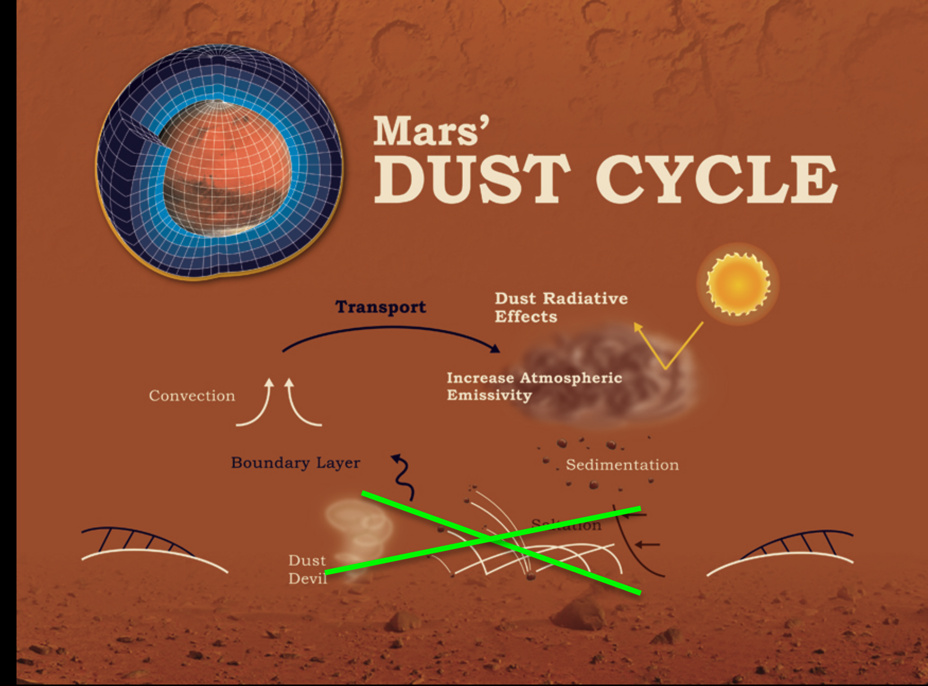
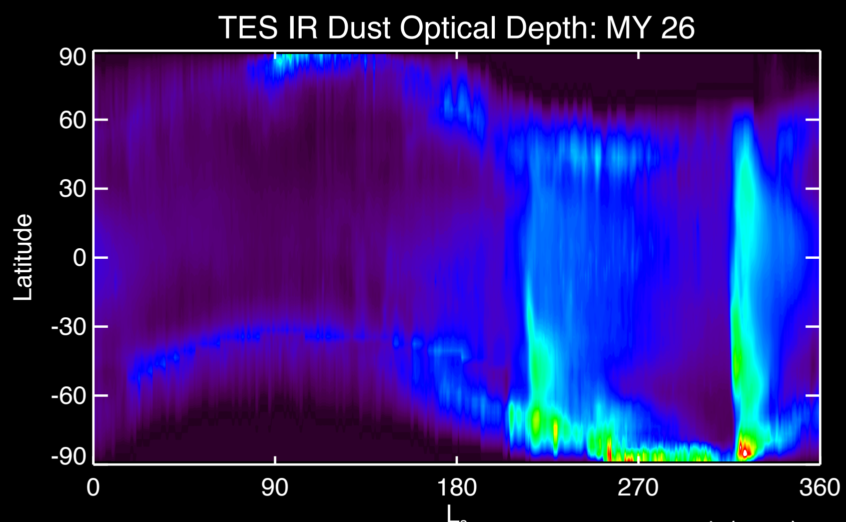
GCMs predict low levels of dust during aphelion and increased dustiness during perihelion

