The geocenter motion from decadal to geological time-scales: geophysical modelling

Marianne Greff-Lefftz and Laurent Métivier

Institut de Physique du Globe de Paris

Institut Géographique National, LAREG/GRGS

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- Theory
- Decadal geocenter variation induced by pressure at the core boundary
- Secular geocenter variation induced by PGR
- Geological geocenter variation induced by mantle dynamics

Degree-one deformations

Equations governing the elastic deformations within a pre-stress planet:

- Impulsion equation
- Conservation of mass
- Poisson equation
- A rheological law necessary to relate the stress to the strain.

Boundary conditions

• at the surface :

- Conservation of the center of mass: the degree-one surface potential is equal to zero.

- Radial and tangential stresses equal to acting tangential traction and acting pressure.

• within the mantle:

- the tangential stresses, the displacements and the gravitational potential are continuous;

- at the depth where is located a mantle mass anomaly, the continuity of the radial stresses and of the gravity depends on the internal loading potential.

• at the CMB and ICB:

- the radial displacement, gravitational potential and gravific attraction are continuous;

- the tangential stress is equal to zero in absence of acting tangential traction;

- the continuity of radial stress depends on fluid pressure acting at the CMB (P^c) and at the ICB (P^{ic})

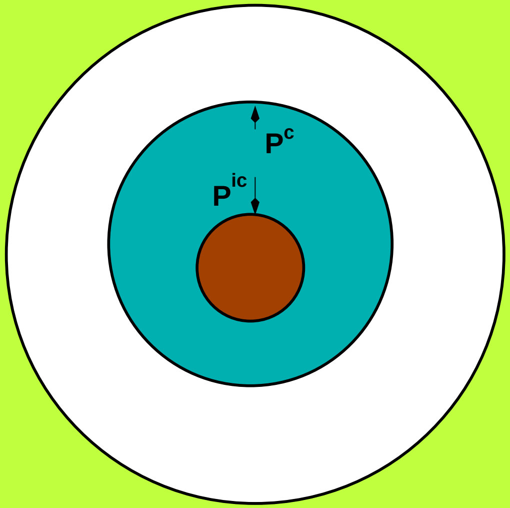
Consistency Relation

Special condition in which the degree-one valid solutions have to obey (Farrell, 1972):
The global resulting force F, in a geographic frame (centred at the centre of mass) has to be equal to zero.

$\Downarrow$

For an inviscid homogeneous fluid core

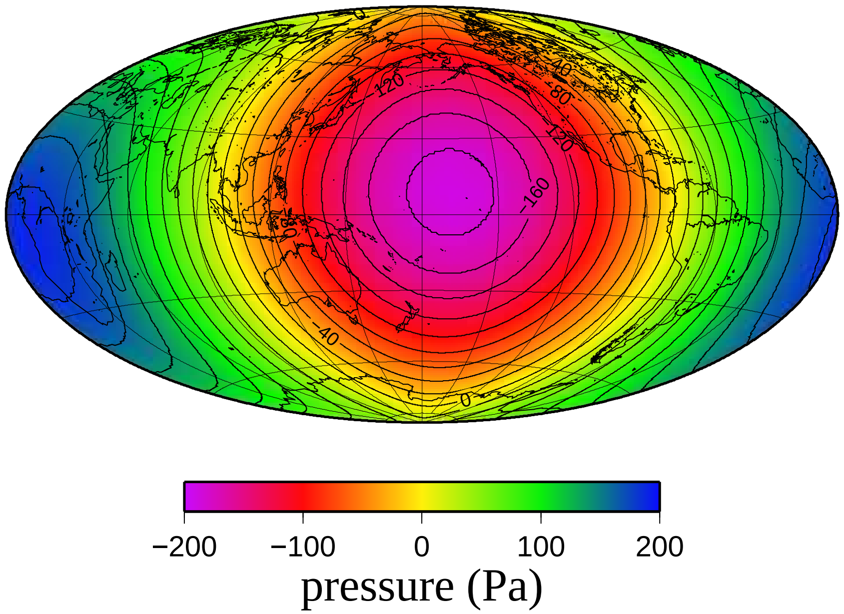
$$\mathbf{F} = \int_{\mathrm{ICB}} -\mathbf{P}^{\mathbf{ic}} \vec{\mathbf{e}}_{\mathbf{r}} \mathbf{ds} + \int_{\mathrm{CMB}} \mathbf{P}^{\mathbf{c}} \vec{\mathbf{e}}_{\mathbf{r}} \mathbf{ds} = \mathbf{0}$$



