57th General Meeting
Main meeting 10th of March 2023
Stavanger

Wellbore Positioning Technical Section

The Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA)

On the Use of Adjacent Land-Based Magnetic Field Data to Correct for Geomagnetic Disturbances During Offshore Directional Drilling

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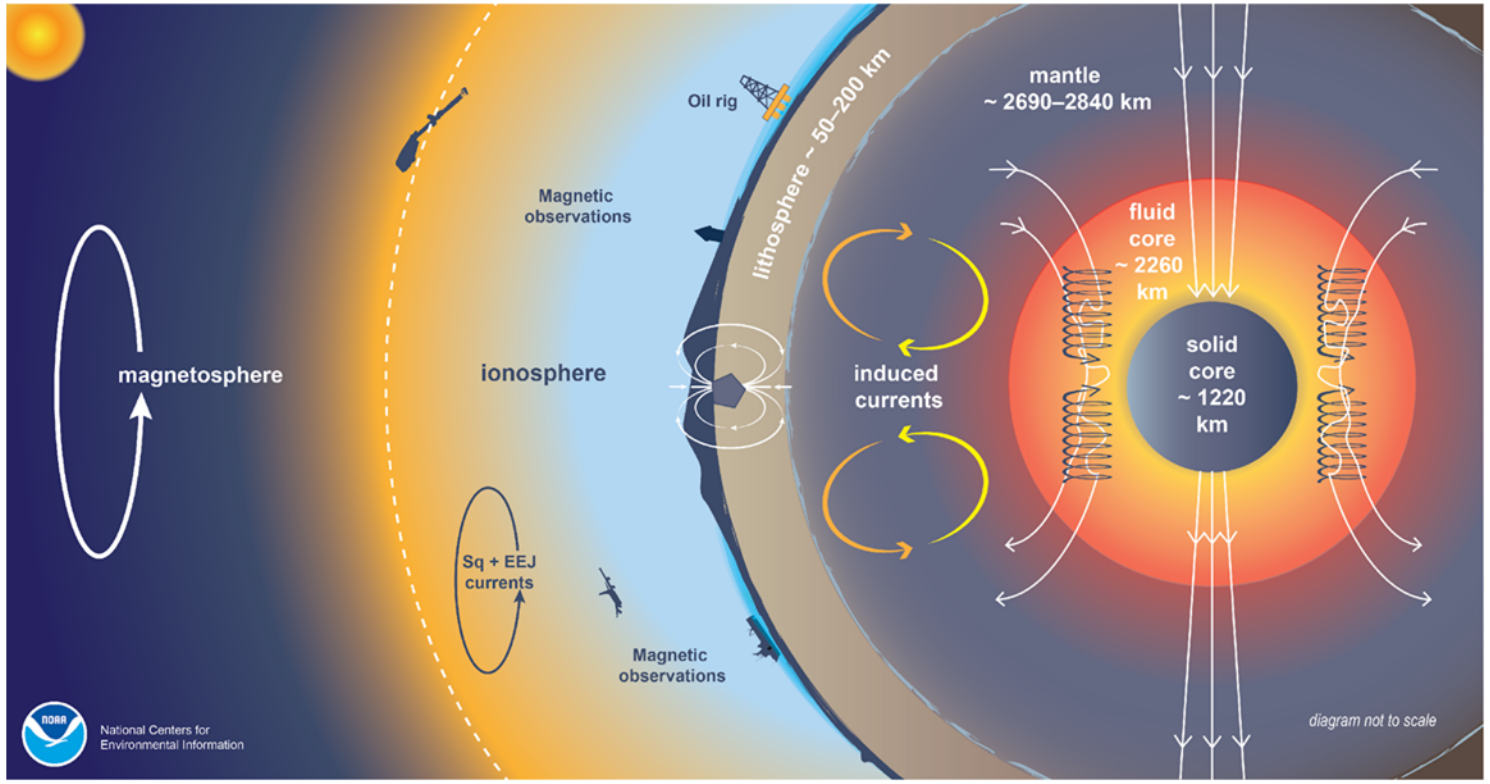
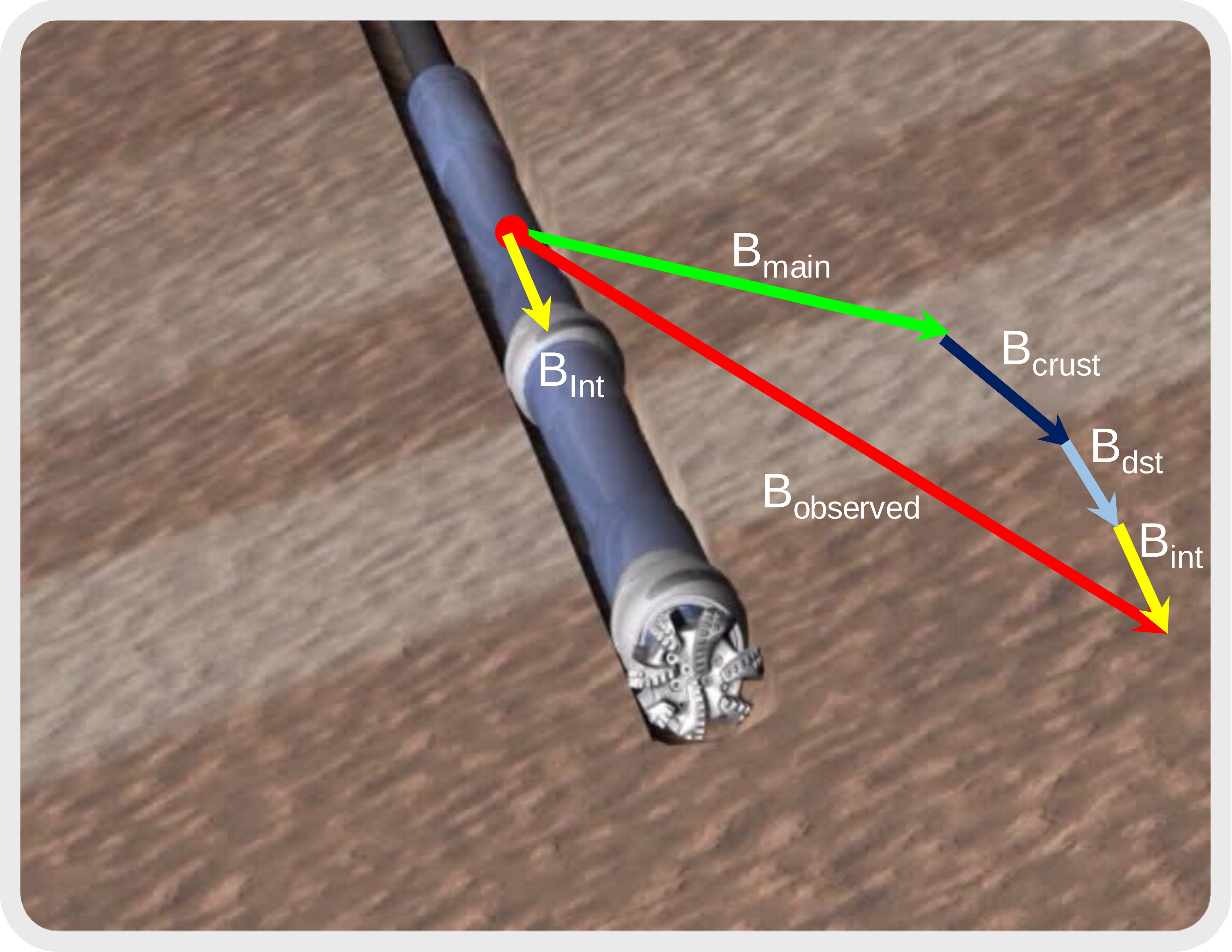
Roadmap

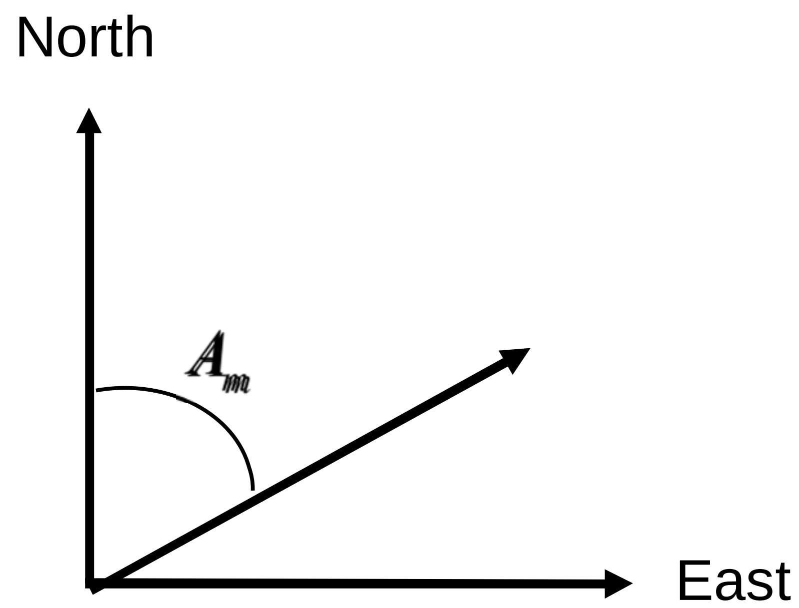
- MWD magnetics
- Electromagnetic induction in oceans
- Numerical simulation of EM effects
- Comparison of simulation results with seabed data
- Proposal for correction method to improve accuracy



The tri-axial magnetometer in the borehole assembly measures both the natural magnetic field and the magnetic interferences caused by the drill string.



