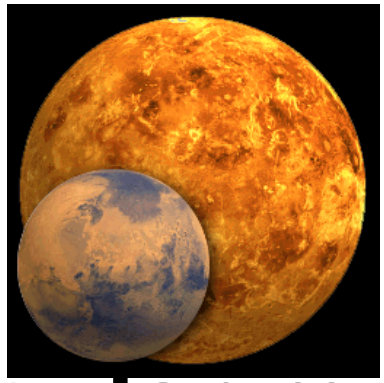


Atmospheric angular momentum variations of Earth, Mars and Venus.

V. Dehant[1], Ö. Karatekin[1], O. de Viron[2], S. Lambert[3], and T. Van Hoolst[1]

[1]Royal Observatory of Belgium

[2]IPGP &Universite Paris Diderot, France

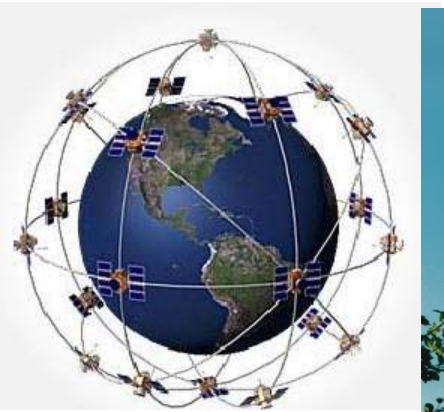
[3]Observatoire de Paris, France;

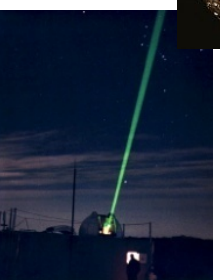
Wind turbines are inducing changes in the Earth rotation!

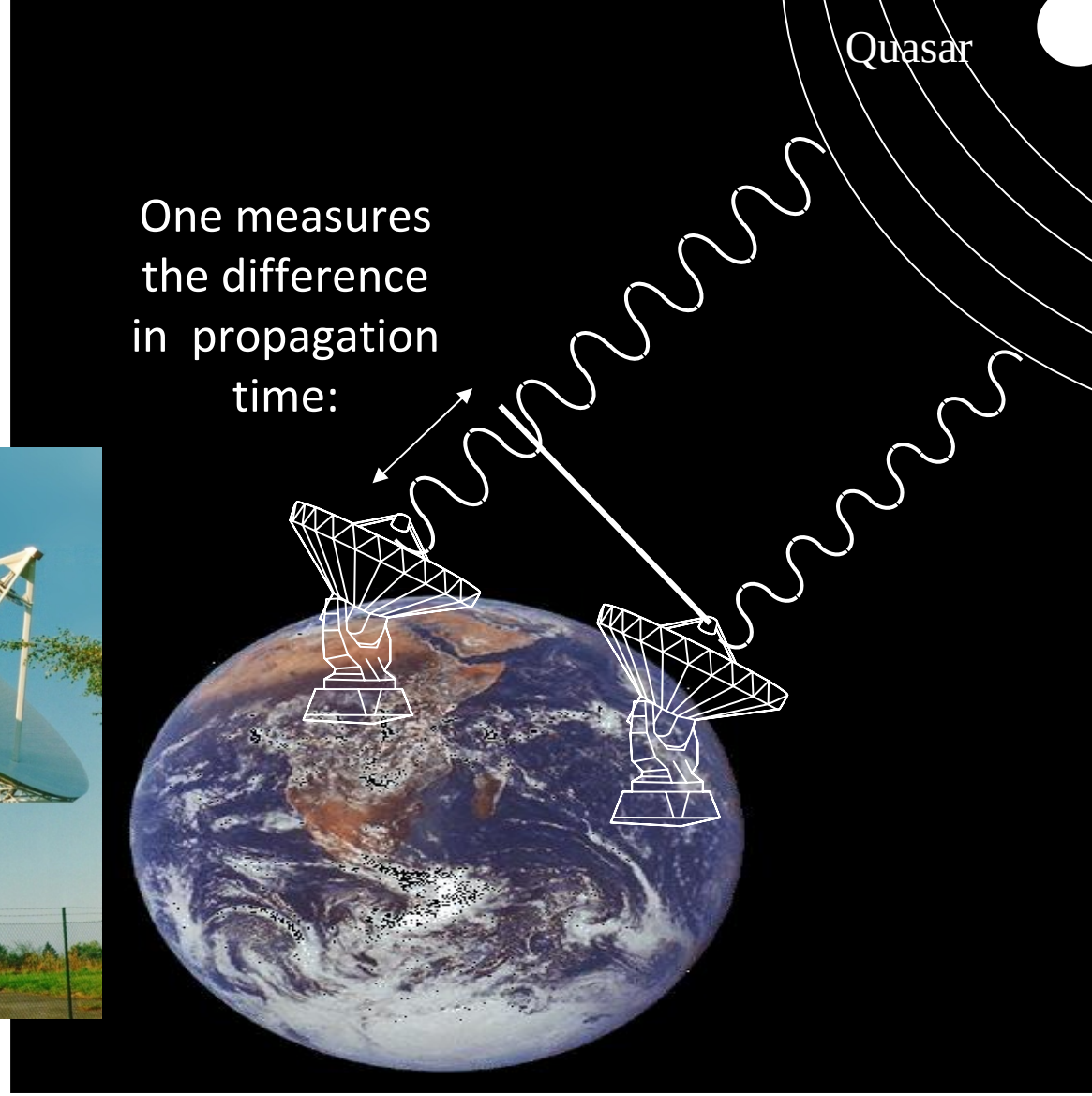
;-)

(in the TV news on April first!)

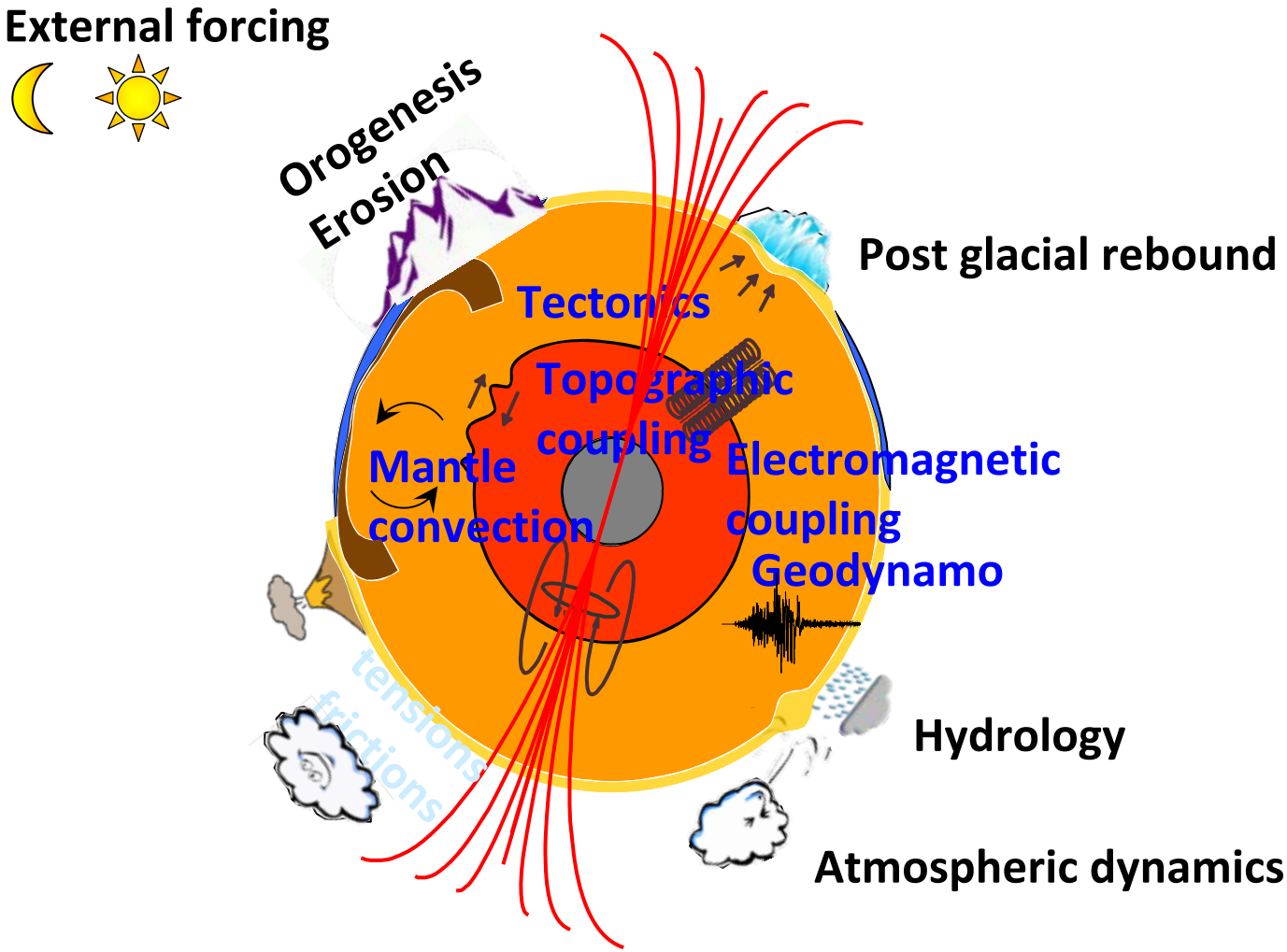
The Earth rotation is very sensitive to all sorts of phenomena. These phenomena are identified and seen in the observation (VLBI, GNSS, SLR, DORIS)



