Simulations to the tides of ancient oceans and the evolution of the Earth-Moon-system

Universität Hamburg – DER FORSCHUNG | DER LEHRE | DER BILDUNG

MIN Faculty
Department of Informatics
Scientific Computing

DFG Deutsche Forschungsgemeinschaft

Max-Planck-Institut für Meteorologie

GFZ Helmholtz Centre Potsdam

Helmholtz Association

P. Nerge, University of Hamburg; T. Ludwig, University of Hamburg; M. Thomas, GFZ German Research Centre for Geosciences; J. Jungclaus, Max Planck Institute for Meteorology; J. Sündermann, University of Hamburg; P. Brosche, University of Bonn

Contact: petra.nerge@informatik.uni-hamburg.de

Abstract

The angular momentum transfer in the Earth-Moon system is mainly determined by the ocean tides and closely interlinked with their resonance characteristics (e.g. Brosche and Sündermann, 1971; Thomas and Sündermann, 1999). The latter are considerably presupposed by the topography of the ocean basins which has changed significantly in the Earth's history.

For the current epoch astronomic and geodetic observations confirm a secular increase of the length of day of ca. 2 ms/century and a lunar recession rate of ca. 4 cm/year (Williams, J.D., et al., 2008), which equals a decrease of Earth's rotational energy of ca. $4 \cdot 10^{12}$ W.

The limited availability of geological proxy data has so far prevented a detailed quantification of the transfer of angular momentum in the Earth-Moon-system far back in the Earth's history. Considering recent palaeontological data and advances in computing science the project GeOGEM (Modellrechnungen zu den Gezeiten früherer Ozeane und zur Geschichte des Erde-Mond-Systems), funded by the DFG, will strive to reduce these deficits.

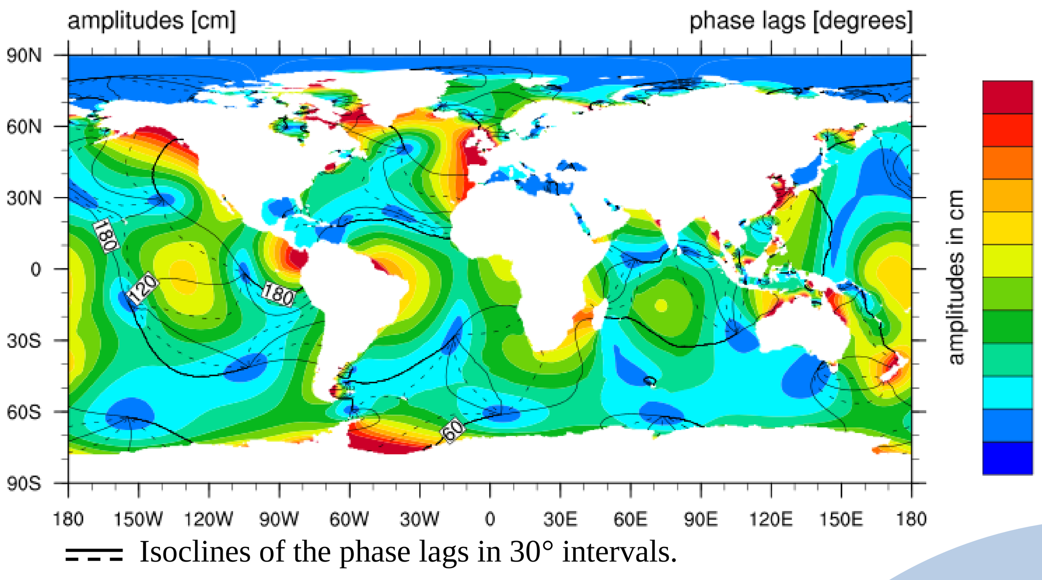
Firstly, self-consistent geological data on ocean tides, Earth's rotational parameters and orbital elements of the Moon have been provided by the research of Williams (2000) on the sediment layers of South Australia for the Neoproterozoic ~620 Ma back. For this time slice we will reconstruct the spatial and temporal characteristics of the tides by means of simulations with the three-dimensional Max-Planck-Institute-Ocean circulation model (MPIOM) forced by the complete tidal potential expressed by the ephemerides. The numerical results will be evaluated with the recent geological proxy data.

Subsequently, the evolution of the ocean tides under the influence of the continental drift from the Neoproterozoic till today will be simulated. In this process a focus will be on the transfer of angular momentum between Earth and Moon in order to explain physically the geological proxy.

