ABSTRACT
Motion of sea water in the Earth’s main magnetic field generates the secondary induced field which can be decomposed into its poloidal and toroidal components. While the toroidal component is not directly observable outside the oceans, the poloidal magnetic field has been already validated by CHAMP satellite magnetic observations, land-based geophysical measurements and sea surface magnetic field measurements, despite the poloidal field being rather weak, reaching an intensity of up to a few nT. New possibilities of observations of the ocean-induced magnetic field came with the launching of ESA’s Swarm mission satellites which have provided a valuable amount of high-resolution measurements of the Earth’s magnetic field. For a detection of weak ocean-induced signatures and their interpretation, numerical modelling is crucial. We present results of modelling of the secondary magnetic field generated by ocean flow. Two ocean flow models are incorporated: 1) DEBOT, a barotropic (BT) model of ocean tide flow, and 2) LSGOM, a baroclinic (BC) model of global ocean currents. The secondary magnetic field is modelled using a three-dimensional time-domain approach. A preliminary comparison of predicted signals and observed signals extracted from Swarm satellite data will be shown. The future aim is to assimilate magnetic data provided by Swarm mission into the models.

1. DEBOT — A BAROTROPIC MODEL OF OCEAN TIDE FLOW

Model description
- Barotropic model, based on the shallow water equations (Einpügel and Martinec, in press)
- Full lunisolar tidal forcing
- Discretization in space: finite differences on the Arakawa C-grid
- Discretization in time: a generalized forward-backward time-stepping scheme, stable and second-order accurate

Key parameters
- Internal wave drag: Conversion of BT tides into BC waves, \( v_{\text{int}} = 2 \nu (N_0)^2 \), \( N_0 \) is bottom roughness, \( N_0 \) is buoyancy frequency, \( \nu \) is scaling factor
- Bathymetric dataset: ETOP01 or GEBOC
- Self-attraction and loading of the seawater: Change of the gravitational potential due to change in mass distribution of the seawater; reduced gravity \( g_L = g (1 - c) \)
- Eddy viscosity: Turbulences on very short scales cause energy losses in the large-scale motions, \( \nu \equiv 0.1 \), \( 0 \) is eddy viscosity, \( \nu \) is strain rate tensor
- Bottom friction, \( \nu = f \nu^1 \)

2. LSGOM — A BAROCLINIC MODEL OF GLOBAL OCEAN CURRENTS

- z-coordinate baroclinic ocean model in hydrostatic and Boussinesq approximations
- Discretization in space: finite differences on the Arakawa C-grid
- Discretization in time: staggered time-stepping of BT and BC subsystems with different time steps; BT system uses the predictor-corrector scheme
- Bathymetry: GEBOC or ETOP01
- Temperature and salinity distributions: World Ocean Atlas 2013
- Wind speed: NCEP/NCAR

3. ELMGIV — TIME-DOMAIN EM INDUCTION MODEL

- Spatial discretization by spherical harmonics and 1-D finite elements (Velímský and Martinec, 2005)
- Crank-Nicolson time integration scheme
- Excitation by a complete Lorenz force vector
- 1-D mantle conductivity profile

- barotropic flows: 2-D near-surface conductance map based on bathymetry and sediment thicknesses
- baroclinic flows: 3-D near-surface conductivity model based on bathymetry and sediment thicknesses

4. PREDICTION OF MAGNETIC SIGNATURES OF TIDAL FLOWS

Snapshot of horizontal velocities of tidal flow at \( t = 2014.20964422 \) L = 10000, 30 x 30 resolution

Induced magnetic field along selected Swarm tracks

Snapshot of induced magnetic field at 480 km altitude

5. SENSITIVITY OF MAGNETIC SIGNATURES TO MODEL SETTINGS

Effect of resolution, eddy viscosity, self-attraction and loading, and internal wave drag

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Induced magnetic field along the track A001755.5

6. PREDICTION OF MAGNETIC SIGNATURES OF GLOBAL CURRENTS

Snapshot of velocities of wind-forced flow at \( t = 2014.20964422 \) in the uppermost ocean layer

Model settings: horizontal resolution: 1°, vertical resolution: 11 layers, BC time step 1800 s, BT time step 30 s

Induced magnetic field along selected Swarm tracks

Snapshot of induced magnetic field at 480 km altitude

7. PRELIMINARY ANALYSIS OF SWARM DATA

Track-by-track analysis
- Swarm Level 1b data in NEC frame, 1 s sampling, version 0404
- Removal of CHAOS-5 main field model
- Night-time (22:00-06:00 LT), magnetically quiet, mid-latitude data (60° - 60°)
- Degree 25 Legendre polynomial fit (smoothing)
- Degree 5 Legendre polynomial fit and extrapolation to polar areas
- Analysis of the expansion coefficients
- Determines whether a source of the field is the only one and whether the source is purely internal or external or a combination of both
- Desired ocean-induced signals have only one internal source, otherwise the data are biased by signals from the magnetosphere or ionosphere
- The signals of the 1st and 2nd order have often an external source in the magnetosphere, hence, only the 3rd-5th order signals are used

Figure description
- Top: Position and time of the track
- Middle top: Residuals after removal of the main field (thin lines) and a fitted expansion into Legendre polynomials to the 5th degree (thick lines)
- Middle bottom: Amplitudes of the signal. A source of the magnetic field is only one if the light blue and red dots overlap, and the source is internal if the purple dots lie on the x axis
- Bottom: The 3rd-6th order signals and residue of the fitted data

REFERENCES
Einpügel, D. and Martinec, Z. A new derivation of the shallow water equations in geographical coordinates and their application to the global barotropic ocean model (the debot model). Ocean Modelling, in press. doi: 10.1016/j.ocemod.2015.05.006.