On the possible detection of inter-annual deformation signal at the Earth's surface due to the fluid core dynamics

Length-Of-Day variations and Torsional waves

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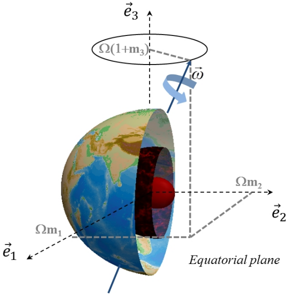
Journées 2019 - Astrometry, Earth Rotation and Reference Systems in the Gaia era

LOD changes

In terrestrial reference system,

$\omega = \Omega(m_1, m_2, 1 + m_3)$

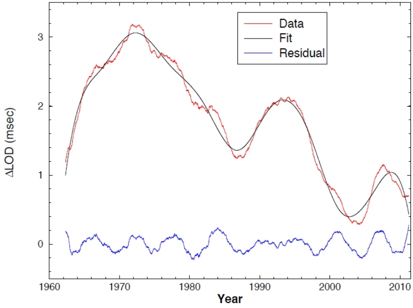
$\Delta LOD = -\overline{LOD} m_3$



Processes	Time scale	Amplitude
Tidal friction, GIA, present-day ice melting, tectonics, etc.	secular	< 2 ms/cy
Core-Mantle interactions	decadal	~ 2 ms
Atmospheric, oceanic and hydrologic	interannual	$\sim$ ms
Core-Mantle interactions	interannual (~ 6 yr)	~ 0.12 ms
Atmospheric, oceanic and tides	seasonal	~ 0.5 ms
Tides	monthly & fortnightly	~ 0.5 ms

A 5.9-yr oscillation in LOD

Abarca del Rio et al. 2000; Holme & de Viron (2013)



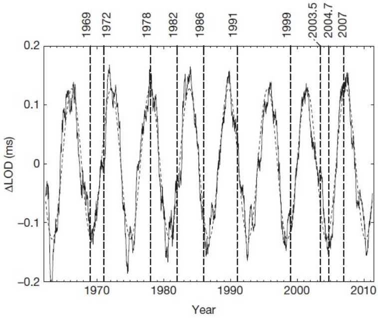


Figure 2 | Decadally detrended LOD data (with 6-month running average), plotted with 5.9-year oscillation fit (dashed line). Vertical lines show best determinations of geomagnetic jerk timings.

Holme & de Viron (2013)

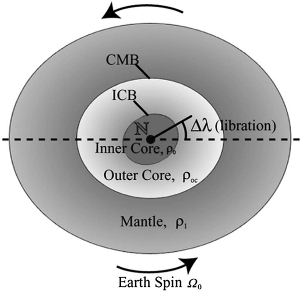
↓

5.9-year oscillation

A 5.9-yr oscillation in LOD: Mechanism?

Mantle-Inner Core Gravitational coupling (MICG)

Buffett (1996, 1997), Mound & Buffett (2006)

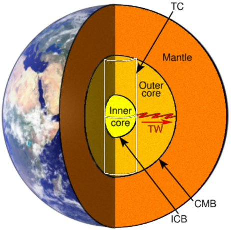


Chao (2017)

Unlikely alone: strength of gravitational coupling too small (Davies et al. 2014)

Torsional waves

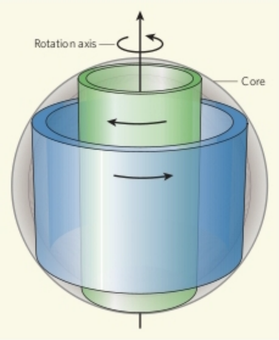
Gillet et al. (2010; 2017)



Teed et al. (2019)

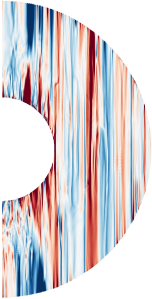
→ Traveling Waves break upon CMB

Core-Mantle Angular Momentum exchanges



axial invariance (quasi-geostrophy) in numerical geodynamo simulation

Schaeffer et al. (2017)



if axially invariant : only concern t_1^0 and t_3^0 "zonal" coefficients

Jault et al. (1988); Jackson et al. (1993); Jault & Finlay (2015)

Core-Mantle Angular Momentum exchanges

Variations in core angular momentum caused by time changes of geostrophic velocity are compensated by variations in mantle angular momentum and thus in LOD.