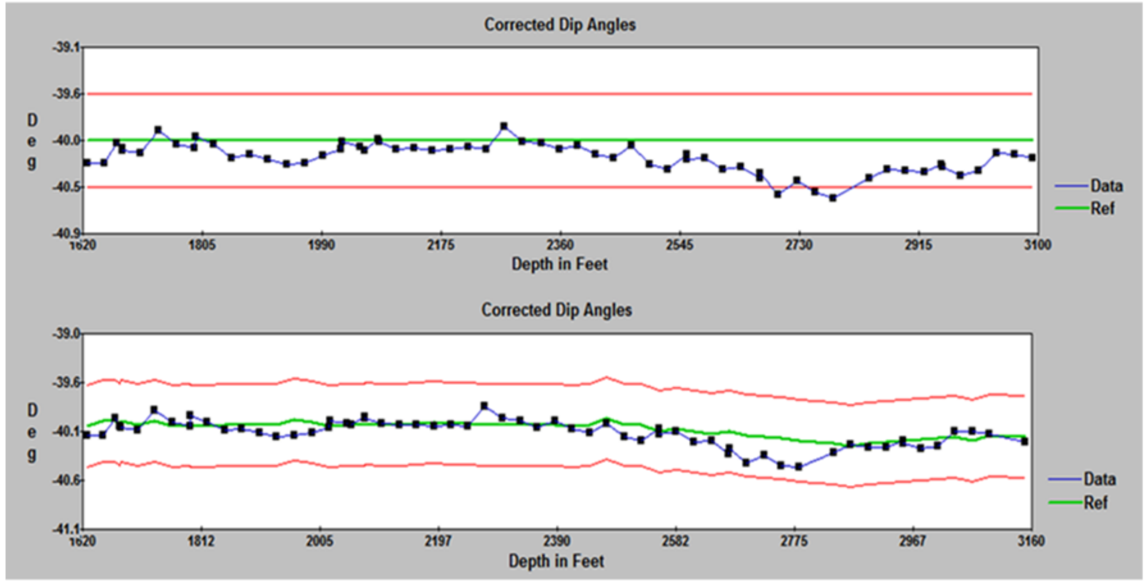
Use of magnetic data in MWD



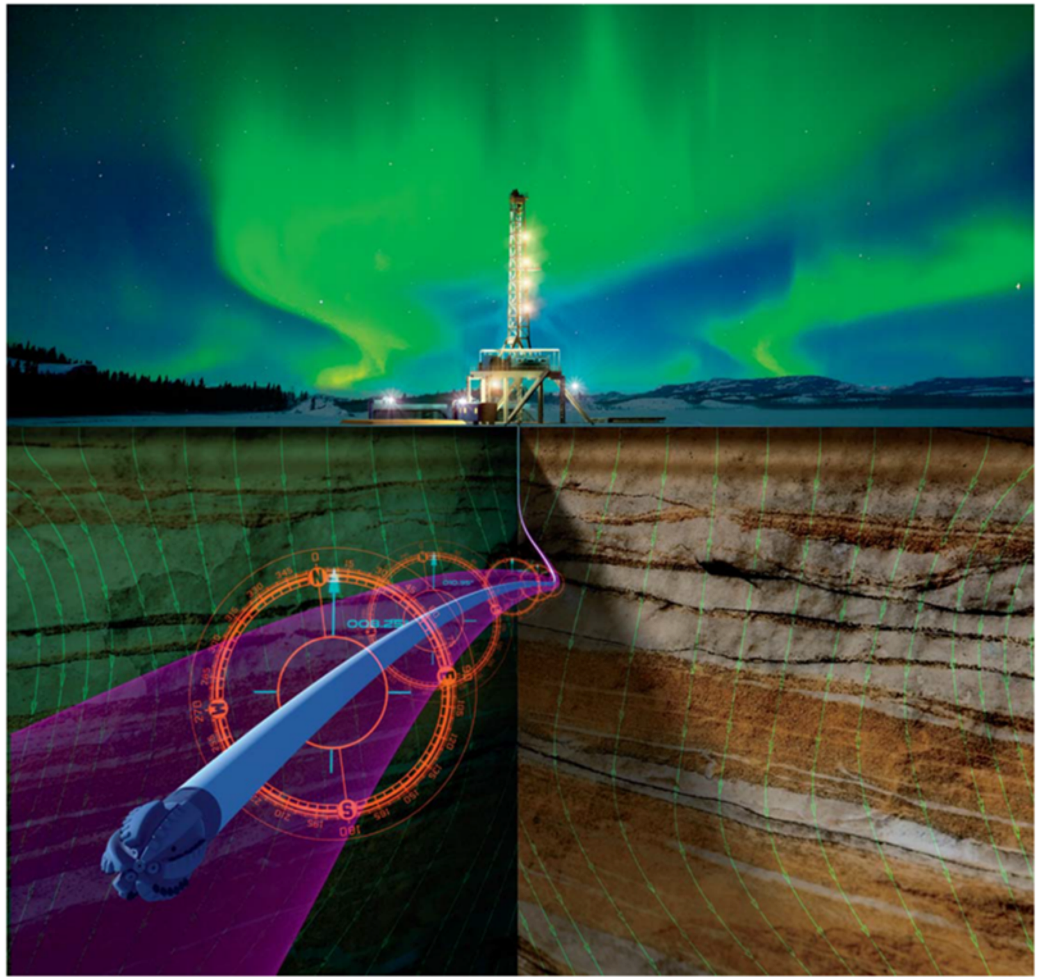
BHA measures the magnetic azimuth, which can then be used to calculate the true azimuth.

The strength and dip angle measurements obtained through MWD are utilized for quality control purposes and to reduce drill string interferences.

Requires external magnetic reference.



- The magnetic data obtained from BHA can be influenced by changing geomagnetic disturbances over time and space. This can cause the well to deviate from its predefined trajectory.



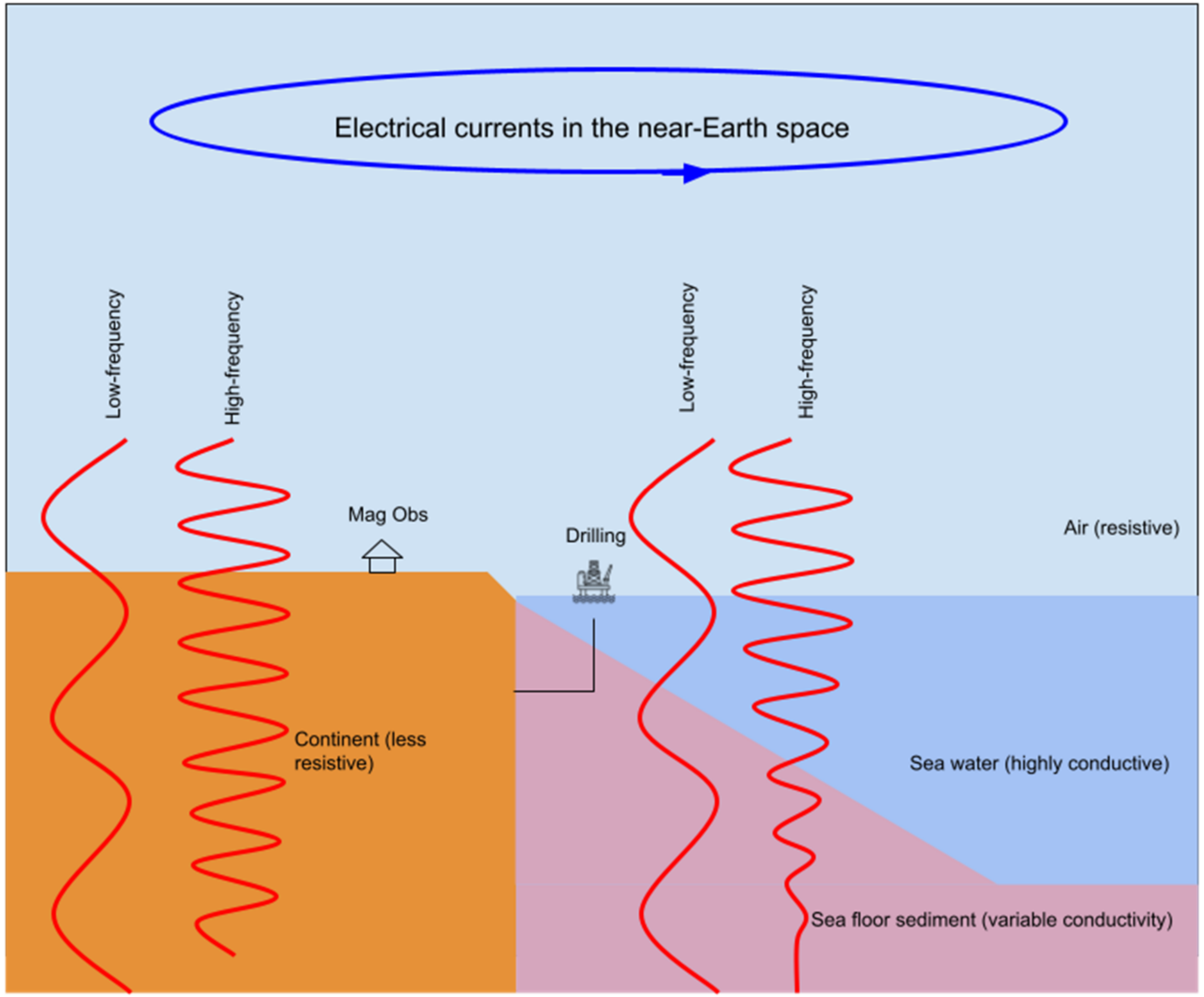
- A common method to address this issue is to use magnetic field measurements from a nearby land-based magnetic observatory/site to correct the magnetic field readings obtained from the BHA.

- But … this method assumes that the land-based signals are the same as at the seabed drilling site

- Using a 3-D electromagnetic simulation of geomagnetic storm activity, we will demonstrate that the magnetic fields in the sea level and seabed are significantly different because of the electrical conductivity of the seawater column

- Additionally, we will introduce and validate a framework that allows MWD operators to obtain accurate seabed signals using land-based data.

- Magnetic field variations are altered (attenuation, phase-shift) as they travel through the Earth and oceans due to electromagnetic induction.
- A function of the frequency of the field and the electrical conductivity of the material it is passing through.
- The skin-depth concept is used to describe how the field is attenuated as it penetrates into a material.
- In the real world, the depth-attenuation of magnetic fields is more complicated than the skin-depth concept alone can explain.



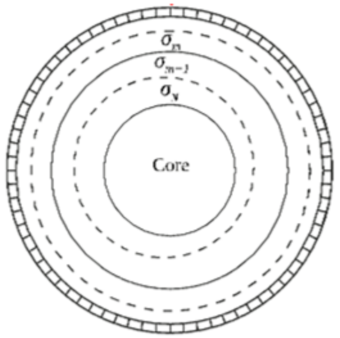
To create a realistic time-domain 3-D electromagnetic (EM) model of geomagnetic storm activity, several things are required:

- A 3-D electrical conductivity model of the Earth
- A spatio-temporal description of the source responsible for the geomagnetic storm activity
- Numerical tools capable of computing the magnetic field in a given 3-D conductivity model, excited by a given source.

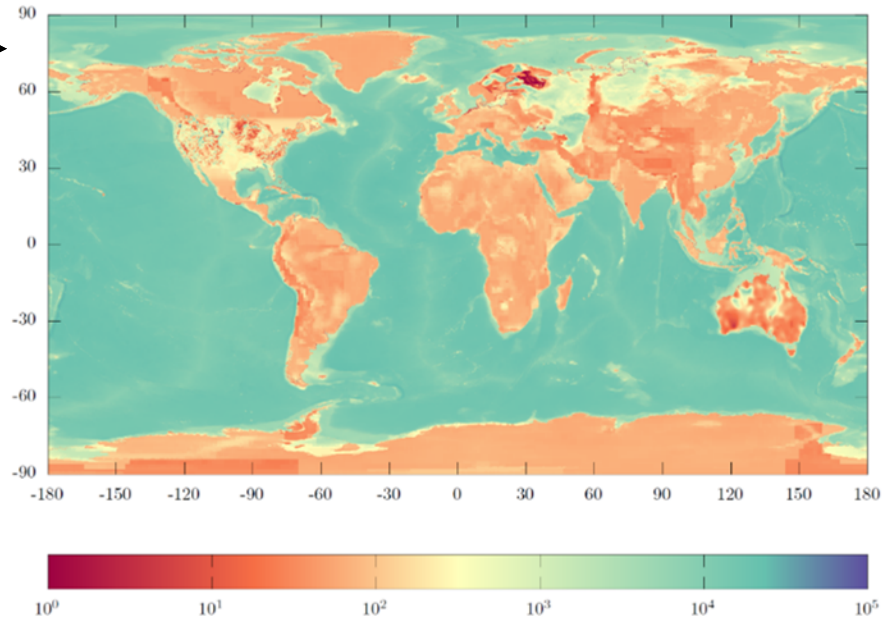
Electrical conductivity model of the Earth

- 3-D part of the model – nonuniform oceans and 1-D* mantle underneath

- Because we are analysing long-period signals with a period range of hours to days, we can simplify the representation of oceans by using a thin shell with laterally-variable conductance.



World conductance**



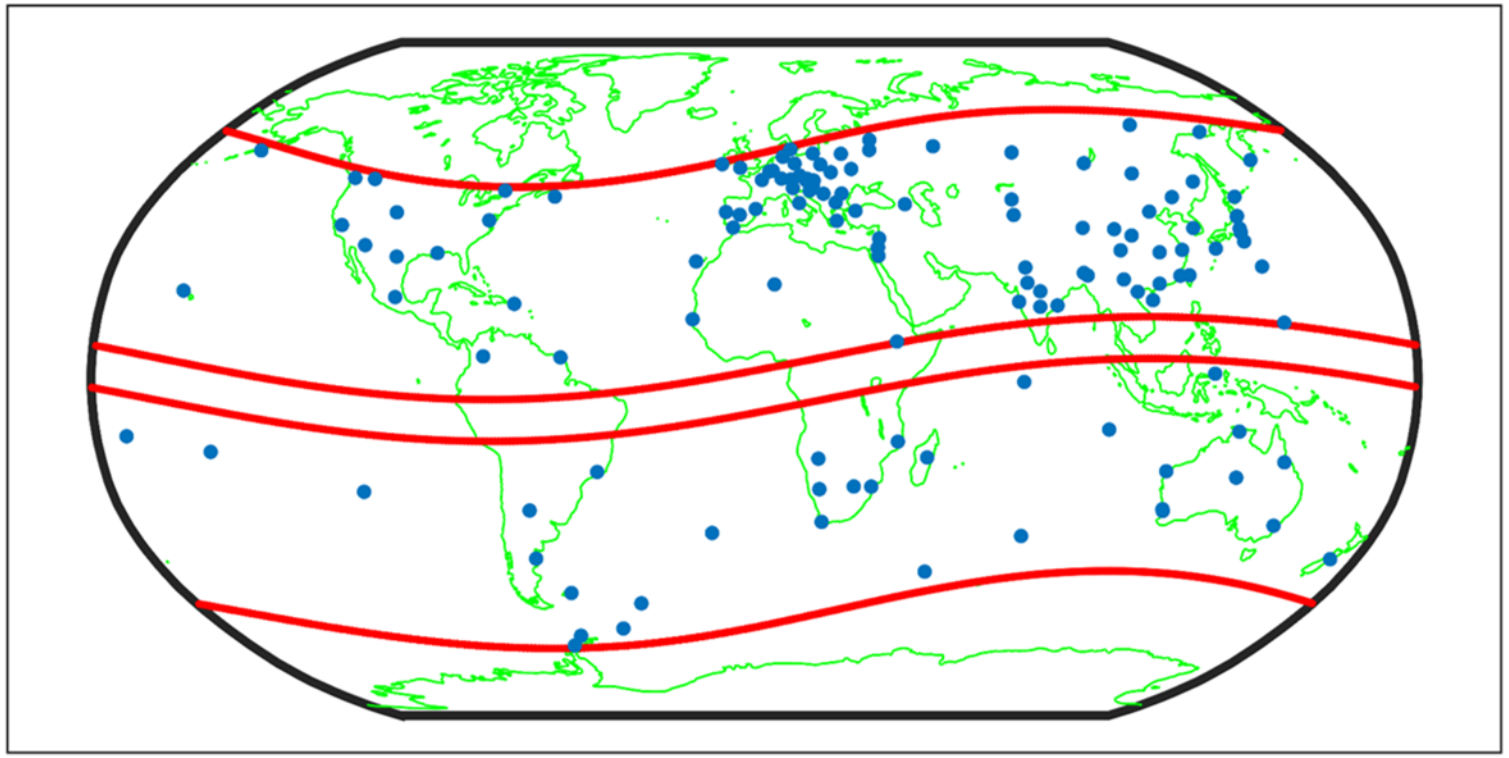
* Kuvshinov, A., A. Grayver A., L. Toffner-Clausen, N. Olsen, 2021. Probing 3-D electrical conductivity of the mantle using 6 years of Swarm, CryoSat-2 and observatory magnetic data and exploiting matrix Q-responses approach, Earth, Planets Space.