Starting Point

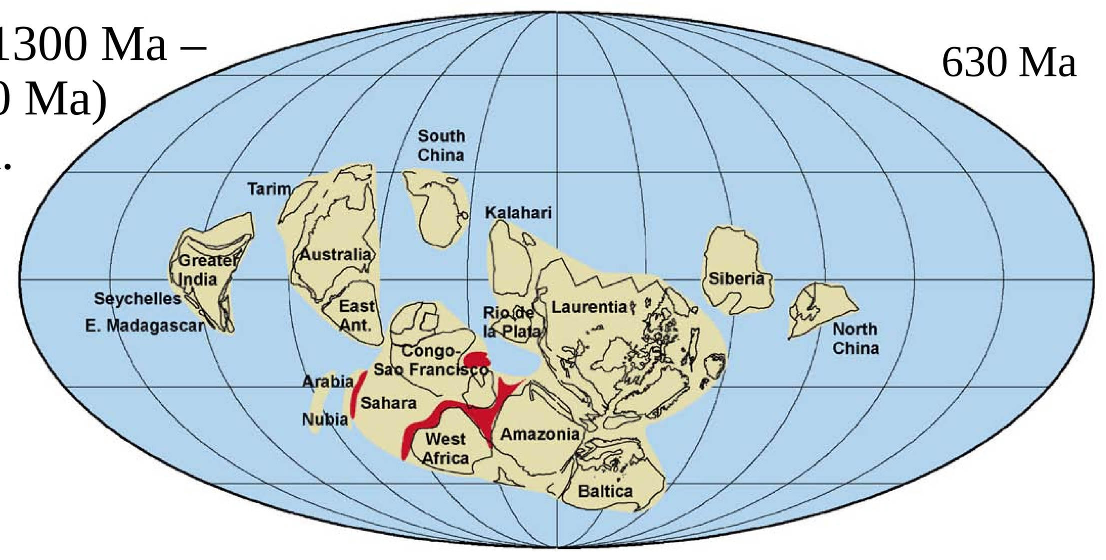
Present M_2 ocean tide simulated by MPIOM

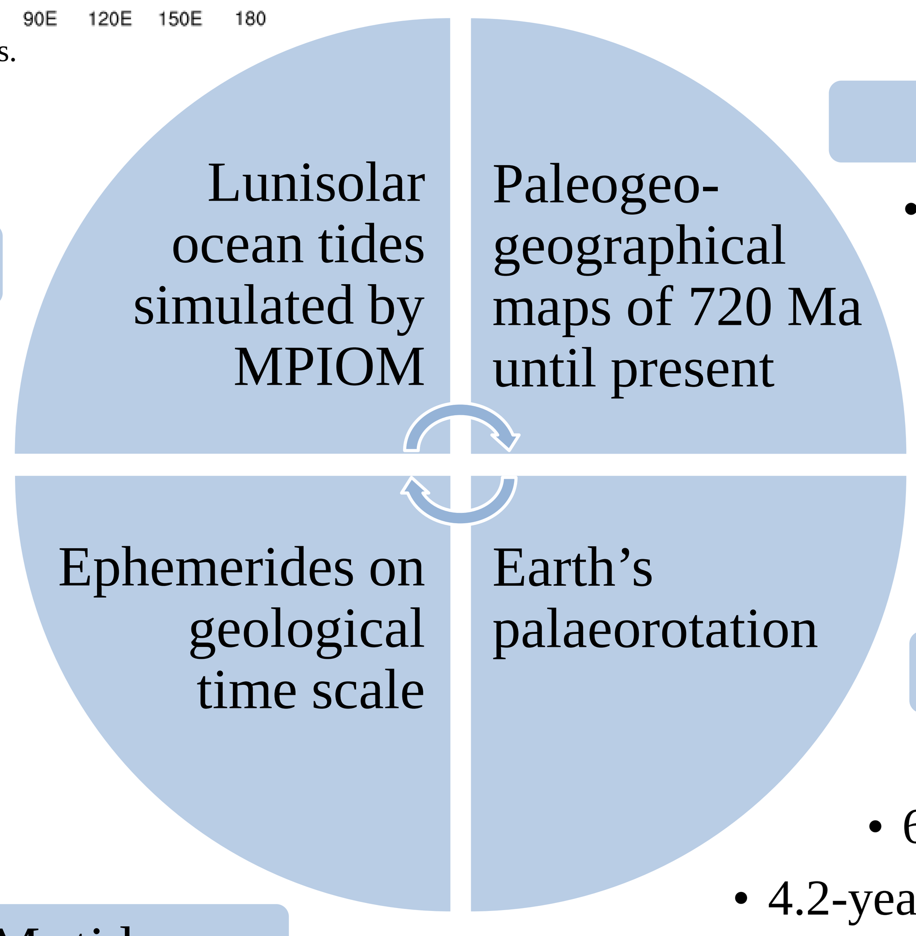
- Bi- or tripolar grid (here with the poles on North America, Asia, and Antarctica).
- The grid poles are freely selectable and the resolution around Australia can efficiently increased for evaluation of the results.
- MPIOM has been used for palaeoclimate studies e.g. for the warm Paleocene/Eocene (Heinemann et al., 2009).



