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-Dimentional)

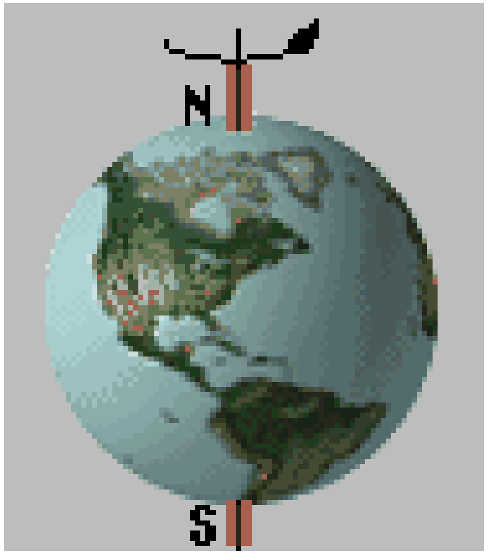
- **LOD change (Axial component, m_3)**
- **Polar motion (Equatorial components, $\vec{m} = m_1 + im_2$)**

Geophysical excitation function

- **Axial term**
- **Equatorial terms**

Atmospheric excitation of Earth's variable rotation

Atmospheric activity is the most important source for exciting the Earth's short-period variations.



Atmospheric excitation function

- Wind term (due to atmospheric wind)
  $\Rightarrow$ *dominant source to LOD Change*
- Pressure Term (due to change of air pressure)
  $\Rightarrow$ *main source to Polar motion*

The AEF is archived and updated in IERS SBA website.

http://www.aer.com/science-research/earth/earth-mass-ε | Special Bureau for the At...

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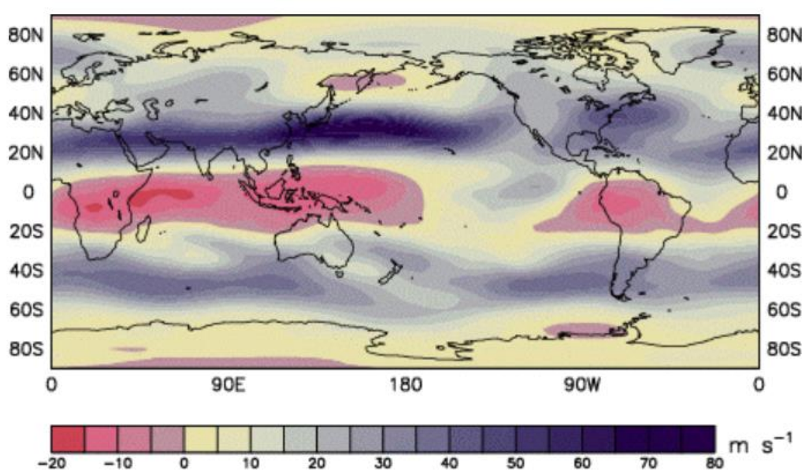
Special Bureau for the Atmosphere

Changes in the angular momentum of the atmosphere, oceans, and the solid Earth are linked, while the mass balance between the ocean and atmosphere is related to the overall gravity field of the Earth.

Atmospheric Angular Momentum and Length of Day

Within the Global Geophysical Fluids Center of the International Earth Rotation and Reference Systems Service (IERS) the Special Bureau for the Atmosphere (SBA) is a joint effort of Atmospheric and Environmental Research (AER) and the U.S. National Centers for Environmental Prediction (NCEP) to provide atmospheric data relevant to the study of the Earth's variable rotation. The SBA is a successor to the Sub-bureau for Atmospheric Angular Momentum, operating within the IERS since 1989.

Zonal Wind



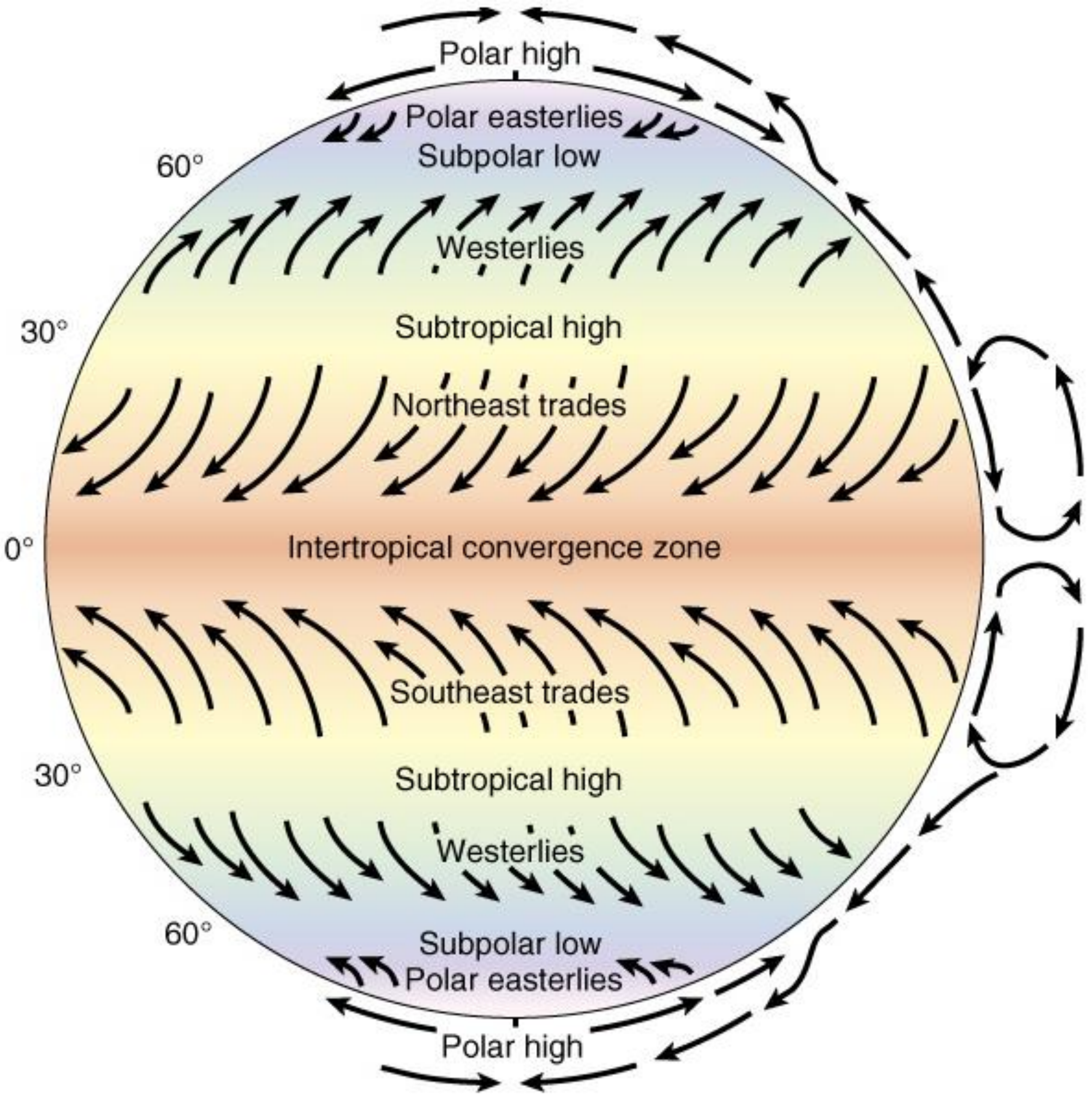
Zonal wind field near jet stream levels (sampled here for January 1997), the primary contributor to atmospheric angular momentum

