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Geoscientific Model Development Discussions
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Interactive comment on "VISIR-I.b: waves and ocean currents for energy efficient navigation" *by* Gianandrea Mannarini and Lorenzo Carelli

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General assessment

This is a reasonably good paper that describes a new version of a ship-routing model. The original model was published in GMD, so the subject matter has already been judged to fall within the scope of the journal. The manuscript assesses the impact of waves and currents on transatlantic crossings, and calculates energy efficiency savings that seem impressive.

–AUTHORS' RESPONSE:

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Discussion paper

We thank the Referee for his/her time and comments on our manuscript: They definitively contributed to improve it. In this document, we report Referee's text in italics and our replies as a normal text, distinguishing wherever needed our response from the manuscripts parts involved by changes. All references to sections, equations, figures, and tables are relative to the submitted gmd-2018-292 manuscript.

GMDD

Interactive comment

Specific comments

1 - *The term "waves" is used throughout the manuscript, but it is never properly defined. The ocean supports a wide variety of wave motions, both internal and at the surface, including gravity waves, Rossby waves, Kelvin waves, Poincare waves, acoustic waves, etc. I believe the manuscript is referring exclusively to surface gravity waves, but this needs to be stated. In the equivalent atmospheric problem of aircraft routing, "waves" usually refers to Rossby waves in the jet stream, and the wave structure (in other words, the* $u(x, y, t)$ *and* $v(x, y, t)$ *velocity field associated with the wave) is used in the calculation of the fastest route. I presume that the flow perturbation associated with the surface gravity waves in the current manuscript is not being used like this, but rather that the waves are being treated as areas of turbulence to be avoided. However, this wasn't entirely clear to me and deserves to be clarified.*

–AUTHORS' RESPONSE:

In this manuscript we refer to and employ numerical fields of ocean surface gravity waves.

This is in fact the kind of wave motion contributing to so called "wave added resistance" of a vessel. Such resistance is in physical terms a force leading to involuntary vessel

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speed loss in waves. This force is traditionally distinguished into a radiation (energy dissipated due to vessel heave and pitch motions) and a diffraction component (energy dissipated by the hull to deflect incoming waves, short with respect to vessel length). As in Mannarini et al. (2016a), diffraction is neglected in the present parametrization (Sect.2.5.1). However, for both radiation and diffraction motions, the relevant wave length scale is set by vessel length (which is up to a few hundred m).

Furthermore, in VISIR we do account also for vessel intact stability (Sect.2.5.2), which sets a time scale given by the vessel natural roll period (usually up to about 20 s, or more than 0.05 Hz). The CMEMS wave fields employed in VISIR stem from the Météo-France model, which considers a wave spectrum discretized into 24 directions and 30 frequencies in the [0.035 – 0.58] Hz range[1]. Classically, this is the realm of ocean surface gravity waves (Munk, 1951).

–MANUSCRIPT PARTS INVOLVED:
We propose to make changes in following parts:

- Title, to be changed into "VISIR-1.b: ocean surface gravity waves and currents for energy efficient navigation".
- Sect.1.1. Add specification of what ocean waves are considered.
- Sect.4.1.4. Add information that the wave spectrum is discretized into 24 directions and 30 frequencies starting from 0.035 Hz to 0.58 Hz[2], comparing to typical vessel natural roll frequencies.

2 - *The manuscript is missing a discussion on whether the ship-routing model is*

[1]https://bit.ly/2KWCHYL
[2]https://bit.ly/2KWCHYL

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intended for operational use or just for research purposes. More generally, it is missing a discussion on how ships are currently routed operationally: are the tracks optimal in some sense? If so, who calculates the optimal routes, and using what model? This is particularly relevant to interpret the energy efficiency gains calculated in the manuscript.

–AUTHORS' RESPONSE:
VISIR can be used either with analysis or forecast environmental fields, since this is not constrained by any of the equations of Sect.2. Thus, VISIR can help for both assessment of past tracks (as in the present work) or prediction of optimal ones (as actually done in the operational system for the Mediterranean Sea described in Mannarini et al. (2016b)).