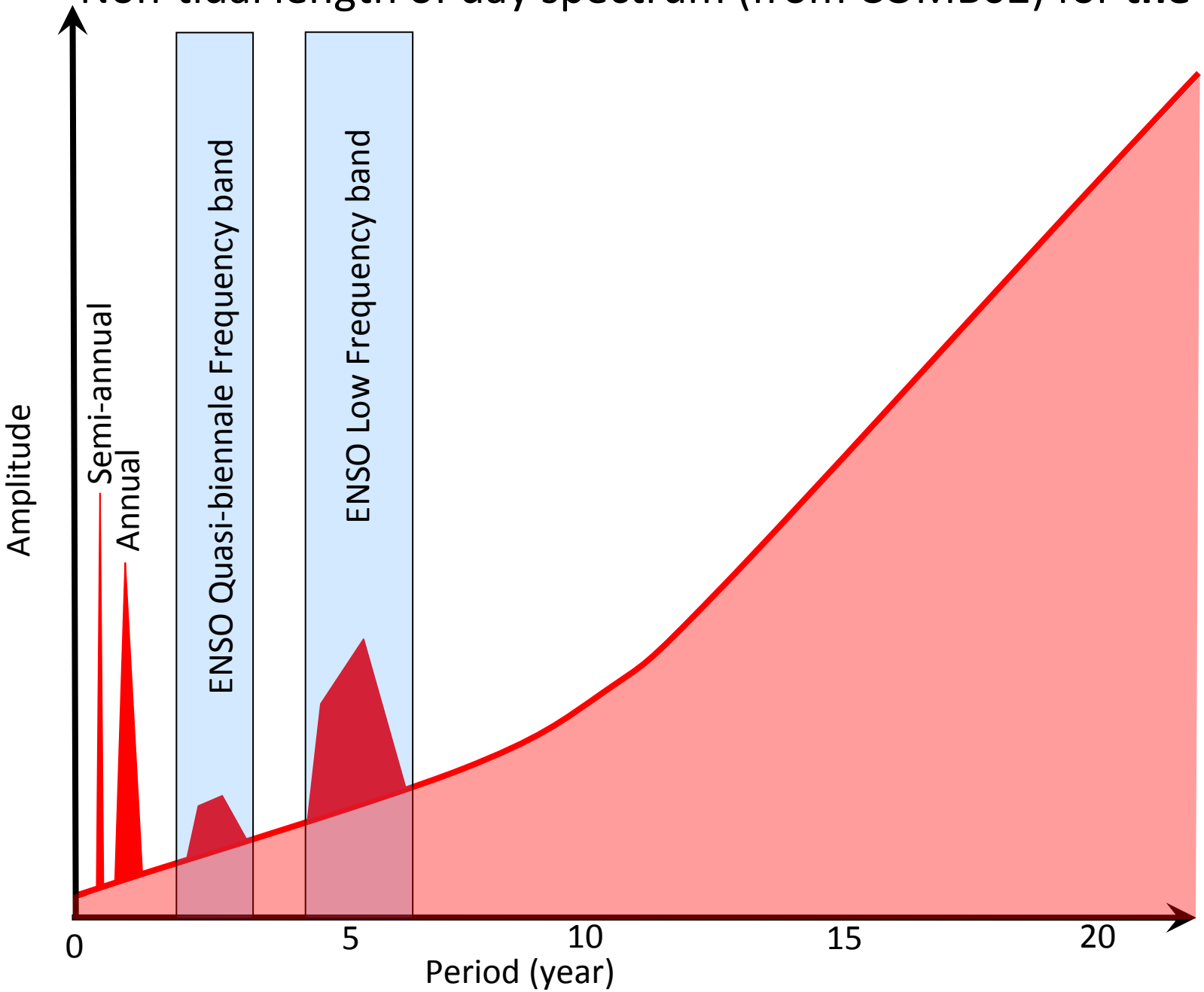


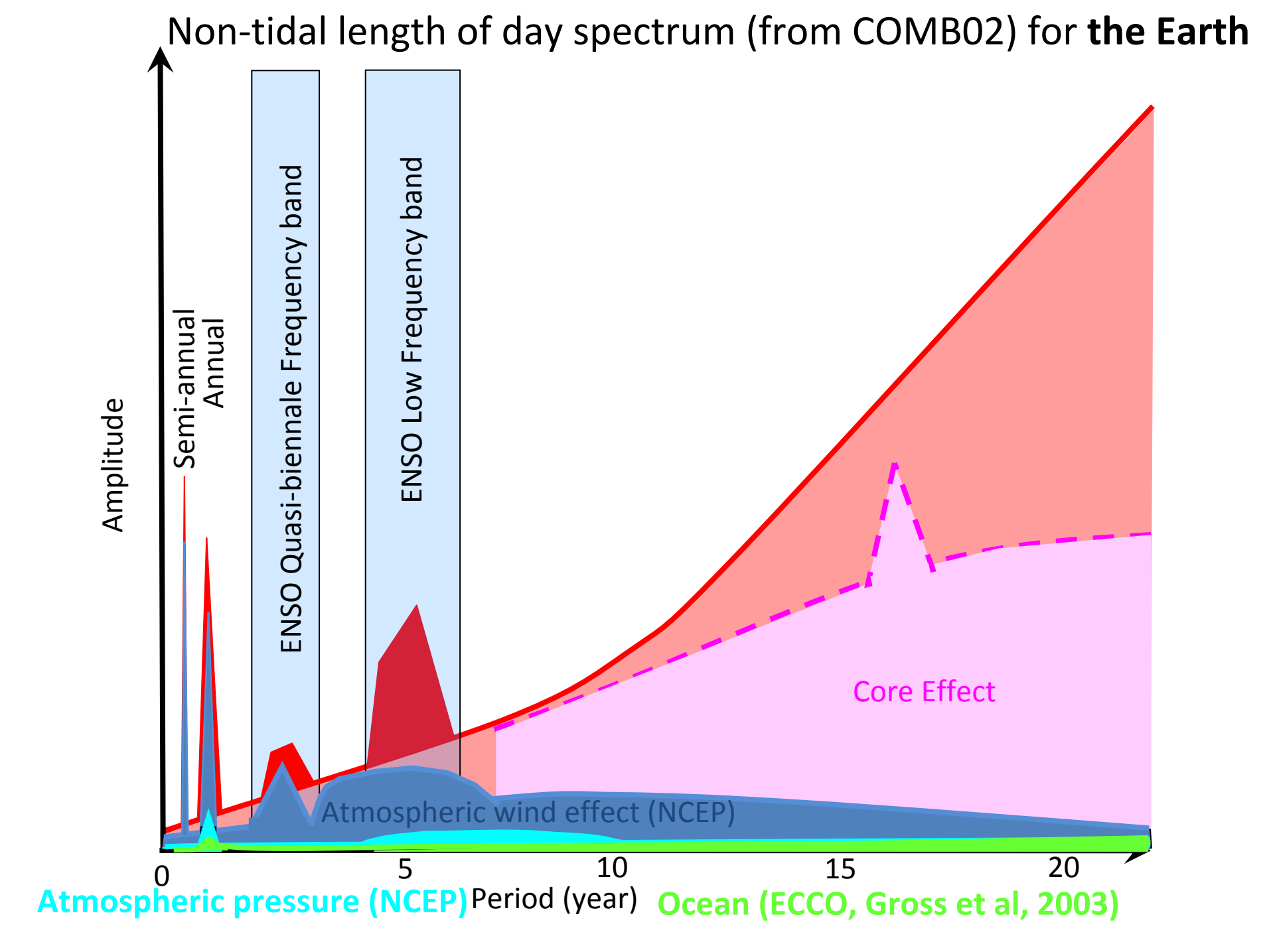


Introduction

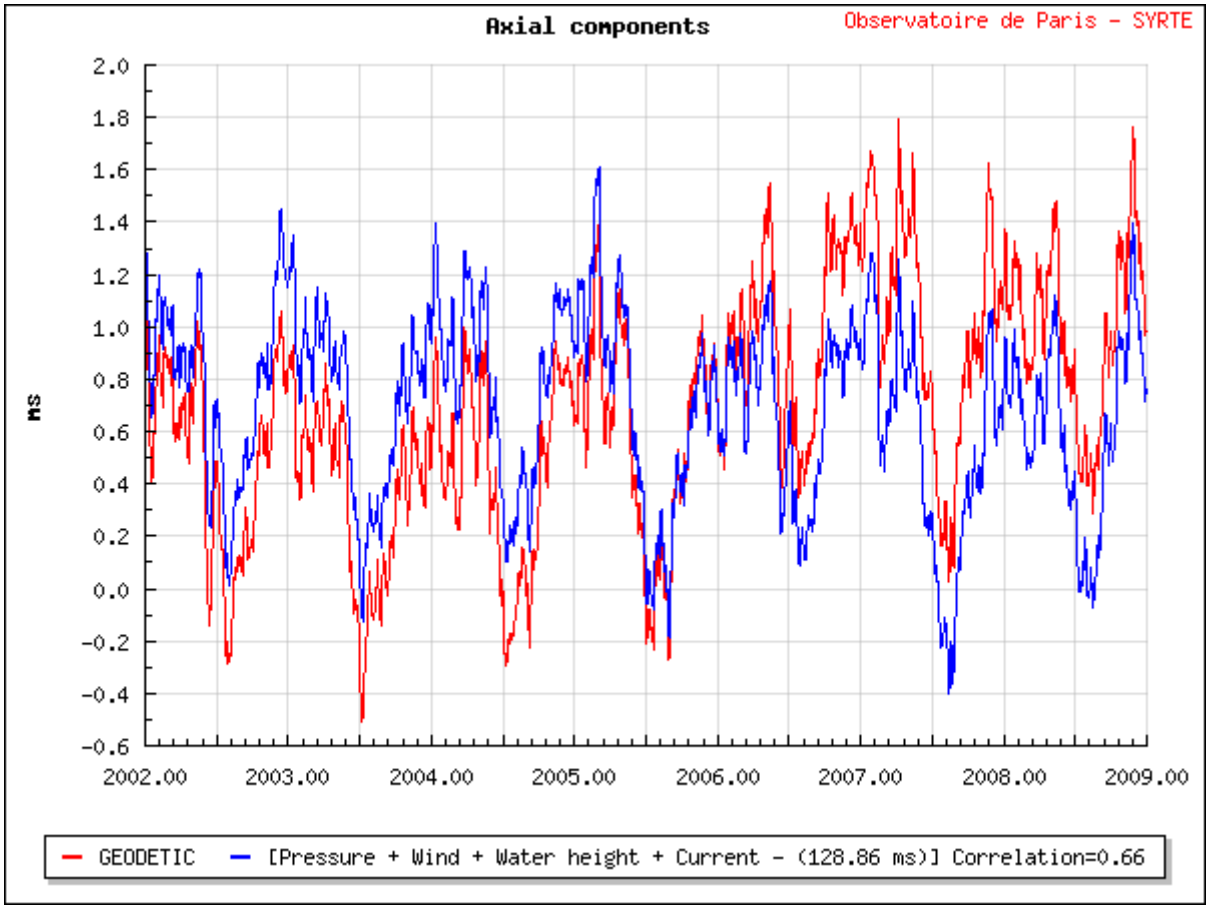


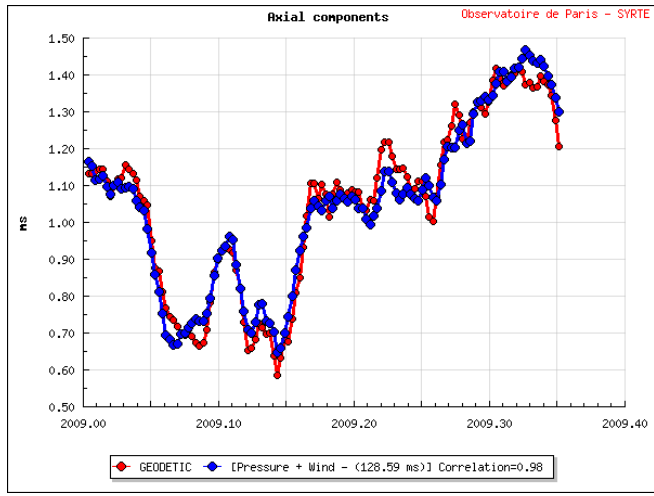
The rotation of the Earth constantly slows down and speeds up due to several factors


Non-tidal length of day spectrum (from COMB02) for **the Earth**
Amplitude
Semi-annual
Annual
ENSO Quasi-biennale Frequency band
ENSO Low Frequency band
0
5
10
15
20
Period (year)


Non-tidal length of day spectrum (from COMB02) for the Earth
Amplitude
Semi-annual
Annual
ENSO Quasi-biennale Frequency band
ENSO Low Frequency band
Core Effect
Atmospheric wind effect (NCEP)
0
5
10
15
20
Atmospheric pressure (NCEP)
Period (year)
Ocean (ECCO, Gross et al, 2003)

Comparison with Observations (Earth)





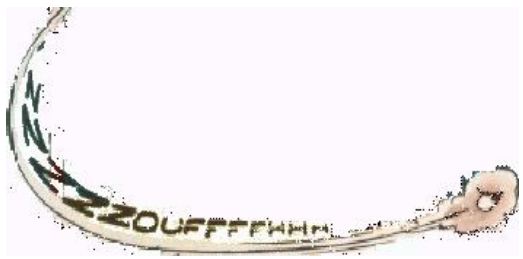
http://hpiers.obspm.fr/

Conservation of Angular Momentum

if total angular momentum of a planetary system is conserved, it follows that when the solid planet loses angular momentum (and the LOD increases), another reservoir of angular momentum must have gained.

solid planet

Atmosphere



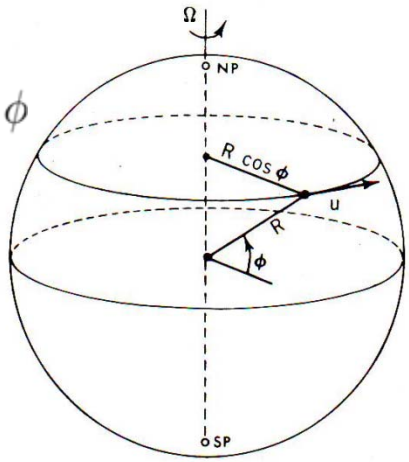
Ocean

To good approximation, the solid Earth and atmosphere/Ocean simply trade angular momentum with one another over a variety of time scales, ranging from days to years

Angular Momentum Exchange

Angular Momentum (AM) Approach:

$$H_{Atm} = \rho(u + \Omega R\cos\phi)R\cos\phi$$

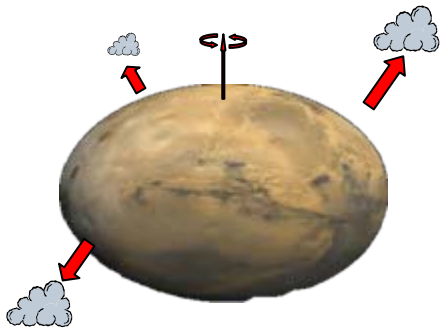


- *Matter (Pressure) term* : rigid rotation of the atmosphere with the solid planet
- *Motion term (Wind)* : relative angular momentum of the atmosphere