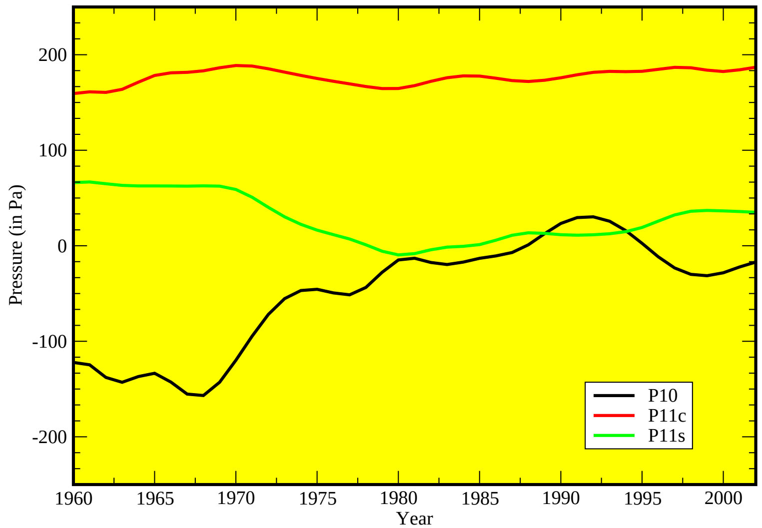
Geocenter decadal variations

• Pressure at the CMB varying at decadal time-scale known from the observations of the surface magnetic field and its secular variation, under the hypothesis of tangential geostrophy.

