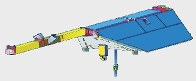

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Ocean Tidal Dynamo Identified in CHAMP Satellite Magnetic Data

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Sea water is an electrical conductor. As it is moved by ocean flow through the Earth's magnetic field, electrical currents are induced. These currents generate secondary magnetic fields which have now been identified for the first time in satellite magnetic data.

Physical background

Dissolved salts in sea water form hydrated, electrically charged ions. As the charged ions are carried by the ocean flow through the Earth's magnetic field they are deflected by the Lorentz force. This induces electric fields and associated currents which in turn generate secondary magnetic fields [1-3].
Ocean generated magnetic fields can be divided into toroidal and poloidal parts. The toroidal field reaches 100 nT in amplitude but is confined to the ocean and sediments. It is therefore not observable remotely. The poloidal field, on the other hand, is much weaker (1-10 nT) but includes large spatial decay scales allowing it to reach remote land and satellite locations. It results from electric current circuits closing horizontally. These currents are generated by large-scale integrals of flow transport quantities.

Motional induction by ocean flow (the subject of this poster) is distinctively different from induction by time-varying external fields in the ocean as a quasi-static conductor:

Induction in a *static* conductor:

Time variations of an inducing magnetic field B induce an electric field E

$$\partial_t \mathrm{B} = -\nabla \times \mathrm{E}$$

which drives an electric current $\mathrm{J} = \sigma \mathrm{E}$

generating an induced magnetic field $\nabla \times \mathrm{B} = \mu_0 \mathrm{J}$

$$\Rightarrow \quad \partial_t \mathrm{B} = -\nabla \times \left(\frac{1}{\mu_0 \sigma} \nabla \times \mathrm{B}\right)$$

Induction in a *moving* conductor:

The current in the conductor is $\mathrm{J} = \sigma(\mathrm{E} + \mathrm{v} \times \mathrm{B})$

$$\Rightarrow \quad \partial_t \mathrm{B} = \nabla \times \left(\mathrm{v} \times \mathrm{B} - \frac{1}{\mu_0 \sigma} \nabla \times \mathrm{B}\right)$$

Setting $\mathrm{B} = \mathrm{B}_{\mathrm{main}} + \mathrm{B}_{\mathrm{ocean}}$ and considering that

- the induced ocean field is small
- the curl of the main field vanishes outside of the core

$$\Rightarrow \quad \partial_t \mathrm{B}_{\mathrm{ocean}} = \nabla \times \left(\mathrm{v} \times \mathrm{B}_{\mathrm{main}} - \frac{1}{\mu_0 \sigma} \nabla \times \mathrm{B}_{\mathrm{ocean}}\right)$$

Observatory data

Ocean dynamo generated magnetic fields have long been identified in observatory data [4]. However, from observatory data it is difficult to distinguish between tides of the ionosphere, induction by these time varying external tidal fields, and a genuine ocean flow signal. This difficulty is illustrated on Z-component data from 3 German observatories (Fig.1 and 3).

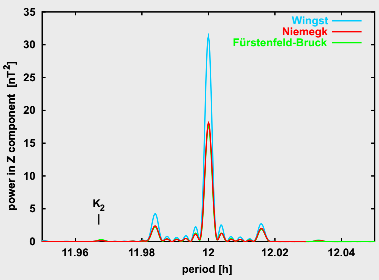

Fig. 1: The strong S2 peak is primarily caused by the Sq current system and associated induced currents.

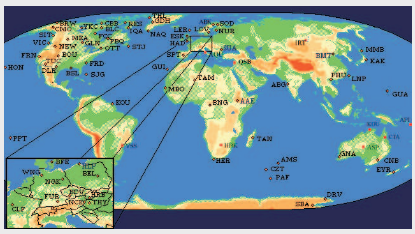

Fig. 2 Intermagnet observatory locations. The Z-component data displayed in figures 1 and 3 are from WNG, NGK and FUR which are located in increasing distance from the sea.

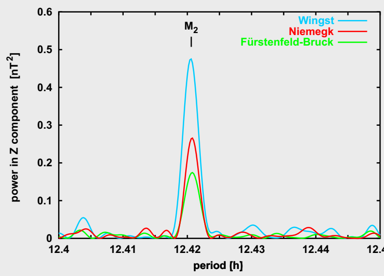

Fig. 3: Compared to the S2 peak, the M2 peak is much weaker. The amplitude now reflects the distance of the observatory to the ocean. Hence, the M2 peak is likely to be a genuine ocean signal.

Satellite data

From the first 2 years of CHAMP total field magnetic measurements we select magnetically quiet periods by using only the night time data (22:00 to 6:00 local time) and discarding periods with a magnetic activity index $K_p > 2$.

The analysis is restricted to track segments of -60 to 60 degrees geomagnetic latitude. Selected track segments are shown in Figure 4.

After subtracting those parts of the CO2 field model [5] which account for the time varying main field, stable magnetospheric fields and the ring current modulated by the Dst index, residuals are still too noisy to identify the weak ocean dynamo signal (Fig. 5) .

To remove long wavelength magnetospheric and ionospheric noise we fit and subtract a best-fitting degree-1 external field (2 parameters) and an independent internal dipole field aligned with the main field dipole (1 parameter). This clarifies the signal substantially (Fig. 6)
but also takes out long wavelength parts of the ocean dynamo signal (see the difference between Fig. 9 and 10).

In the future, this filtering can possibly be substituted by a joint inversion of multiple satellite and ground observatory data.

Prior to the harmonic analysis of the satellite magnetic residuals we further subtract the MF1 crustal magnetic field model [6].

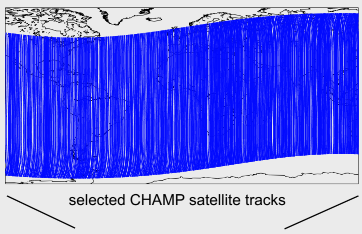

Fig. 4: In order to stay clear of the ionospheric polar electrojets we limit the analysis to track segments extending from -60 to 60 degrees geomagnetic latitude. A total of 2600 segments of quiet night time data are selected.

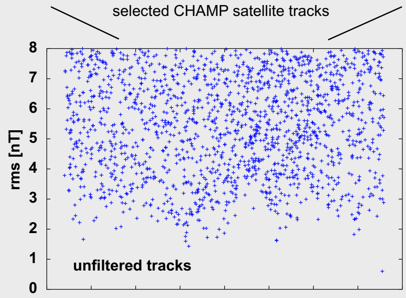

Fig. 5: Root mean square (rms) residuals of the selected track segments against the longitude of the equator crossing. Even after correcting for the magnetospheric ring current the residuals are still dominated by time varying magnetospheric fields.

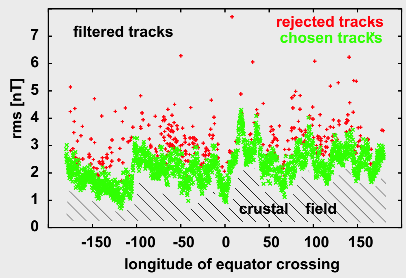

Fig. 6: Along-track high-pass filtering removes most of the long-wavelength magnetospheric noise. The crustal field is now clearly visible in the residuals. It is within the remaining scatter of approximately 1 nT in the selected data (green) that we identify a clear M2 tidal signal.