RESOURCE LIBRARY

Revised atmospheric excitation function series related to Earth's variable rotation under consideration of surface topography

The Sub-bureau for Atmospheric Angular Momentum of the International Earth Rotation Service: A Meteorological Data Center with Geodetic Applications

Atmospheric Circulations



Atmospheric GCM

US：NCEP/NCAR

Europe：ECMWF

JMA：JMA

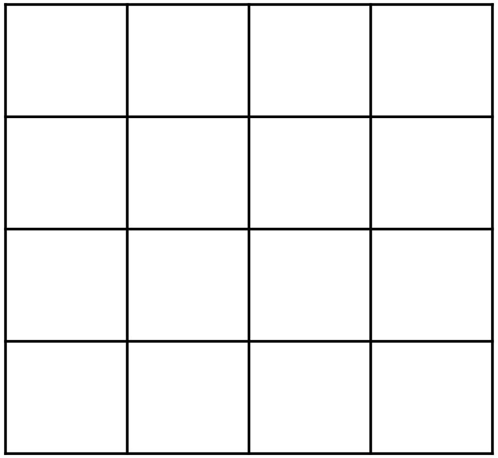
China：LASG

How large are Differences between NCEP/NCAR and ECMWF?

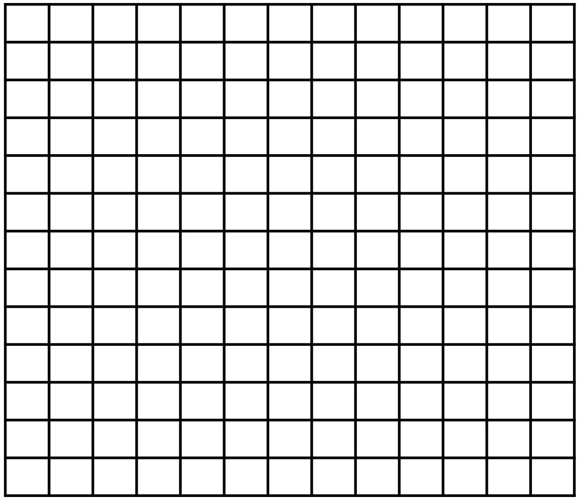
NCEP/NCAR *vs* ECMWF

Temporal resolution：6 hours

Spatial resolution



$2.5^\circ \times 2.5^\circ$



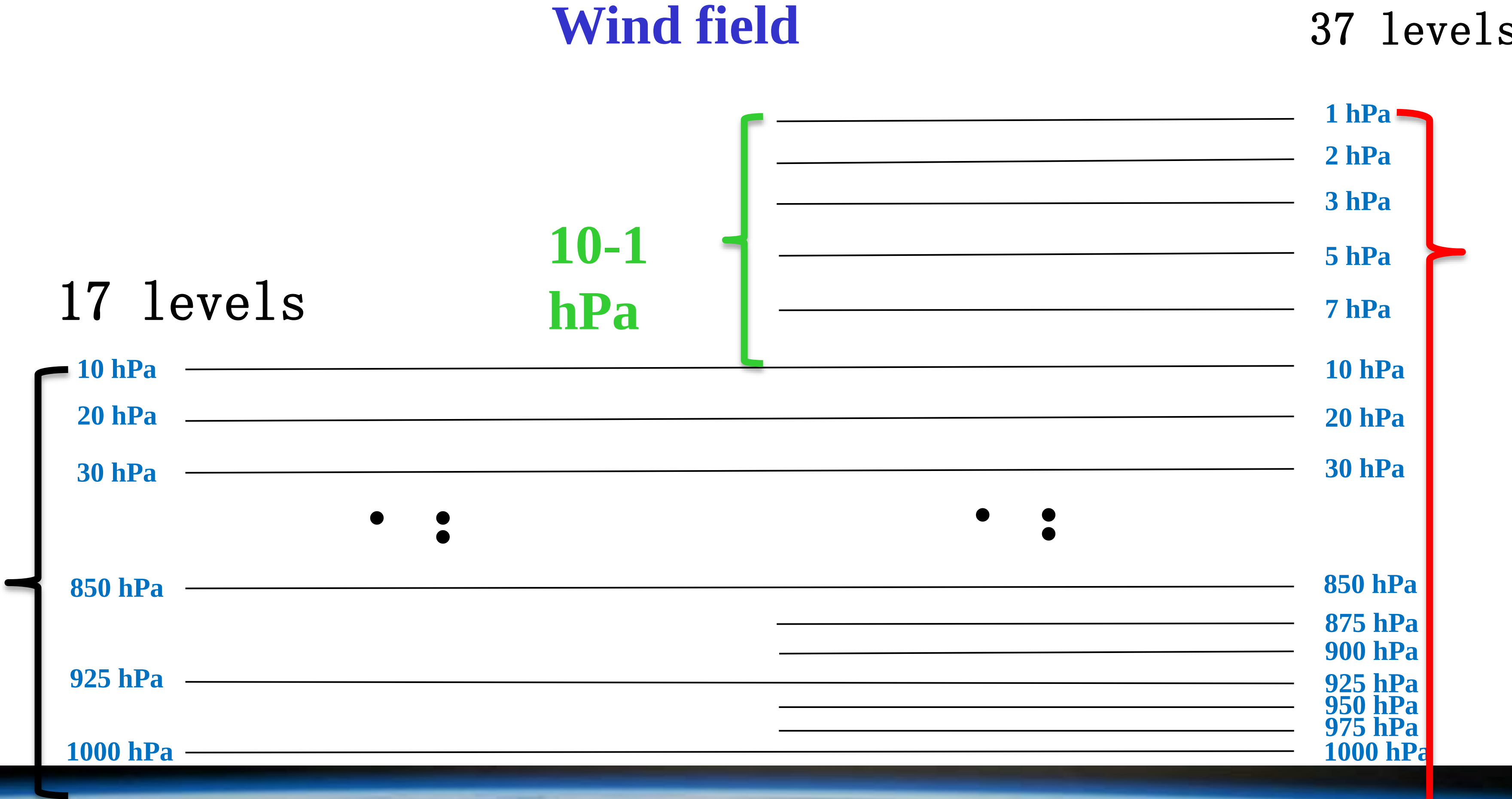
$0.75^\circ \times 0.75^\circ$

NCEP/NCAR *vs* ECMWF

Pressure field: Similar

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

Wind field



Earth vs. Mars

"The Blue Marble"

"The Red Planet"