• Degree-one pressure, for the year 2000

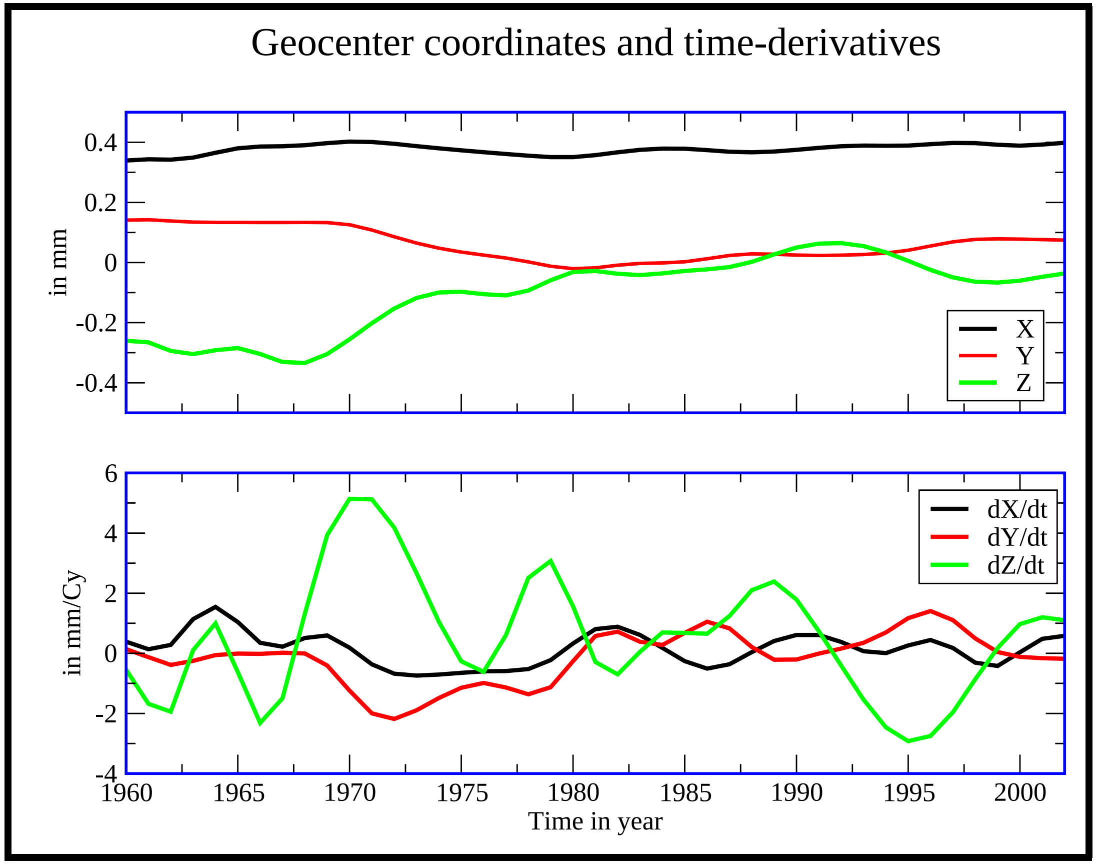


• Degree-one coefficients of the geostrophic pressure at the CMB, as a function of time, in Pa



computed by Alexandra Pais from Coimbra University

Geocenter variations induced by the degree-one geostrophic pressure since 1960



- **Mantle translation:** less than one millimeter
- **Decadal variations:** about 1 mm/Century
- **Gravity perturbation:** $\simeq$ 100 nanogals

Geocenter secular variations

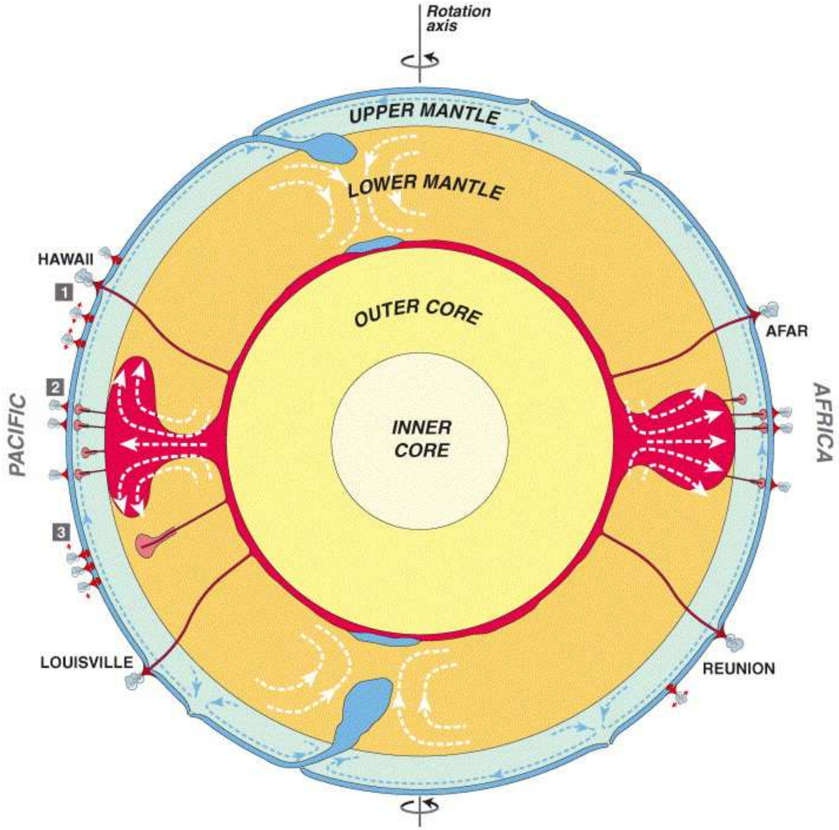
V. Klemann and Z. Martinec, EGU2012-5115:

"Solid-Earth Processes and Secular Geocenter Motion"

The predicted GIA contribution ranges in amplitude from 0.1 to 1 mm/yr, depending on the considered rheological structure of the earths mantle, but is quite robustly directed towards Laurentide pointing inward.