Torque Approach

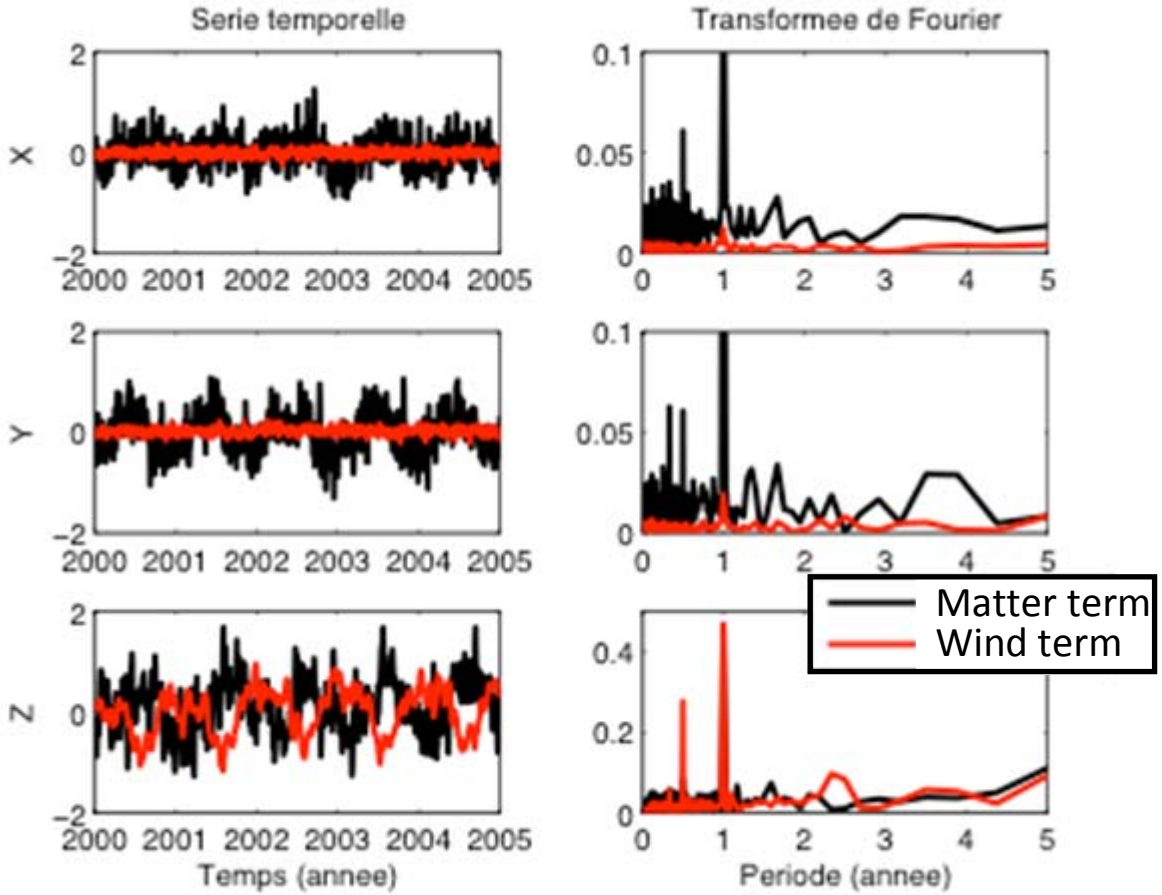
$$\frac{d\vec{H}}{dt} = \vec{\Gamma}_{pressure} + \vec{\Gamma}_{gravitation} + \vec{\Gamma}_{friction}$$

- *Pressure torque* is due to the action of a different surface pressure on the two sides of a Mountain.
- *Gravitational torque is* due to the gravitational interaction between the masses inside the planet and fluid layer.
- *Friction torque* associated with the relative motion of the fluid with respect to the surface



The AM approach has been shown more successful than the torque approach to estimate the effect of the fluid layer on the Earth's Rotation. The reason is that the AM approach is based on integration of well constrained quantities (large scale pressure and wind) over the globe whereas the torque approach is based on delicate computation from less known quantities (local pressure and friction drag). In the present study we will concentrate on **AM approach**.

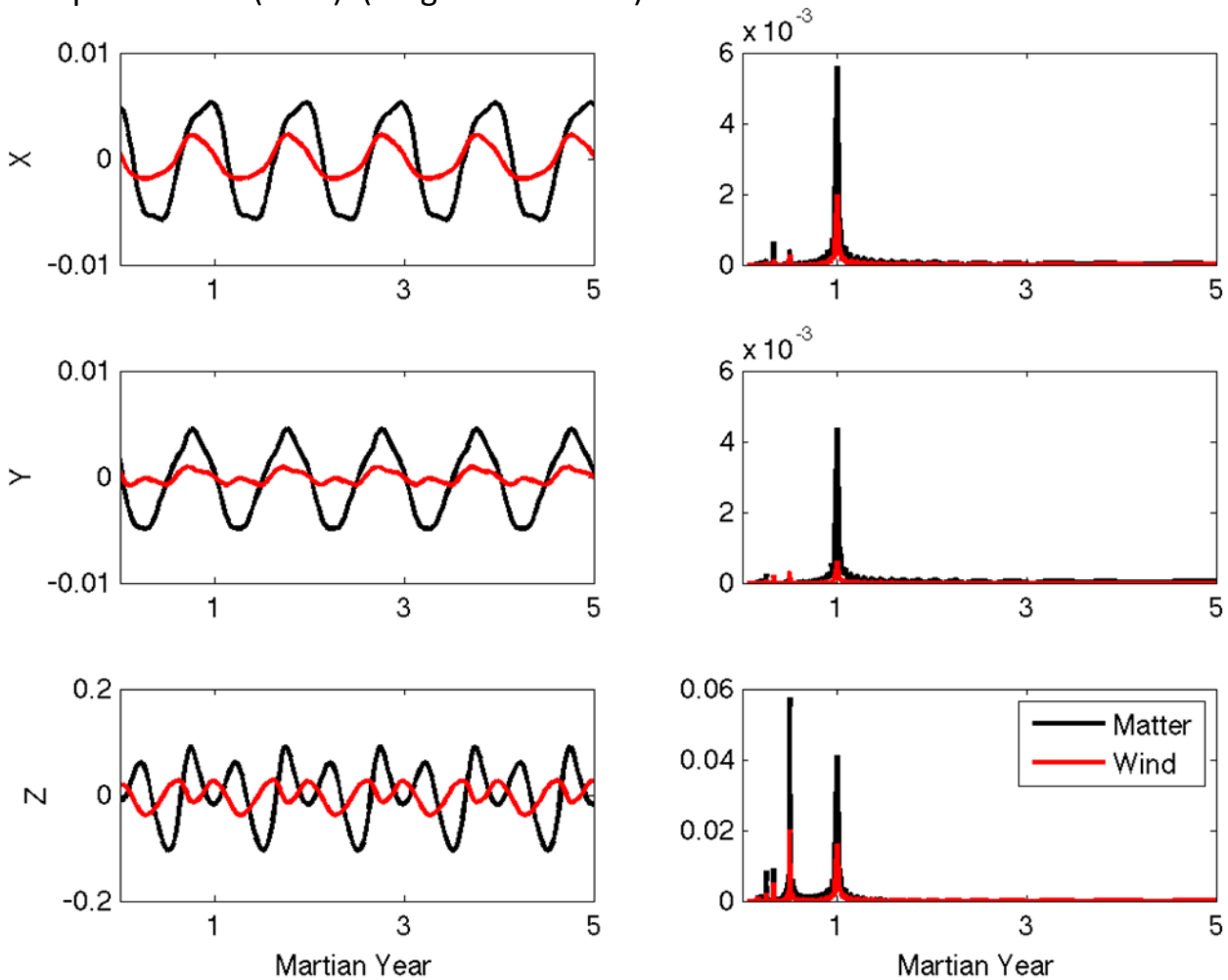
Atmospheric Angular Momentum (AAM) Variations on the Earth



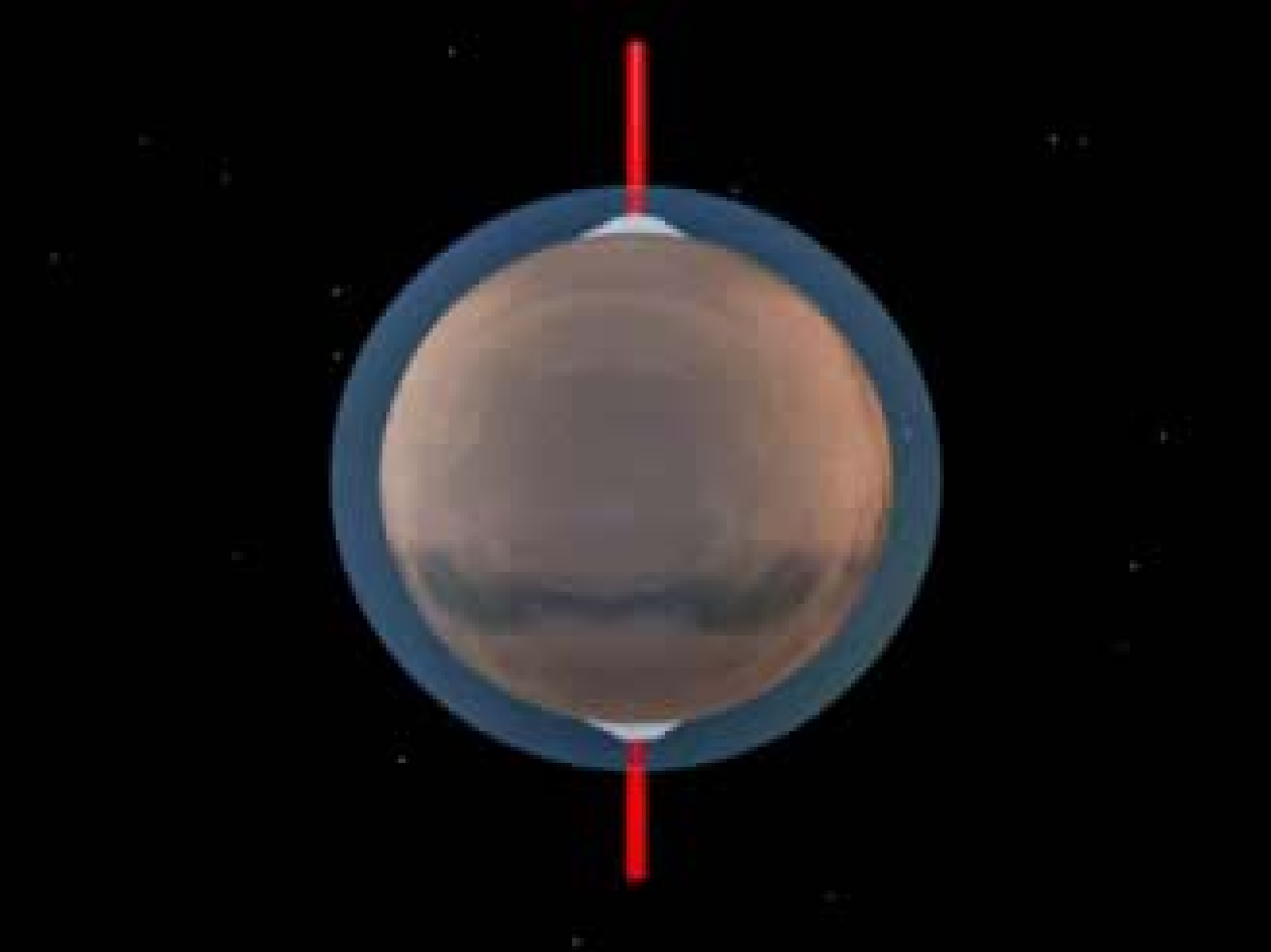
AAM variations of the Earth. Time variations are shown in the left column (units in 10^{25} Nms) and the corresponding spectrum in the right column.