Interannual variability is illusive

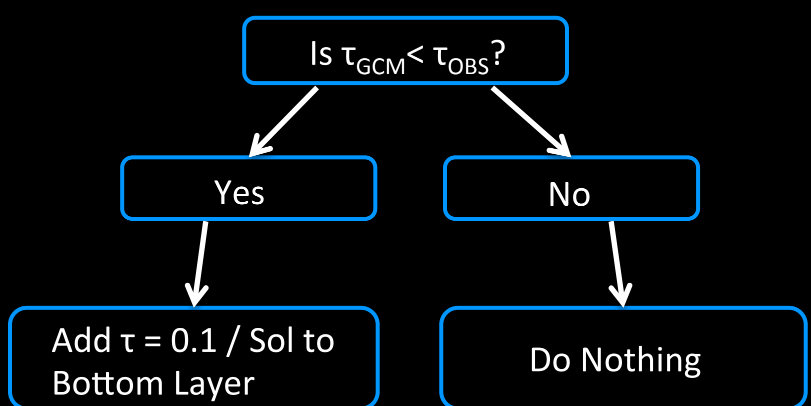
- Finite surface reservoirs?
  Kahre et al. (2005); Newman et al. (2015); Mulholland et al (2013)
- Coupling to the water cycle through clouds?
  Kahre et al. (2011); Jha and Kahre (2017)

CURRENT MARS: DUST CYCLE (Part II)





Smith (2008)



Prescribed (or Semi-Prescribed) Dust

1. Use observed dust maps to constrain model
   - Vertical distribution either prescribed or self-consistently determined

   Montabone et al. (2015)

2. The best way to control the dust cycle for current Mars simulations
   - Most realistic temperatures/circulations

   Madeleine et al. (2011)

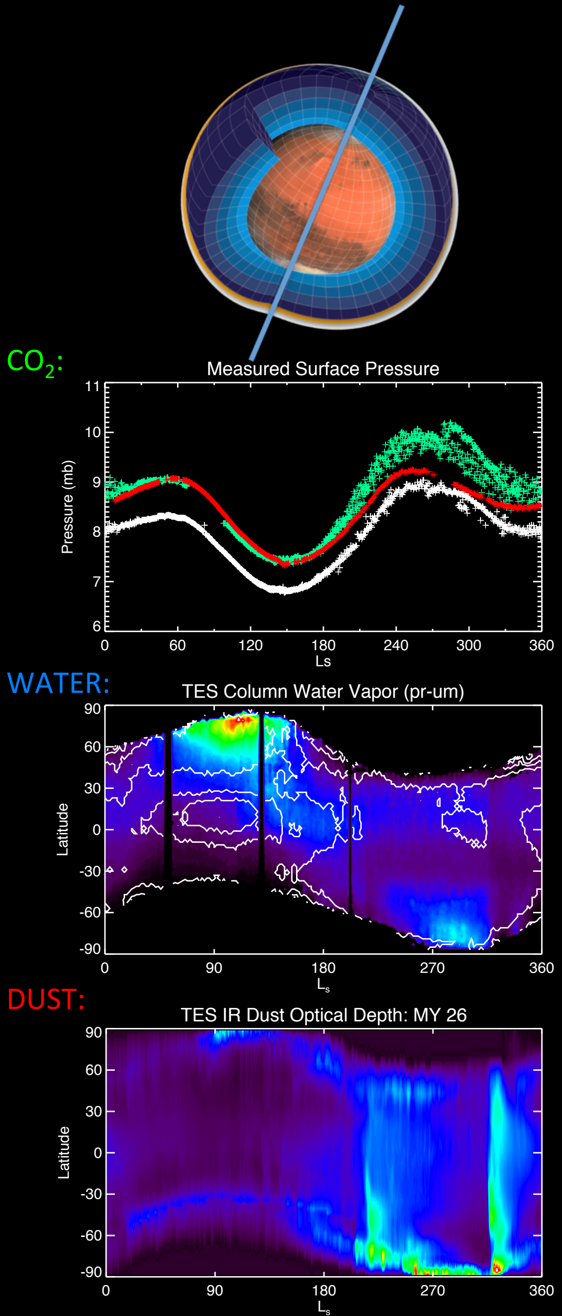
3. Not as useful for past climate simulations