- Geostrophic flow velocity:

$$U_G = -\sum_{n=0}^{\infty} t^0_{2n+1} P_{2n+1}$$

- Core angular momentum (C_c core moment of inertia):

$$H_c \simeq C_c \left(t^0_1 + 1.776 t^0_3 + 0.0796 t^0_5 + 0.002 t^0_7 + 4.10^{-5} t^0_9 + ... \right),$$

- Conservation of total angular momentum of Earth:

$$\rightarrow \boxed{\Delta LOD = -H_c \frac{2\pi}{\Omega^2 C_m} \simeq 1.232 \left(\delta t^0_1 + 1.776 \delta t^0_3 \right)}$$

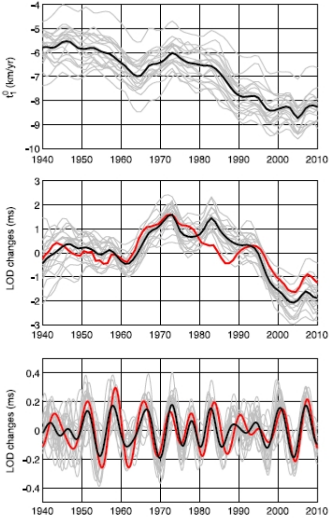
(LOD in ms, flows in km/yr) Jault & Finlay (2015)

Inter-annual LOD changes and core flows

(top) Flow coefficient t_0^1 (km/yr)
(middle) predicted (black) and observed LOD changes (red) (ms)
(bottom) LOD band-pass filtered between 4 and 9.5 years.

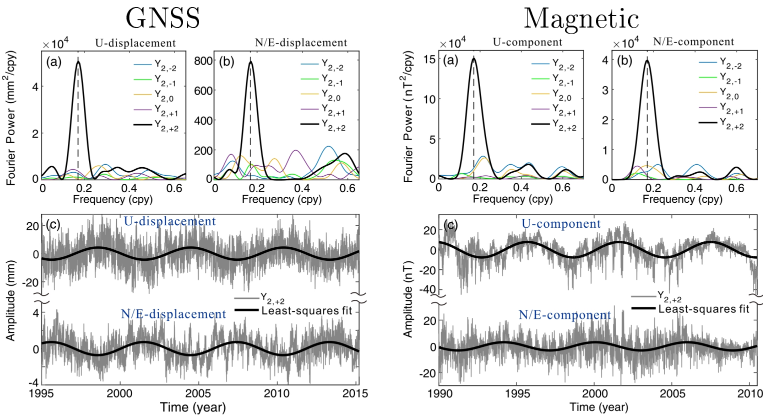
→ inter-annual LOD changes well-explained by core flow models inverted from (independent) geomagnetic data

(Gillet et al. 2015)



A 5.9-year signal in GNSS and magnetic data?

Ding & Chao (2018): Y_2^2 pattern, linked to MICG coupling

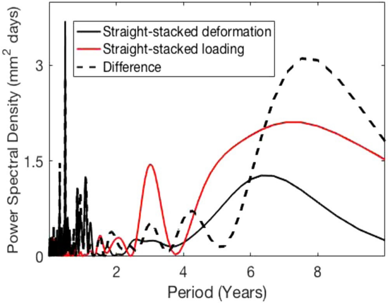


amplitudes a few mm (on Z) and 5-10 nT (on B_r) (Ding & Chao 2018)

A 5.9-year signal in GNSS data?

Watkins et al. (2018):

- stacked spectra (BUT only 12-years of time-series)
- a 5.9-year signal detected in GNSS data but not conclusive



→ Is the observed 5.9-yr oscillation compatible with core flows models?
→ Can we reproduce previous results?

Surface deformation and core flows

- vertical displacement at the Earth's surface:

$$u_r = \sum_n \bar{h}_n \frac{\Delta P_n}{\rho g_0},$$

- $\bar{h}_n$ degree-n Love numbers $(h_2,\ h_4,\ h_6) \simeq (0.23, 0.05, 0.01)$
- geostrophic pressure $\Delta P_n = 2\rho_c \Omega U_n L_n$, with $L_n \simeq 2\pi r_c/(2n+1)$

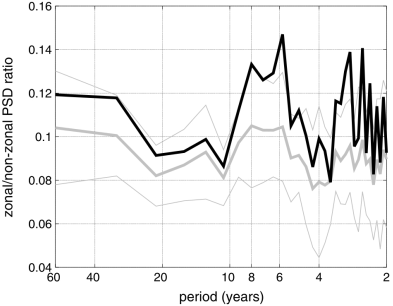
Ding & Chao (2018):
- vertical surface displacement of 4.3 +/- 1.7 mm $\rightarrow \Delta P \sim 1000$ Pa

$\rightarrow U_Z \sim 10^{-4}$ m/s ~ 3 km/yr

... good order of magnitude?

Zonal and non-zonal motions

Only **zonal toroidal** motions of the core wrt mantle contribute to axial component of angular momentum of the core.