About half diameter of Earth

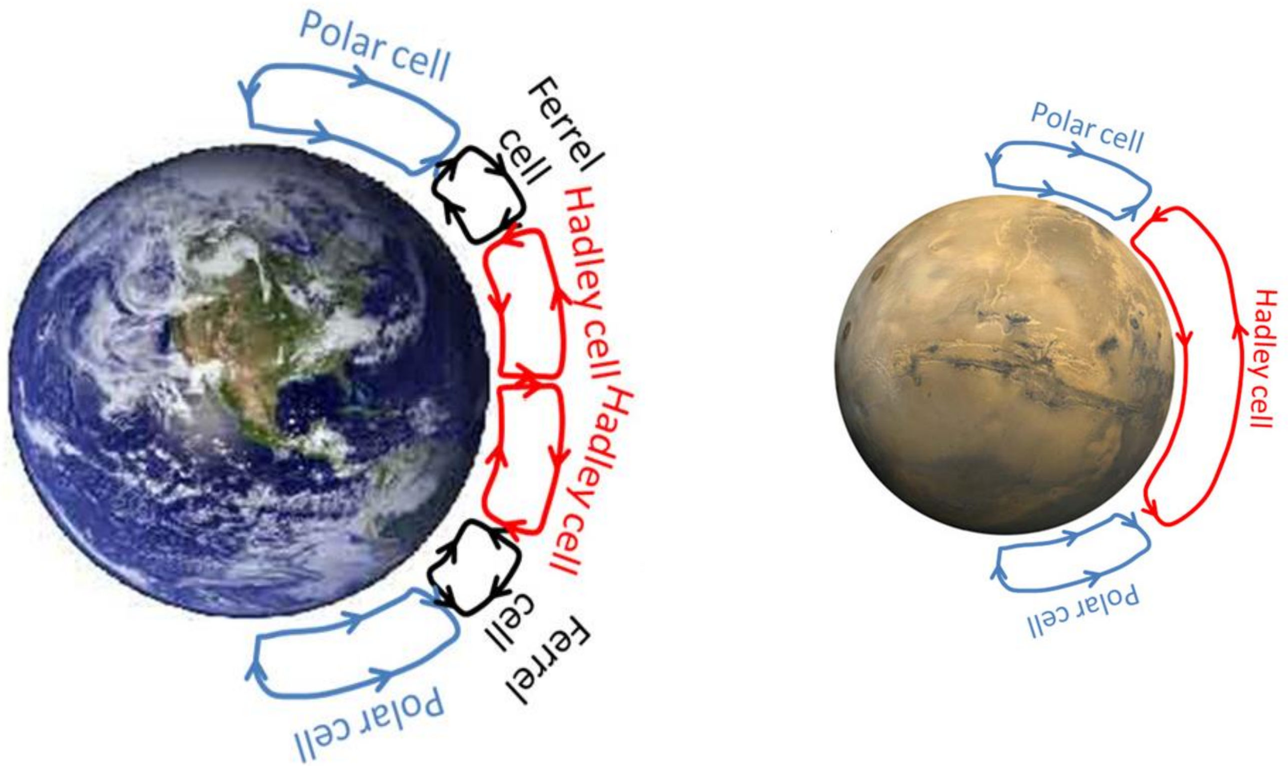
LOD： 86,400 seconds
Axial inclination： 23.5 degrees

LOD： 88,775 seconds
Axial inclination： 25.2 degrees

Rotational period and seasonal cycles are similar.

Earth vs. Mars

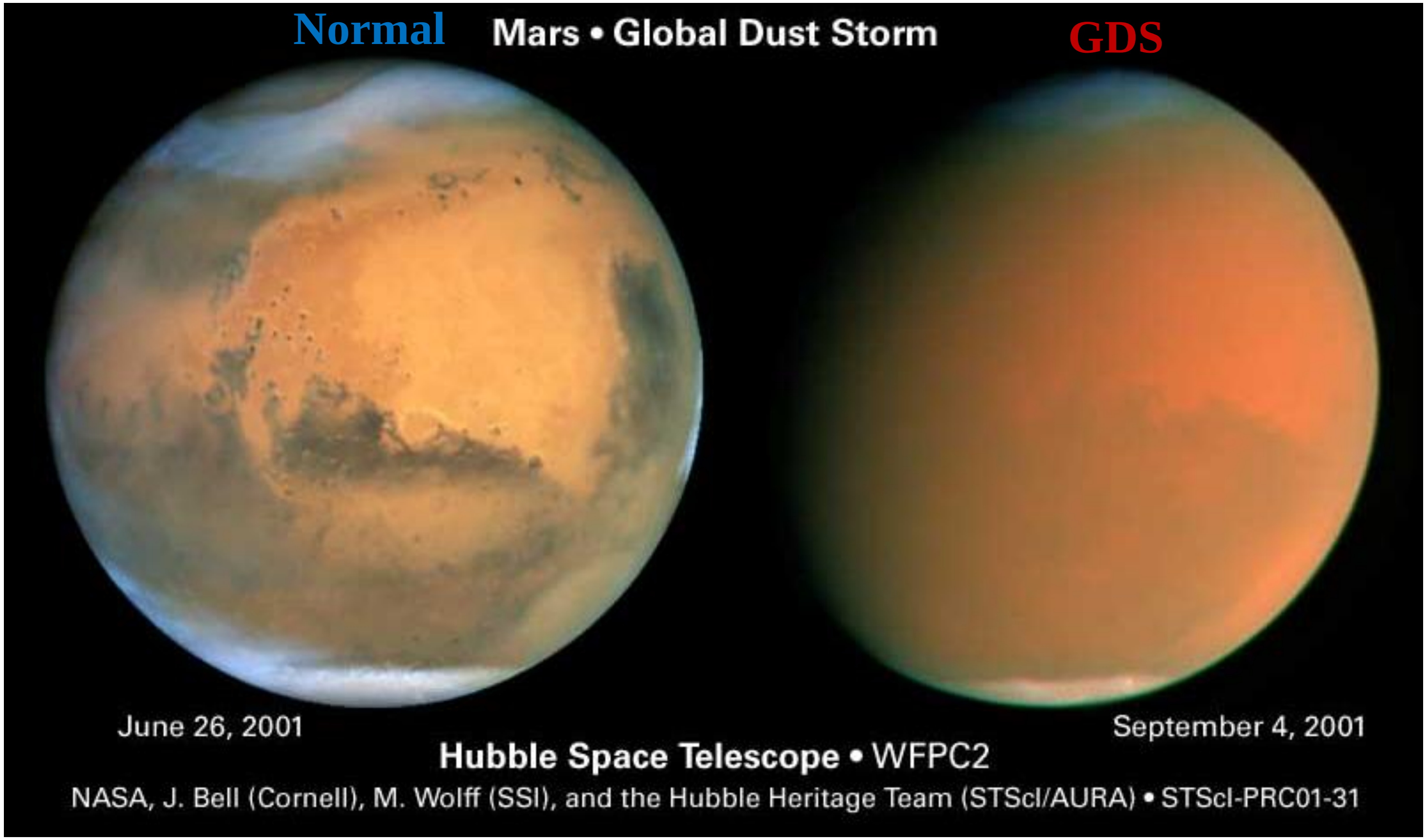
Earth's meridional circulation is more complex than Mars'.



