Remote Sensing of Mars

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Outline

1. Basics of Mars, missions, some results
2. Atmospheric correction of OMEGA data
3. Lithologic unit mapping based on OMEGA imagery
4. Optical depth of water vapor absorption bands of OMEGA data and its relation to water vapor abundance
5. Water and CO2 ice in polar seasonal caps based on THEMIS, MOC, OMEGA
Some basic knowledge of Mars

- Distance from Earth = 35 \sim 162 \times 10^6 \text{ miles}
- Mars year = 687 \text{ days}
- Radius = \frac{1}{2} \text{ of Earth}
- Mass = 11 \% \text{ of Earth}
- Gravity = \frac{1}{3} \text{ of Earth}
- Extremely acid (-1 to 3)
- Extremely saline (10 times of seawater)

<table>
<thead>
<tr>
<th>Mars</th>
<th>Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation period (hrs)</td>
<td>24.66</td>
</tr>
<tr>
<td>Obliquity (tilt)</td>
<td>25.2°</td>
</tr>
<tr>
<td>Cold (mean T -63°C, range -140°C to 20°C)</td>
<td></td>
</tr>
<tr>
<td>Dry (no rainfall)</td>
<td></td>
</tr>
<tr>
<td>Thin atmosphere (~6 mbar CO₂, 4% Earth)</td>
<td></td>
</tr>
<tr>
<td>Windy (dust storms, devils)</td>
<td></td>
</tr>
</tbody>
</table>
Mars Topography

- Olympus Mons
- Valles Mariner
- Hellas Crater

West

East

Altitude [km]
Goal 1: Determine if Life ever arose on Mars

Goal 2: Characterize the Climate of Mars

Goal 3: Characterize the Geology of Mars

Goal 4: Prepare for Human Exploration of Mars

from: http://mars.jpl.nasa.gov/science/
Mars Exploration Missions

- **Pathfinder**
- **Viking 1**
- **Viking 2**
- **Mars 3**
- **Beagle 2**
- **Opportunity**
- **Spirit**

![Diagram of Mars exploration missions](image-url)
Current and Near Future Missions

- 2001 Mars Odyssey
- Mars Express
- Mars Reconnaissance Orbiter (MRO)
- CNES Science Orbiter
- ASI/Telecom
- ASI/NASA SAR
- Spirit & Opportunity
- Phoenix
- Mars Science Lab (MSL)
- Netlanders
Polar caps
The change of CO$_2$ and H$_2$O ice in North Polar
Gullies in Newton Basin (MOC2-320)

39.0°S, 166.1°W
NASA/JPL, 2002-10-07
Gullies formation mechanism

One model for the formation of Martian Gullies

Sun

Ice Barrier

"steam" clouds

Semi-permeable Water Layer

Channel erosion

Rock/Debris field
Layered Sediments

Hock, 2004
Terra Meridiani mesas, 16.87°, 331.23°

West Arabia Terra, 8°N, 7°W
MOC Release No. MOC2-261, 2000-10-4
Eberswalde Delta, MGS MOC Release No. MOC2-1225, 2005-09-20

In northeast of Holden Crater near 24.0°S, 33.7°W
Juventae Chasma

Discovery of salts by Omega on Mars Express

HRSC orbit 243 (~true colour) 5°S, 297°E, 2004-03-26, by G. Neukum
Sulfate-rich layer deposit (Bibring et al. 2005)
Hydrated Sulfates in Layered Terrains

- **Red** - kieserite - $\text{MgSO}_4 \cdot (\text{H}_2\text{O})$
- **Green** - polyhydrated sulfate
- **Blue** - gypsum - $\text{CaSO}_4 \cdot 2(\text{H}_2\text{O})$
- **Pink** - other hydrated minerals, identified by their absorptions at 1.4 and 1.9 µm.
Burns Clif, Endurance Crater, Opportunity/MRO, NASA

Sols 287B - 294B, Nov. 13 - 21, 2004

Extremely fine, well developed laminations
Outcrop, sand dune, and “strawberry”
2. Atmospheric correction of OMEGA data

<table>
<thead>
<tr>
<th>Substance</th>
<th>Percentage or Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>95.32%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2.7%</td>
</tr>
<tr>
<td>Argon</td>
<td>1.6%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.13%</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0.07%</td>
</tr>
<tr>
<td>Water vapor</td>
<td>0.03%</td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>0.01%</td>
</tr>
<tr>
<td>Neon</td>
<td>2.5 ppm</td>
</tr>
<tr>
<td>Krypton</td>
<td>300 ppb</td>
</tr>
<tr>
<td>Xenon</td>
<td>80 ppb</td>
</tr>
<tr>
<td>Ozone</td>
<td>30 ppb</td>
</tr>
<tr>
<td>Methane</td>
<td>10.5 ppb</td>
</tr>
</tbody>
</table>
Algorithms