** Grayver A., 2021. Global 3-D electrical conductivity model of the World Ocean and marine sediments, Geochemistry, Geophysics, Geosystems.

** Alekseev D., A. Kuvshinov, N. Palshin, 2015. Compilation of 3-D global conductivity model of the Earth for space weather applications, Earth Planets Space.

Spatio-temporal description of the source responsible for the magnetic storm activity. Inputs:

- Hourly-mean time series of three components of magnetic field observed at mid-latitude observatories (1997-2019)
- Thin-shell conductivity model of the Earth

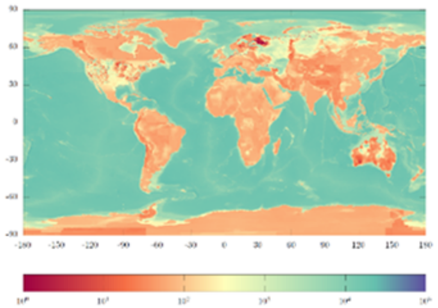


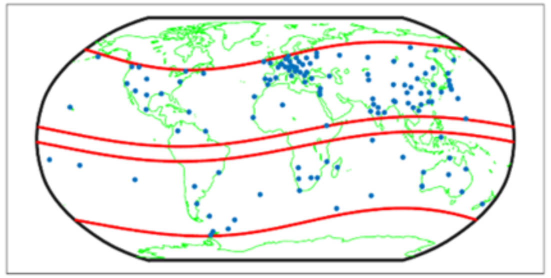
$$\mathbf{B}(\mathbf{r},t_k;\sigma)=\sum_{l,m}\sum_{n=0}^{N_t}\varepsilon_l^m(t_k-n\Delta t)\mathbf{M}^n_{\mathbf{B}_l^m}(\mathbf{r};\sigma)$$

Magnetic output at any location

Estimated from global observatory data

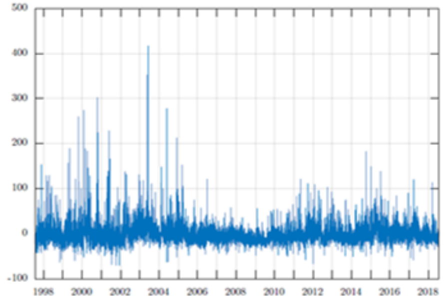
Precomputed using 3D conductivity model





We calculated (at 0.1^0 x 0.1^0 grid) magnetic field at sea level and seabed for several geomagnetic storms.

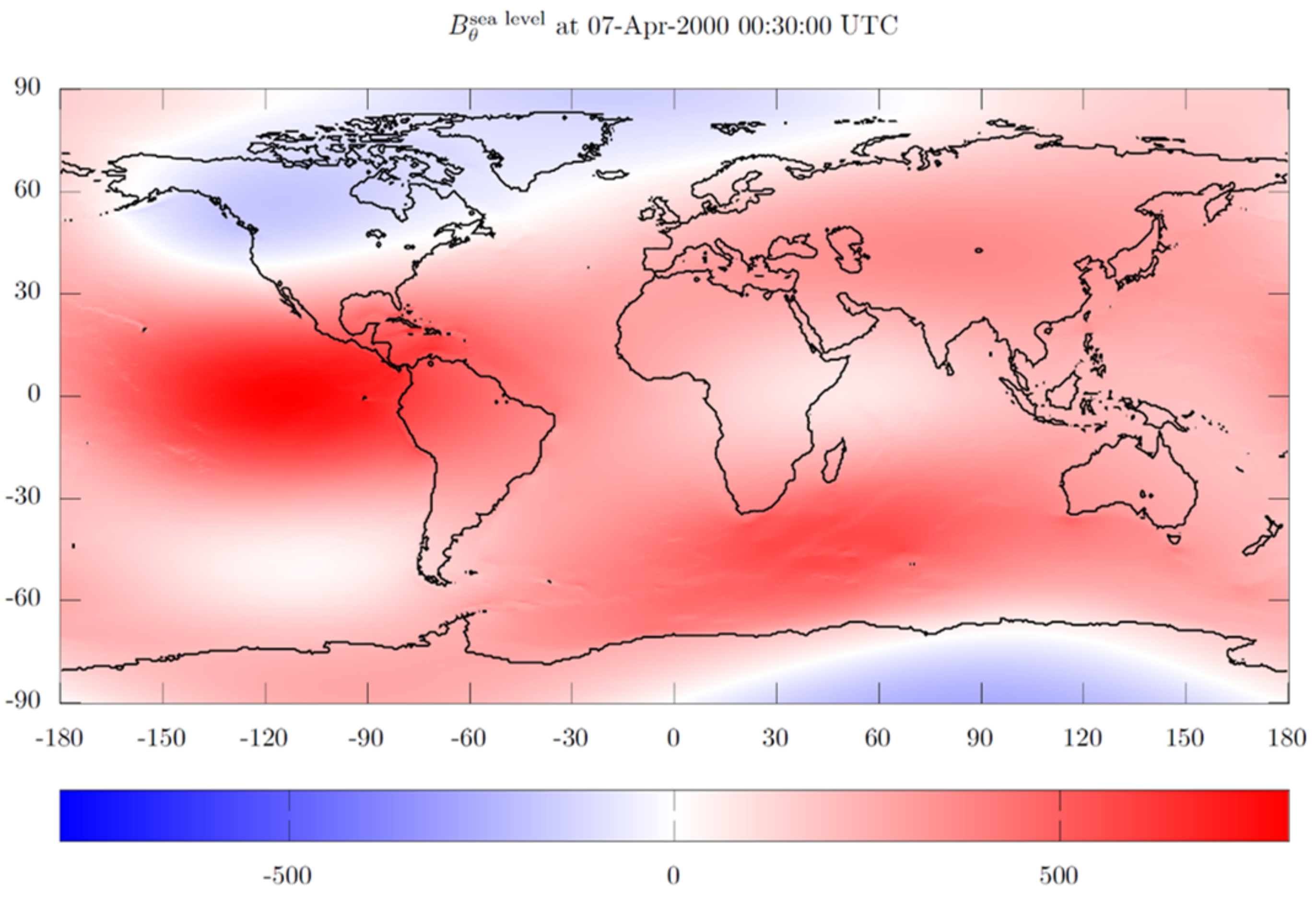
We demonstrate that the sea level and seabed magnetic fields differ significantly



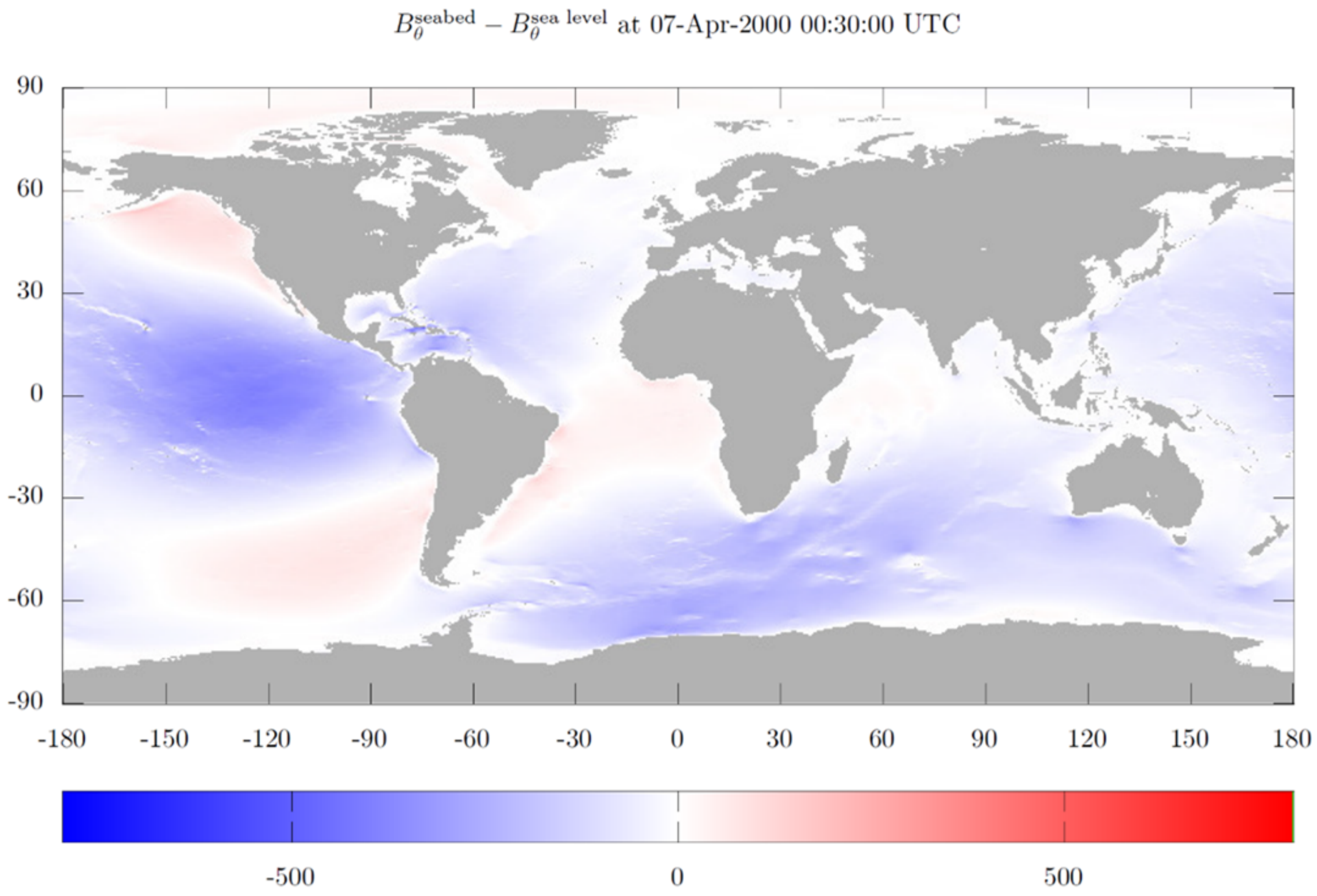
Kruglyakov, M., Kuvshinov, A., & Nair, M. (2022). A Proper use of the adjacent land-based observatory magnetic field data to account for the geomagnetic disturbances during offshore directional drilling. *Space Weather*, 20, e2022SW003238. https://doi.org/10.1029/2022SW003238