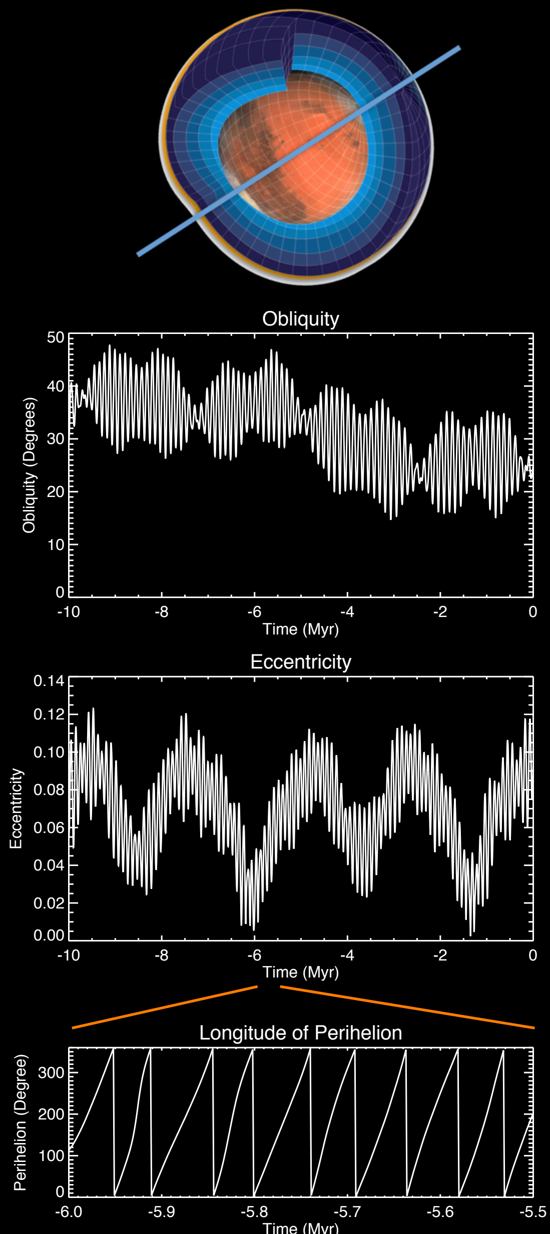
   INSTEAD:

   i. Use simplified prescriptions

   ii. Interactively predicted lifting

CURRENT MARS + MODIFIED ORBIT PARAMETERS = AMAZONIAN MARS





Laskar et al. (2004)

CO_2 CYCLE?

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MODIFYING ORBIT PARAMETERS: STRATEGY

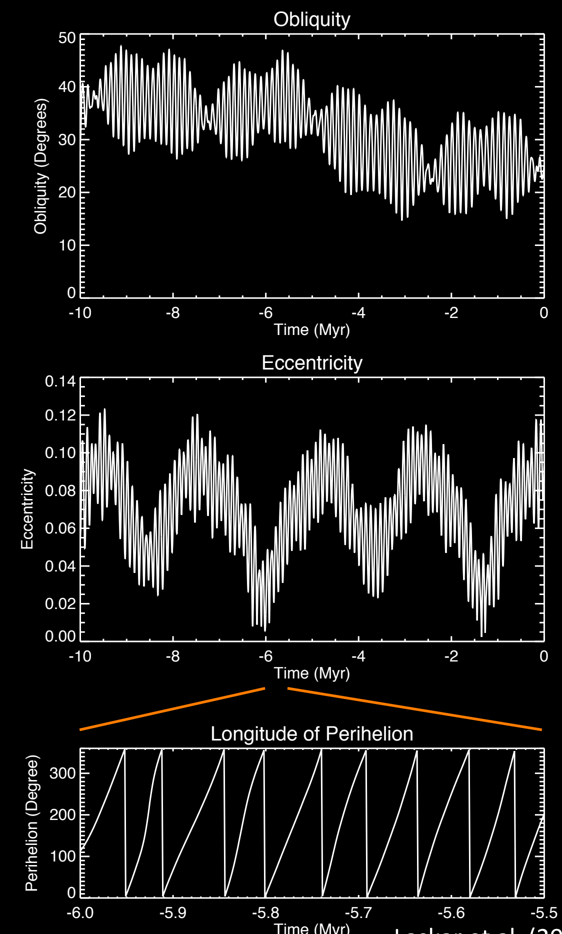
GCMs do not run fast enough to explicitly simulate changing orbit parameters.