- Empirical transmission function (ETF) by OMEGA science team (Bibring et al., 1989, Combe et al., 2005, Mustard et al., 2005, Langevin 2006)
  - Assumption of atmosphere free on top of Olympus Mons

- LLEE algorithm by UTSA LRSG group
  - Prescribed CO2 absorption bands (Guan et al. 2006)
ETF method based on Olympus Mons

- Top of Olympus Mons is 21.23 Km above the Mars mean surface
- The base of the Mons is -2.7 Km
- Between the top and base of Olympus Mons is the major atmospheric layer

Olympus Mons
ETF (or atmospheric effect factor S):

\[ S = \frac{(I/F)_{\text{Mon-base}}}{(I/F)_{\text{Mon-top}}} \]
ETF

\[ x = \frac{\log((I / F_{\text{image}})_{2.011} / (I / F_{\text{image}})_{1.899})}{L_{\text{ref}}} \]

\[ L_{\text{ref}} = \log((s)_{2.011} / (s)_{1.899}) = -0.977 \]

Atmospherically corrected image = \((I / F_{\text{image}}) / (s)^x\)

Where \( S = (I/F)_{\text{Mon-base}} / (I/F)_{\text{Mon-top}} \)
LLEE algorithm

Based on Beer’s law:

\[ I_{\tilde{\lambda}} = F_{\tilde{\lambda}} \tau e^{-\tau_{\tilde{\lambda}}} \]  \hspace{1cm} (1)

\[ \frac{(I/F)_{\tilde{\lambda}}}{(I/F)_{\lambda}} = \frac{re^{-\tau_{\tilde{\lambda}}}}{re^0} = e^{-\tau_{\tilde{\lambda}}} \]  \hspace{1cm} (2)

\[ \log \left( \frac{(I/F)_{\tilde{\lambda}}}{(I/F)_{\lambda}} \right) = -\tau_{\lambda} \]  \hspace{1cm} (3)
Optical Depth ($\tau$) vs Elevation ($z$)

$$\tau = A * e^{-kz}$$ \hspace{1cm} (4)

A is the physically optical depth at the MOLA zero surface;
Depends on CO2 column density of each CO2 absorption band;
K depends on vertical profile of atmospheric column

$$\log \tau = \log A - kz$$ \hspace{1cm} (5)
A, CO2 column density; k, vertical profile of CO2 column, a constant within a small latitude change, but seasonal change.

For one image, same k but different A in different CO2 absorption bands.
Optical Depth ($\tau$) vs Elevation ($z$)

\[
\tau = A \, e^{-kz} \quad (4)
\]

\[
\log \left( \frac{(I/F)_{\lambda}}{(I/F)_{\lambda}} \right) = -\tau_{\lambda} = -(A \, e^{-kz}) \quad (6)
\]

\[
\log \left( -\log \left( \frac{(I/F)_{\lambda}}{(I/F)_{\lambda}} \right) \right) = \log(\tau) = \log(A) - kz \quad (7)
\]
We estimate $LL_0$ a value of -4.6, which is equivalent to 1/10 CO2 optical depth at the top of the Olympus Mons.

\[
\Delta = \left[ \log \left( -\log \frac{(I/F)_{\lambda}}{(I/F)_{\lambda}} \right) \right] - LL_0 
\]

@ 2.011 \mu m

\[
LL' = LL - \Delta
\]

\[
(I/F)_{\lambda'} = \exp(-\exp(LL'))(I/F)_{\lambda}
\]

EE

LL EE
Example:

ORB0529_3

Opportunity Site
3. Lithologic unit mapping

- Existing Martian geologic map and its geologic units were based on their geomorphology, crater features and density, albedo, multi-spectral properties, and thermal characteristics (USGS, 1987). It was the best geologic map based on available data during that time, though it was no way to tell really what minerals and lithologies for each unit.
- Martian atmospheric correction
- Minimum noise fraction (MNF) transformation

MNF b1: 56%, MNF b2,3,4: 19%

Zhu et al. 2006
Hyperion hyperspectral image at the Goldfield/Cuprite of the Nevada desert area (dry and no vegetation)
Summary of Results