7 April 2000 storm; north-south component

Sea level



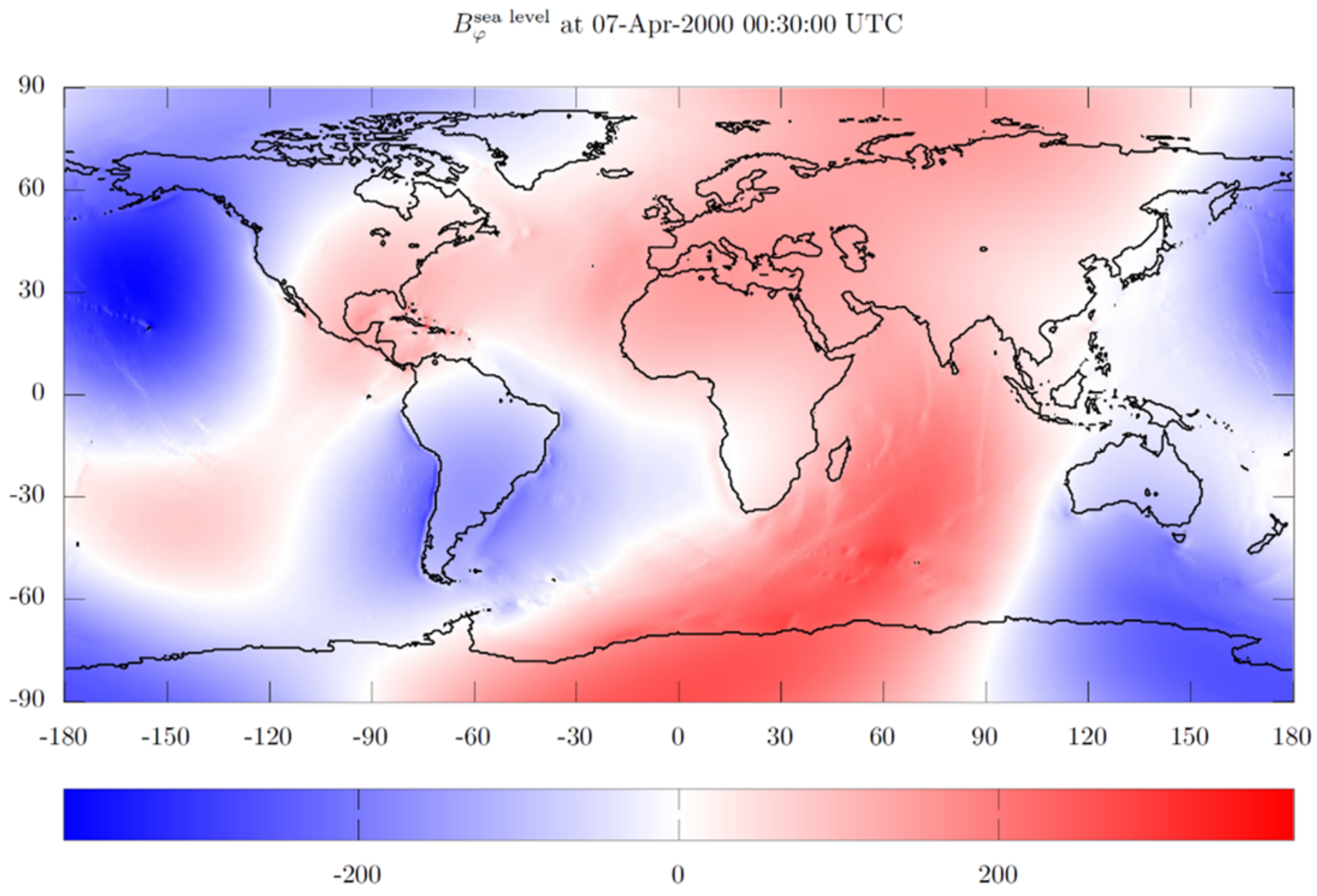
Seabed minus sea level



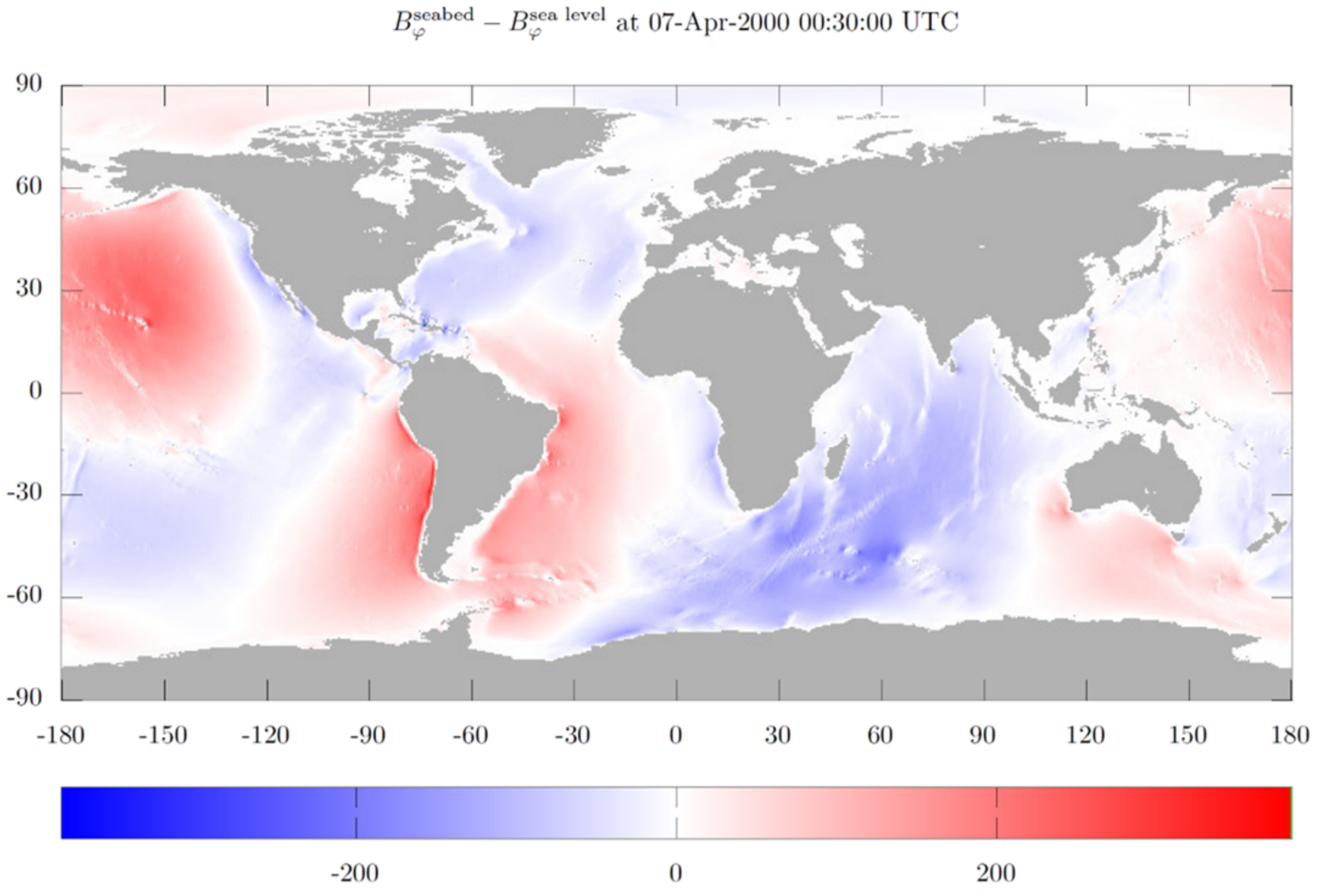
- The difference reaches 50 %

7 April 2000 storm; west-east component

Sea level



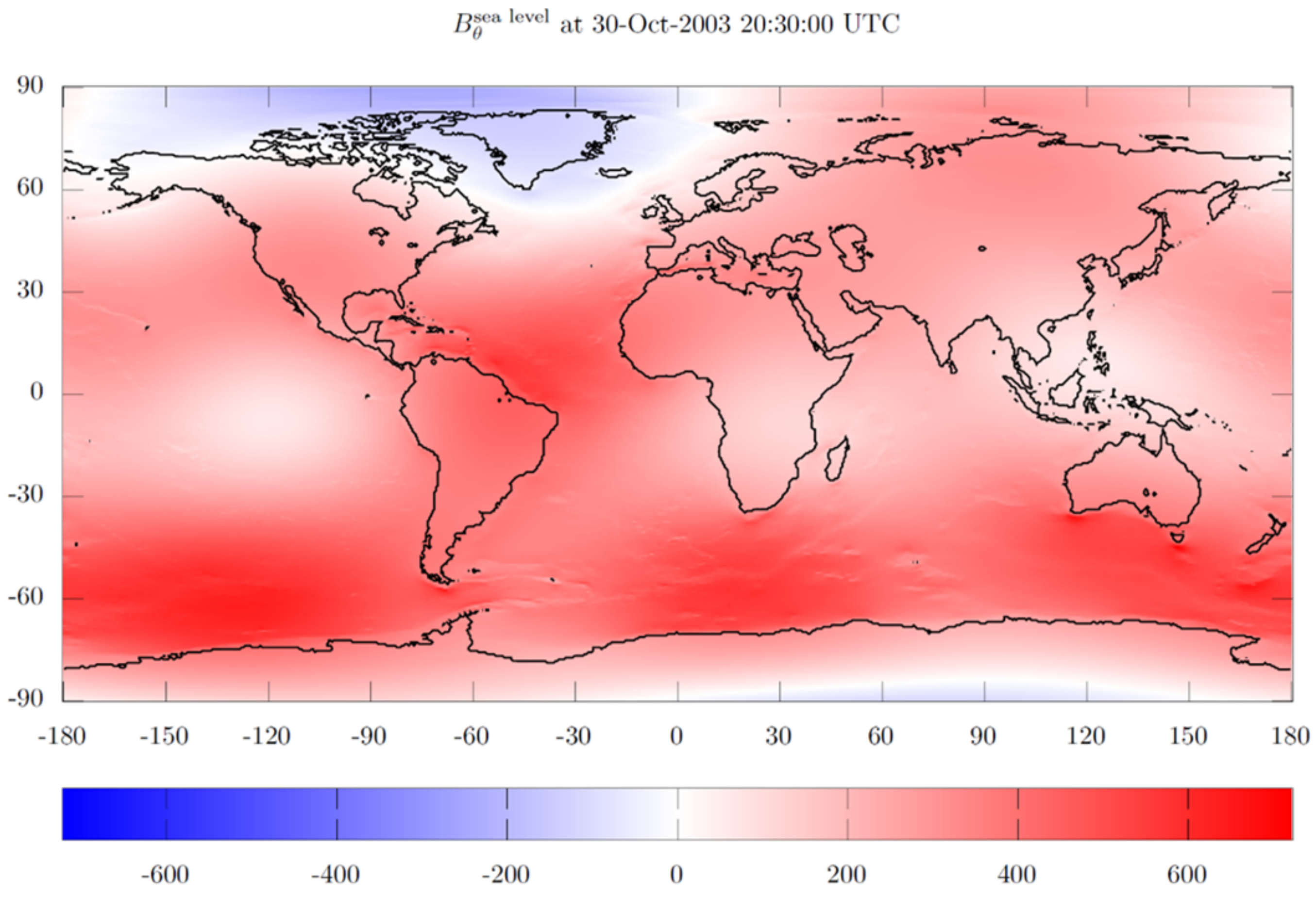
Seabed minus sea level



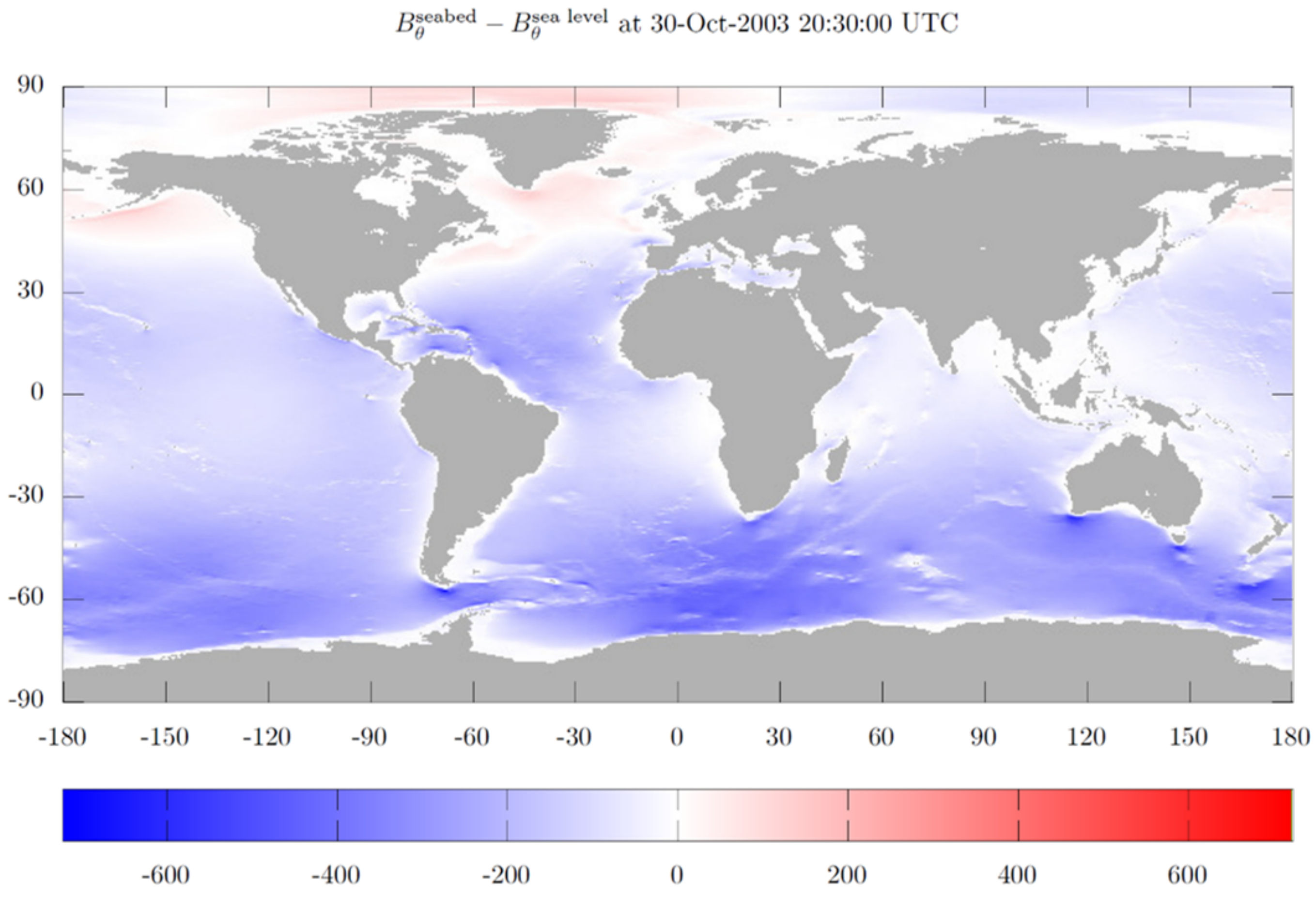
- Similar difference for the west-east component

