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Geoscientific Model Development Discussions

Interactive comment on "NEMOTAM: tangent and adjoint models for the ocean modelling platform NEMO" *by* A. Vidard et al.

Anonymous Referee #2

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General comments:

This manuscript discusses the development and validation of tangent linear and adjoint models for the NEMO modelling platform (NEMOTAM). As communicated by the authors in the introduction, adjoint models are highly valuable tools for a diverse range of applications (e.g sensitivity analysis, data assimilation, stability analysis) in climate science, making the motivation for this undertaking clear. The development of an adjoint for a complex and nonlinear model, such as NEMO, is notoriously difficult. Algorithmic differentiation (AD) tools exist that can greatly facilitate the derivation. However, since NEMO has not been developed in compatibility with an AD tool, the authors have elected to fully hand-code this release of NEMOTAM. I appreciate the

substantial effort entailed in both approaches, but suspect this choice will limit the "pool of potential users" to a rather small group unless more detailed information on the implementation specific to NEMO is provided. Furthermore, I feel that much of the mathematical description is - although relevant - well-known and could be replaced with suitable references. Although the authors provide a useful summary of key choices made in NEMOTAM (section 2) and guidelines for evaluating the impact of necessary approximations, the validation performed and example applications provided are rather insubstantial. I recommend publication in Geoscientific Model Development following revision to address these issues. Specific comments are listed below. I also include a list of minor alterations to the text; I believe most are necessary grammatical corrections, but some are suggestions that I feel would increase the readability of the manuscript.

Detailed comments:

I feel there are two important aspects of this manuscript that should be addressed prior to publication:

(1) Application of NEMOTAM: As noted above, a substantial part of the paper is occupied by a general mathematical description that I feel could be streamlined. This is especially true in section 4, where definitions do not offer new insights for the modelling community. Section 4 would be greatly improved by placing emphasis in each subsection on computational aspects specific to NEMOTAM. Although detailed discussion of the dynamics implied by the diverse applications is not required here, confirmation that NEMOTAM output is sensible is certainly suitable, but is missing from section 4.2.

(2) Scientific contribution: Since NEMOTAM is hand-coded it would be helpful if the authors would offer some concluding remark on the flexibility of the current release. Although it is hinted that "more flexibility" would be "very beneficial" in the conclusions section, I feel it is appropriate to give a more explicit indication of the potential for NEMOTAM to be applied (to sensitivity, assimilation, stability investigations etc.) under different experimental configurations. I feel that confirming some degree of existing flexibility is important in ensuring that the substantial effort invested in NEMOTAM translates to a useful scientific contribution.

Further minor aspects that I feel could be improved are listed below.

Pg 6707, L1: By noting that "automatic tools are now mature enough" for application to complex models, the authors somewhat undermine their later decision to hand-code the adjoint for NEMO.

Pg 6707, L11-L17: The authors cite limitations of automatic differentiation relating to the fact that it is rarely truly automatic (hence why many authors commonly refer to *algorithmic* differentiation instead). These are not really "limitations *compared* to hand-coding".

Pg 6711, L10-L16: Is the oscillatory advection term retained in the full nonlinear model but neglected by the gradient computations (i.e in both the TLM and the adjoint)? I am confused by the justification of the choice here, since the exactness of the adjoint with respect to the full nonlinear model is relevant.

Pg 6711, L15: Remove "(see next section)" as the loss of exactness is not really discussed in detail.

Pg 6711, L22: Please elaborate a little on what is meant by "well-chosen" (i.e choice is determined by resources? nonlinearities in the code? etc.).

Pg 6712, L1-L5: I may have misunderstood this part of the discussion, but linearly interpolating between checkpoints to relieve storage demands seems drastic. Please included additional citations if this approach is taken in other model frameworks. Although this simplification does not appear to significantly impact the TAM for the test cases referenced in table 2, it will surely become important in other experimental configurations; for example where checkpoints are spaced further apart during longer integrations. Could the authors not employ a higher level checkpointing scheme here? The MITgcm employs a 3-level scheme enabling efficient generation of the adjoint and retaining the conjugate gradient solver (relevant to the authors' discussion on pg 6712). (e.g see Heimbach et al, (2002) Automatic generation of efficient adjoint code for a parallel Navier-Stokes solver). It would be helpful if the authors could offer some insight into the limitations encountered using this subsampling/interpolation approach (e.g perhaps state the maximum time period accessed using NEMOTAM with the SEABASS configuration).

Pg 6714, L9: add a subscript 0 to x in $\gamma\delta x$?

Pg 6714, Eq 3: the truncation error is the size of the full perturbation squared? i.e $O(\gamma\delta {x_0}^2)$ (consistent with the text on pg 6715, L8)

Pg 6715: I found section 3.3 confusing. I think the aim is to define an error measure for approximating the full model physics in the generation of the TLM but must admit that I can't see how this is provided by E in Eq 9. Are the I components of ε in Eq

7 related to different approximations made to the nonlinear model M? And then is it necessary to assume linearity to obtain Eq 8?

Pg 6715, Eq 7: $\delta {x_0}^{-2}$ should be replaced with $\delta {x_0}^2$ and the truncation error should be corrected to account for the full perturbation $((O(\gamma \delta x_0)^4))$?

Pg 6721, Eq 18: Time is here denoted by a capital (T) when it was previously denoted using lower case (t).

