Martian Atmosphere and Cycles

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Kobe/Cornell Universities

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The Inner Planets

Earth

Mars

Mercury

Venus

Displayed in their correct relative sizes
## Inner Planets in General

<table>
<thead>
<tr>
<th>Planet</th>
<th>d (AU)</th>
<th>R (km)</th>
<th>Period (days)</th>
<th>albedo</th>
<th>g (m/s²)</th>
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<td>0.2056</td>
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Albedo examples

- Mercury
- Mars
- Earth
- Venus

- Fresh Snow & Ice
- Thick Clouds

- Oil
- Snow & Ice
- Thin Clouds
- Sand Dune
- Concrete
- Grass or Crop
- Forest
- Tundra
- Deep Water
- Soil
- Asphalt

Albedo
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- **Small tilt**: No “seasons”
- **Large tilt**: Prominent “seasons”
Earth’s Circular Orbit

- Vernal Equinox
- Summer Solstice
- Autumnal Equinox
- Winter Solstice
Mars’ Highly Eccentric Orbit

\[ L_s = 0^\circ \]
\[ L_s = 90^\circ \]
\[ L_s = 180^\circ \]
\[ L_s = 270^\circ \]

Solar flux \( \sim 1/r^2 \) so …

aphelion vs. perihelion is about 45% difference in insolation!

\[ a(1+e)=1.66 \text{ AU} \]
\[ a(1-e)=1.38 \text{ AU} \]

\[ L_s \equiv \text{“Solar Longitude”} \]
The land area of the Earth is approximately equal to the total surface of Mars.

The land area of Africa is about the same as the total surface of the Moon.
# Inner Planet Atmospheres

<table>
<thead>
<tr>
<th>Planet</th>
<th>T (K)</th>
<th>P (fraction of Earth)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>100 (night) 590-725 (day)</td>
<td>$10^{-15}$</td>
<td>He, H$_2$</td>
</tr>
<tr>
<td>Venus</td>
<td>737</td>
<td>91</td>
<td>CO$_2$ (N$_2$, SO$_2$)</td>
</tr>
<tr>
<td>Earth</td>
<td>283-293 (day)</td>
<td>1</td>
<td>N$_2$, O$_2$ (H$_2$O, Ar, CO$_2$)</td>
</tr>
<tr>
<td>Mars</td>
<td>184-242 (day)</td>
<td>0.007 - 0.009</td>
<td>CO$_2$ (N$_2$, Ar)</td>
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Particles on ballistic trajectories do not constitute an “atmosphere”!
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- **N₂**: Weak greenhouse gas
- **CO₂**: Strong greenhouse gas
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Primary Factor for Weather

**Earth**
- Water
  - Latent heat exchange
    - (evaporation and condensation)

**Mars**
- Aerosol Dust
  - Absorption and emission of solar energy
Mars vs. Earth

Temperature
Earth Air Temperatures

Kansai International Airport (Osaka, Japan)

New York City

Local time (Sep 5 to 7, 2004)
What’s the difference?

Earth
- Thicker atmosphere
  - Better able to hold heat
- Weaker absorber
- Moisture
  - Holds and transports heat
- Oceans
  - Source of moisture
  - Giant reservoirs of mostly constant temperature

Mars
- Thinner atmosphere
  - Responds quickly to diurnal solar radiation
- Stronger absorber
- No water! (essentially…)
- Aerosol dust can’t
  - change phase
  - transport heat efficiently
- No oceans
  - no “memory” of recent conditions
Martian Daytime T profile

- A-B: “Superadiabatic” conduction layer, C: Convecting zone, D: Nighttime radiative-cooling inversion layer
Repeatability of Martian Temperatures

(a) Mean T15 at 2am

- **Mariner 9 IRIS**
- ♦♦♦ Viking Year 1
- △△△ Viking Year 2
- □□□ Viking Year 3
- XXX TES Year 1
- +++ TES Year 2
- ○○○ TES Year 3
- ▽▽▽ TES Year 4

(b) Mean T15 at 2pm

Brightness Temperature (K)

Areocentric Solar Longitude = Ls
Important Cycles on Mars

1. Temperature
   - Diurnal
     - Nearly perfect match to theoretical equation forced by rising and setting of sun
   - Annual
     - Matches theoretical equation based on distance from sun
     - Important exception we’ll talk about later…
Mars vs. Earth

Pressure (CO$_2$)
Martian Annual Cycle of Surface Pressure

For Earth, curve would be nearly flat at 1000 mbar, with much smaller variations (≤ 5%) due to weather systems (storms, typhoons, etc.).

\[ \frac{\Delta P}{P} = \frac{2 \text{ mbar}}{8 \text{ mbar}} \approx 25\% \]
What causes the surface pressure change by over 25%?