30 October 2003 storm; north-south component

Sea level



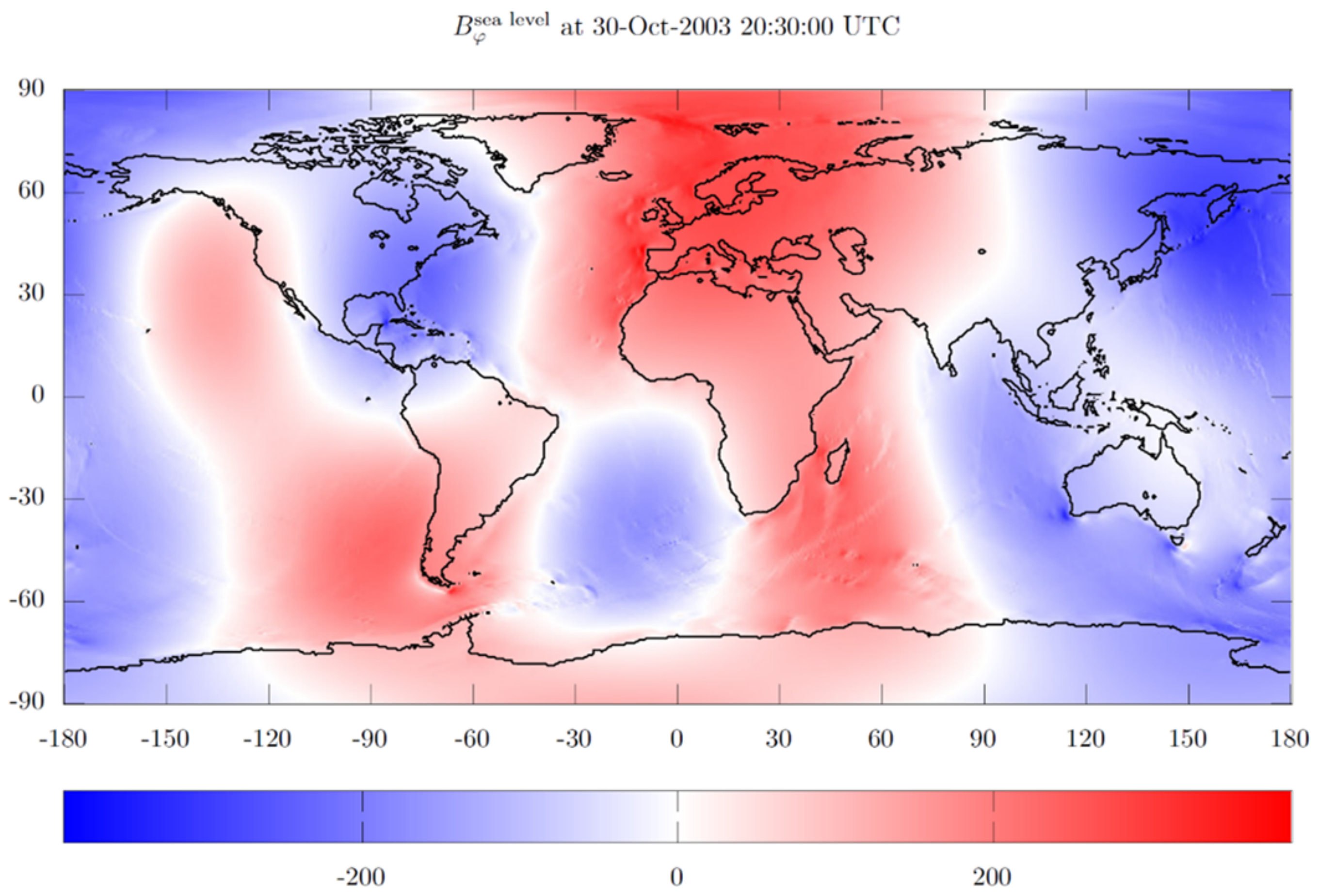
Seabed minus sea level



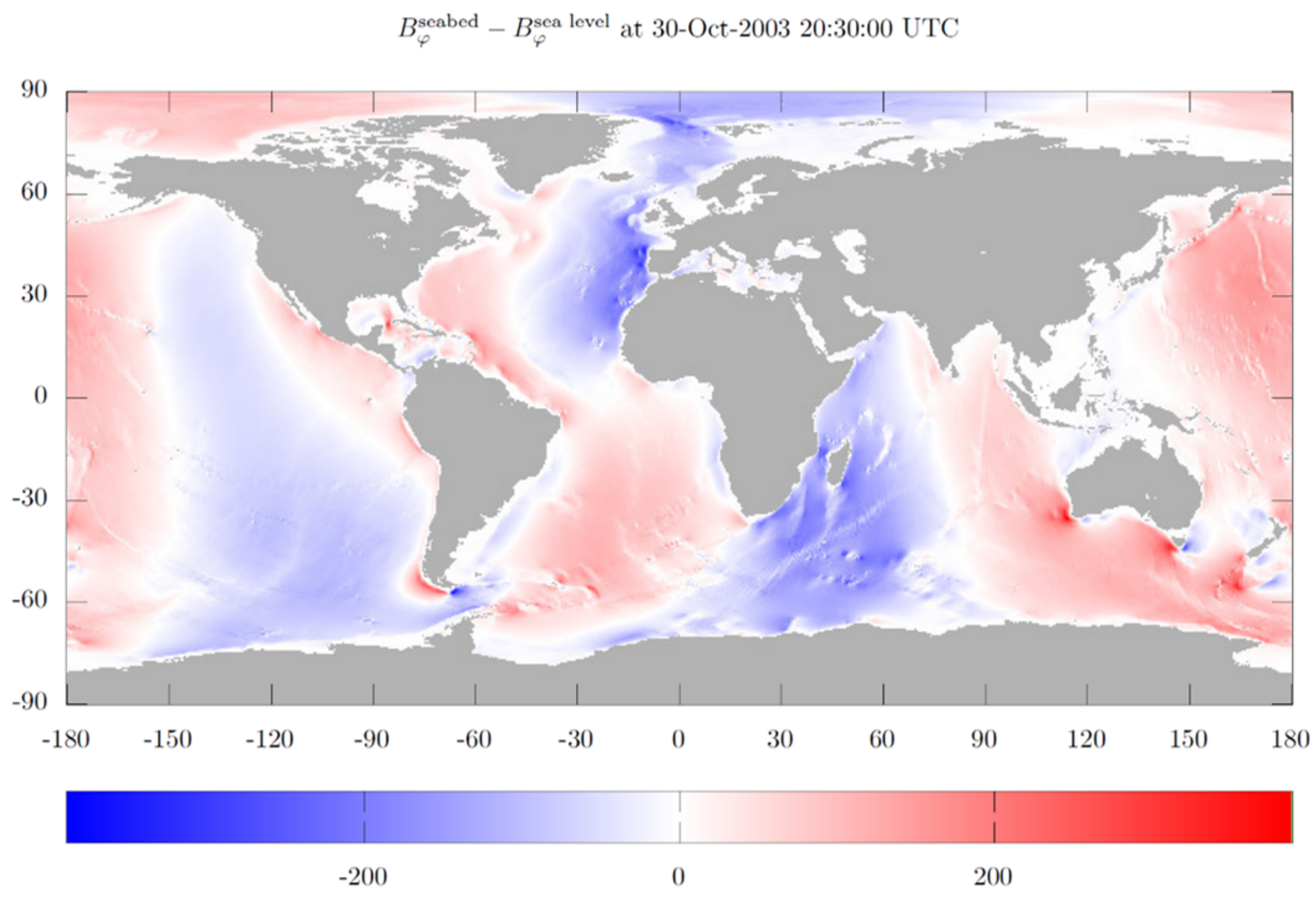
- The same for another storm

30 October 2003 storm; west-east component

Sea level



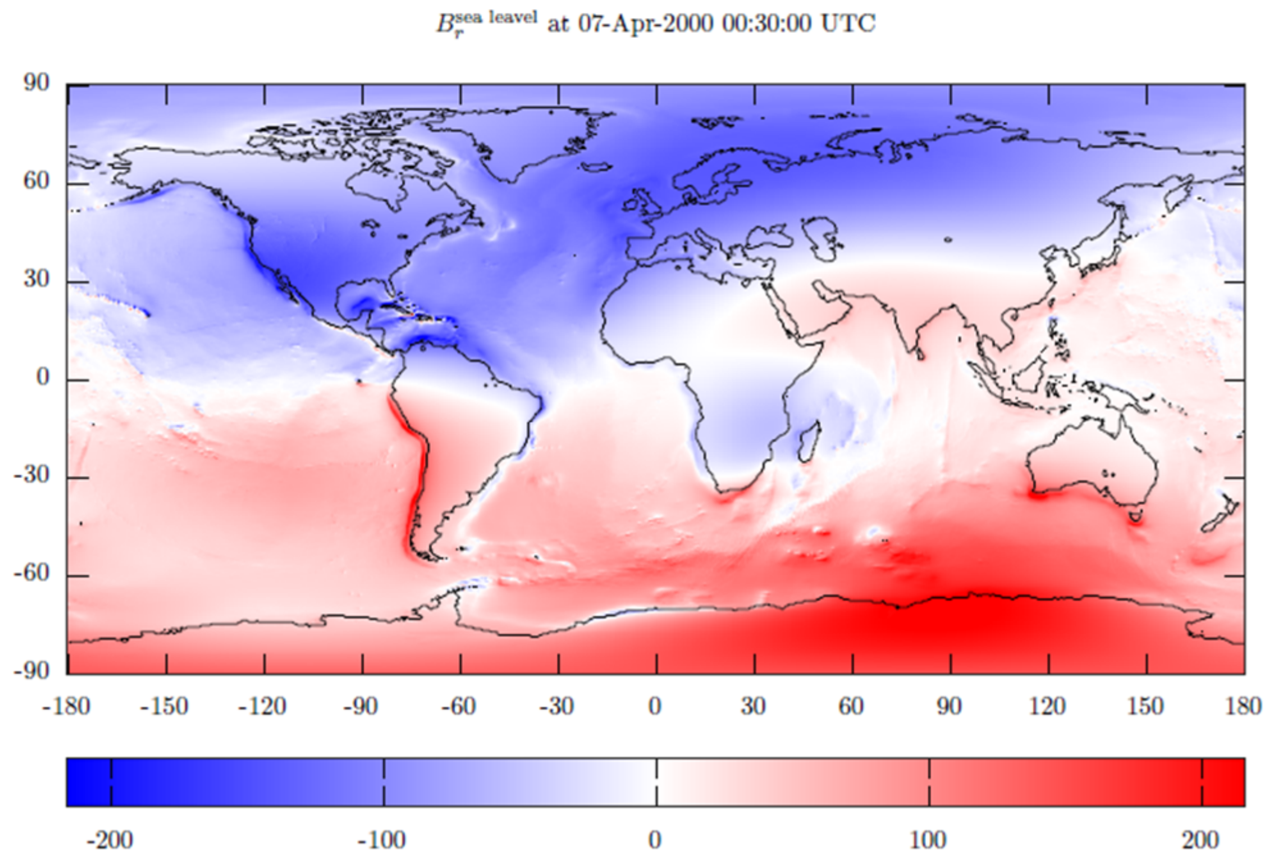
Seabed minus sea level



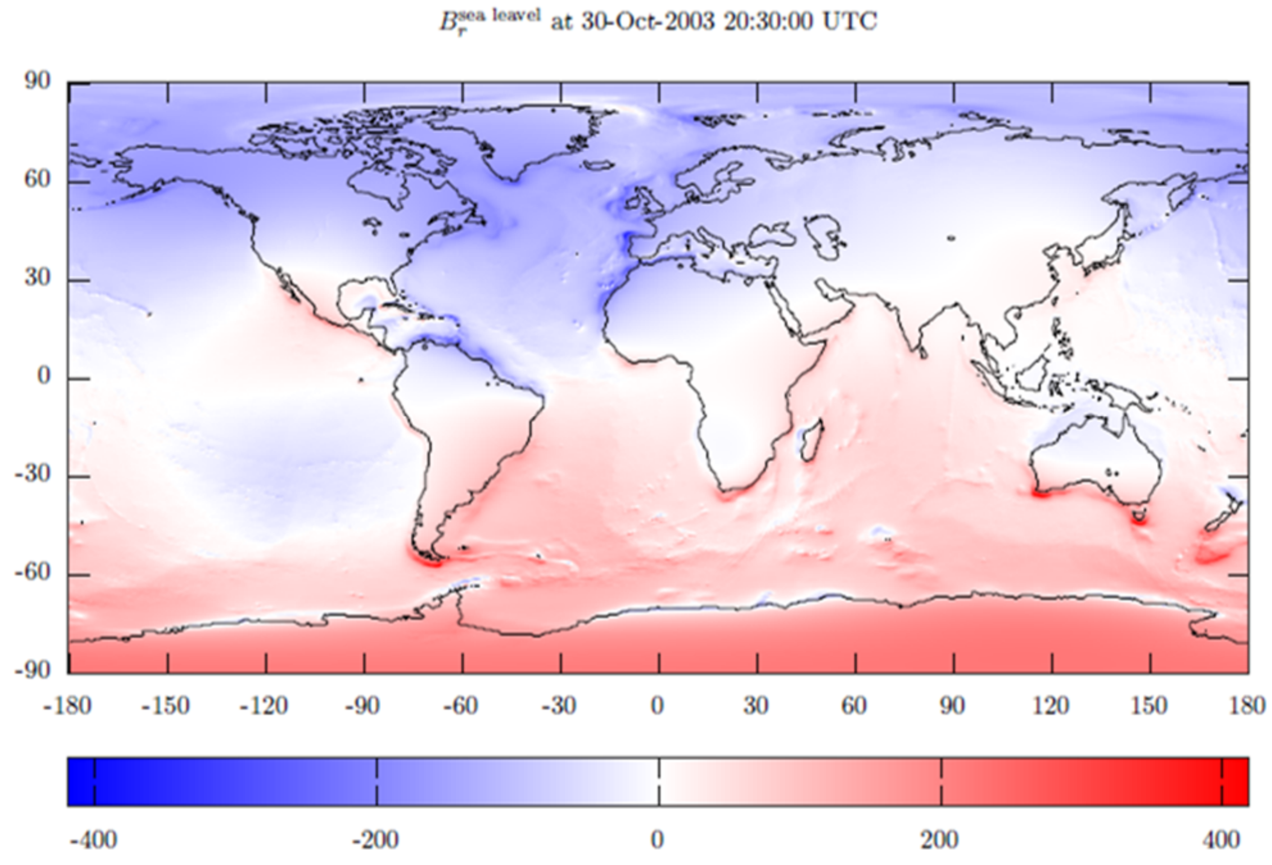
Summing up: sea level and seabed magnetic (horizontal) fields differ significantly.

But vertical component is continuous across water column (thus the same at sea level and seabed)

7 April 2000 storm



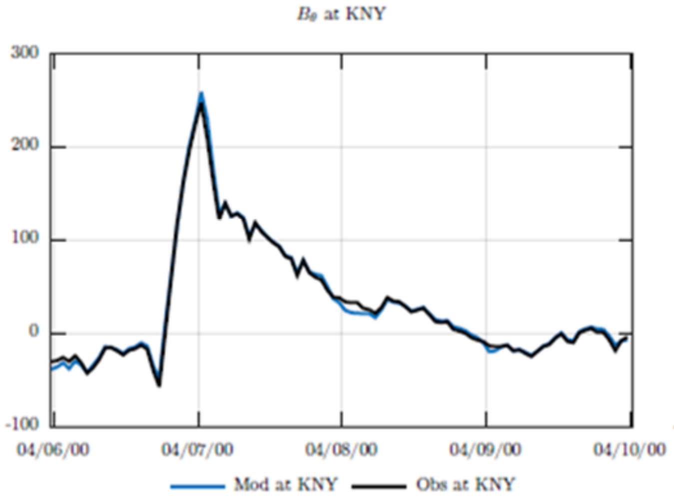
30 October 2003 storm

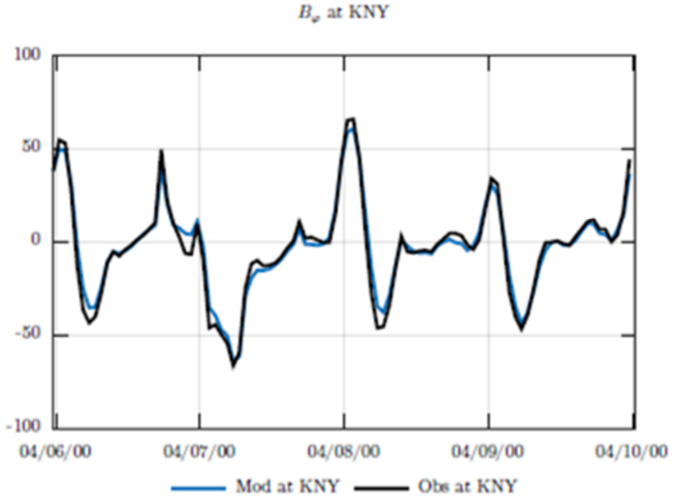


Enhancement near the coasts

Are modeled results agree with observations?

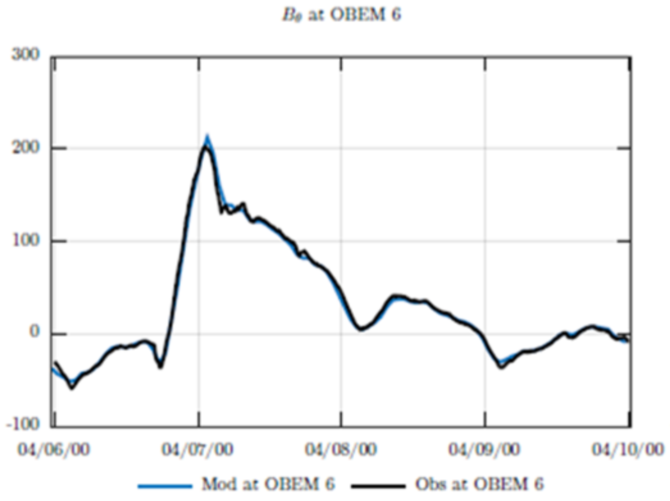
KNY (land)