Instead:

- Choose combinations of:
  - obliquity, eccentricity, longitude of perihelion
- Goal: map out trends and branch points in behaviors

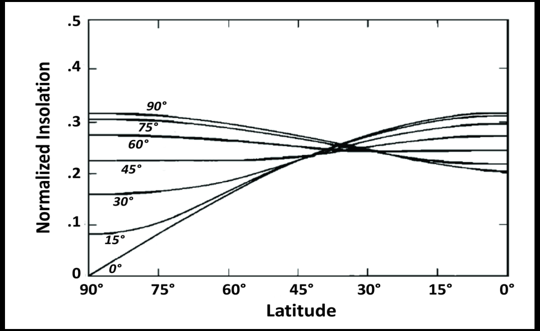
Considerations:

- Surface reservoirs and total inventories
  1. CO_2: assume entire inventory starts in the atmosphere
     → what about buried CO_2 in south?
  2. Dust: infinite availability (?)
  3. Water: surface source regions depend on study goals



Laskar et al. (2004)

AMAZONIAN MARS: CO_2 CYCLE



Ward (1974)

Obliquity variations have important consequences for the CO_2 cycle

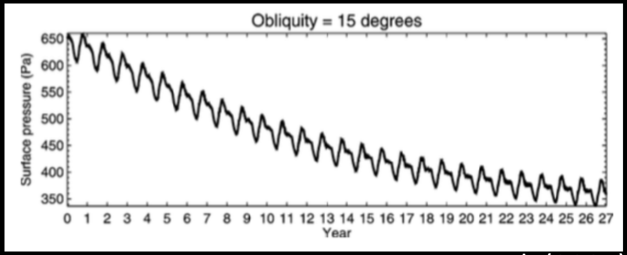
As obliquity increases:

1. Annual mean insolation at the poles increase
   - For obliquities > 54°:
     - Poles receive more insolation than equator
2. Seasonal variations are more extreme
   - Seasonal CO_2 ice caps more massive & latitudinal extensive
   - Global average surface pressure decreases

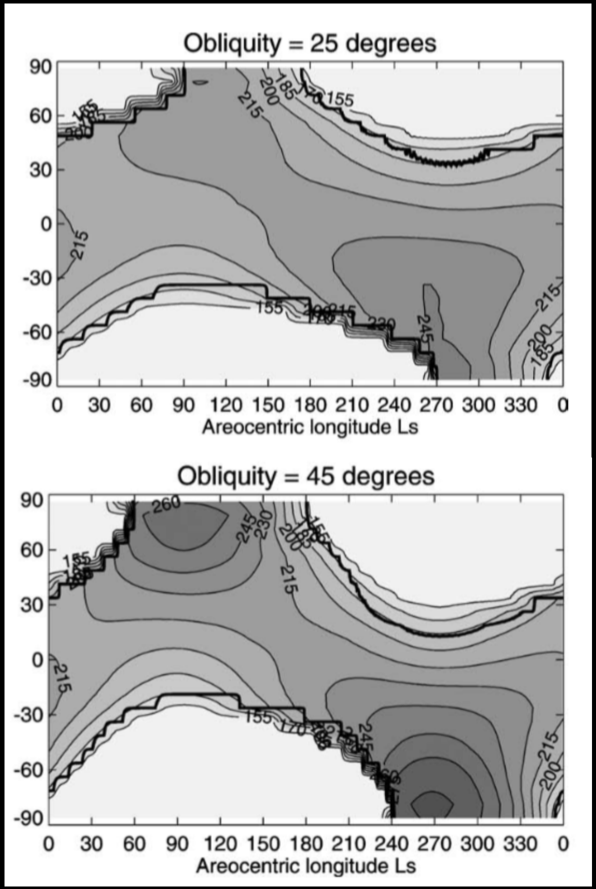
   Mischna et al. (2003); Haberle et al. (2003); Newman et al. (2005)