Pg 6728, Table 1: It may be helpful to redefine γ and ϵ in the caption?

Pg 6732, Figure 3: Please include details of the perturbed field here.

Suggested minor language changes:

Pg 6707, L13: "automatic derived" to "automatically derived"
Pg 6707, L14: "of hand-coded one" to "of the hand-coded one"
Pg 6707, L16: "code still require to be" to "code are still required to be"
Pg 6707, L28: remove "etc." at the end of the sentence?
Pg 6708, L9: "by (Tber et al., 2007)" to "by Tber et al., 2007"
Pg 6708, L26: remove the full stop in "AD tool. compatible"
Pg 6708, L28: "do not allow yet" to "do not yet allow"
Pg 6709, L24: "non supporting" to "not supporting"
Pg 6709, L1: The abbreviation "Autodiff" has not yet been introduced
Pg 6709, L25: "actually on its way" to "in progress"
Pg 6710, L1: "cells size depending on the flow (they become then active variables)" to

"cell size dependent on the flow (thus becoming an active variable)"?
Pg 6710, L4: "remaining of this section" to "remainder of this section"
Pg 6710, L20: "than in" to "as in"
Pg 6711, L2: "has been sorted out by simplification. . ." to something like "differentiation is achieved by first simplifying. . ."?
Pg 6711, L4: "to keep" to "of keeping"
Pg 6712, L1: "long period of time" to "long integrations"?
Pg 6712, L2: "too important" to "severe"?
Pg 6713, L4: finish the end of the sentence by changing "is a crucial aspect." to "is a crucial aspect of the model development."?
Pg 6714, L21: "And the first order accuracy index" to "The first order accuracy index is defined as follows"
Pg 6714, L24-L25: "tends to one when γ tends to zero" to "tends to 1 as γ tends to 0"?
Pg 6715, L6: "approximations have to be done" to "approximations have to be made"
Pg 6716, L11: "allows to" to "allows us to"
Pg 6716, L18: "incertitude" to "uncertainty"
Pg 6716, L22: "of gradient" to "of the gradient"
Pg 6717, L15: "is the local. . ." to "where S_α is the local. . ."
Pg 6719, L2: "(again we could have guessed)" to "(which again we could have guessed)"
Pg 6719, L15: please define "FGAT"
Pg 6719, L20: I don't understand what is meant by "B (resp R) is the background (resp observation)". Please clarify.
Pg 6720, L12: "dynamics is" to "dynamics are"
Pg 6720, L14: "DA" has not been defined
Pg 6720, L24: Please replace "not that bad"
Pg 6721, L2: "is the stability analysis" to "is stability analysis"
Pg 6722, L18-L20: the sentence beginning "Apart from" needs to be rewritten, or could be removed.

Pg 6722, L25: “and a most” to “and most”
Pg 6722, L27: “as illustration of” to “as an illustration of”
Pg 6723, L3: “recompilation” to “recomputation”?
Pg 6723, L8: remove “approaches were used” from the sentence and change “depending of” to “depending on”
Pg 6723, L12: “effort has been done” to “effort has been invested”
Pg 6723, L16: “TL” has not been defined
Pg 6723, L17: “approximations on” to “approximations of”
Pg 6723, L20: “applications were exposed” to “applications were presented”
Pg 6723, L24: “leaves the room” to “leaves room”
Pg 6723, L25: “modules, as LIM” to “modules, such as LIM”
Pg 6723, L26: please define “MPP”

Missing “with”
Pg 6706, L12: “derivatives respect to” to “derivatives with respect to”
Pg 6711, L15: “model respect to” to “model with respect to”
Pg 6716, L23: “functions respect to” to “functions with respect to”
Pg 6717, L1: “gradients respect to” to “gradients with respect to”
Pg 6730, Fig 1 caption: “error respect to” to “error with respect to”

Missing/misplaced “s”:
Pg 6706, L6: “major method” to “major methods”
Pg 6706, L11: “modelling tool” to “modelling tools”
Pg 6706 L25: “differentiation tool” to “differentiation tools”
Pg 6707 L8: “parameters estimation” to “parameter estimation”
Pg 6707 L11: “differentiation suffer” to “differentiation suffers”
Pg 6707 L15: “differentiable part” to “differentiable parts”
Pg 6709 L20: “counterpart” to “counterparts”

Pg 6711 L9: “tracer’s advection term” to “tracer advection terms”
Pg 6711 L10: “such scheme” to “such schemes”
Pg 6711 L11: “one differentiate” to “one differentiates”
Pg 6711 L11: “then apply” to “then applies”
Pg 6711 L20: “which need” to “which needs”
Pg 6712 L2: “test only ensure” to “test only ensures”
Pg 6712 L25: “optimisation have” to “optimisations have”
Pg 6712 L27: “all these effort” to “all these efforts”
Pg 6715 L3: “This diagnostics” to “This diagnostic”
Pg 6715 L8: “first estimates” to “first estimate”
Pg 6716 L20: “three kind” to “three kinds”
Pg 6719 L10: “computing gradient” to “computing gradients”
Pg 6719 L13: “types schemes” to “type schemes”
Pg 6723 L13: “each adjoint routines and gives” to “each adjoint routine and give”

Also please choose between “non-linear”, “nonlinear” and “non linear”.