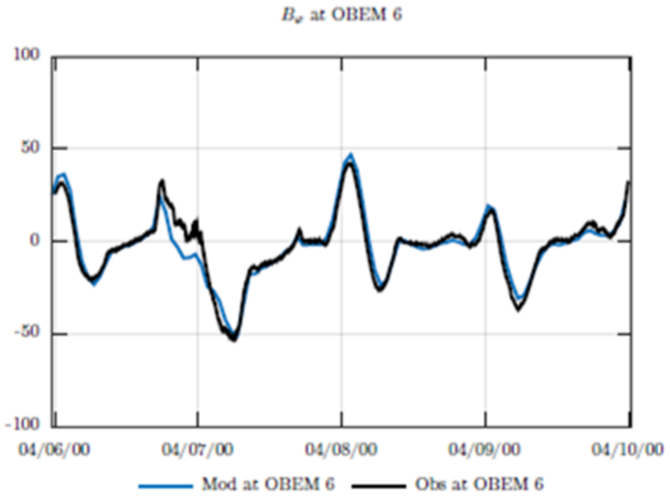


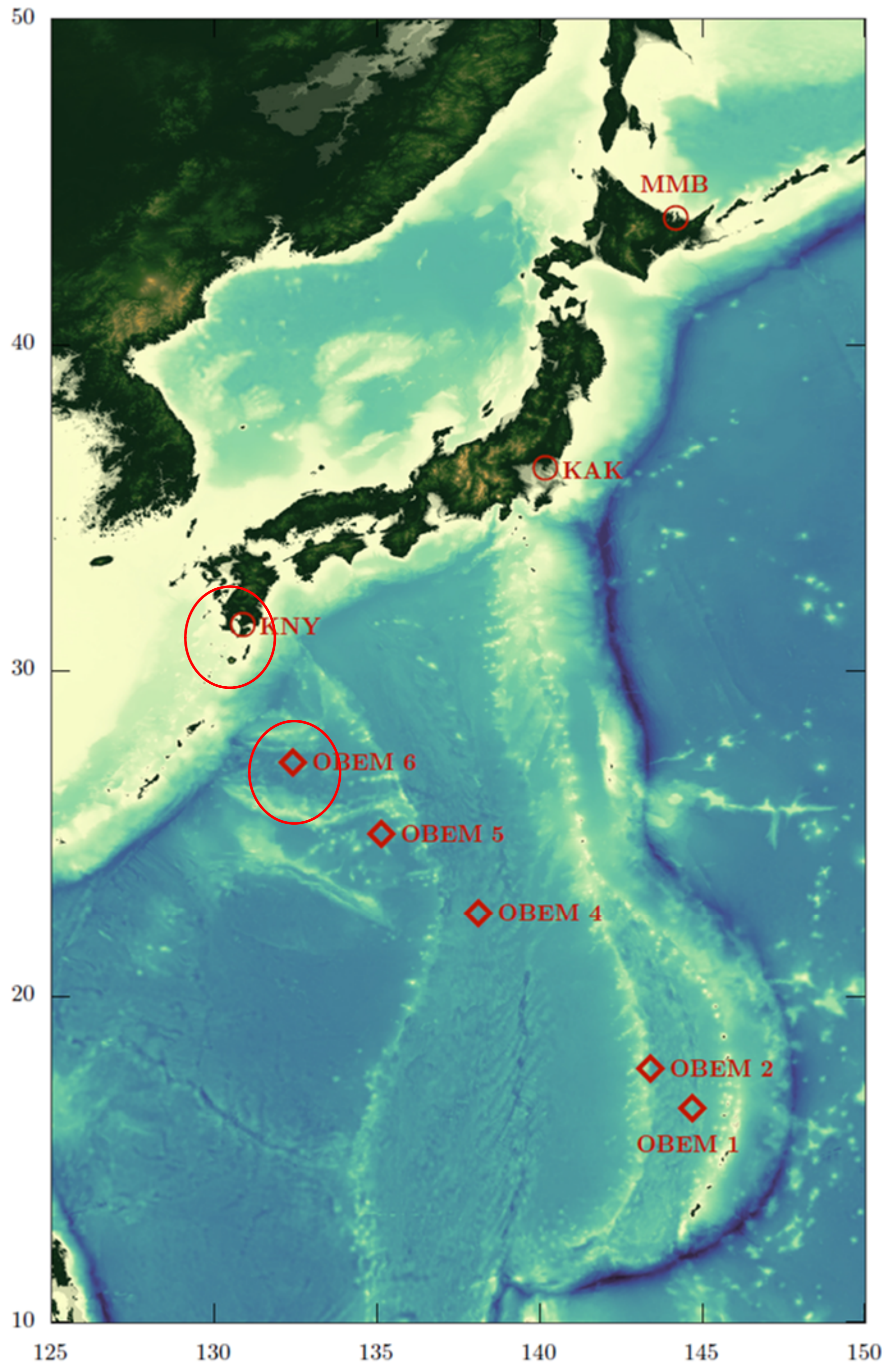


April 2000 storm

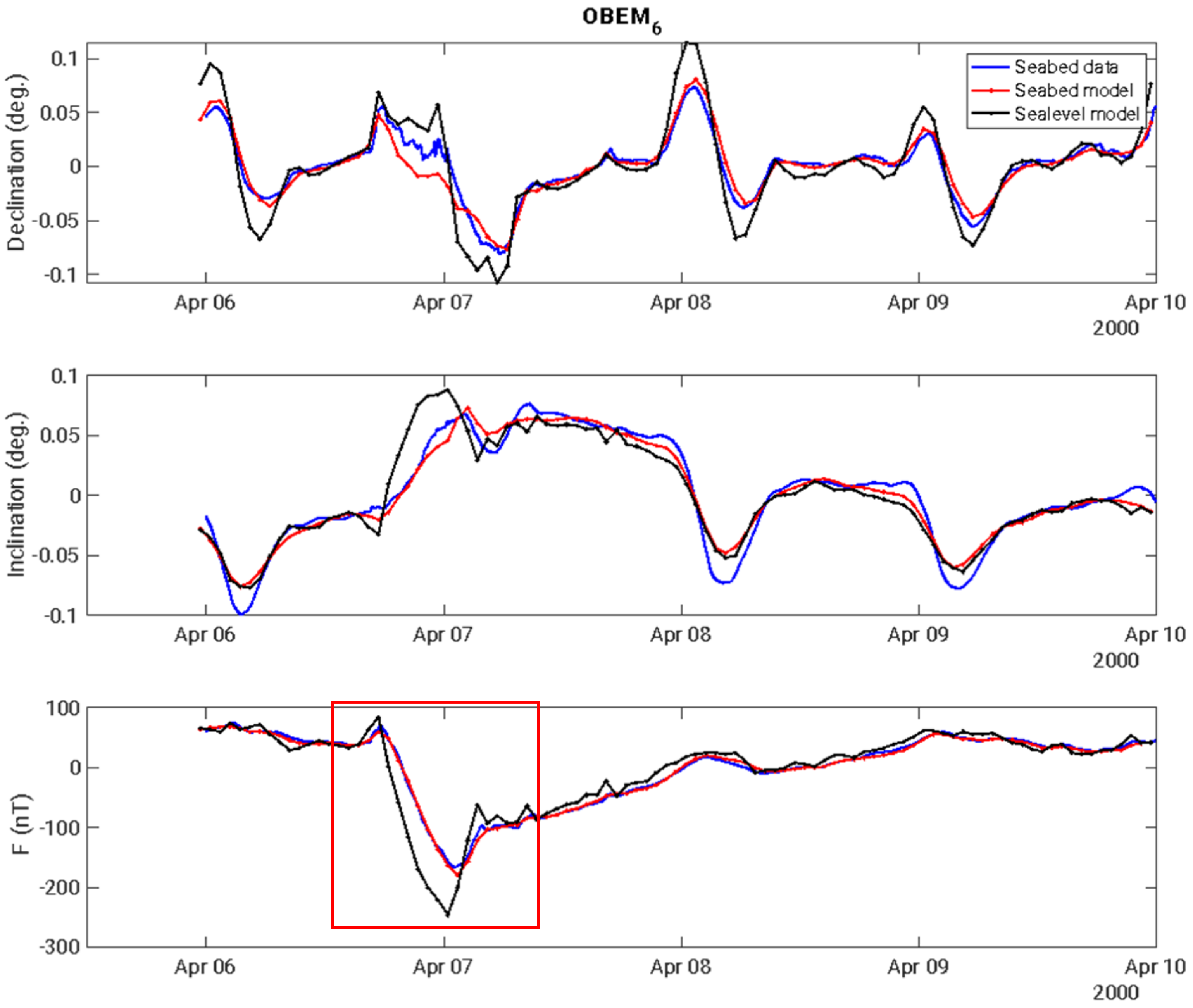
OBEM 6 (seabed, depth 5,431 m)





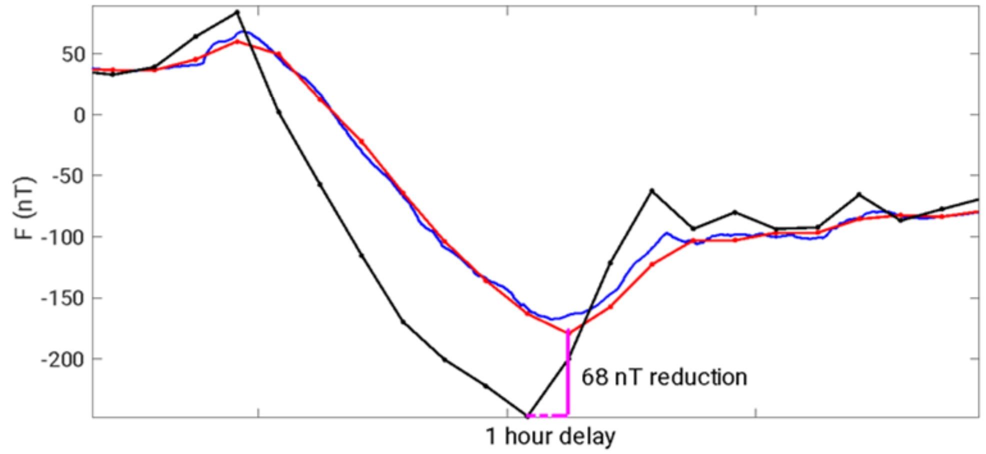


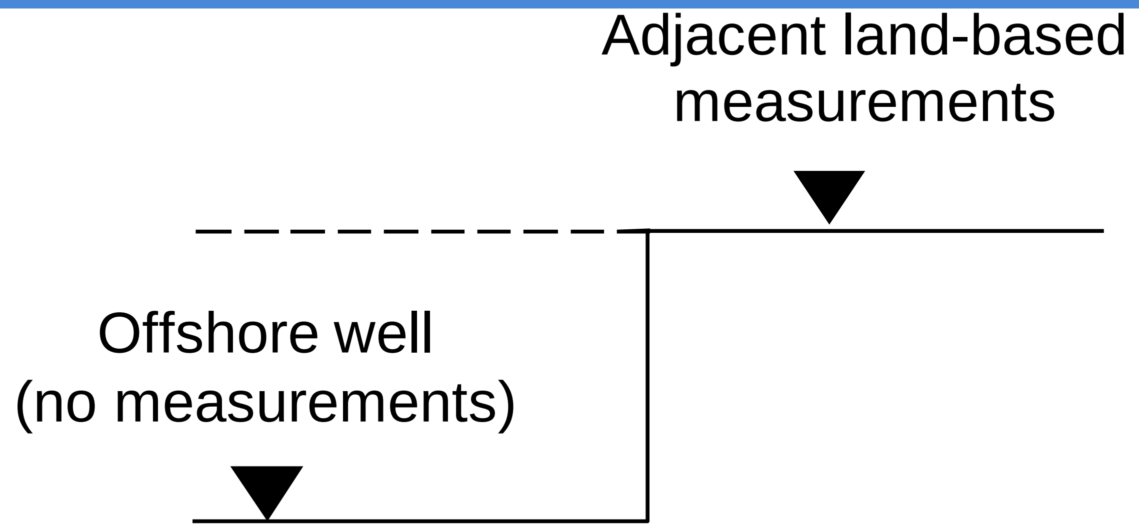
Yes, they do



Sea-level vs Seabed signals

At the seabed, induction leads to both amplitude reduction and phase delay!





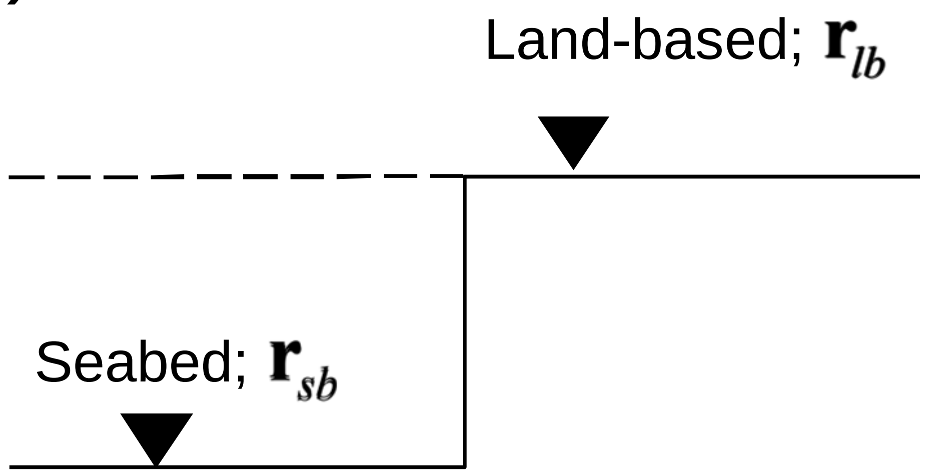
- Seabed signals differ from the land-based (sea level) signals.
- No measurements at seabed (near well); instrumentally challenging/expensive

Can we obtain trustworthy seabed signals using measurements at adjacent land-based site?

Introducing inter-site transfer functions (ISTFs)

$$\mathbf{B}(\mathbf{r}_{sb},\omega;\sigma)\approx \mathrm{T}(\mathbf{r}_{sb},\mathbf{r}_{lb},\omega;\sigma)\mathbf{B}(\mathbf{r}_{lb},\omega;\sigma)$$