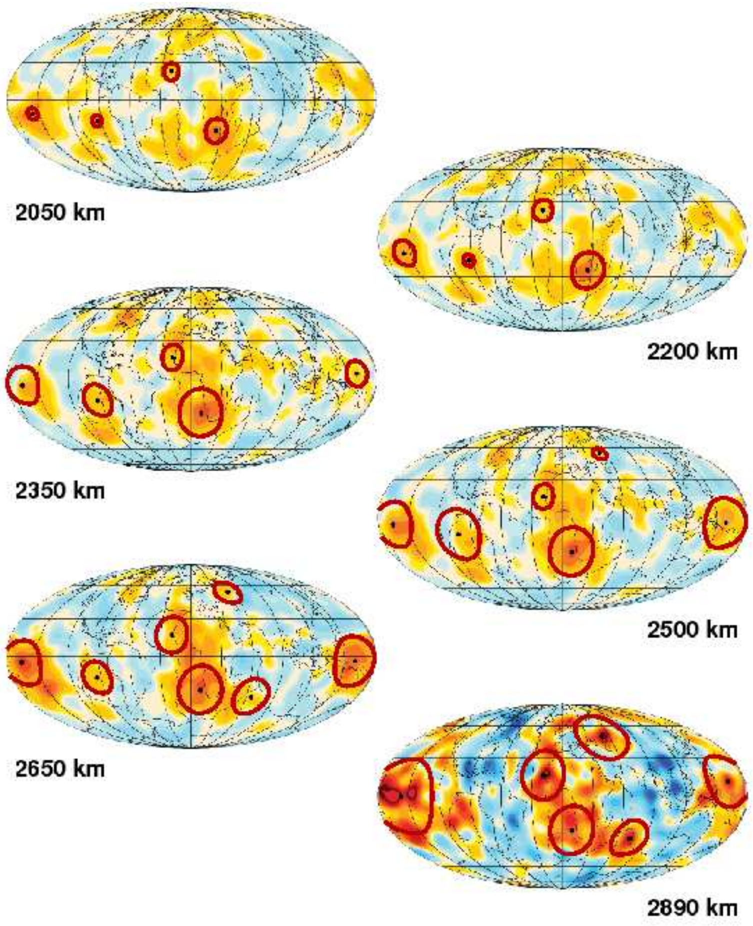
Geocenter geological variations induced by mantle dynamics

Mantle mass anomalies



from [Courtillot et al., 2003]

Mantle Upwellings

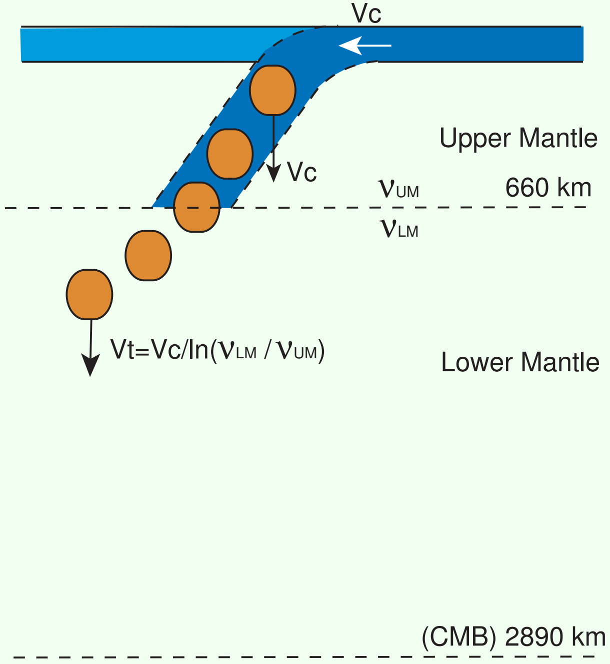


from Rouby, Greff-Lefftz and Besse, (2009)