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;

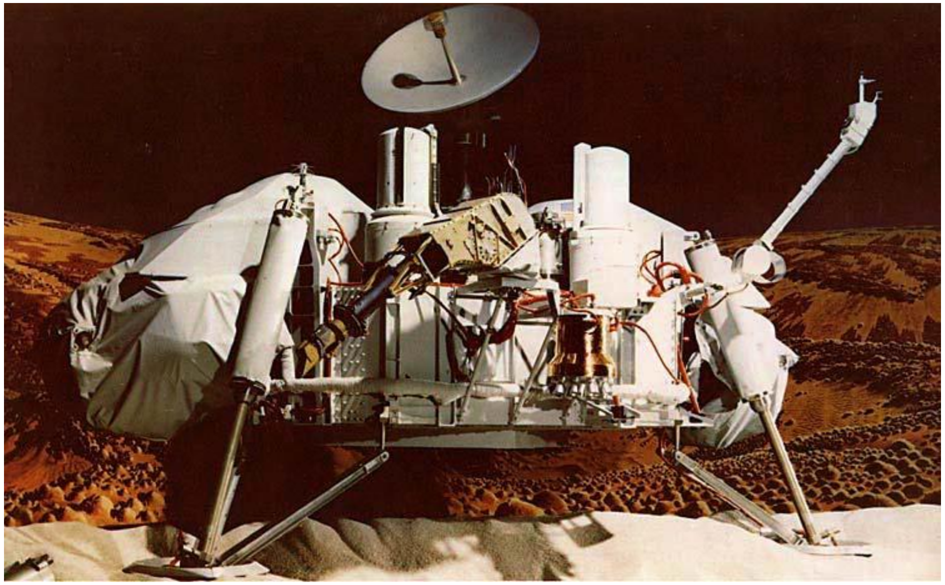
Happen irregularly about every 3 Martian years, usually last 6 months.

What cause Mars' rotational variation?

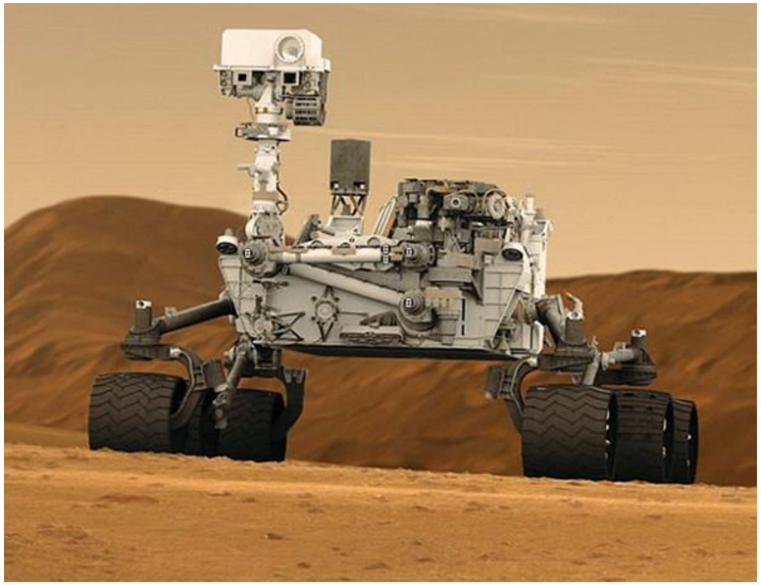
- **Change of atmospheric circulation**

- **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

freeze ↓

Polar ice caps

~25%
Martian atmosphere

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?

LMD Martian Climate Database (MCD) (version 5)

- employ a new GCM, with many improvements
  new dust radioactive properties,
  improved clouds microphysics, CO_2 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

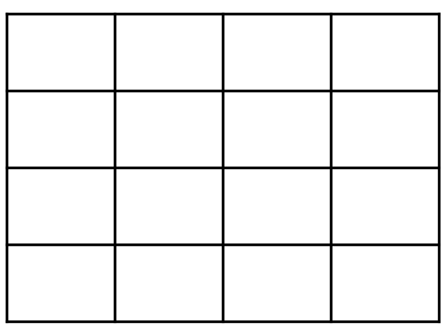
  Wind & Dust mass mixing ratio (30 levels: 0.0045 ~ 108.2992 km)

LMD Martian Climate Database (MCD) (version 5)

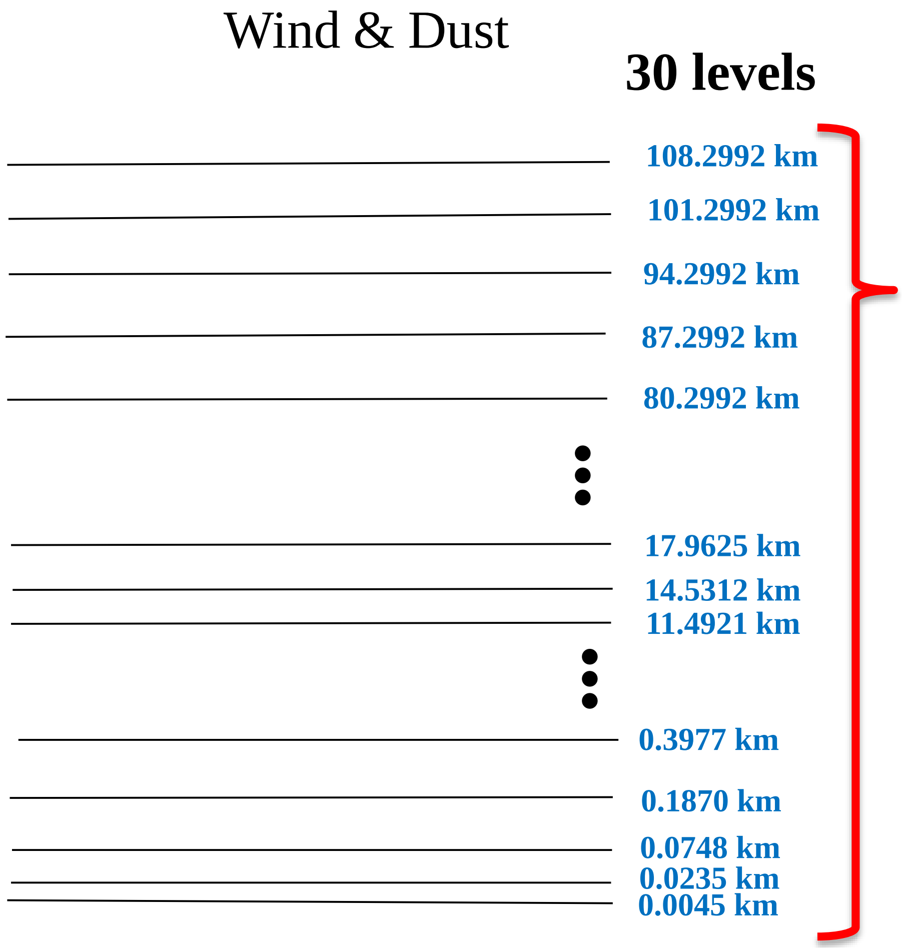
- **Data**:

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

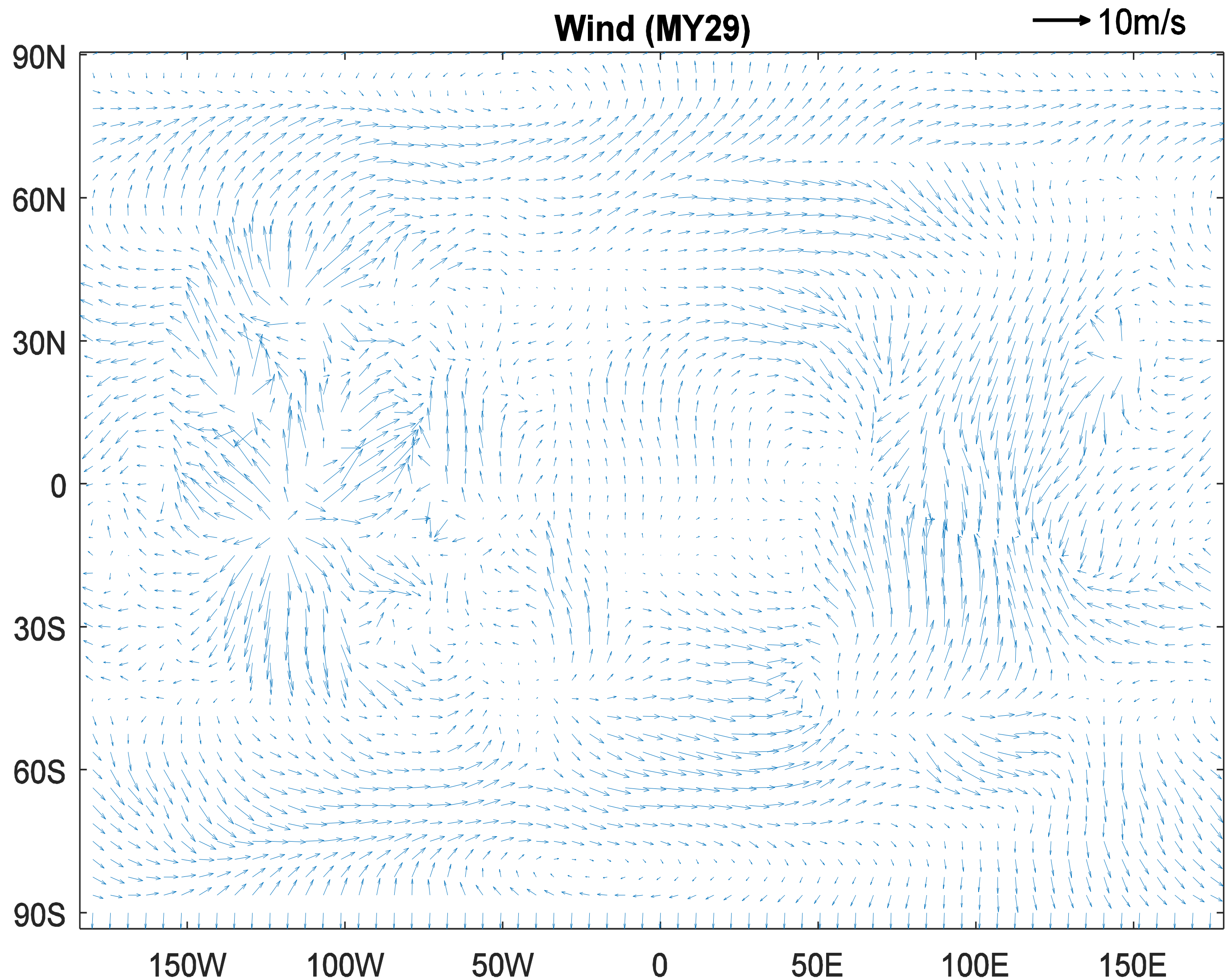
  Spatial resolution:
  Grids (5.625° x 3.75° long.-lat.)



$\mathbf{5.625^{\circ} \times 3.75^{\circ}}$

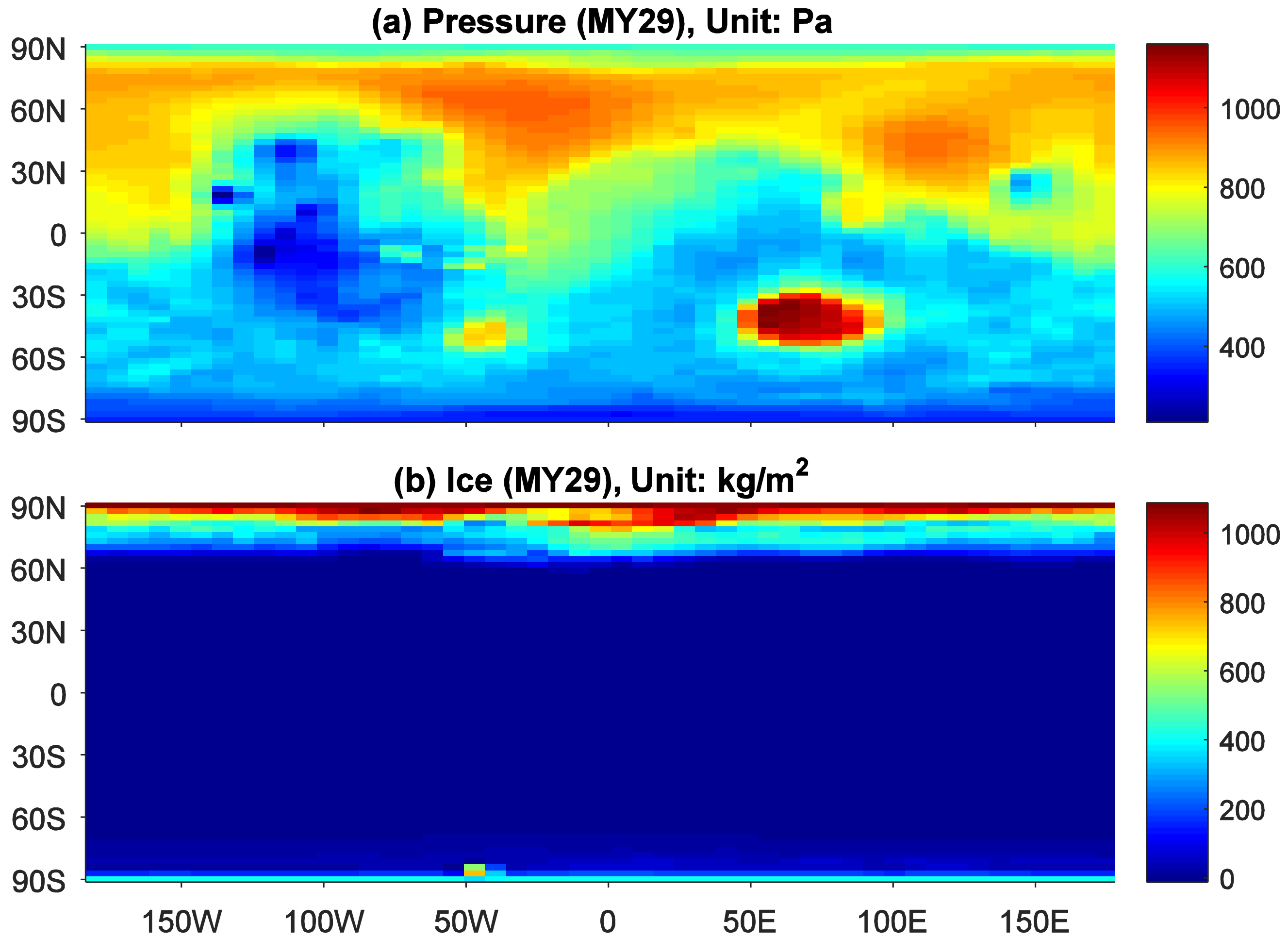


Pattern of wind: Meridional cells flowing from one longitude to another.