The polar caps
Atmospheric Pressure and the Polar Caps

- During that hemisphere’s winter, the polar regions get so cold that the atmosphere’s main constituent actually freezes out and condenses on the surface!
  - It would be like if liquid nitrogen rain were to fall out of the Earth’s atmosphere over the poles during winter.
- In the pressure curve, there are two peaks and dips, one for each pole’s winter, but they have different magnitudes due to the different length and coldness of each pole’s winter.
Seasonal Polar Cap

Permanent Polar Cap
Important Cycles on Mars

1. Temperature

2. CO$_2$
   - Condenses and sublimes in polar regions
   - Causes surface pressure variation
   - Also forms polar clouds
     - in polar night
     - can’t be seen in visible images
     - detected by IR reflectance
Mars vs. Earth

$\text{H}_2\text{O} \ (\text{Water})$
Earth:
Water vapor clouds
and 70% of the planet covered in oceans

August 25, 1992: Americas and Hurricane Andrew
Mars: Some Water Ice Clouds (and no oceans) and a water ice polar cap!
Topographically Forced Clouds: the Tharsis Volcanos

- Olympus Mons
- Ascraeus Mons
- Pavonis Mons
- Arsia Mons
Topographically Forced Clouds
(and Lee Waves)
Terrestrial Convective Clouds

Open cellular convection over the oceans
Martian Convective Clouds
Tropical Water Cloud Belt

Develops during northern spring and summer (aphelion, when Mars is furthest from the sun)
North Polar Cap

Made almost entirely of water ice

Sublimates water vapor during northern summer

Gets covered with CO$_2$ in the winter
Important Cycles on Mars

1. Temperature
2. CO₂
3. H₂O

- Released from polar caps in summer
  - Much more so for north polar cap
- Water vapor transported by winds
- Forms clouds
  - Air rising due to topography or global circulations (e.g., Hadley) reaches dew point and condenses
- Partially stored in pore space in soil (regolith)
- Deeper regolith? Buried ice reservoirs?
Water on Mars

- And, as best as we understand now, water is necessary for life.
- So knowing how water interacts with the atmosphere presently can also tell us how that interaction was in the past.
- And if we’re lucky, it helps guide us on search for possible life on Mars.
Martian Water Cycle

- Condensation
- Evaporation
- Transport
- Sublimation
- Deposition
- Diffusion into and out of regolith

H2O Ice

North Pole

Equator

CO2 ice covering H2O ice

South Pole

Deep ice?
Mars vs. Earth

Dust (aerosol)
Blue Water

Red Soil (& Dust)
Dust on Mars
Dust in the Martian Atmosphere

~ 40 km
Primary Factor for Weather

Earth
Water

Mars
Aerosol Dust

Latent heat exchange (evaporation and condensation)

Absorption and emission of solar energy
Movement of dust on the surface
Dust Clouds

$L_s \sim 300^\circ$ (southern summer)

South polar layered terrain
Cycle of dust from surface to atmosphere and back
Regional Dust Storm: Dust front coming down Chryse Planitia
Local Dust Storms
Polar Cap Edge Dust Storms
Similar Dust Storms

Terrestrial dust storm (26 February 2000)
Storm extends about 1800 km off NW Africa
near the equator

North Polar Cap
Important Cycles on Mars

1. Temperature
2. $\text{CO}_2$
3. $\text{H}_2\text{O}$
4. Dust
   - Expression of “weather” in absence of $\text{H}_2\text{O}$
   - Interaction of atmosphere with surface
   - Largest present source of erosion
   - Water can act faster, but too little of it presently to be of much effect
Summary: Mars & Earth

- **Similarities**
  - rotation rate (fast vs. slow spinning planet)
  - obliquity (seasons)
  - convection and boundary layer behavior
  - water clouds
  - Hadley circulation and jets

- **Differences**
  - dust vs. water as primary weather control
  - moderate vs. extreme diurnal temperature cycles
  - condensation of main atmospheric constituent leading to annual pressure cycle
  - eccentricity of orbit (hemispheric difference of seasons)