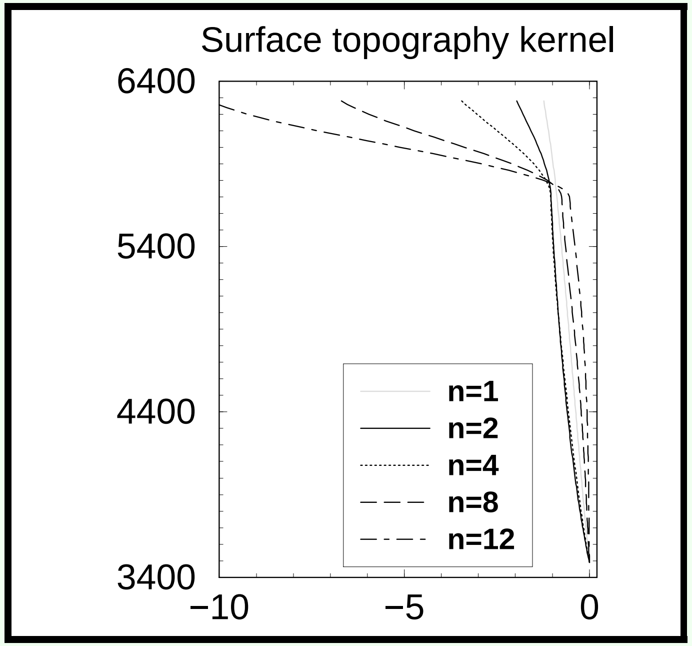
- Mass anomalies of the domes modeled from tomography (Mégnin and Romanovitch, 2000) within the lower mantle: at each depth, the mass anomalies are spherical sheets

- Domes stable over the last 120 Ma.

Mantle Downwellings



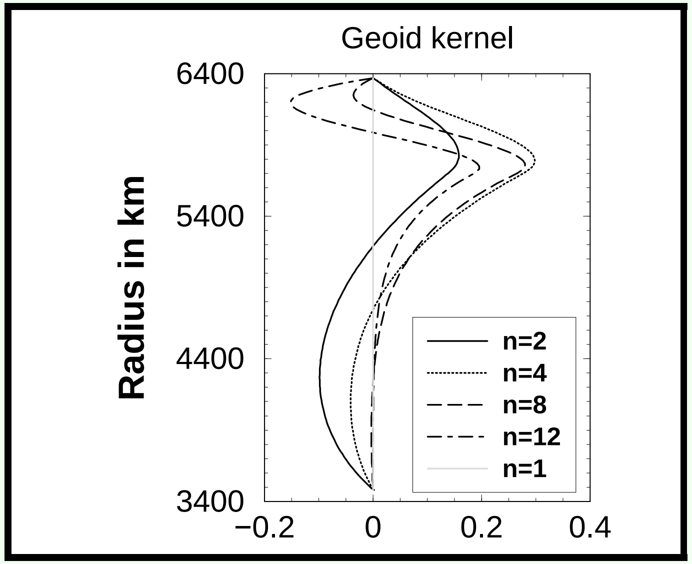
- **Input:** position of the subduction zones and surface velocities since 250 Myr.
- **Hypothesis:** Subducted plates sink vertically into the mantle [*Ricard et al., 1993*]
- **Output:** Temporal evolution of the mantle density heterogeneities since 120 Myr



- **Topography kernel:**

- Negative such as a positive mass anomaly in the mantle will induce a negative topography.

- Surface topography essentially induced by mantle density in the upper mantle.