AAM Variations (Mars)

Data are from Mars Climate Data Base (MCD) version 4.2 of the Laboratoire Météorologie Dynamique de Paris (LMD). (Forget et al. 2007)

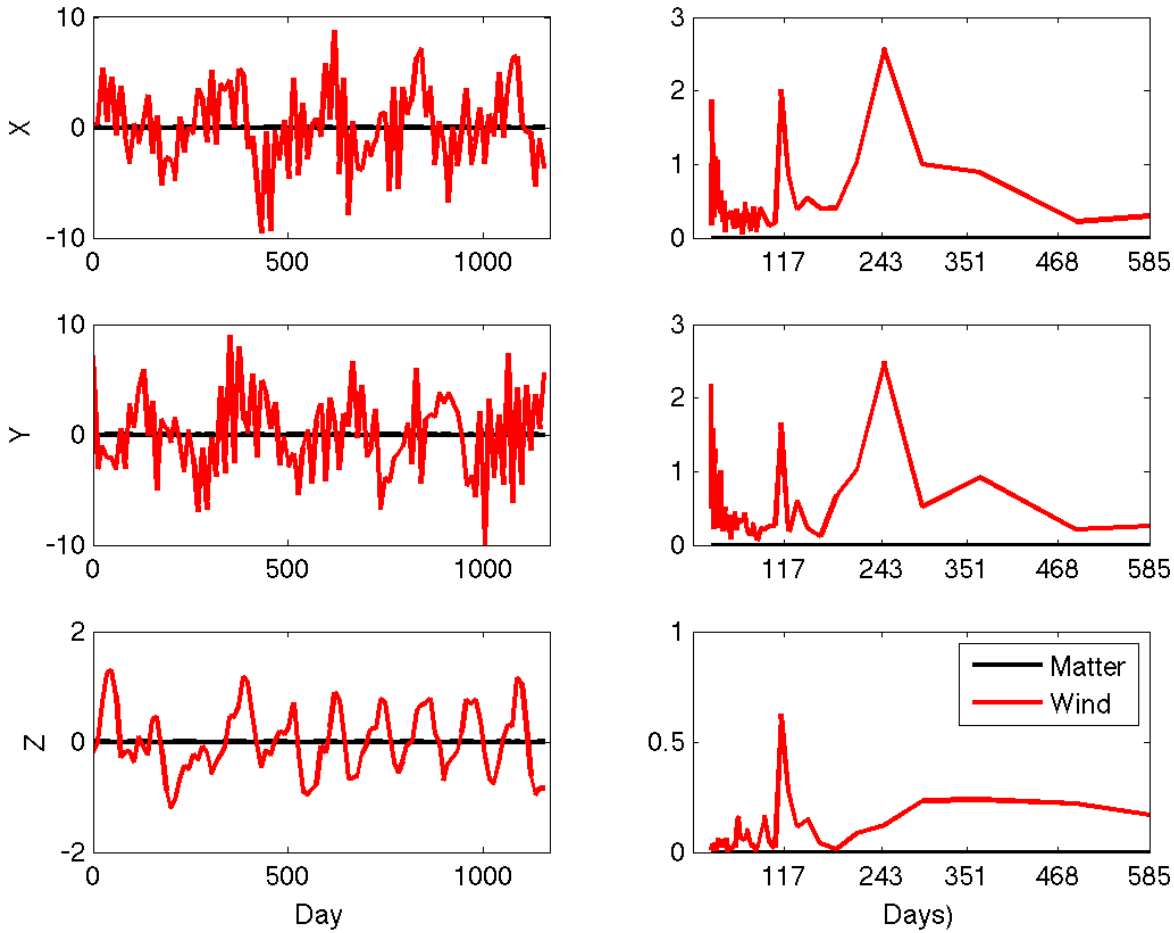


AAM variations of Mars. Time variations are shown in the left column (units in 10^{25} Nms) and the corresponding spectrum in the right column.



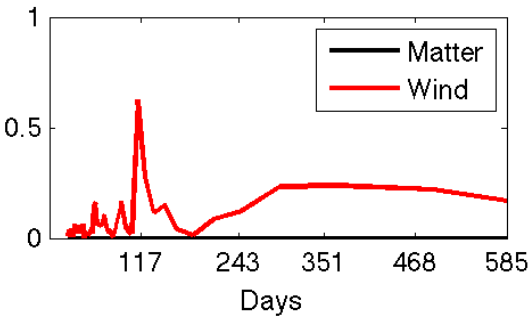
AAM Variations (Venus)

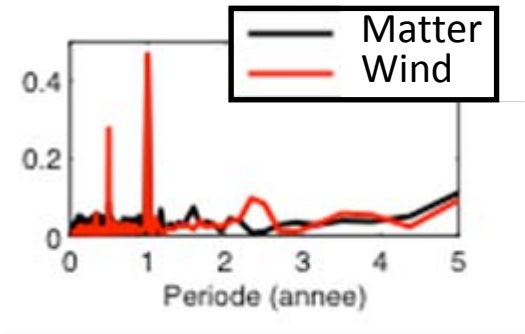
Preliminary run of 3D GCM from the LMD (48x32 surface grid with 50 vertical layers)

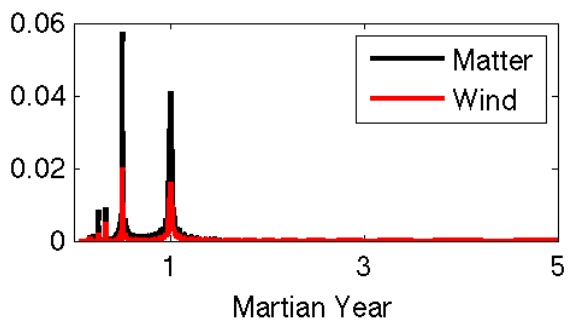


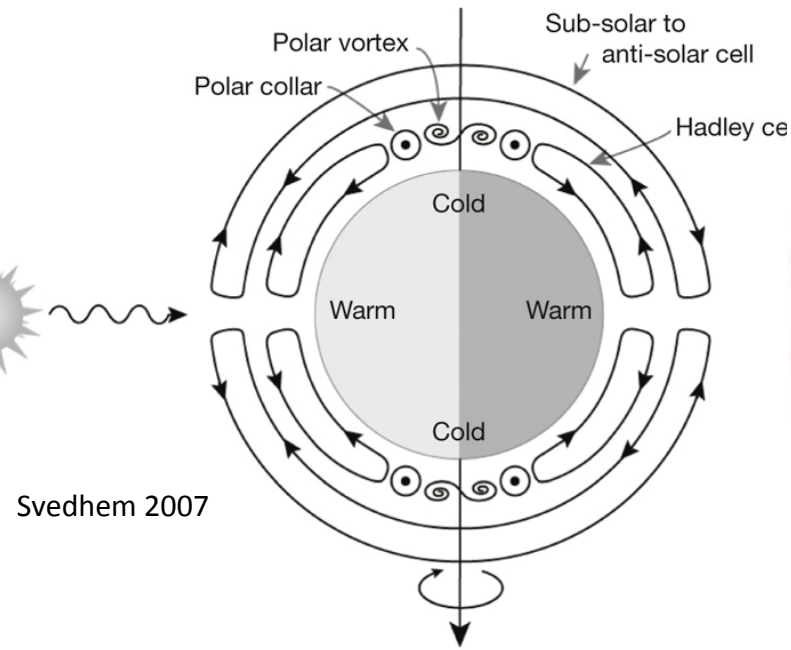
AAM variations of Venus Time variations are shown in the left column (units in 10^{25} Nms) and the corresponding spectrum in the right column.

Atmospheric Circulation

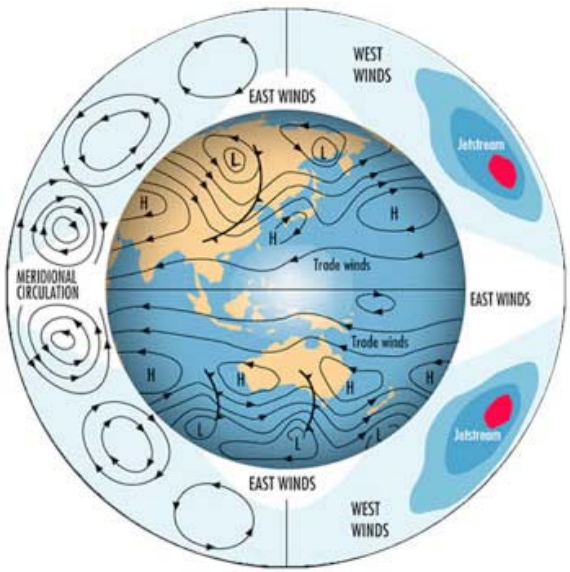


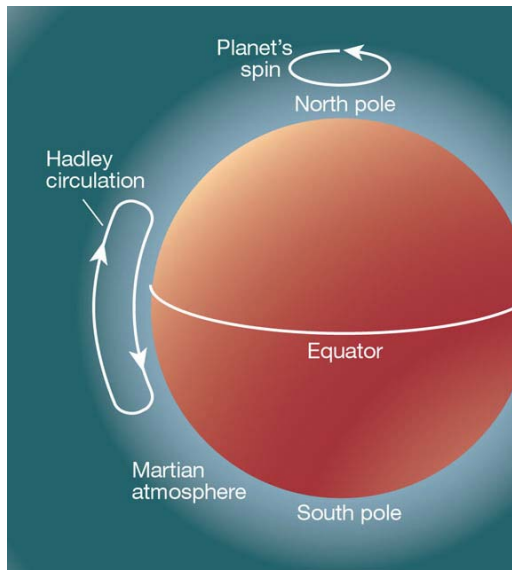






Svedhem 2007



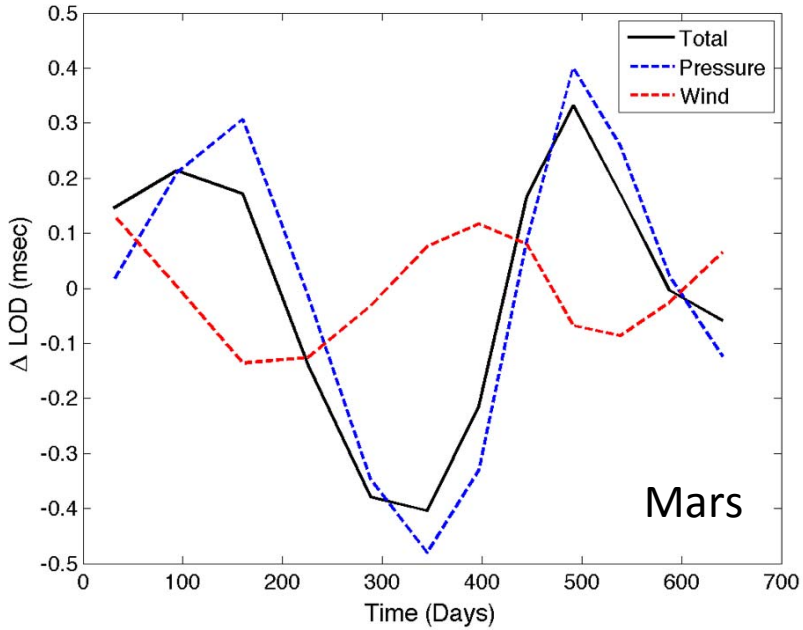


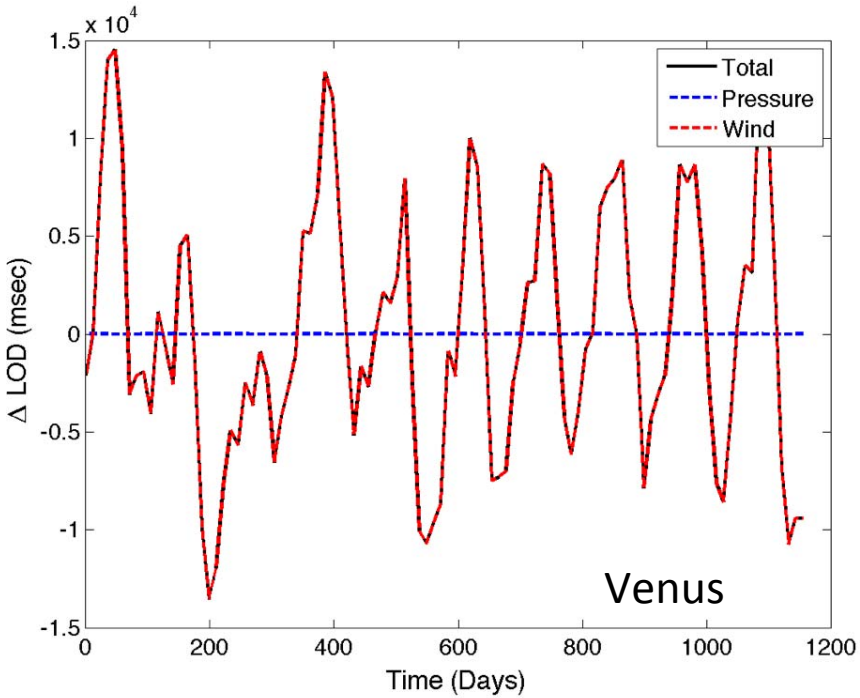
Gierasch 2002

LOD Variations

$\Delta LOD_{Total} = \Delta LOD_{Pressure} + \Delta LOD_{Wind}$

- Wind Terms are dominant on Earth and Venus whereas it is the pressure term on Mars.
- ΔLOD is about the same order of magnitude on Mars and Earth. On Venus can be ΔLOD 4 order of magnitude larger.





