Excitations of the Earth and Mars’ Variable Rotations by Surficial Fluids

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Outline

- Earth’s variable rotation
  Differences between NCEP/NCAR and ECMWF atmospheric excitation functions
- Atmospheric excitation of Mars’ rotation
  Mars’ semidiurnal LOD amplitude and the dust cycles during the Martian Years 24-31
- Summary and discussion
Earth rotation and Geophysical excitation function

Earth rotation vector (3-Dimensional)

- LOD change (Axial component, $m_3$)
- Polar motion (Equatorial components, $\mathbf{m} = m_1 + im_2$)

Geophysical excitation function

- Axial term
- Equatorial terms
Atmospheric activity is the most important source for exciting the Earth’s short-period variations.

Atmospheric excitation function:

- **Wind term** (due to atmospheric wind) ➞ dominant source to LOD Change
- **Pressure Term** (due to change of air pressure) ➞ main source to Polar motion
The AEF is archived and updated in IERS SBA website.
Atmospheric Circulations

Atmospheric GCM

US: NCEP/NCAR
Europe: ECMWF
JMA: JMA
China: LASG
How large are **Differences** between NCEP/NCAR and ECMWF?

NCEP/NCAR  vs  ECMWF

**Temporal resolution**: 6 hours

**Spatial resolution**

- NCEP/NCAR: $2.5^\circ \times 2.5^\circ$
- ECMWF: $0.75^\circ \times 0.75^\circ$
Pressure field: Similar

- **AEF Differences:** ≤3%
- **AEF of ECMWF correlates slightly better with Earth rotation than that of NCEP/NCAR**

Wind field

```
17 levels
10 hPa
20 hPa
30 hPa
850 hPa
925 hPa
1000 hPa

10-1 hPa

37 levels
1 hPa
2 hPa
3 hPa
5 hPa
7 hPa
10 hPa
20 hPa
30 hPa
850 hPa
875 hPa
900 hPa
925 hPa
950 hPa
975 hPa
1000 hPa
```
Earth vs. Mars

“The Blue Marble”

LOD: 86,400 seconds
Axial inclination: 23.5 degrees

“The Red Planet”

LOD: 88,775 seconds
Axial inclination: 25.2 degrees

About half diameter of Earth

Rotational period and seasonal cycles are similar.
Earth's meridional circulation is more complex than Mars’.

Karatekin et al., 2011
Dust storms on the Earth (Scale: Regional)
Global dust storms (GDSs) on Mars (Scale: Global)

Unique meteorological events in the solar system
Occur during the southern summer, when the planet is near perihelion;
Happen irregularly about every 3 Martian years, usually last 6 months.
What cause Mars’ rotational variation?

- Change of atmospheric circulation
- Change of surface pressure
  *Seasonal change up to 30%*

Mars’ Viking Lander

Mars’ rover “Curiosity”

http://pds.jpl.nasa.gov
What can cause Mars’ rotational variation?

- Exchange of $CO_2$ mass between the atmosphere and the polar caps

**Winter**

$CO_2$ atmosphere

$\sim 25\%$ Martian atmosphere freeze

Polar ice caps

**Summer**

$CO_2$ atmosphere

sublime

Polar ice caps
Motivation

- Mars’ rotational rate, or equivalently its length-of-day (LOD), varies slightly due to global atmospheric changes.

- The atmospheric dust cycle is considered to be one key process impacting the Mars’ atmosphere.

- Lewis and Barker (2005) demonstrated the close link of the semidiurnal tidal amplitude with the atmospheric dust content.

- In consideration of tidal effects in the Mars’ variable rotation, could possible connection exist between the Mars’ semidiurnal LOD amplitude variation and atmospheric dust cycles?
employ a new GCM, with many improvements
new dust radioactive properties,
 improved clouds microphysics, CO₂ cycle, convective boundary layer, etc.

present eight realistic scenarios of Martian Years (MYs) 24-31,
 rather than characteristic scenarios in previous versions

Data:

Surface pressure & Surface density of ice
Wind & Dust mass mixing ratio (30 levels: 0.0045 ~ 108.2992 km)
LMD Martian Climate Database (MCD) (version 5)

Data:

Temporal resolution:
12 times a Martian day for each of 12 Martian months per Martian year, representing annual/semiannual and diurnal/semidiurnal cycles.

Spatial resolution:
Grids (5.625° x 3.75° long.-lat.)

Wind & Dust

30 levels

108.2992 km
101.2992 km
94.2992 km
87.2992 km
80.2992 km
17.9625 km
14.5312 km
11.4921 km
8.0748 km
0.3977 km
0.1870 km
0.0748 km
0.0235 km
0.0045 km

5.625° × 3.75°
Pattern of wind: Meridional cells flowing from one longitude to another.