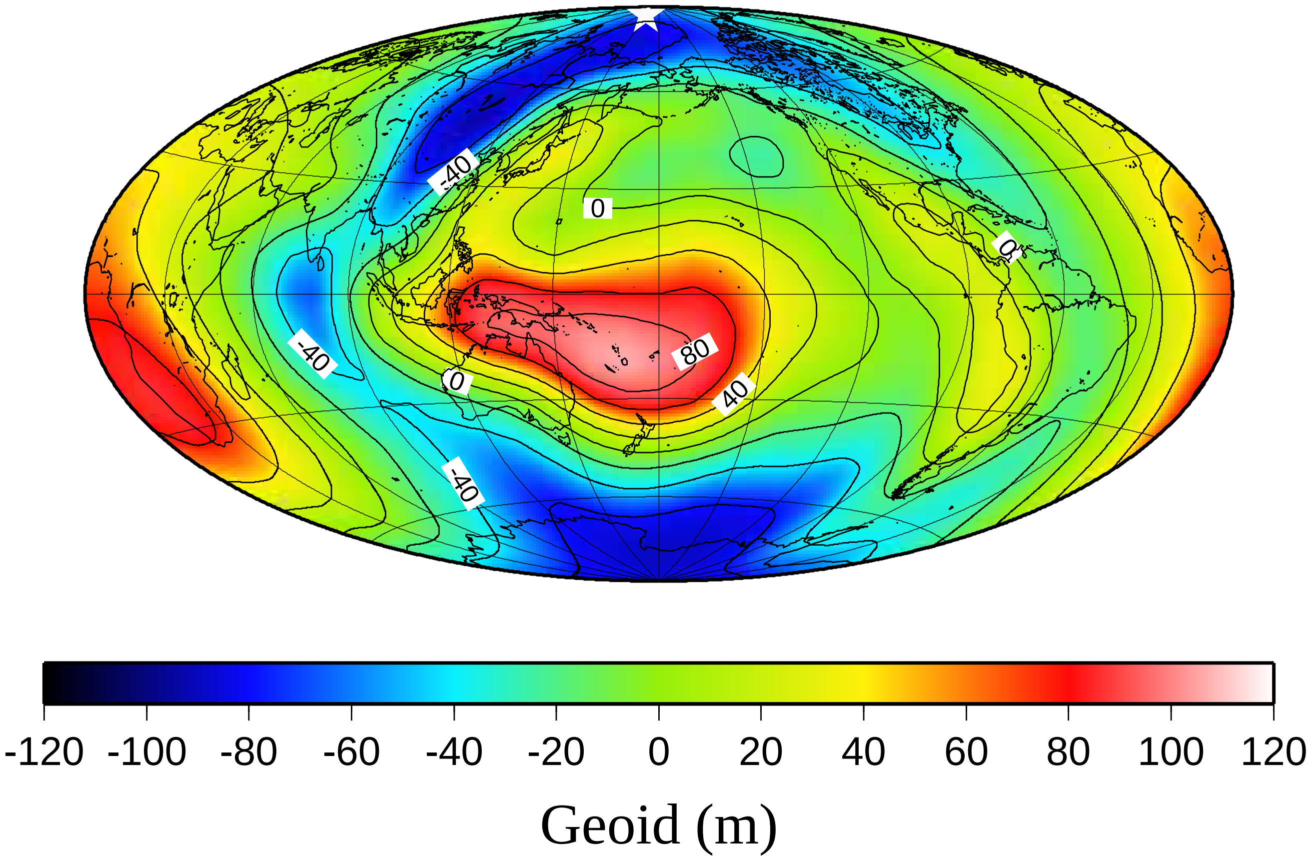


- **Geoid kernel:**

- A positive mass anomaly located in the upper part of the mantle will involve a positive geoid whereas a positive mass anomaly in the lower mantle will involve a negative geoid.

- The depth in which the geoid vanishes depends on the degree n. The larger is n, the larger is the depth.