Maps of the Neoproterozoic, Li et al. (2008)

- Synthesis on the formation (1300 Ma – 900 Ma) and break-up (<600 Ma) of the supercontinent Rodinia.
- 530 Ma formation of Gondwanaland completed.
- Based on palaeomagnetic constraints and on geological correlations.





Maps of the Phanerozoic

- Li and Powell (2001), Schettino and Scotese (2005), Müller et al. (2008), and the Paleomap Project of C. R. Scotese.

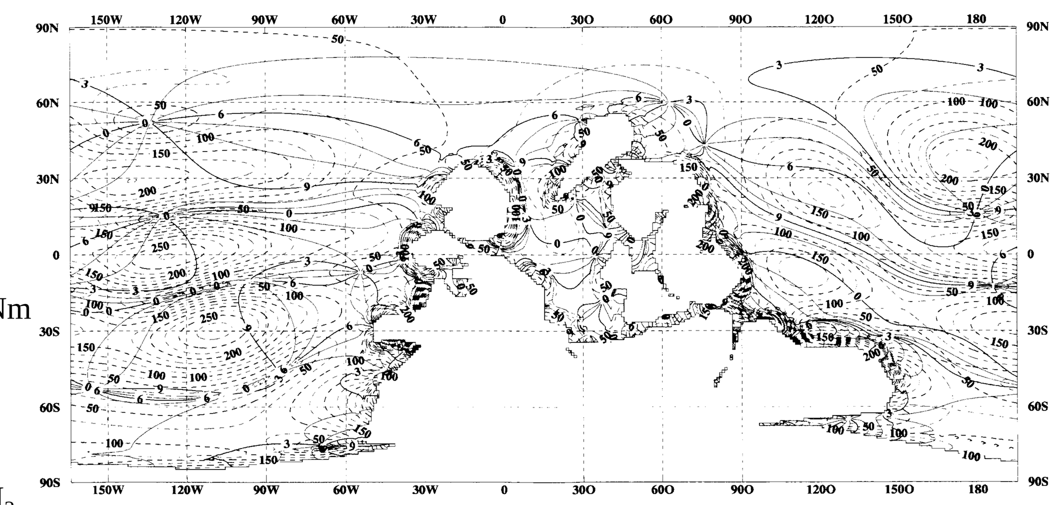
Palaeobathymetry

- The shelf and the ocean will be taken into consideration as well as possible (Williams, G.E., et al., 2008; Li and Powell, 2001).

M_2 ocean tide for topographies of the Proterozoic

— Isoclines of the phase lags in 30° intervals.
- - - Isoclines of the amplitudes in 25 cm intervals.

max. $\langle L_{tid} \rangle_z = 7.1 \cdot 10^{16}$ Nm at $T_{M2} = 8.99$ h ($\langle L_{tid} \rangle_z$: Mean tidal torque along the Earth's rotation axis, T_{M2}: Period of the M_2 tide)