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).

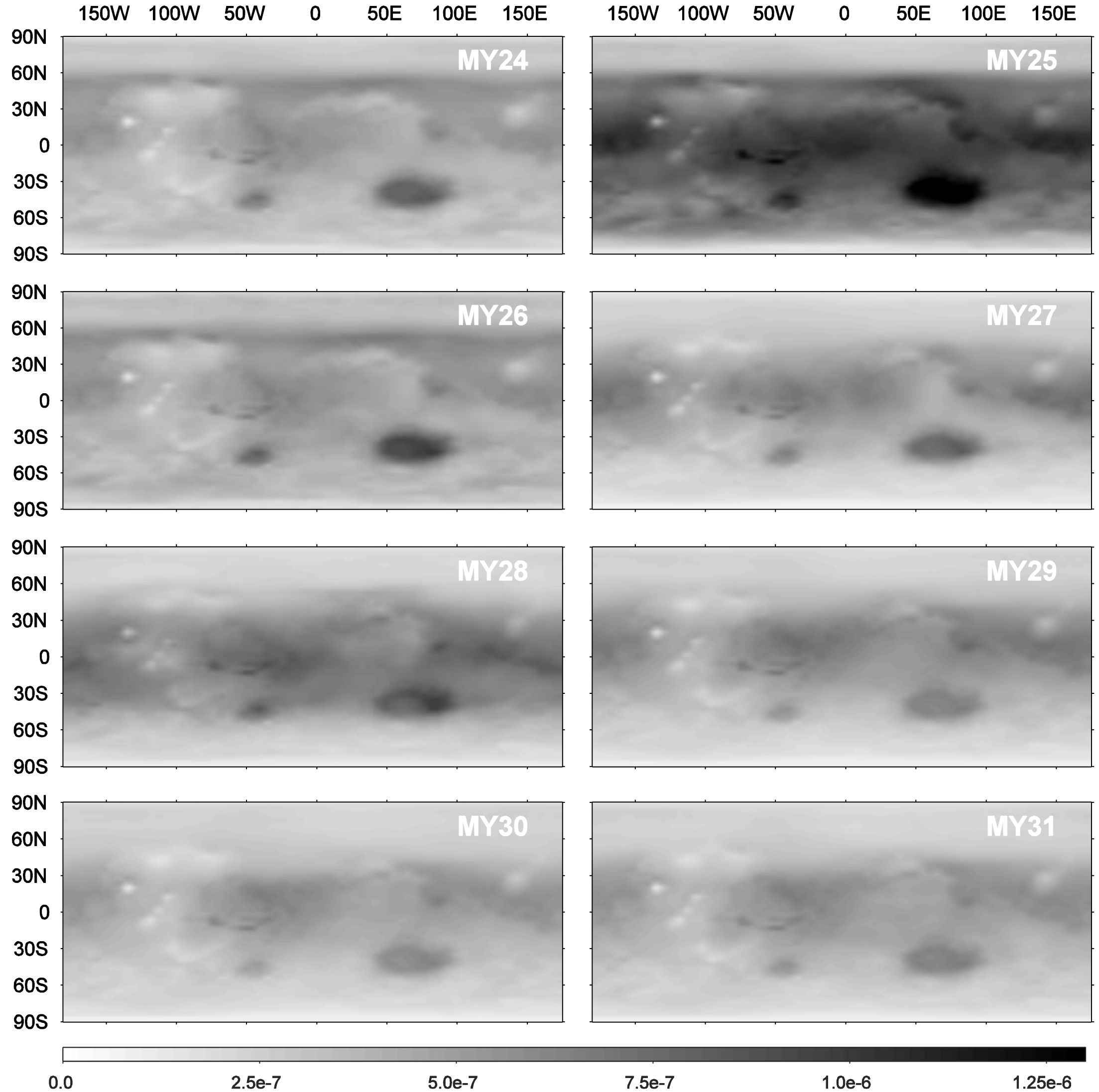
(a): Dichotomy in air pressure between northern and southern hemispheres.
Highest in Hellas Planitia (42S, 71E), lowest in Olympus Mons (19N 134W).



(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.

LOD, AEF & ADCI

small deviation in LOD

atmospheric excitation function (AEF)

$$\frac{\Delta LOD}{LOD_0} = \chi$$

AEF

surface pressure

zonal wind velocity

$$\chi = \frac{R^3 k_r}{g\Omega C}[(1+k_2')\Omega R\iint(p_s + q_{ice} g)\cos^3\varphi d\lambda d\varphi + \iiint u\cos^2\varphi \mathrm{dpd}\lambda \mathrm{d}\varphi]$$