$$\begin{pmatrix} B_r^{sb} \\ B_\vartheta^{sb} \\ B_\varphi^{sb} \end{pmatrix} = \begin{pmatrix} T_{rr} & T_{r\vartheta} & T_{r\varphi} \\ T_{\vartheta r} & T_{\vartheta\vartheta} & T_{\vartheta\varphi} \\ T_{\varphi r} & T_{\varphi\vartheta} & T_{rr} \end{pmatrix} \begin{pmatrix} B_r^{lb} \\ B_\vartheta^{lb} \\ B_\varphi^{lb} \end{pmatrix}$$



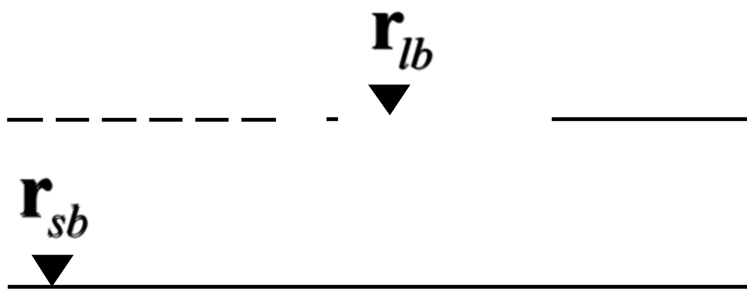
Once elements of 3x3 matrix *T* are estimated at a predefined number of frequencies, magnetic field at seabed site at a given time instant is calculated as

$$\mathbf{B}(\mathbf{r}_{sb},t_k;\sigma) \approx \sum_{n=0}^{N_t} \mathbf{T}^n(\mathbf{r}_{sb},\mathbf{r}_{lb};\sigma)\mathbf{B}(\mathbf{r}_{lb},t_k - n\Delta t)$$

Seabed signals

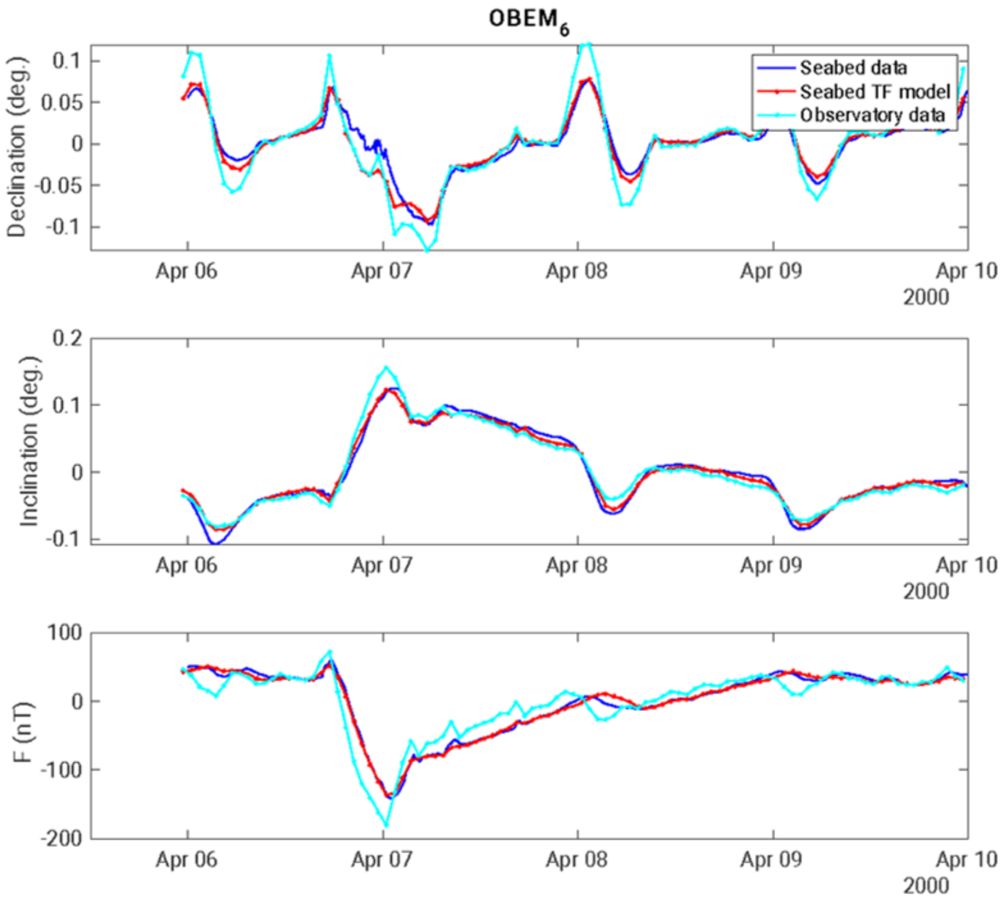
Precomputed (in 3-D model); time-invariant

Land-based signals (measured)