In the mapping exercise in the Atlantic Ocean included in the present manuscript, for the reason discussed in Sect.4.5. (duration of the transatlantic crossing exceeding maximum lead time of wave forecasts) and the fact that an operational system was not required by the funding project, we resorted to analysis fields. We think this approach can be useful for ex-post assessments of energy efficiency savings. To this end, the main limitation of our approach is the parametrization of speed loss in surface gravity waves (cf. Question 1) above and Sect.2.5.1), which suffers from still large uncertainties in the literature for the wave added resistance (Bertram and Couser, 2014). Energy efficiency gains resulting from VISIR refer to comparison of the least-time to the orthodromic path and their entity also depends on the amount of speed loss in waves.

Concerning the degree of optimization of actually sailed ship tracks, this is an open research question. Weather ship routing systems are used both offshore and onboard for planning, but the final decision is up to the shipmaster (Fujii et al., 2017). Furthermore, route planning may involve sensitive commercial information that a ship operator will not easily share. Thus, the extent to which a ship track is optimized is not always publicly known.

Nevertheless, we recently addressed this question by comparing VISIR optimal tracks vs. reported ship tracks per AIS (Automated Identification System) data, for a route in the Southern Ocean (Mannarini et al., 2019). By computing both spatial and temporal discrepancies between VISIR and AIS tracks, we could infer that optimization likely took place in several but not all tracks. While the method by Mannarini et al. (2019) is still in its infancy, we believe its extension to a larger statistics could contribute to shed light on questions like the one posed in this Referee's comment.

–MANUSCRIPT PARTS INVOLVED:
The above discussion can be added to Sect.4.5.

3 - *I generally found the manuscript difficult to read and understand, mostly because of the poor quality of English usage throughout. This problem could and should be fixed by calling on a native English speaker or professional proof-reading service.*

–AUTHORS' RESPONSE:
Thanks for feedback. We have already contacted a professional proof-reading service for reviewing the final version of the manuscript.

–MANUSCRIPT PARTS INVOLVED:
Whole manuscript.

Minor Comments

1) Page 1, line 20: "which capacity" -> "whose capacity".

–AUTHORS' RESPONSE:
Thanks, this will be fixed.

2) Page 2, line 2: please define "dead reckoning".

–AUTHORS' RESPONSE:
Dead reckoning refers to the computation of a vessel's position by means of its position at a past time and advancing it, based upon estimated speed and course over elapsed time. In the work by Richardson (1997), ship drift was defined as the difference of the velocity vector between two position fixes (by means of some reliable method) and the velocity vector resulting from dead reckoning. In Meehl (1982) a similar definition of ship drift was given, with the specification that dead reckoning is to be computed 24 h in advance of the position fix.

–MANUSCRIPT PARTS INVOLVED:
Above answer will be added in the Introduction.

3) Page 4, lines 15-16: what are the manoeuvrability and actuation issues that arise, and what are the consequences of not considering them?

–AUTHORS' RESPONSE:
VISIR computes heading and fraction (EOT) of maximum engine power to be held along an optimal ship track.

In order to head as prescribed by the optimal track, the ship has to be manoeuvred (e.g. acting on rudder and/or lateral thrusters). Action on rudder is realized through some hydraulic device converting pressure into a mechanical action to move the rudder[3].
In order to implement prescribed EOT, the high level order from the control bridge is

[3] https://www.wartsila.com/encyclopedia/term/rudder-actuator

transmitted through potentiometers[4] to the main engines (and possibly also to other components of the propulsion system such as clutches, gearbox, controllable pitch propeller, cf. Harvald (1992)).