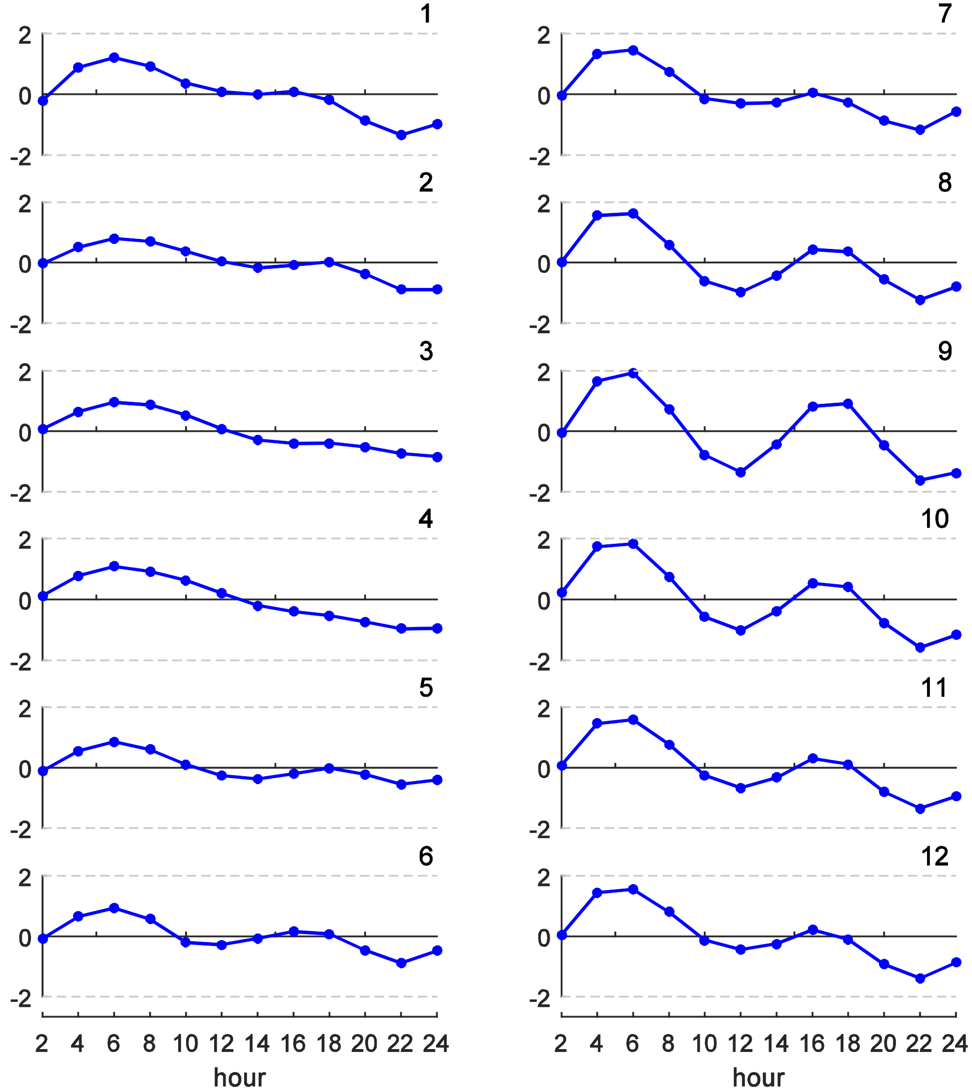
surface mass density of polar ice caps

LOD_0: a standard LOD;
R and Ω: mean radius and angular velocity;
C: principal moment of inertia; g: gravitational acceleration;
λ and φ: longitude and latitude; k_2': second order load Love number;
k_r: rotational Love number;

atmospheric dust cycle index (ADCI):

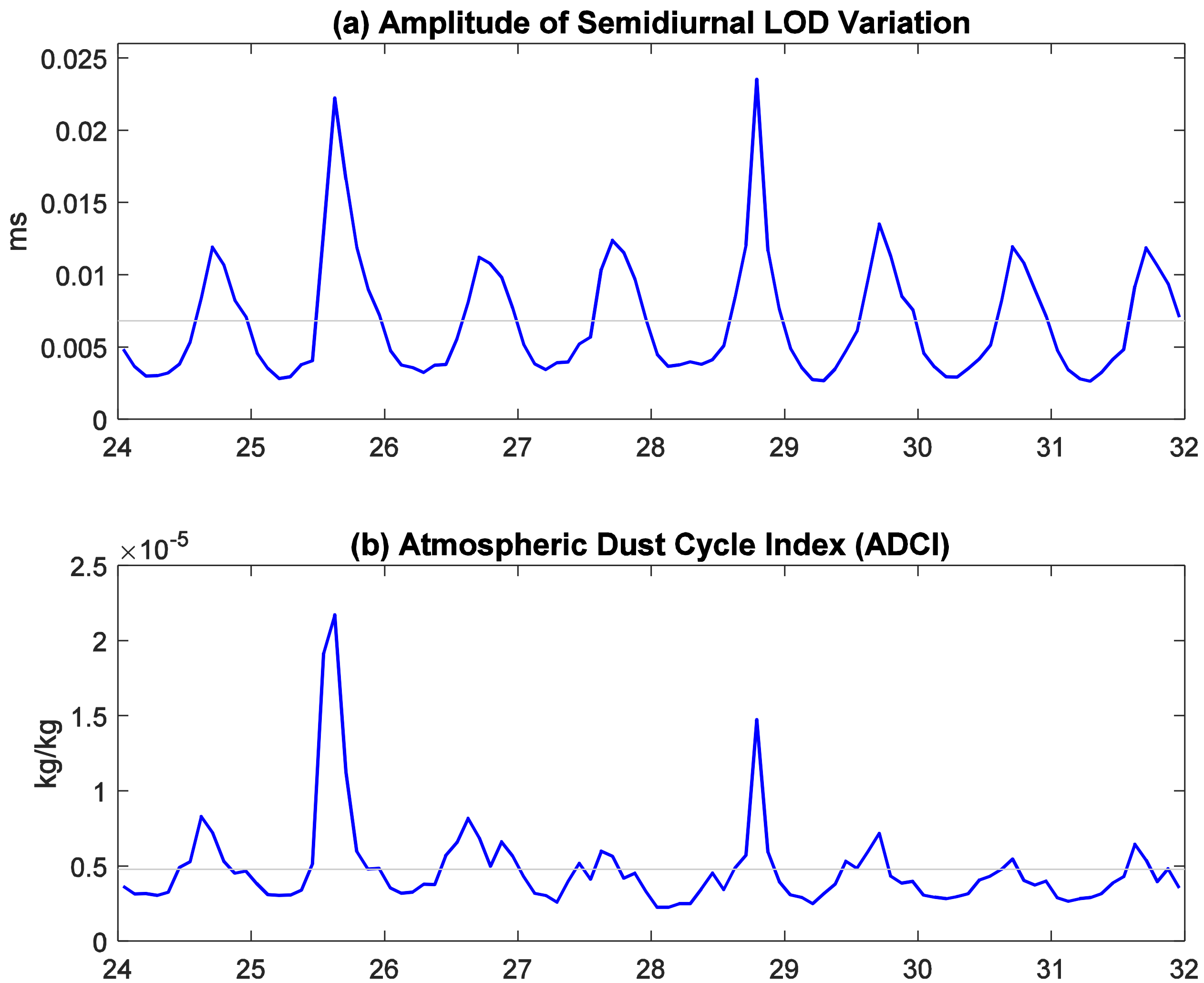
Globally weighted mean of the dust mass mixing ratio

- Semidiurnal variation is predominant;
- It varies much more strongly in second half of the year than that in first half.



