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Noordwijk, 31-03-2017

Subject: Report thesis "Time-domain modelling of global barotropic ocean tides" by D. Einšpigel

The subject of the thesis is to improve ocean modelling driven by tidal forces. This topic by itself is not new and even goes back a long time as explained also in the thesis. Many approaches focus on frequency domain methods which at first sight fit very well with the generating sources, but are less flexible and adaptive when the response of the ocean is not one to one in sync with these generating sources. This can occur on shelf edges, shelf seas where even mixed (non-linear) tidal responses occur and narrow passages. For these aspects time-domain approaches are better suited. On top of this frequency domain approaches benefit from rather continuous data streams with common time intervals and without too many interruptions in case of data assimilation. These arguments and drawbacks of existing approaches form the basis of the method developed in the thesis of D. Einšpigel. The time-domain approach was chosen based upon shallow water equations to accommodate non-linear tidal effects resulting in compound tides mainly in continental shelf areas. The discrete implementation of the approach is done from scratch and a thorough analysis of the relevance of all individual contributions to the solutions is carried out. Through analytic analysis of the order of magnitude of certain contributions and sensitivity tests for others, decisions have been made to neglect or maintain certain elements in the discrete implementation or to alter the implementation in order to provide stable solutions. Through comparison against independent (deep ocean) tide gauge data, confidence is gained in the validity of the implemented procedure. In addition through assimilation of altimetry derived “measurements”, i.e. kind of space tide gauge information, the model was allowed to alter and the results are compared with the outcome of the free model runs. This allows to get a feeling for the global performance of the implemented approach. Furthermore, many comparisons were included with other results from different groups and the implementation developed in this study appears to be competitive with the state of the art. A great advantage of this new time-domain implementation is that it will allow easier assimilation of all kind of datasets, even irregular and inhomogeneous in space and time, in the future. The developed model has already been used for generating the magnetic signature of ocean tidal signal of all relevant tidal components for comparison with measured signals from the Swarm satellites. This is a unique and new field of research which aims ultimately at improving ocean models, and in the end heat transport in the ocean, by incorporating magnetic field data.

D. Einšpigel has performed an impressive task which is well documented in his doctoral thesis. He implemented a known approach from theory based upon shallow water equations completely from scratch. This forced him to review carefully and thoroughly all steps that play a role during the implementation and he succeeded to achieve a unique and novel setup for his model. In addition an eye was kept on validation of the results during sensitivity tests and final model runs to justify the chosen path. As a result of this process and critical review of the results he also formulated steps for future research to even further improve the implementation. Last but not least his implemented approach has already been successfully applied in a neighbouring area for innovative studies of the ocean circulation based upon magnetic field data. In my opinion D. Einšpigel has performed, as a true independent scientist, new and original scientific studies. He clearly provided evidence to prove that he is able to produce creative scientific work.

Yours sincerely,

Roger Haagmans

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Subject: Questions to thesis "Time-domain modelling of global barotropic ocean tides" by D. Einšpigel

As an outcome of the review of the thesis I formulated the following questions:

1. You have chosen to implement a barotropic ocean model, which assumes a certain ocean response to the driving forces. What is the justification to choose a barotropic rather than a baroclinic model for your intended applications? Does the justification actually hold for the shallow waters in which non-linear response results in compound tides (see also page 43 last paragraph); please elaborate?
2. Page 10 1st paragraph after eq. 1.10. You introduce the notion of the geoid as a reference surface for bathymetry and sea surface elevation. However, you simplify the geoid concept to a surface with constant radius r=a=const. The actual Earth has an approximately 22 km difference in radius between equator and pole:
    a. Is this difference relevant in terms of the tidal driving forces: please elaborate and if possible quantify?
    b. Could this be relevant in case the ocean model results are in a second step translated into magnetic signature (source) for the comparison with ground or satellite measurements? Please explain.
    c. How does the "spherical approximation" in chapter 1.3 relate to this? Can you distinguish between the approximation of operators and the evaluation on a sphere?
    d. Would it be possible (if needed with small changes to the equations in 1.3) to evaluate in the actual points on the ellipsoid but still use spherical approximation for the operators, since the shallow water equations are in geographic (ellipsoidal) coordinates?
3. Section 2.1 and Figure 2.1:
    a. Please explain what the different variables are in the figure that are evaluated at different locations: are these all "point" values?
    b. What is the meaning of the averaging operators in the equations of section 1.2? The geometry remains "point" values and the physics is averaged? If so what the interpretation of this?

c. The grid in Figure 2.1 suggest an equiangular (not equidistant) representation (in spherical approximation) resulting in different area sizes depending on the latitude of the cell. What is the consequence of this for the interpretation and validation of results with external data like tide gauges or altimetry?

4. Page 30 Table 2.1: with the discrete implementation of models like discussed under the previous question it is not directly obvious what the actual resolution of the physical contents of the model is irrespective of the representation resolution. In this context the analysis in Table 2.1 shows results obtained with smaller spatial resolution and smaller time steps at the same time.
   a. What is not possible to understand from the table is what the role of decreased spatial resolution alone or smaller time steps alone is: please elaborate on this?
   b. Parameters of the physical forcing and the expected ocean response is dictating spatial and temporal scales to be captured in the model. If you are not able to capture the fastest and smallest scale features in one specific area in the world does this have a global or only a neighbouring influence on your courser (space/time) global model results?
5. Section 3.2 Tidal forcing in oceans: the solid Earth tides are introduced in section 3.2. In addition the combination of ocean column changes due to forcing have an indirect effect on the solid Earth usually expressed as ocean loading.
   a. Could you please explain what this is and explain its role in the deep ocean or shallow waters?
   b. If taken into account does it have any impact on the developed ocean modelling?
6. Section 3.4. Sentence: "The reason is that ....two harmonics are only distinguishable only if the ...." If we consider the sun and moon generating driving forces that have different distinct periods is it not possible to use the spatial amplitude/phase information in addition to point time series to help separate the harmonics on shorter intervals? Please explain.
7. Section 4.3, table 4.2 and figure 4.8: The comparison against deep sea gauges is done for many different parameters and shown in the figures 4.2-4.6. The deep sea gauges (but also altimetry) represent a certain point/area response. The model analysis is done with a variety of settings for the (representation) resolution of the model (Figure 4.4. see also question 4). What is the interpretation of sometimes increasing RMS when going to smaller resolution: does it mean that the deep sea gauges are representative for the resolution with minimum RMS; or does the finer resolution model contain additional physics which cannot be observed by the gauges; or are time steps not compatible with the spatial resolution to describe the physics better at the finer resolution; or ....? Please explain.
8. Section 4.4. The best setting: the chosen set of parameters in the beginning of the section are a compromise between deep ocean and shelf seas.
   a. As DEBOT is a non-linear model can you rely on the parameter by parameter analysis that has been performed rather than to rely on tests with coupled sets of parameters due to the non-linearity? Would the latter lead to the same conclusion for the choice of the global set as mentioned in section 4.4?
   b. Would it be possible to change the implementation of the model or follow and alternative approach to accommodate regional setting of these parameters rather than global ones?

9. Figure 5.3: It is shown that only little assimilation is needed to arrive at good results.
    a. Can this be considered as a completely independent judgement of the impact of assimilation of altimetry? Please consider here the potential role of the background hydrodynamic model FES2004 used in DTU10.
    b. What needs to be done with the model to directly ingest/assimilate altimetry satellite data and tide gauge data?
10. Page 95: Can you explain how the model has been used for magnetic field and Earth's rotation analyses?

Yours sincerely,

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