Physical Properties

	Ω (s^{-1})	R (km)	C ($kg\ m^2$)	g ($m\ s^{-2}$)	P_{atm} (atm)
Venus	2.99×10^{-7}	*6052*	6.24×10^{37}	8.87	92
Earth	7.29×10^{-5}	*6371*	8.03×10^{37}	9.81	1
Mars	7.09×10^{-5}	*3396*	2.70×10^{36}	3.71	0.007

$$\Delta LOD = (\Delta H_{Atm} / H_{Solid}) LOD$$

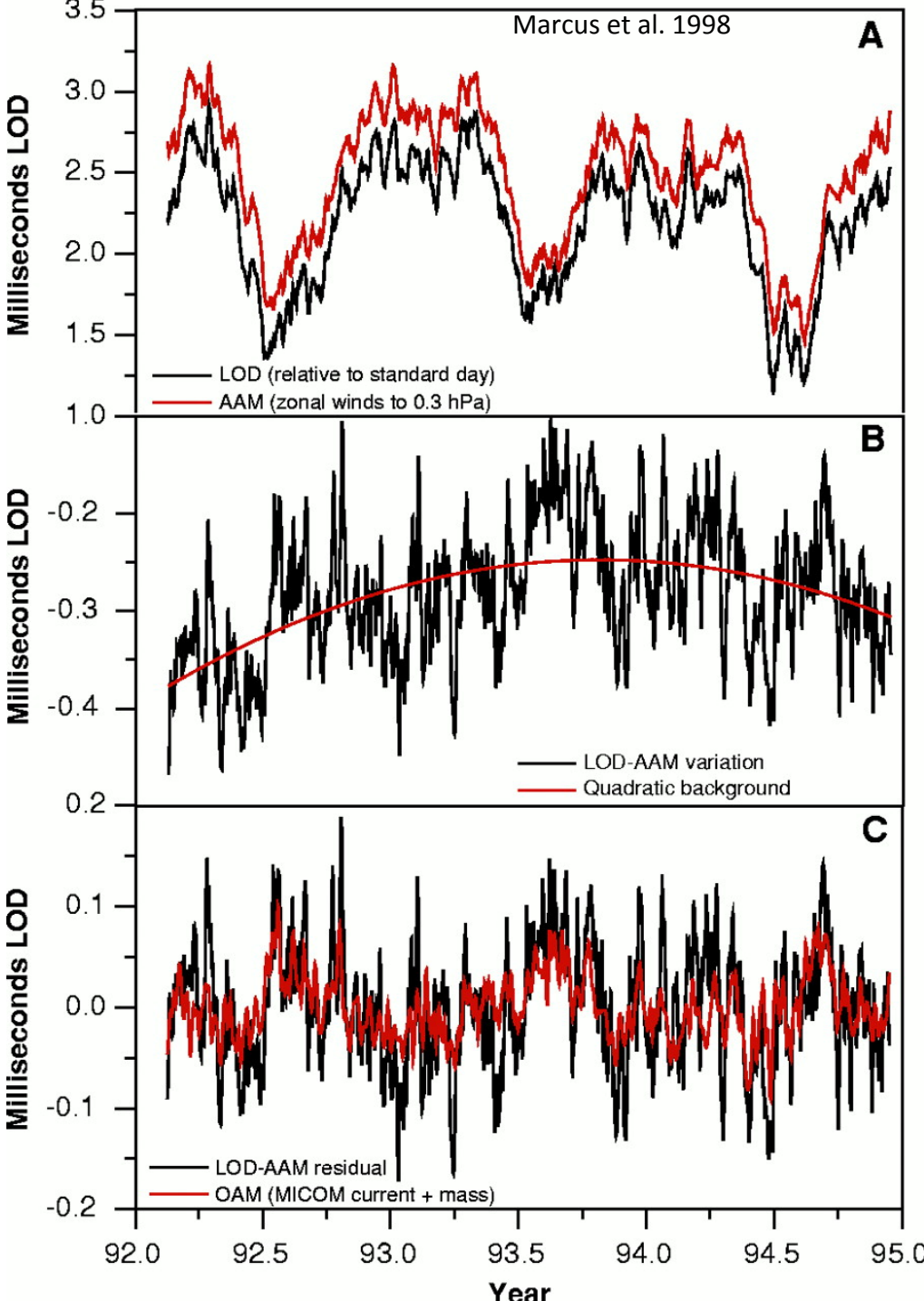
	H_{solid} ($kg\ m^2\ s^{-1}$)	$P_{atm}R^2/g$ (kg)	H_{atm} ($kg\ m^2\ s^{-1}$)	ΔH_{atm} ($kg\ m^2\ s^{-1}$)	$\Delta H_{atm}/H_{atm}$	$\Delta H_{atm}/H_{solid}$ ($\times 10^{-8}$)	ΔLOD
Venus	1.87×10^{31}	3.84×10^{19}	4.21×10^{26}	1×10^{25}	*0.02*	*54*	*11 s*
Earth	5.86×10^{33}	4.19×10^{17}	1.24×10^{27}	2×10^{25}	*0.02*	*0.3*	*0.3 ms*
Mars	1.91×10^{32}	2.24×10^{15}	1.83×10^{24}	0.1×10^{25}	*0.5*	*0.5*	*0.5 ms*

What if both the LOD and the Atmospheric angular momentum variations are well known?

Ocean Influence

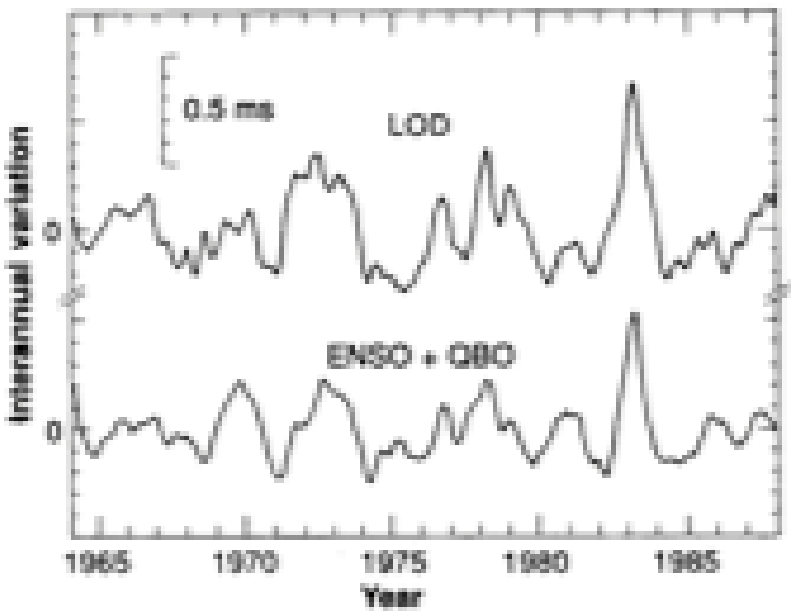
Ocean current and mass distribution changes also induce detectable LOD variations. Global ocean models can successfully capture the large-scale circulation changes that drive OAM variability on seasonal and shorter time scales.

A) Comparison of observed LOD with atmospheric forcing, computed from zonal winds integrated from 1000 to 0.3 hPa. Because the LOD is defined with respect to an arbitrary reference value, its vertical offset has no physical significance. (B) Difference between the LOD and AAM curves plotted in frame (A) compared with a least-squares-fit second-order polynomial used to represent the effects of core-mantle coupling. (C) Difference between the LOD-AAM and quadratic terms plotted in frame (B) compared with total OAM computed from the MICOM simulation



Climate & LOD

Angular momentum variation may also serve as a measure of the "climate" of the oceans, in the same way that the Southern Oscillation Index is used to measure the climate of the atmosphere. This possibility is suggested by the discovery in the LOD of a distinct signature of the 1997-1998 El Niño event.



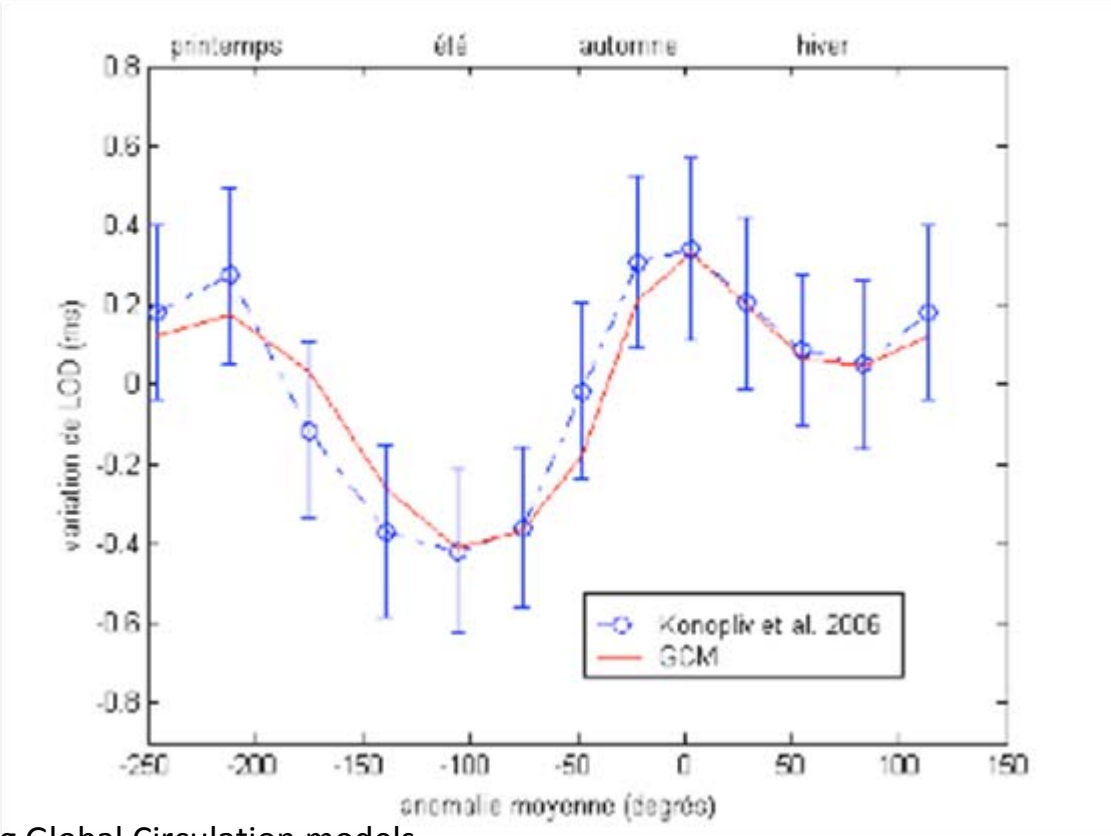
Chao 1998

The excitation of interannual variations in the earth's axial spin, or equivalently the length- of-day (LOD) variations, caused by two prominent interannual fluctuations in the atmosphere, the El Nino-Southern Oscillation (ENSO) and the Quasi-Biennial Oscillation (QBO).

Like the oceans, there are few globally integrated measures of variability in other important elements of the Earth system, such as polar ice and continental water storage. As a better understanding of variability in angular momentum develops, even these smaller participants in the global budget of angular momentum can be studied.