When obliquity is low (< ~20°):

- Permanent CO_2 caps form and atmosphere collapses
- Equilibrated atmospheric mass could be quite low (~30 Pa)



Newman et al. (2005)



Newman et al. (2005)

AMAZONIAN MARS: WATER CYCLE

Obliquity variations largely control where water ice is stable on the surface

Low obliquity (<30°):

- Water ice is stable at the pole
  → N or S likely depends on Ls of perihelion
- Atmosphere is relatively dry (low polar insolation)
  Mischna and Richardson (2003); Forget et al. (2006); Levrard et al. (2007)

Moderate obliquity (30°-40°):

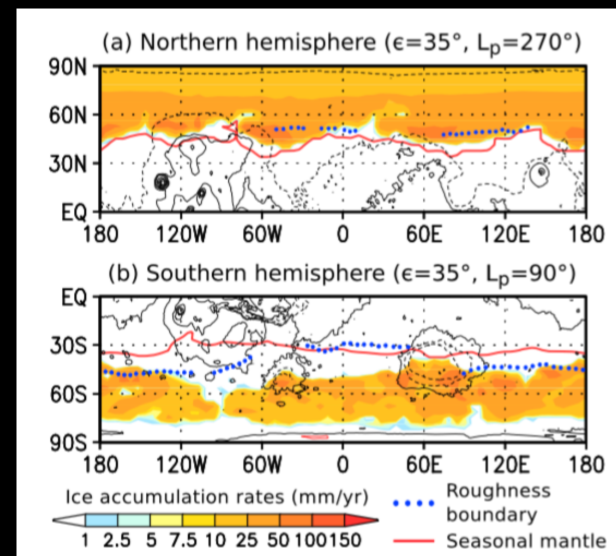
- Water becomes stable in the mid-latitudes
- Atmosphere is considerably wetter (higher polar insolation)
  Madeleine et al. (2009/2012)

High obliquity (>40°):

- Water ice destabilized at the poles
- Water ice becomes stable at low latitudes
  Mischna and Richardson (2003); Forget et al. (2006); Levrard et al. (2007)

Radiative effects of water ice clouds have significant effects!

- Warm surface; enhance circulation, cloudiness and snowfall
  Madeleine et al. (2014); Haberle et al. (2012); Kahre et al (2015)



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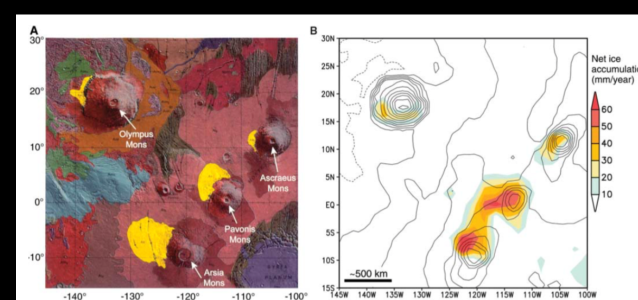


Forget et al. (2006)

AMAZONIAN MARS: DUST CYCLE

Increasing obliquity significantly enhances predicted dust lifting & dust loading

