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Geoscientific Model Development Discussions

Interactive comment on "Semi-Lagrangian advection in the NEMO ocean model" *by* Christopher Subich et al.

Christopher Subich et al.

christopher.subich@canada.ca

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To begin, we are thankful for the review comments provided by the reviewers Florian Lemarié (reviewer #1) and Mike Bell (reviewer #2). Collectively, the reviews have highlighted areas where the manuscript was lacking, particularly with respect to its clarity and presentation. We have revised the manuscript with this feedback in mind, making changes to incorporate or otherwise address this feedback.

Because both reviewers were in broad agreement about the weaknesses of the paper and did not provide conflicting feedback, a summary of changes is listed below by section. Additionally, the revised manuscript and a "diff" of changes will be submitted after this comment is finalized.

Title and abstract

Both reviewers noted that the original title of the article was too bold, to put it bluntly. Additionally, the executive editor pointed out the GMD requirement that papers which refer to development for a single model must mention the model name and version number in the title. Consequently, the title is now "Development of a semi-Lagrangian advection scheme for the NEMO ocean model (3.1)."

Reviewer #2 additionally noted that the original abstract gave the impression that the method developed in this article is "very similar to the SISL algorithms used in atmospheric models." The first paragraph of the abstract is now revised to hopefully make the distinction more clear, and the second paragraph is reworded for simplicity.

Introduction

The introduction has been greatly expanded in response to the reviewers' comments. In textual order:

- Reviewer #2 noted that the leading paragraphs on coupled modeling seemed to be a tangential motivation. This has the awkward characteristic of being tangential yet true – the idea of applying semi-Lagrangian advection to the ocean model at CMC came out of realizing the computational cost of running coupled forecast systems. This section has been revised and modestly expanded to make the practical focus more clear.
- Both reviewers note that the discussion of why semi-Lagrangian advection might help the timestep size in ocean models was lacking. This is now more comprehensibly discussed in new section 1.1, which draws the suggested direct contrast between timestep-limiting factors in atmosphere and ocean circulation models.

Grid stretching is now a subsection to this discussion, which (at Reviewer #2's request) now also includes a brief description of the ocean flows in the gridpoint-clustered portion of the Canadian Arctic Archipelago.

- The "existing work" subsection (now 1.2) more directly engages with the literature on conservation-preserving semi-Lagrangian methods (noting this as not implemented but a future possibility, and without this interpretation semi-Lagrangian advection has a finite-difference interpretation) and ALE coordinates.

The other points raised by reviewer #1 (the "two other levels of constraints") are generally agreed to but addressed in the main body of the text as the issues arise.

Time discretization

- Both reviewers note that the notation in this section was awkward. Consequently, we have entirely revised this section to use a simpler notation of f^B ("before"), f^N ("now"), and f^A ("after") that should be familiar to readers from the leapfrog context, adapting it to semi-Lagrangian advection to add f^D ("departure"). This also resulted in small changes to the notation in subsequent sections for consistency.
- This section is also reorganized to separate the semi-Lagrangian advection (2.1) from its reconciliation with the leapfrog algorithm (2.2) to clarify the changes in perspective.
- Reviewer #1 also expressed doubts about whether semi-Lagrangian advection as-defined was robust to the Asselin timestepping filter. This analysis is now present in the new subsection (2.3), and the Asselin filter does not negatively affect the stability of semi-Lagrangian advection as-implemented.

Interpolation

- Reviewer #2 remarked that the discussion of two-dimensional interpolation was cumbersome and verbose. What was formerly the non-numbered "two-dimensional application" subsection has been removed, with the comment briefly summarized and placed just before the slope-limiting discussion.
- Reviewer #2 also noted that the discussion of vertical advection was confusing, especially the claims about discontinuous derivatives. Subsection 3.2 has been revised and reworded.
- We also revised the subsequent discussion of vertical slope-limiting to clarify (at reviewer #2's note of confusing language) why it is necessary at the bottom boundary in the presence of partial cells.
- A reference (Turkington et al., 1991) has been added for the numerical example on this section, at reviewer #2's request. To our knowledge this is not a standard test-case in the semi-Lagrangian literature, but nonlinear generalizations of this approach are a standard technique for calculating the profiles of nonlinear internal gravity waves.
- Reviewer #1 noted that the description of the advection constraint for the Eulerian/leapfrog numerical example in this section was "fuzzy," and so we have adopted the more precise definition. This led to no practical difference in the calculation, since the maximum Courant number in the domain is reached at the top and bottom boundaries where the vertical velocity is zero. (This did, however, lead to a discovery of a small bug in the code that generated this figure, which used the wrong vertical mode number to calculate wave-induced horizontal velocities for the purposes of evaluating the Courant number. This has been addressed in the submitted code repository and the figure regenerated; there is essentially no difference in results.)