Comparison with Observations (Mars)

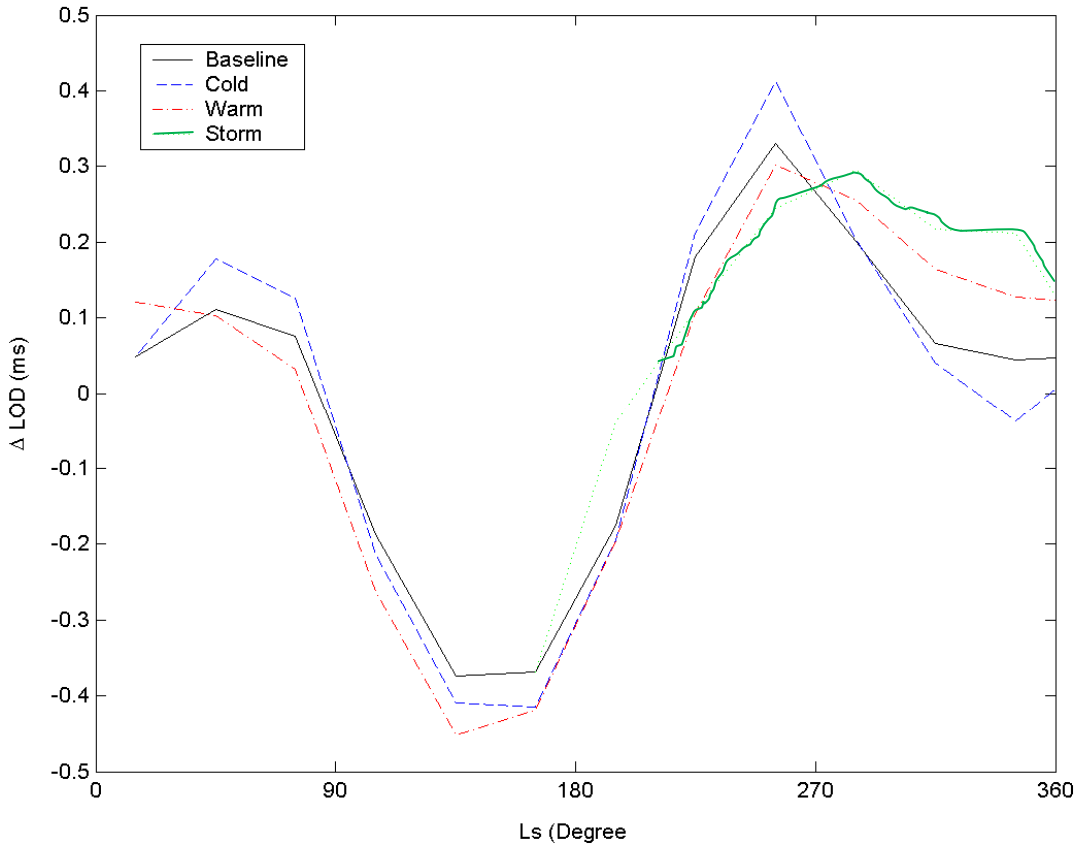
Martian ΔLOD determined using both lander and orbiter data. ΔLOD from the observations and Mars Climate Data Base (from LMD) are in good agreement.



Previous studies on Martian LOD using Global Circulation models

	MCD			NASA AMES
	Defraigne et al. (2000)	Van den Acker et al. (2002)	present study	Sanchez et al. (2003)
Annual	0.223	0.250	0.217 ± 0.0076	0.187
Semi-annual	0.375	0.240	0.194 ± 0.0070	0.136

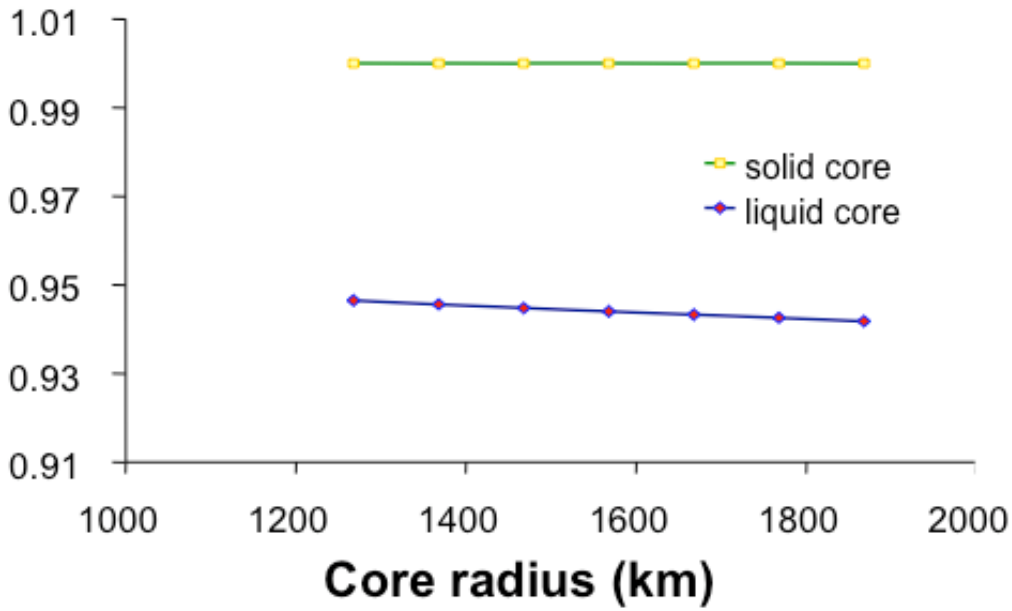
Interannual variability - Effect of Martian Dust Storms



The Martian atmosphere is highly variable. The MCD includes 4 different dust scenarios. The largest variations in ΔLOD occurs during 270<Ls<360

Martian Interior

$$\frac{\Delta LOD(t)}{LOD}\frac{1}{\chi^{load}}$$



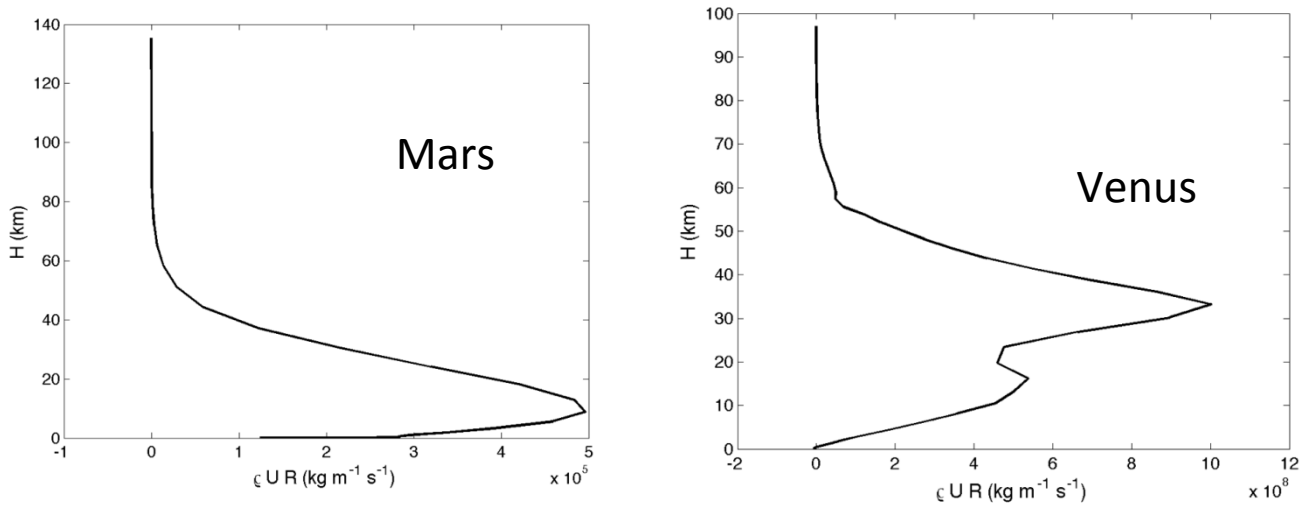
ΔLOD and surface mass loading must be known within the 5% uncertainty level to determine whether the core is liquid.

LOD Variations of Venus

No observations. From preliminary GCM data ΔLOD ≈ 10 sec

Magellan radio science team determined the rotation period of Venus with an error of ≈43 sec (Konopliv et al. 1993).
Magellan radar team team determined the rotation period of Venus with an error of ε≈2.5 sec (Davies et al. 1992)

We need future orbiter and/or Earth based Radar/Wind measurements to confirm present LOD variations of Venus.



Angular momentum: Vertical Profiles

Conclusions

-AAM variations are mainly annual and semi-annual on Mars and Earth whereas they are expected to be diurnal on Venus.

- Wind terms have the largest contribution on the rotation changes of the Earth and Venus whereas it is the pressure term which is dominant on Mars due to its $C0_2$ cycle.

-LOD variations have similar amplitudes on Mars and Earth. They are much larger on Venus (Angular momentum of the solid part of Venus is much smaller compared to the Earth and Mars, therefore its rotation can be more easily excited)

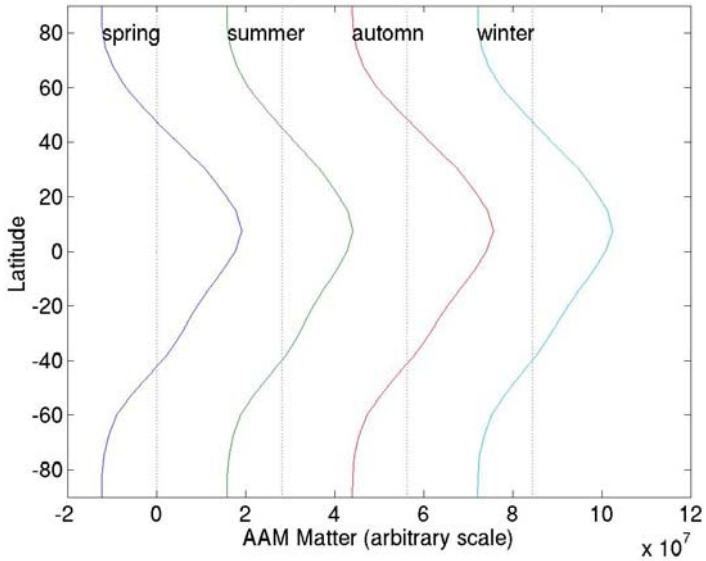
-The precise determination of LOD and the atmospheric variability on Earth helps to better understand the variability of other AM reservoirs (Oceans, polar-ices, Glaciers, hydrology) and climate.

-More precise ΔLOD observations on Mars (LaRa, Lander Radioscience) would provide better insight on inter-annual variability of its atmosphere and on planetary interior.

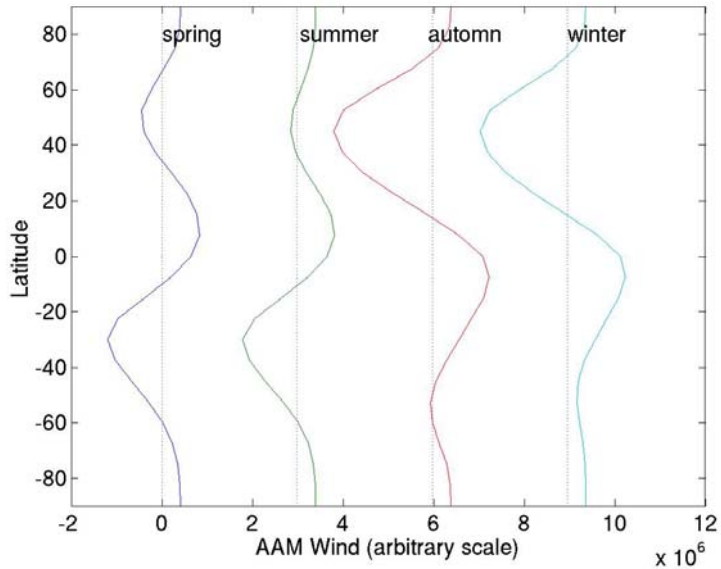
- On Venus, determination of ΔLOD would yield valuable information on the variability of the lower atmosphere (0>H>50 km). If combined with precise wind measurements, it can can help to constrain the interior.