- In Mars
  - MNF band1 in the OMEGA image accounts ~50% of the total information, which is mostly the Martian surface sand information.
  - MNF band 1 is related to the albedo of the image ($r^2=0.83-0.98$).
  - MNF band 2,3,4 together are mostly related to the geological unit and can be used to make useful lithologic unit map.
  - Spectral matching approaches (SFF and SAM) can be used to match the best possible lithological type (or mineral type) for each unit.
Summary of Results

- In dessert of the Earth
  - MNF band1 is not related to albedo, while band 3 is mostly related to albedo ($r^2=0.8$), which only represents $\sim 6\%$ of the total information.
  - MNF band1 is only account $15\%$ of all information, in comparison of $\sim 50\%$ in Mars.
  - MNF band1 and 2 are mostly related to the geological information, in comparison of bands 2, 3, 4 in Mars.
  - The first 6 MNF bands account only $39\%$ of the total information, in comparison of $\sim 80\%$ in Mars.
Our proposed 5 steps

- Atmospheric correction
- MNF analysis
- MNF band 2, 3, 4 composite image to delineate lithologic units
- Inverse MNF transform to original spectrum domain, after removed the MNF band1,
- Spectral matching reprehensive unit spectrum with standard spectrum library
4. Optical depth of water absorptions and its relation to water vapor abundance

- Black is ETF (s)
- Synthetic ratio
  - Red: 150 ppm H2O
  - Green: 300 ppm H2O
  - Blue: 600 ppm H2O

Encrenaz et al. 2005
Algorithms

\[
I_{\lambda} = F_{\lambda} \cdot e^{-\tau_{\lambda}} \quad (1)
\]

\[
e^{-\tau_{\lambda}} = \frac{(I/F)_{\lambda}}{(I/F)_{\lambda}} \quad (2)
\]

\[
\tau_{\lambda} = -\log\left(\frac{(I/F)_{\lambda}}{(I/F)_{\lambda}}\right) \quad (3)
\]
Algorithms

\[ \tau_{1.126} = -\log\left(\frac{(I/F)_{1.1411}}{(I/F)_{1.126}}\right) \]
\[ \tau_{1.385} = -\log\left(\frac{(I/F)_{1.3280}}{(I/F)_{1.3855}}\right) \]

\[ \tau_{1.871} = -\log\left(\frac{(I/F)_{1.8568}}{(I/F)_{1.871}}\right) \]
\[ \tau_{2.566} = -\log\left(\frac{(I/F)_{2.5402}}{(I/F)_{2.566}}\right) \]
Results: Optical depth vs elevation

\[ \tau = A \cdot e^{-kz} \]

**OMEGA, 501-4 (Ls=46)**

Ls, solar longitude, is the position of Mars relative to the Sun
Vertically, the H2O and CO2 seems not uniformly mixed.
Optical depth vs latitude

OMEGA, 72-1 (Ls=342)
In the tropical area, the CO2 and H2O are uniformly mixed across latitude.
Optical depth vs water vapor abundance

164 OMEGA images

$Ls = 330^\circ$ to $118^\circ$

Latitude = $-75^\circ$ to $+75^\circ$

TES data from M.D. Smith
"Jackknife validation"
Water vapor in Latitude-Ls plain

164 OMEGA images
Ls = 330° to 118°
Latitude = -75° to +75°
Water ice found in an unnamed crater (70.5° N, 103° E)  
By HRSC/Mars Express  
2/2/2005, Ls=153.6
5. Water and CO2 ice in crater-like features of seasonal polar caps

Ice found in

15 crater-like features (impact craters and volcanic mouths)

Latitude 73° N - 85° N

Reason suggested

Episodic advance of the polar ice cap margin or continuous ice depositions

Garvin et al. 2000
• Water ice was covered by CO2 and water frost in winter and early spring.
• CO2 sublimate very fast in early spring, while water frost sublimate later.
• In later summer water frost deposit first then CO2 frost deposit in autumn to winter time. And mostly covers the H2O frost.

Xie et al. 2006
Proposed conception model

Titus, 2003
MOC/MGS wide-angle images of the Korolev crater
Sublimation of H$_2$O frost and even old water ice. This infers the water ice is not so thick.
TES albedo and temperature of the Korolev crater

Armstrong et al. 2005

North plain, outside of the crater

Crater Interior
80% infill

Garvin et al. 2000
Water frost sublimation (small grain size to larger grain size)

10% aerosols in atmosphere decrease to 7% aerosols

Vincendon et al. 2006
In conclusion

- UTSA Mars program just started,
- Got some preliminary results,
- Still a lot of works to do,
- Need your encouragements and supports!

Thanks for your attentions!