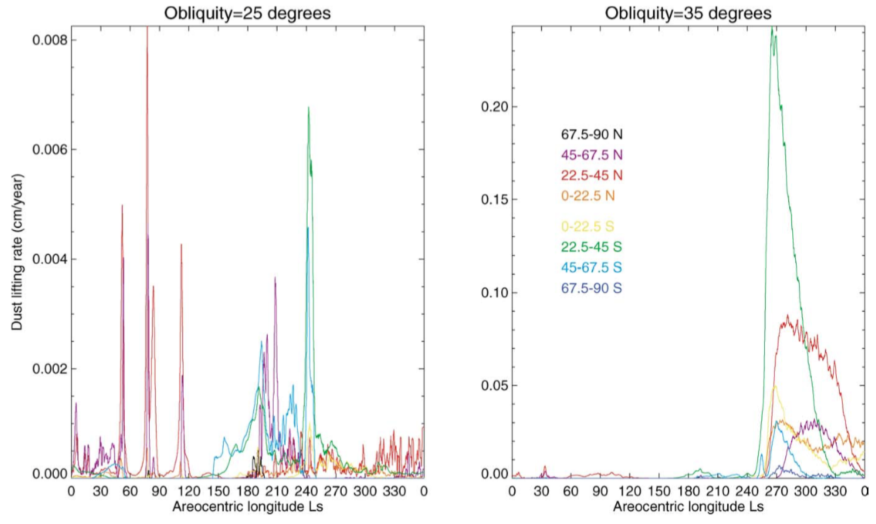
Increasing obliquity:

- Enhances equator-to-pole temperature gradient
- Drives an enhanced Hadley cell
- Stronger return flow increases surface stresses
- Increases dust lifting

  Haberle et al. (2003)

- Positive radiative-dynamic feedbacks
  - → increases Hadley cell strength more
  - → even more dust lifting

  Newman et al. (2005)



Newman et al. (2005)

Notes and caveats:

- Infinite surface dust reservoirs?
- Dust-only simulations: what would coupling to water cycle (cloud formation) do?
- Physics of lifting (availability of sand, resolution effects)?

AMAZONIAN MARS: MODELING POLAR LAYER DEPOSITS

There have been a relatively limited number of GCM studies that directly relate to the PLDs

1. Newman et al., 2005: Polar deposition rates of dust under different orbital configurations
   - Interactive dust cycle simulations
   - Dust deposition increases with obliquity
   - South pole gains more dust than north when obliquity > ~30°

     → Did not include a water cycle

2. Levrard et al., 2007: Net ice deposition/ sublimation under different orbital configurations
   - Water cycle model of Montmessin et al. (2004)
   - Loss of ice from pole increases with obliquity (obliquity > ~30°)
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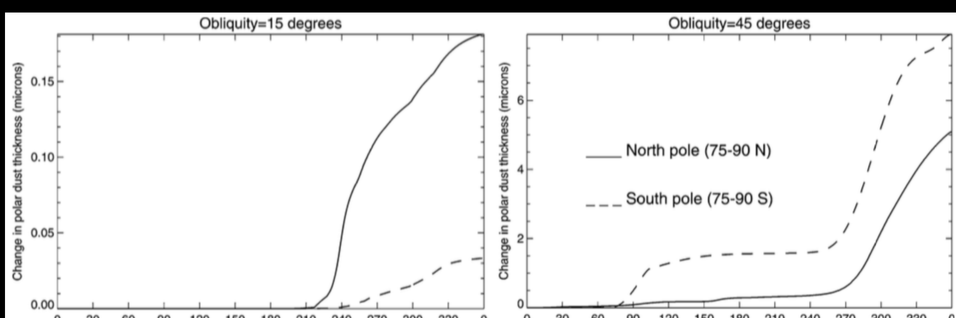

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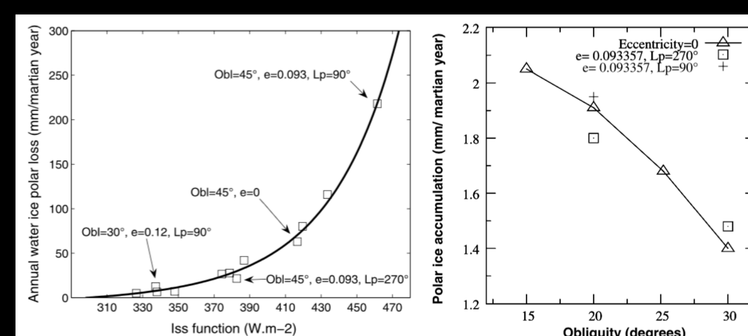