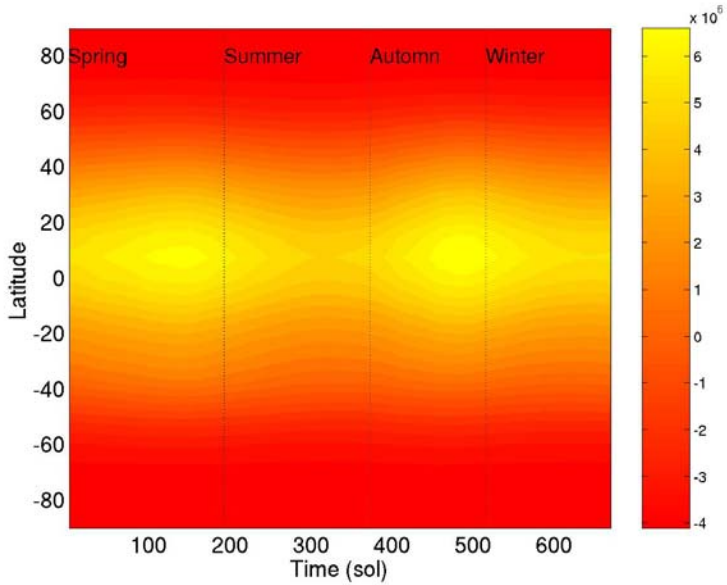
Seasonal Variations of AAM (Mars)

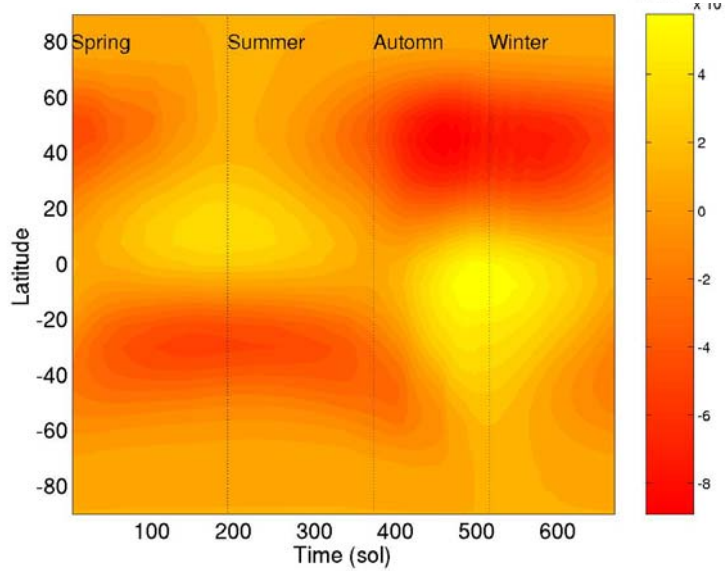
Matter AMM



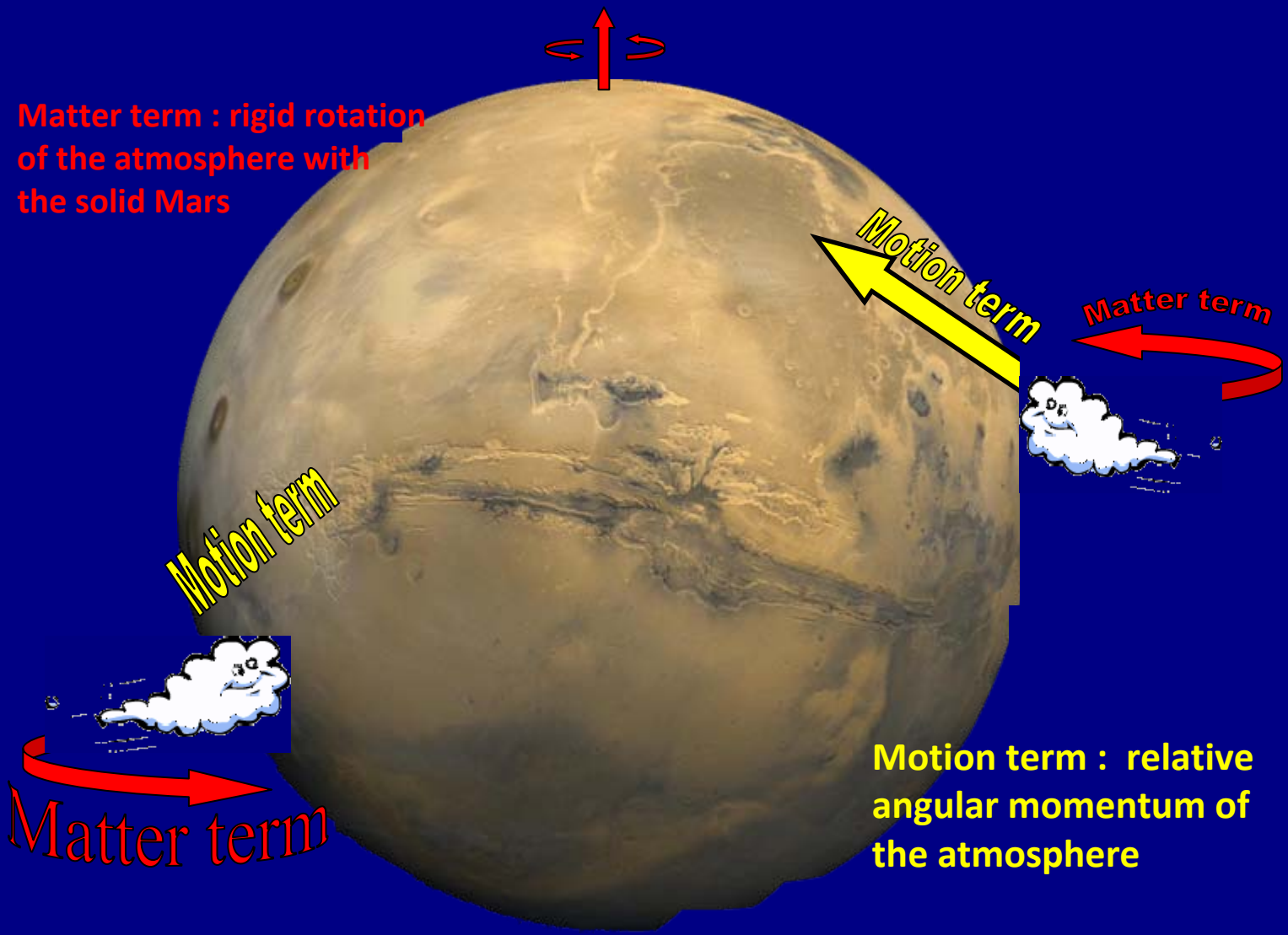
Relative AAM







Computation of the Atmospheric angular momentum

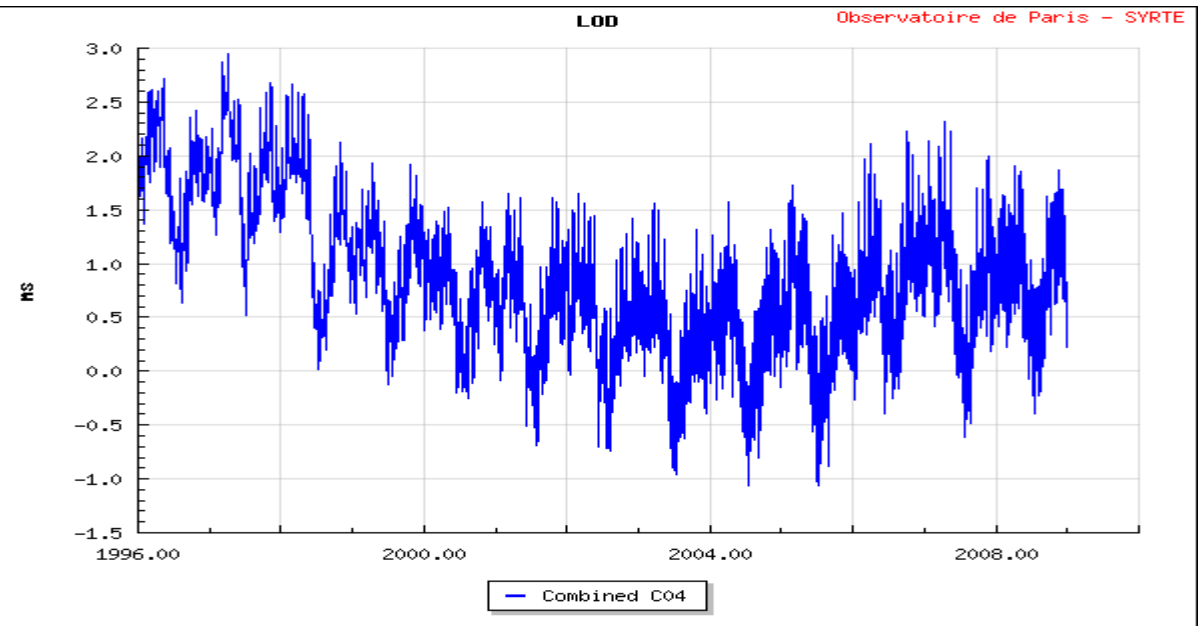


LOD

Earth: ~1 msec, seasonal variations of AAM. (Dickey 1995)

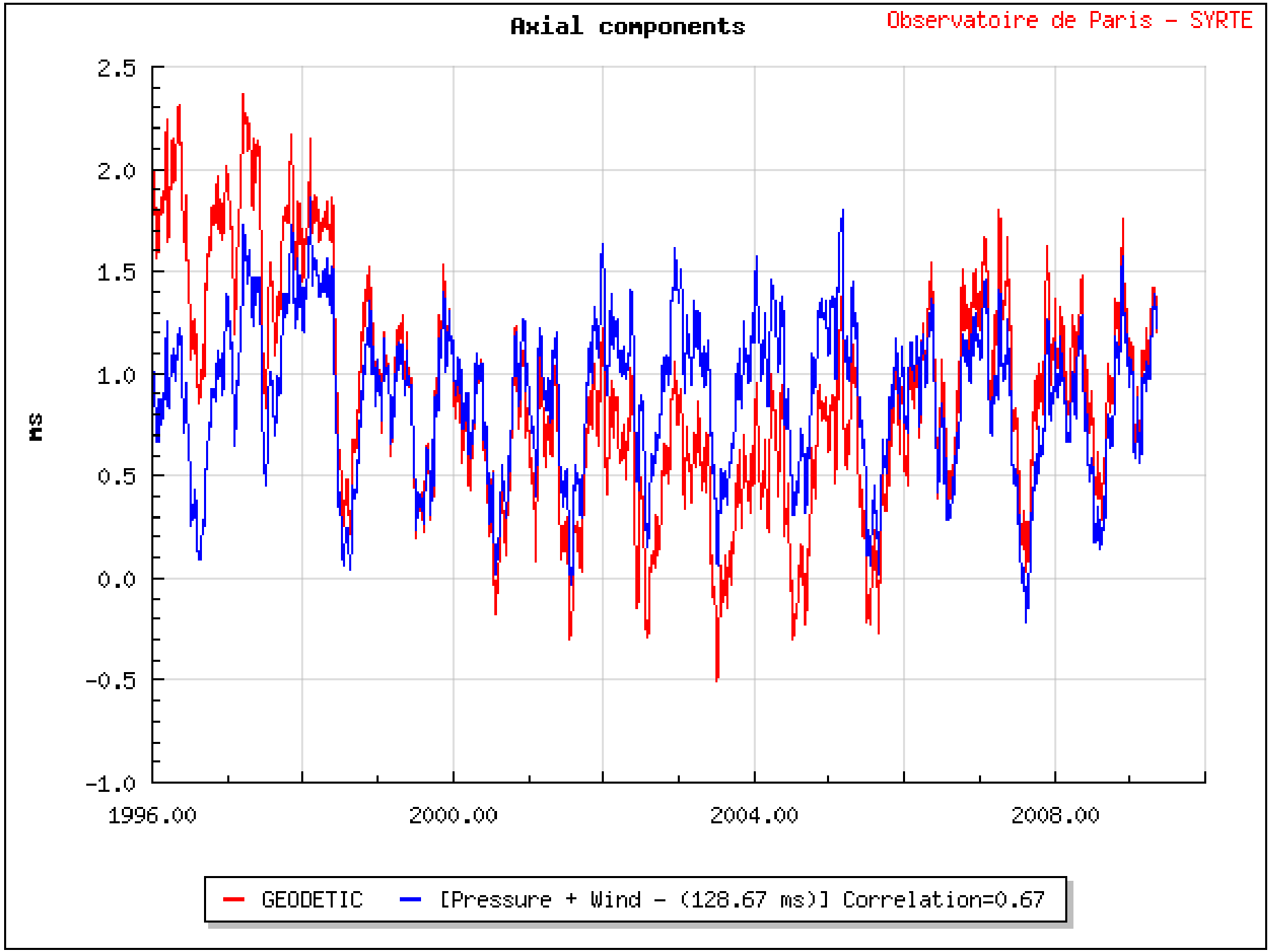
Mars: ~ 0.3 msec, seasonal variations of AAM.

Venus ?