Motions of the bottom layer (rudder, main engine), being related to electro-mechanical devices, should occur on a much shorter timescale (probably seconds to a few minutes) than the top level controls needed for following the optimal track (requiring changes in the order of minutes, cf. ROT_M in Tab.7, to hours, cf. Fig.6). Thus, a routing system must ensure that the top level control requires feasible manoeuvers (e.g. in Sect.4.3.2 we check that maximum vessel Rate of Turn ROT_M is in an acceptable range; other feasibility criteria are defined in IMO (2002)). If this condition is given, it should be possible, for the sake of computation of the optimal track, to safely ignore the temporal dynamics of the underlying actuation level (Techy, 2011). If instead actuator time scale were comparable to the time over which heading and EOT changes should take place, the hypothesis of top-bottom level separation would break down. We suppose that this is much less likely to occur in open-sea navigation (object of the present manuscript) than e.g. during harbour operations. However, on board data would be needed for a thorough assessment of this issue.

–MANUSCRIPT PARTS INVOLVED:
Sect.2.1.

4) Page 7, line 17: "preliminary" -> "preliminarily".

–AUTHORS' RESPONSE:
Thanks, this will be fixed.

5) Page 7, line 29: the final sentence makes no sense.

–AUTHORS' RESPONSE:

[4]https://www.kwantcontrols.com/product/systems/integrated-telegraph-system/

Thanks for feedback, we will explain this better, as reported below:
First, we recall that VISIR-1.b graph pruning methodology leaves in the graph both sea and land arcs not intersecting the shoreline. At the beginning of the execution of the code for track computation, such a graph is employed for determining, for each of the requested track endpoints (i.e., start and end location of the route), what is its next node on the graph. This can even be a land and not a sea node.

In a subsequent step, the graph arcs are screened for the condition UKC $= z - T > 0$ (Mannarini et al., 2016a, Eq.44). Thus, if the start node was found on land (UKC $\leq$ 0), no path outgoing from that node can be computed and VISIR quits with a warning. The coordinate of the requested endpoint has then to be shifted by the VISIR user, in order its next node not to be on land any more.

In an operational use, where the user would set the endpoints for just a single computation, this may be a disturbing feature and will be improved in next VISIR version. For the current assessment exercise, whereby the endpoint are chosen just once and then used for many computations (288 tracks per route, cf. Sect.4.5), we think this approach is still acceptable.

–MANUSCRIPT PARTS INVOLVED:
Sect.2.3, last paragraph.

6) Page 10, line 14: "anthropic" -> "anthropogenic".

–AUTHORS' RESPONSE:
Thanks: "climate change of anthropic origin" will be changed into "anthropogenic climate change".

7) Page 26, line 25: please specify which version of Matlab.

–AUTHORS' RESPONSE:
Matlab 2016a was used on both the workstation (Mac OS 10.11.6 "El Capitan", em-

ployed for the performance analysis of Sect.3.2) and the cluster (Unix CentOS release 6.9 "Final", employed for mass production of Sect.4). In addition, the MEXCDF library is required. Furthermore, the list of all third-party Matlab functions is provided along with the VISIR-1.b release (https://zenodo.org/record/2563074).

–MANUSCRIPT PARTS INVOLVED:
We are going to add this information in the "Code and data availability" section.

8) Figure 5: the geodetic curves look piecewise linear (i.e. local geodetics between waypoints) rather than continuous - why?

–AUTHORS' RESPONSE:
Flattening of the geodetic and the piecewise linear geometry of the tracks are due to the finite angular resolution of the graph. In particular, for Fig.5 and 7 a graph with order of connectivity $\nu = 8$ is employed, resulting in an angular resolution $\Delta\theta \sim 7$ (cf. Eq.13).

–MANUSCRIPT PARTS INVOLVED:
We will expand related explanation in Sect.4.3.

9) Figure 7: the captions refer us to an external website for the animations. I think they should probably refer us to the supplementary material instead.

–AUTHORS' RESPONSE:
In the caption of Fig.7 we will add a reference to the Supplementary Material. However, we would also like to keep reference to the TIB website which is recommended by Geosci. Model Dev.'s official guidelines for videos[5].

–MANUSCRIPT PARTS INVOLVED:
Caption of Fig.7.

[5] https://www.geoscientific-model-development.net/for_authors/manuscript_preparation.html

10) Figure 7: "oncean" -> "ocean" in the ordinate label.

–AUTHORS' RESPONSE:
Thanks, this will be fixed.

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