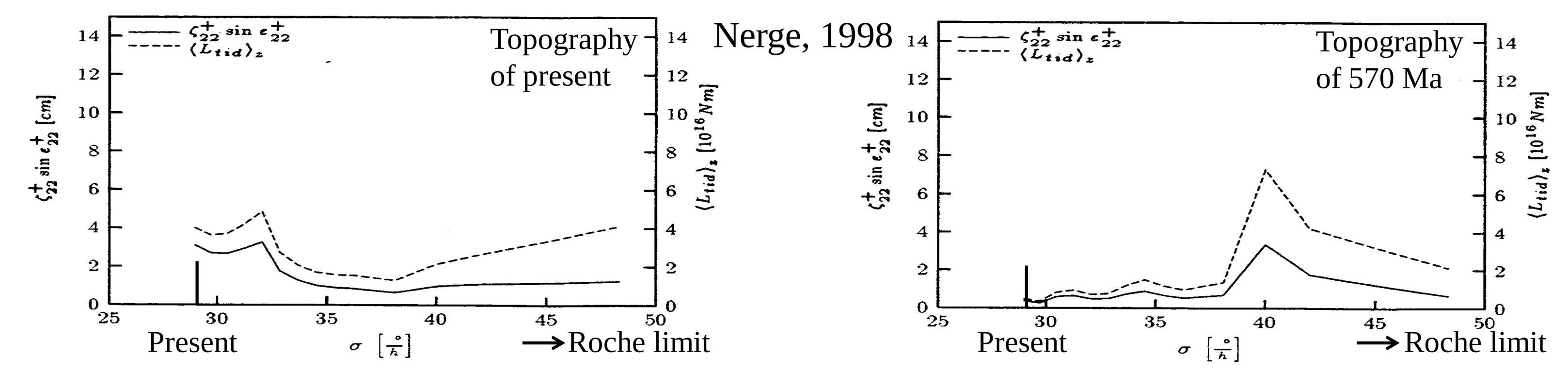
Nerge, 1998

Palaeorotation parameters, Williams (2000)

- Analysis of sedimentary rhythmites from South Australia.
- 60-year record of 1580 neap-spring cycles.
- 4.2-year record of 1337 diurnal laminae from 110 neap-spring cycles.

Palaeorotation parameters	~620 Ma	Present
Lunar days per synodic month	29.5 ± 0.5	28.53
Solar days per synodic month	30.5 ± 0.5	29.53
Solar day per sidereal month	28.3 ± 0.5	27.32
Synodic months per year	13.1 ± 0.1	12.37
Sidereal months per year	14.1 ± 0.1	13.37
Lunar apsides periode [a]	9.7 ± 0.1	8.85
Lunar nodal periode [a]	19.5 ± 0.1	18.61
Solar days per year	400 ± 7	365.24
Length of solar day [h]	21.9 ± 0.4	24.00
Lunar semimajor axis [R_E]	58.16 ± 0.30	60.27

Tidal torque in relation to the angular velocity σ of the M_2 tide



Ephemerides on geological time scale

- Astronomical computation of the insolation quantities on Earth spanning from -250 Ma to 250 Ma (Laskar, 2004).
- Collaboration with J. Laskar, Observatoire de Paris, Institut de mécanique céleste et de calcul des éphémérides (IMCCE), and U. Röhl, Center for Marine Environmental Sciences (MARUM), University of Bremen.

Outlook

Earth's system research

One considerably denser reconstruction of the tidal dynamic from Neoproterozoic till present and an important component of the evolution of the Earth-Moon system.

Geodesy and Astronomy

Energy and angular momentum budgets for the evolution of the Earth-Moon system – Dissipative effects by tidal friction are one of the main uncertainties.

Geology

Analysis of periodic growth features or sedimentary rhythmites.

The oceanographic data and the ensuing data to the celestial mechanics will be stored and made available at German Climate Computing Center (DKRZ).

References

Brosche, P., Sündermann, J., 1971. Pure App. Geophys., 86, 95–117.
Heinemann, M., et al., 2009. Climate of the Past, 5, 785-802.
Laskar, J., et al., 2004. A&A, 428(1), 261–285.
Li, Z.X., Powell, C.M., 2001. Earth-Sci. Rev., 53, 237-277.
Li, Z.X., et al., 2008. Precambrian Res., 160, 179–210.
Müller, D., et al., 2008. Science 319, 1357.
Nerge, P., 1998. Diplomarbeit, Inst. für Meereskunde, Uni. Hamburg, Germany. 117p.
Schettino, A., Scotese, C.R., 2005. Geophys. J. Int., 163, 727-759.
Thomas, M., Sündermann, J., 1999. J. Geophys. Res., 104, C2, 3159–3183.
Williams, G.E., 2000. Rev. Geophys., 38, 37–59.
Williams, G.E., et al., 2008.Precambrian Res., 163, 307-331.
Williams, J.G., et al., 2008. JPL IOM 335-JW,DB,WF-20080314-001, March 14, 2008.

Acknowledgement

We are grateful for the support from the German Research Foundation through the grant LU 1353/6-1, the German Academic Exchange Service through the grant 55934490 funded by the Federal Ministry of Education and Research, and the German Climate Computing Center.