Additionally, we replaced "CFL number" in the paper with "Courant number" throughout, since the latter concept is indeed the intended use of the term.

- Reviewer #1 also inquired about the performance of the Eulerian/leapfrog method in this section with a maximum Courant number close to 1. We investigated this over the range 0.2–0.99 and found little difference in error compared to the exact solution; this is mentioned in-text rather than by adding more lines to figure 3.

Trajectory calculation

- Reviewer #2 notes that the discussion about extrapolating into the boundary is confusing, and reviewer #1 asks whether this semi-Lagrangian method faces a Lipschitz stability condition. These are the same issue: the problem of extrapolating into the boundary arises only when a calculated trajectory would cross that of a fluid parcel that begins and remains on the (no normal flow) boundary. Consequently, we have revised the first part of subsection 4.1 to make this connection.

Numerical results

- Reviewer #2 requested more clarification on the inconsistency between the semi-Lagrangian advection and the Eulerian application of forcing. This amounts to an $O(\Delta t)$ approximation in the integral form of the semi-Lagrangian advection equation, and this is now noted in the discussion in subsection 5.1.
- Reviewer #1 notes that NEMO's TVD scheme is really a "tracer variance dissipation" scheme. This has been changed throughout with a citation to Lévy et al. (2001) at the first mention.

- Both reviewers remarked on the relatively short timestep used in the ORCA025 runs of section 5.2. New footnote 8 has been added to provide more context; in brief the ice/ocean drag parameter is increased following Roy et al. (2015), which makes the problem more apparent for the operational forecasting configuration than for typically-presented runs. At the same time, we wanted to maintain the same physical parameterizations between the operational configuration and the runs presented in this paper. Addressing this problem would be ideal and is the focus of ongoing work, but the runs of section 5.2 took long enough to complete on the shared supercomputing resources that they cannot be practically be repeated in GMD's peer-review timeframe even if a solution were immediately at hand.
- Reviewer #1 asked about the number of iterations taken to find trajectories and the effect of trajectory truncation. This is now discussed further in section 5.2; the mean number of trajectory iterations per cell for the semi-Lagrangian tracer run was 1.004, so truncated trajectories were truly exceptional. The performance cost of trajectory iteration is also addressed in the conclusions.
- Reviewer #2 requested expanded commentary on the MOC and circumpolar current results, which we have provided. Because these runs do report preliminary results, we want to be cautious about reporting false confidence that semi-Lagrangian advection causes physically-relevant changes in results that may not in fact be robust, but we agree that we erred on the terse side here.
- Reviewer #2 also requested a look at the mean global temperature profile at the start and end of the simulation. This is the new figure 9, with brief discussion at the end of section 5.

Conclusions

- Reviewer #2 requested a longer summary of the achievements, particularly one that highlights new algorithms. This is now added at the beginning of section 6, where we have added a list that highlights the core algorithms of this paper.
- Both reviewers had questions about the performance of the method and its parallel implementation. This is now dealt with in the conclusions, under the new (non-numbered) “performance and implementation” subsection.
- Reviewer #2 requested a deeper look at the application to climate simulations, and consequently we have expanded the discussion in the commentary on the results. The temperature profile results (specifically temperature stability in deep water) seem to be encouraging for climate applications, but we reserve a full recommendation for a future day when either temperature/salinity drift is fully characterized (and found to be acceptable) or conservation is explicitly added.
- Reviewer #2 also requested a brief discussion of how this algorithm might apply to the RK3 timestepping algorithm used in upcoming versions of NEMO. Since this is very much “future work” for both NEMO and semi-Lagrangian advection, we have added this discussion to the conclusions.

References

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