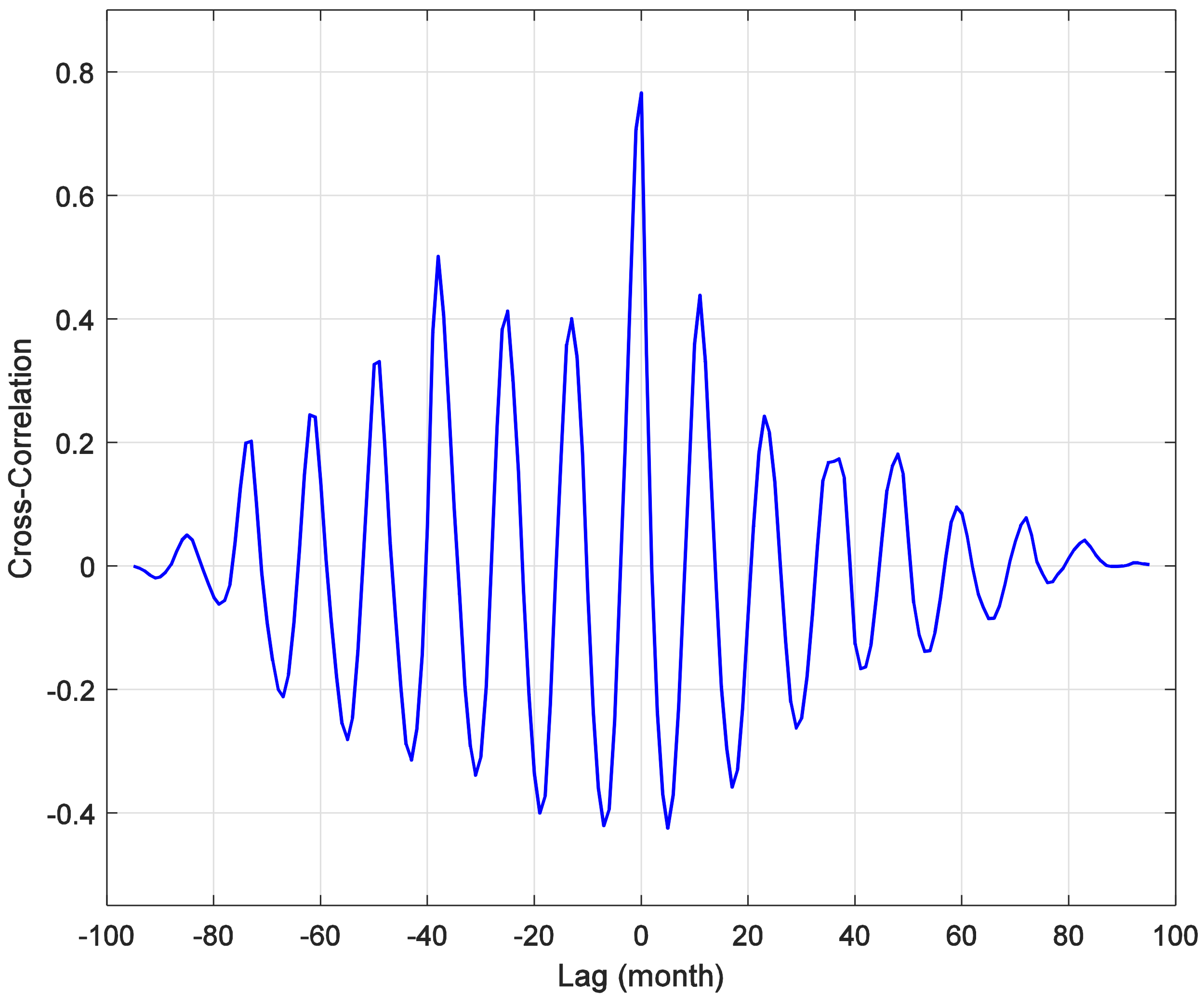
Daily variation pattern of atmospheric excitation functions during months 1-12 of MY 29. Unit is 10^{-7}.

- 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.



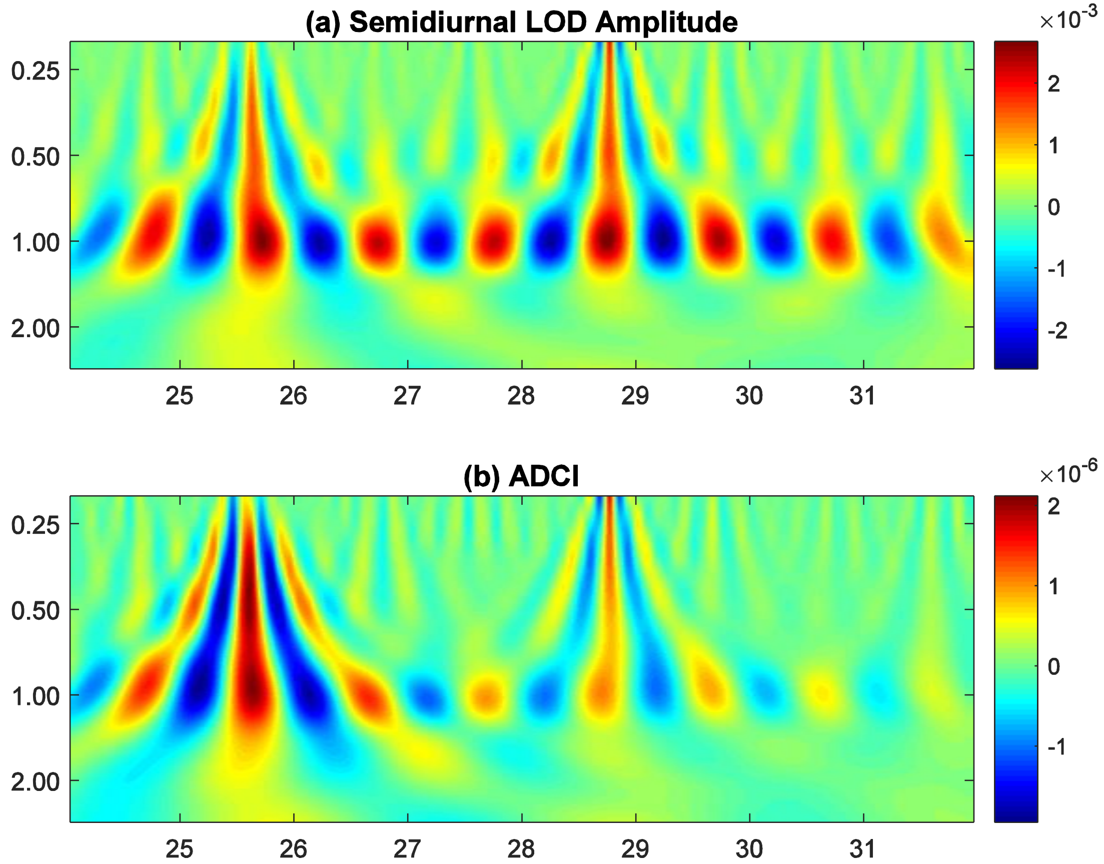
(a) **Amplitude of the semidiurnal LOD variation** and (b) **atmospheric dust cycle index (ADCI)** during MYs 24-31.

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

⇓

Stronger absorption of solar radiation

⇓

Thermal tides are enhanced

⇓

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

⇓

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

	Earth		Mars	
	Obs.	Modelling	Obs.	Modelling
Secular	√	√	?	
Decadal	√	√		
Interannual	√	√		
Seasonal	√	√	√	√
Subseasonal	√	√	?	
Diurnal/Semi-diurnal	√	√	?	√
Subdiurnal	√	√	?	

Much *known* -- Earth's rotation

Much *unknown* -- **Mars**' rotation

Discussions

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 Mar's atmosphere

Understand more about Mars' rotation and influences of Martian atmosphere

Thank you !