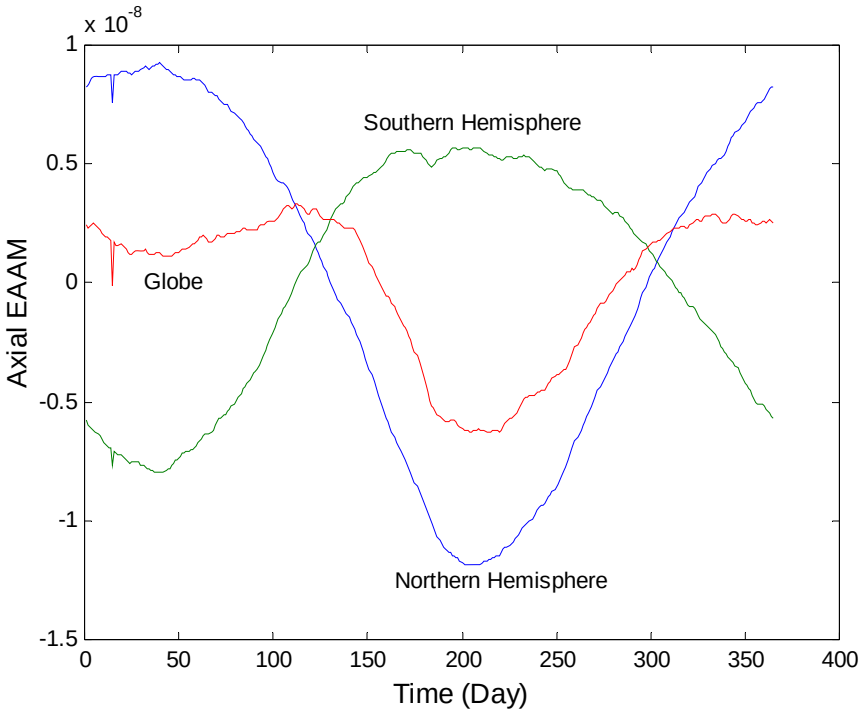


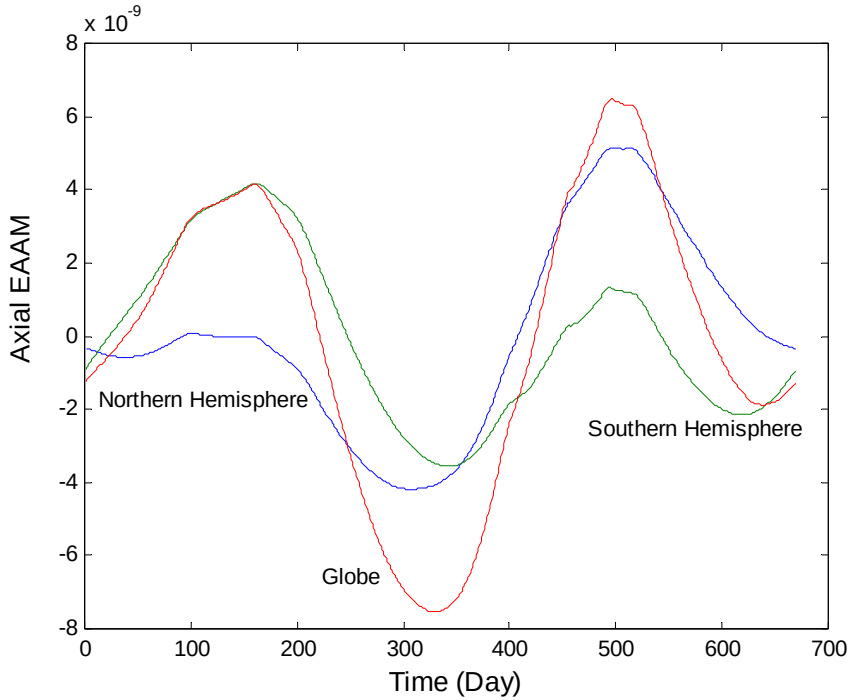
The order of magnitude is similar when the dimension and dynamics are different!

- Earth and Mars have seasons and insolation changes very similar
- When looking at the symmetry, one would expect no angular momentum changes, but:
  - For the Earth, the ocean and their anti-symmetrical location induced angular momentum
  - For Mars, the eccentricity of the orbit plays a role, and as well, the properties of the soil
  - For Venus, diurnal timescale at 117 Earth days.
  - For Mars, additionally effects on global storms.


Axial components
Observatoire de Paris - SYRTE
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
mS
1996.00
2000.00
2004.00
2008.00
GEODETIC
[Pressure + Wind - (128.67 ms)] Correlation=0.67

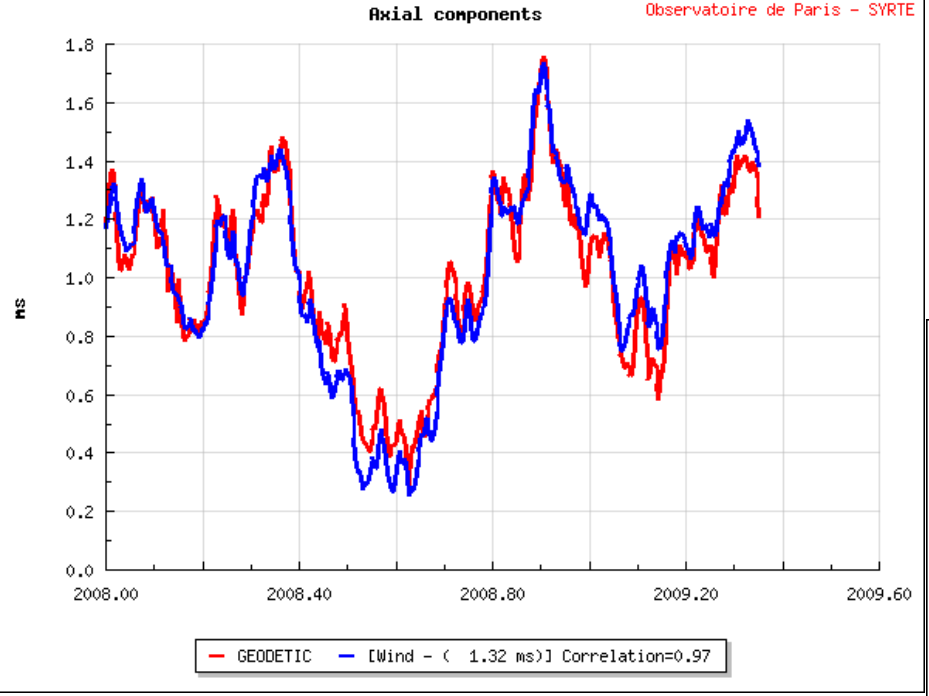
Contribution of Hemispheres

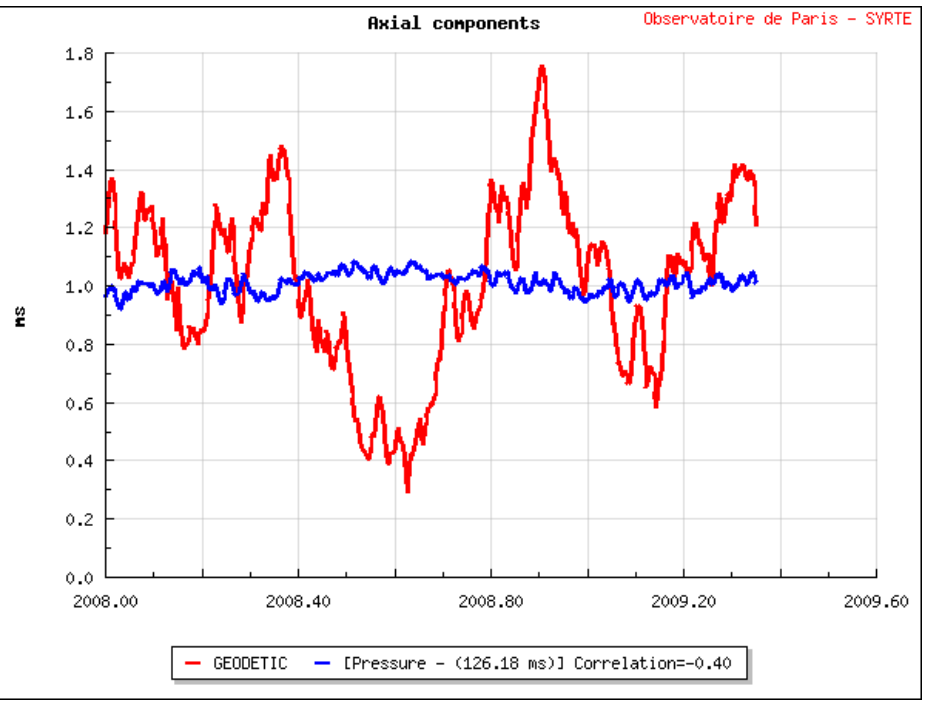


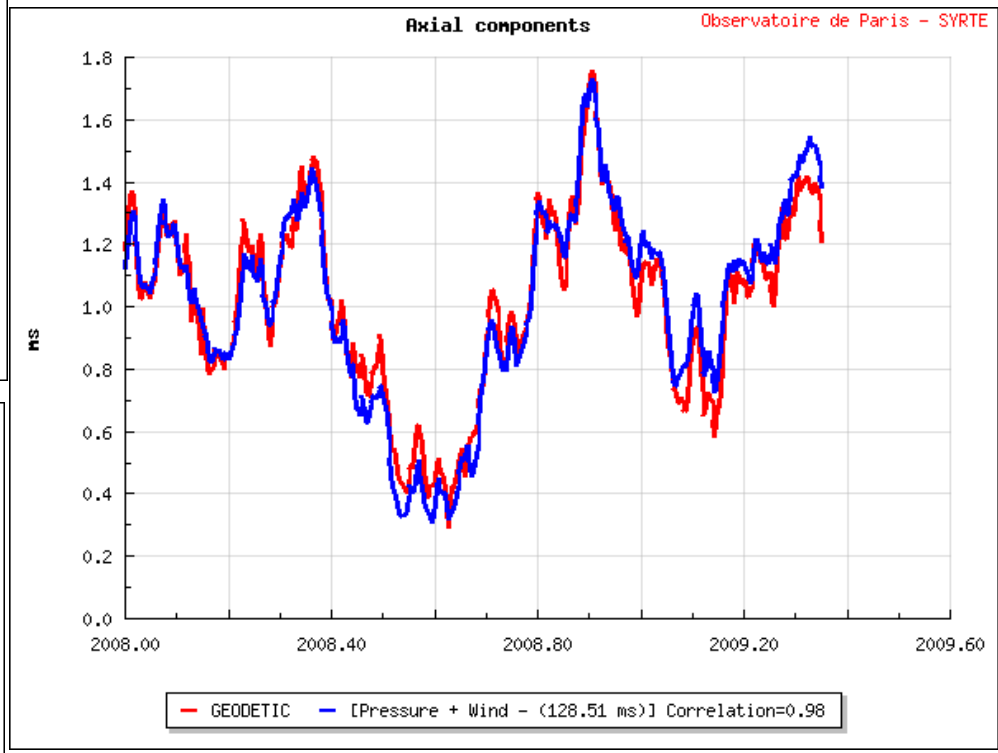


On Earth, annual AAM cycle is associated with seasonal changes in the major jet streams of the two hemispheres, with the largest of these changes occurring in the northern hemisphere due to the larger proportion of land surface in this hemisphere

On Mars, AAM is governed by the surface pressure variations as shown before. Hence, both hemispheres plays an important role as their ice cap dimensions changes during the year. The first peak in global X3 corresponds to northern summer season whereas the second peak to southern summer period.


Axial components
Observatoire de Paris - SYRTE
ms
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2008.00
2008.40
2008.80
2009.20
2009.60
GEODETIC
[Wind - (1.32 ms)] Correlation=0.97


Axial components
Observatoire de Paris - SYRTE
ms
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2008.00
2008.40
2008.80
2009.20
2009.60
GEODETIC
[Pressure - (126.18 ms)] Correlation=-0.40


Axial components
Observatoire de Paris - SYRTE
ms
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2008.00
2008.40
2008.80
2009.20
2009.60
GEODETIC
[Pressure + Wind - (128.51 ms)] Correlation=0.98

- The rotations of the Earth, Mars and Venus constantly slow down and speed up, due to the angular momentum exchange between the surface and the atmosphere, altering the length of the day (LOD).
- Variations on the order of millisecond over seasonal time scales have been observed for Mars and Earth, but LOD variations of Venus have not yet been measured.
- Eccentricity and Obliquity of the Earth and Mars causes seasonal variations. Despite the near-circular orbit and very small obliquity, and the resulting absence of seasons, important variations in the rotation of Venus can still exist due to the variability of the winds in the lower atmosphere over diurnal time scales.