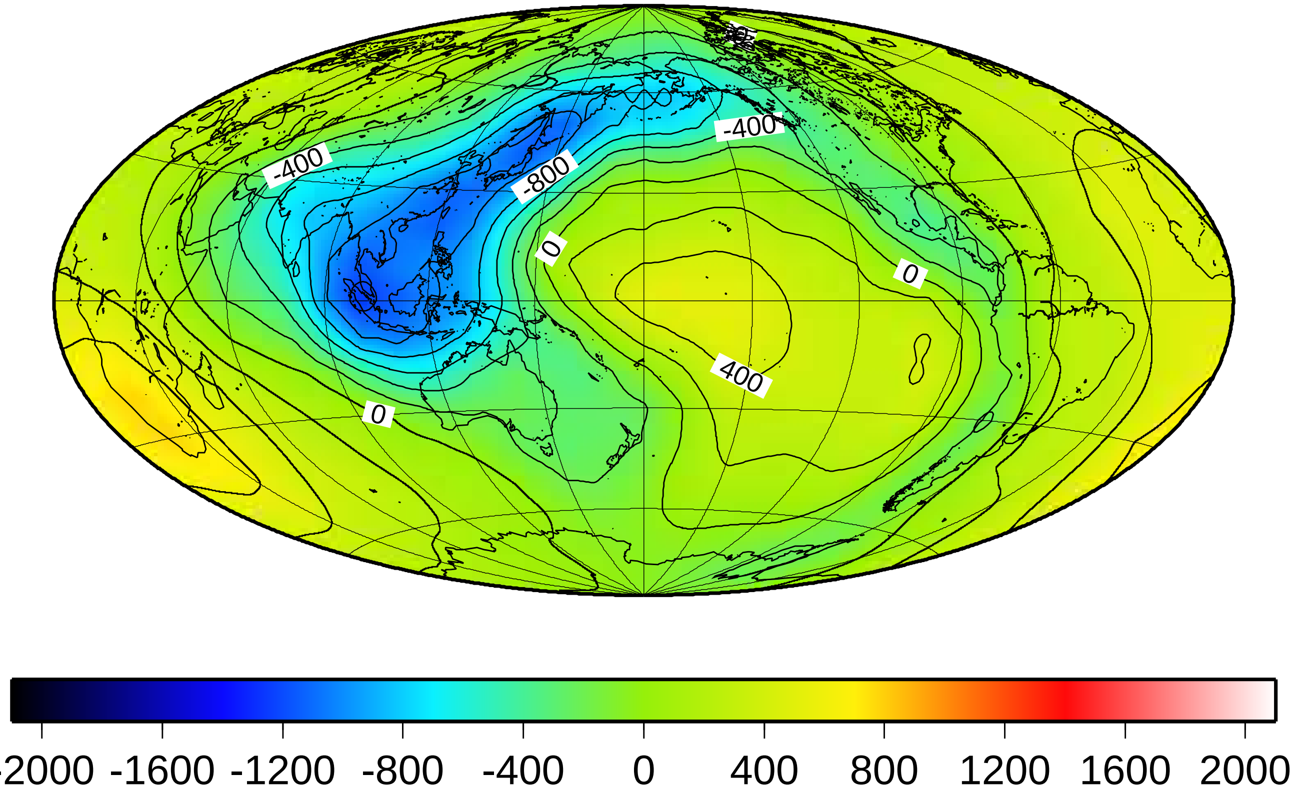
Present-day Geoid from degree 2 to 12



- Contour interval is 20 m.
- Variance reduction between the present computed and observed geoid of $\Phi = 0.91$ for the degree 2 alone, and $\Phi = 0.79$ for degree 2-12.

from Rouby, Greff-Lefftz and Besse, 2009.