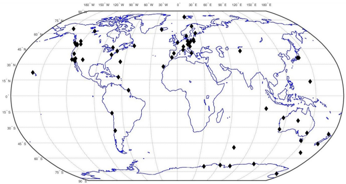


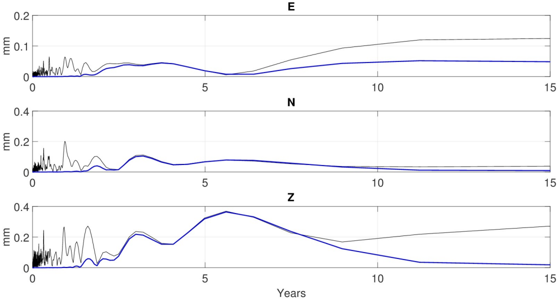
$|U_{NZ}| = O(2)$ km/yr
$|U_Z| = O(0.6)$ km/yr
$\rightarrow |U_{NZ}| \approx 3|U_Z|$
(Gillet et al. 2015)

5.9-year oscillation: weak in zonal flows (torsional waves), absent in non-zonal flows
$\rightarrow$ do not expect strong 5.9-year signal: 0.2-1 mm vertical displacement

GNSS data analysis: vertical displacement

International GNSS Service (IGS) solutions from 2nd data reprocessing campaign in ITRF2014 with geophysical corrections (tides, ocean loading, non-tidal atmospheric loading) after IERS Conventions (2010) (Rebischung et al. 2016)

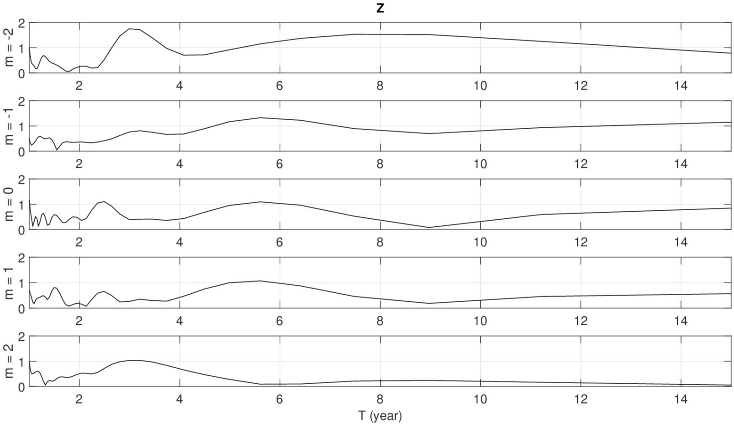




Stacked FFT of solutions from 63 stations with duration 18.5 years (band-pass filtering [2 - 12] yr) $\rightarrow$ 0.4 mm on Z at $\sim$ 6-year

GNSS data analysis: vertical displacement

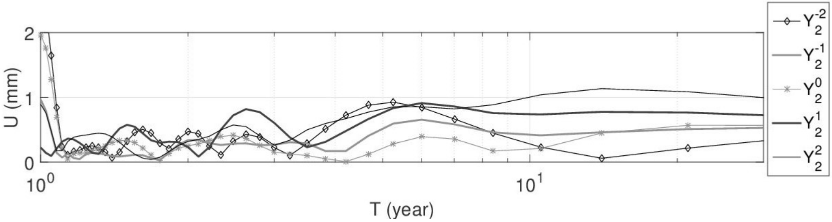
Optimal Sequence Estimate as in Ding & Chao (2018) applied on IGS Repro2 solutions from 63 stations with duration 18.5 years



GNSS data analysis: vertical displacement

Peak at 6-year period in hydrological loading predictions?

↓ 6 year



Optimal Spectral Estimate on GLDAS predictions at GNSS sites

http://loading.u-strasbg.fr/

→ 1 **mm vertical displacement at 6-year in GLDAS predictions**

Summary

- 6-year oscillation in LOD well-explained by torsional waves in fluid core
- if detected 6-year oscillation in vertical GNSS data originates from fluid core, then associated core flows of the order of 3 km/yr ($\gg$ 0.6 km/yr from torsional waves obtained from geomagnetic observations)
- if Y_2^2 pattern confirmed, then **non-zonal** flows should play a major role, but no peak at 6-year period in reconstructed non-zonal flows
- even with non-zonal flow 3 to 5 times larger than zonal flows, associated pressure flows (in quasi-geostrophic approximation) similar to zonal ones $\rightarrow$ **not enough to induce 1-mm vertical displacement at surface**
- our attempts have not yet confirmed previous detection: a peak present at $\sim$ 6-year with amplitude 0.4 mm
- but hydrological loading signal also has a peak at $\sim$ 6-year with similar amplitude...
- effect on polar motion known to be small (e.g. Dumberry (2008); Greff-Lefftz & Legros (1995))...

Acknowledgments

Thank you for your attention