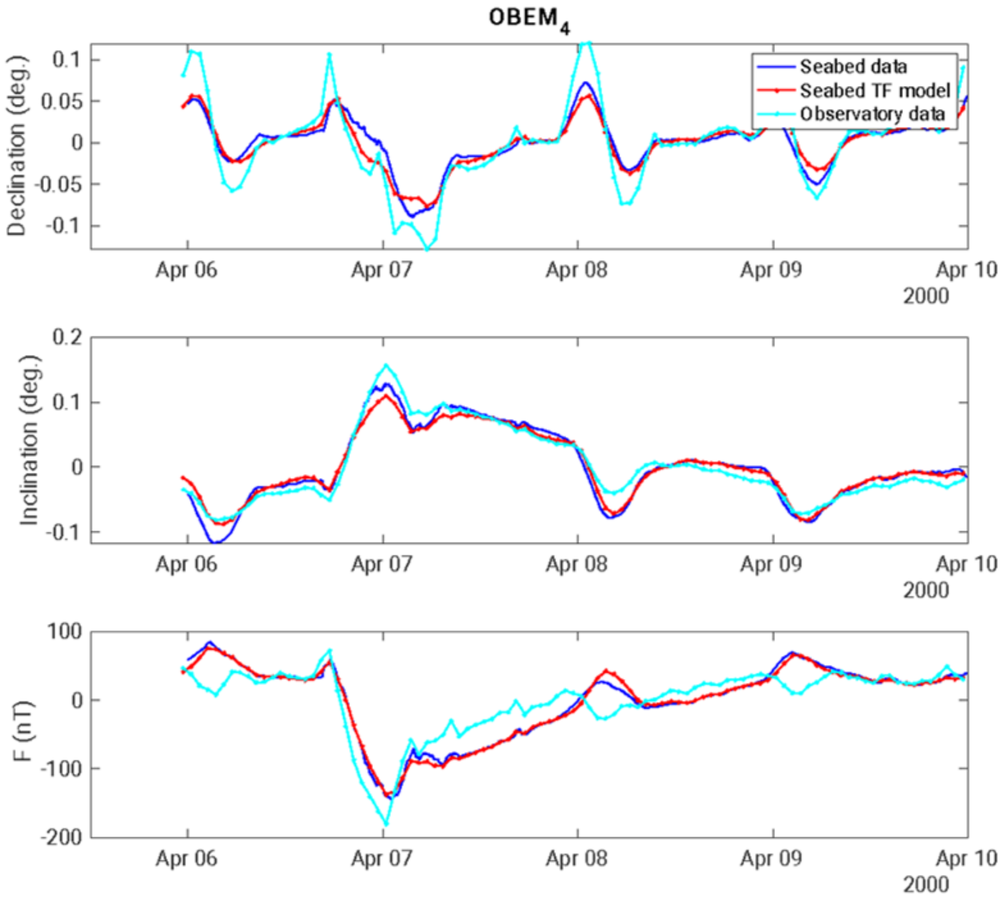


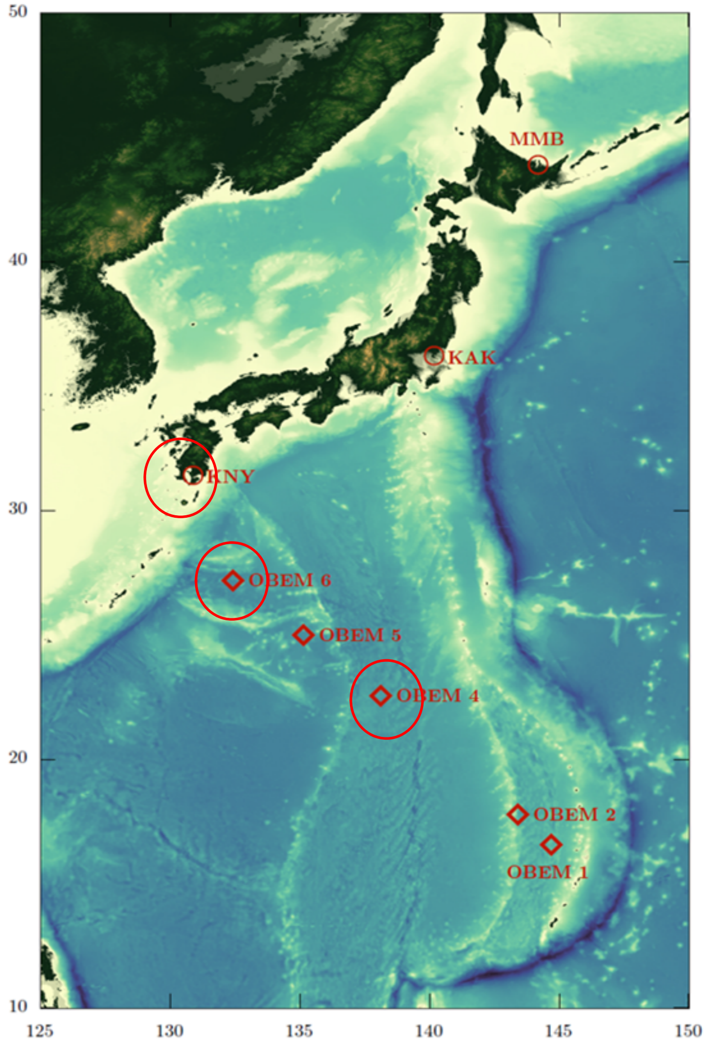
Does it work?

OBEM 6 (seabed, depth 5431 m)



OBEM 4 (seabed, depth 5102 m)





Yes, the ISTFs concept works

April 2000 storm

Conclusions

- Our approach efficiently calculates the spatio-temporal evolution of magnetic fields for a given conductivity and source model, enabling accurate assessment at any location.
- We utilized our approach to model magnetic field behavior during various magnetic storms, revealing significant differences between sea level horizontal magnetic fields and those at the seabed.
- By comparing our modeling results with observations from land-based and seabed sites, we observed remarkable agreement for all sites and components.
- We introduced and substantiated the concept of ISTFs, which allows MWD operators to obtain corrected seabed signals using adjacent land-based observatory data.

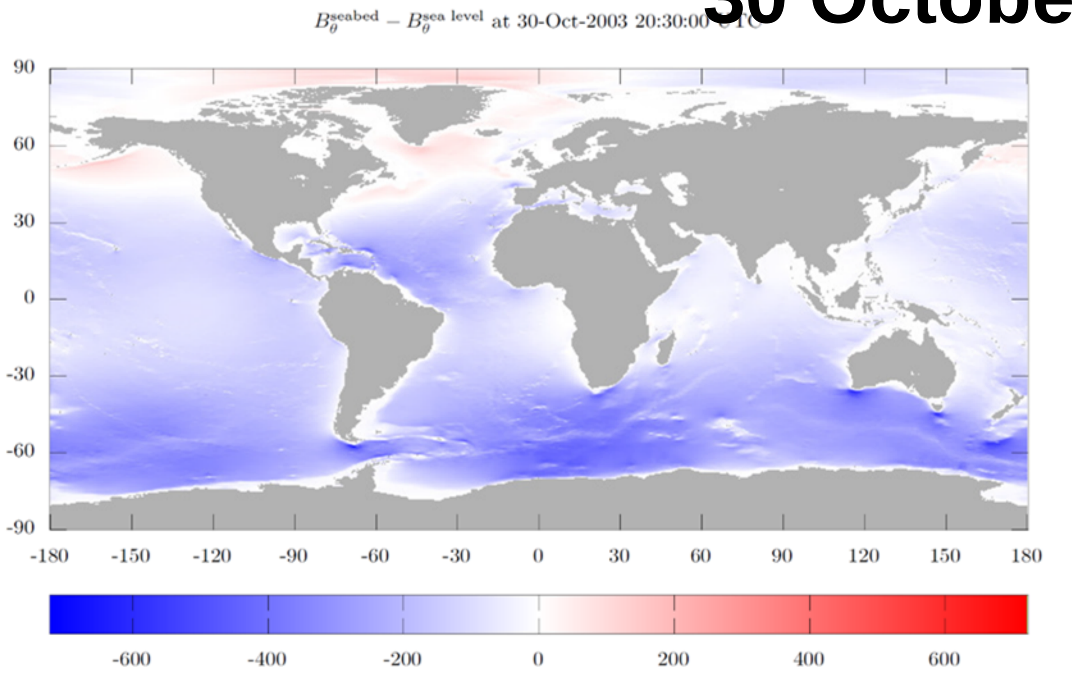
Outlook

- Validate using sea-bed MWD data
- Create grids of attenuation and phase-shifts values for dominant frequencies
- Account for the complex geomagnetic signals in the auroral electrojet regions

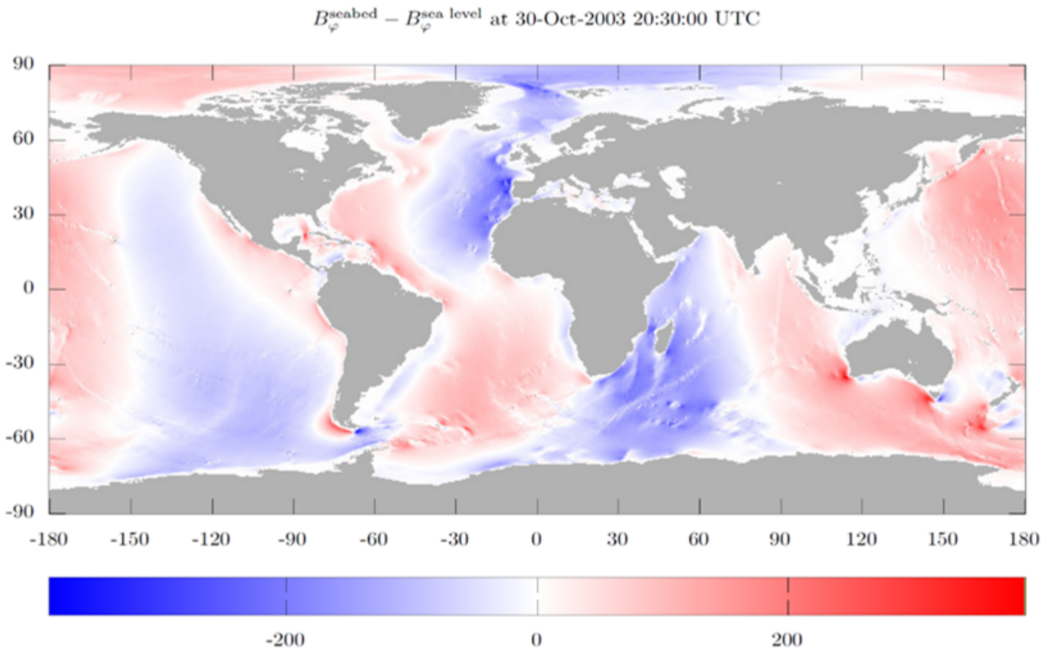
Backup slides …

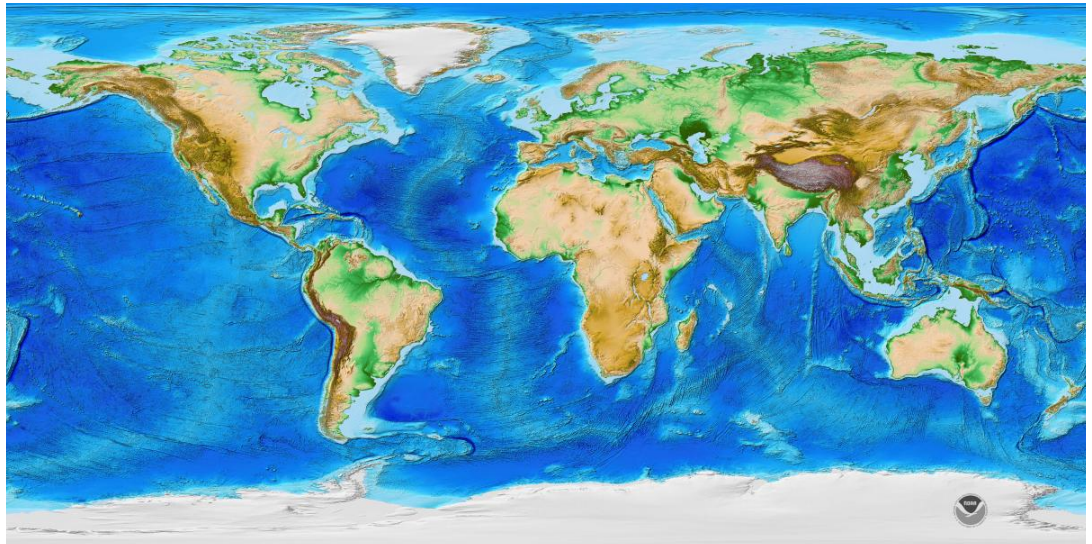
30 October 2003 storm

north-south



west-east





bathymetry