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Model that used GCMs (in part) for behaviors/parameterizations:

Hvidberg et al (2012): modeled PLD layering

- Parameterized dust deposition based on NH summer equator to pole temperature gradient
  → proxy for obliquity
  → based on behavior from Haberle et al. (2003) and Newman et al. (2005).
- Parameterized ice deposition based on computed saturation vapor pressure (not GCM-based).
- Depositing dust and ice together allow for lag formation and layering
- Otherwise, dust and water are uncoupled and higher order effects are not included

AMAZONIAN MARS: MODELING POLAR LAYER DEPOSITS

A logical next step for GCM work is to predict water and dust deposition/removal together

Jeremy Emmett's PhD project:

Use the NASA Ames GCM with coupled dust and water cycles to investigate the PLDs

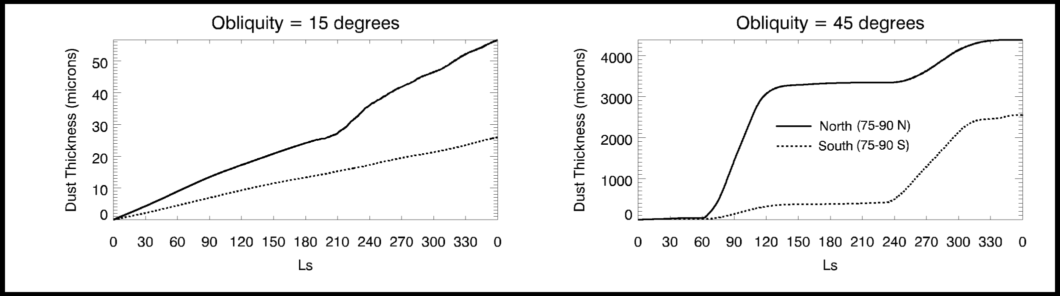
Dust and Water are coupled via:

1. Cloud microphysics
   - Scavenging, etc
   - Radiative/dynamic feedbacks
2. Lag deposit formation
   - Throttle sublimation when thick enough

Allows for the simultaneous, self-consistent tracking of dust and water ice in the polar regions for a range of orbital configurations

→ temporally *and* spatially

DUST:



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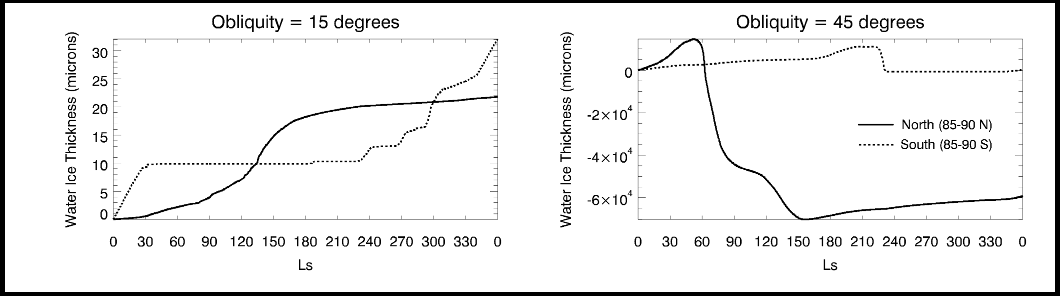

GOAL: Improve our understanding of how the PLDs relate to the climate of Mars over time

AMAZONIAN MARS: FINAL THOUGHTS

1. We have learned a lot since GCMs were initially used to investigate aspects of the PLDs
   - The radiative effects of water ice clouds are significant for the climate, particularly at high obliquity
   - Coupling between the dust and water cycles is also likely quite important for both the water and dust cycles

2. GCMs are powerful, but complex
   - Interpreting results needs to be done with caution

3. GCMs will be improved in multiple ways in the near future
   - Pole problem
   - Spatial resolution
   - Computational speed