Mean horizontal wind over 187 m altitude at hour 12 of a Martian day in “month” 1 (unit in m/s) of the Martian Year 29 (MY29).
(a): Dichotomy in air pressure between northern and southern hemispheres. Highest in Hellas Planitia (42S, 71E), lowest in Olympus Mons (19N 134W).

(b): Most of ice appears in north polar areas in month 1; it varies from month to month due to seasonal CO$_2$ sublimation/condensation.

(a, b) Surface pressure (unit in Pa) and surface density of ice (unit in kg/m$^2$) at hour 12 of a Martian day in month 1 of MY 29.
• Dust is mainly distributed in a belt (50S ~50N), more dust on basins and less dust on mountain.
• More dust are seen in MYs 25 and 28 during global dust storm events.

Latitude-longitude distributions of dust mass mixing ratio during MYs 24-31. A yearly mean and a vertically weighted mean are employed. For a mass element, the ratio of its mass over the total mass is designated as the weight.
\[ \frac{\Delta LOD}{LOD_0} = \chi \]

\[
\chi = \frac{R^3 k_r}{g \Omega C} \left[(1 + k_2')\Omega R \int \int (p_s + q_{ice g}) \cos^3 \phi d\lambda d\phi + \int \int \int u \cos^2 \phi dpd\lambda d\phi \right]
\]

- \( LOD_0 \): a standard LOD;
- \( R \) and \( \Omega \): mean radius and angular velocity;
- \( C \): principal moment of inertia; \( g \): gravitational acceleration;
- \( \lambda \) and \( \phi \): longitude and latitude; \( k_2' \): second order load Love number;
- \( k_r \): rotational Love number;

**atmospheric dust cycle index (ADCI):**

Globally weighted mean of the dust mass mixing ratio
• Semidiurnal variation is predominant;
• It varies much more strongly in second half of the year than that in first half.

Daily variation pattern of atmospheric excitation functions during months 1-12 of MY 29. Unit is $10^{-7}$. 
• Semidiurnal LOD amplitude changes seasonally and peaks in latter half of the year;
• Strong interannual GDS signals in MYs 25 and 28;
• ADCI and semidiurnal LOD amplitude change in similar time-varying behavior.

(a) Amplitude of Semidiurnal LOD Variation

(b) Atmospheric Dust Cycle Index (ADCI)

(a) Amplitude of the semidiurnal LOD variation and (b) atmospheric dust cycle index (ADCI) during MYs 24-31.
The correlation coefficient (0.766) at zero time lag exceeds the threshold value of the 99% significance level.

**Cross-correlation function** between the ADCI and semidiurnal LOD amplitude variation at time lags ranging from -96 to 96 months.
- Semidiurnal LOD amplitude change and ADCI present similar time-varying wavelet spectral structures.
- In mature stages of global dust storms, relatively high values occurred synchronously.

Morlet wavelet time-frequency spectra of (a) semidiurnal LOD amplitude and (b) ADCI for MYs 24-31. Oscillatory signals are displayed by exhibiting the positive/negative phasing of amplitude undulations w.r.t time. Range of periods shown is from 0.2 to 2.8 Martian years.
Physical Explanation

Higher dust loadings in the atmosphere

\[ \downarrow \]

Stronger absorption of solar radiation

\[ \downarrow \]

Thermal tides are enhanced

\[ \downarrow \]

A large amount of angular momentum transfer between the global atmosphere and the solid planet below

\[ \downarrow \]

**Significant variations in Mars’ rotation**
Summary

- The semidiurnal LOD amplitude change and the atmospheric dust cycle index (ADCI) are found to be correlated at the 99% significance level.

- The semidiurnal LOD amplitude change and the ADCI present similar time-varying wavelet spectral structures.

  In mature stages of global dust storms, relatively high values occurred synchronously, ranging from a few months’ high frequency to seasonal and over one year’s lower frequency band.

- The close relation between the semidiurnal LOD amplitude variation and the ADCI reflects the strong coupling between the solid Mars and surficial atmosphere system, which relates primarily to the atmospheric tide.
## Discussions

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Much *known* -- *Earth’s* rotation  
Much *unknown* -- *Mars’* rotation
More accurate radio tracking data from Mars’ orbiters and landers

Assimilations of more observations of meteorological variables

Improve determination of Mars’ variable rotation

Reduced modeling uncertainties of Mars’ atmosphere

Understand more about Mars’ rotation and influences of Martian atmosphere
Thank you!