Present-day Surface topography from degree 1 to 12

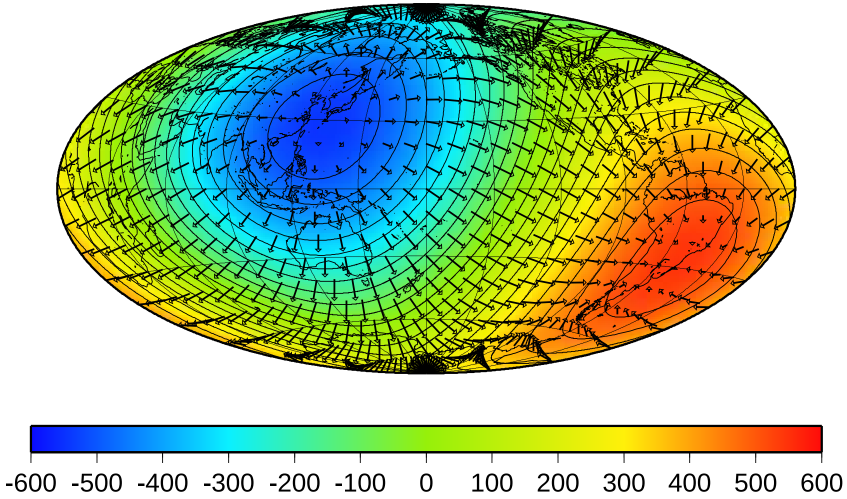


Present-day surface topography (in meter)

- Contour interval is 200 m.

from Greff-Lefftz, Métivier and Besse, 2010.

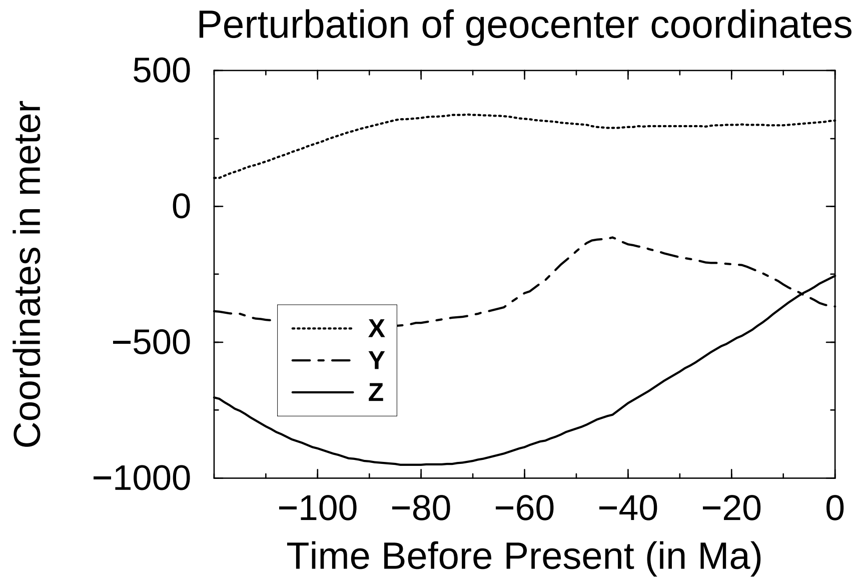
Geocenter



Degree on present-day topography in meter, with contour interval of 50 m

⇒ **Translation of about** 550 **meters toward the direction** $-28^o S$, $311^o E$.

⇒ $\left[X, Y, Z\right] = \left[316, -368, -256\right]$ **m**



⇒ **Present rate of secular variation of the geocenter:**

$\dot{X} = 0.17;\ \ \dot{Y} = -0.85;\ \ \dot{Z} = 1.12\ \ \mathrm{mm/Cy}$

Conclusion

- **Decadal geocenter variation induced by pressure at the core boundary:**

Translation < 1 mm with a rate about 1 mm/Cy

- **Secular geocenter variation induced by PGR:**

Translation of ten meters towards the opposite direction of Laurentide with a rate from 0.1 to 1 mm/yr

- **Geological geocenter variation induced by mantle dynamics:**

Discrepancy of about a few hundred meters between the center of figure and the center of mass of the Earth with a rate about 1 mm/Cy

Is there possible to detect such a static geocenter with the geodetical data ?