

## Initial response to reviewer 2 after first review

26 May 2025

We thank Guillaume for his time, his suggestions and for his positive comments about our manuscript. Our responses below are in blue.

### **Reviewer 2:**

This is a review of the manuscript entitled “Impact of non-normal flow rule on linear kinematic features in pan-Arctic ice-ocean simulations.” The study discusses the effect of allowing the rheology used in the CICE large-scale sea ice model to deviate from the normal flow rule, which is normally used to determine the direction of deformations when sea ice undergoes plastic deformation. It is largely motivated by a previous study that showed that using a nonnormal flow rule resulted in more realistic linear kinematic features (LKFs) in a more idealized setup. In particular, it had been shown to significantly improve the model’s ability to reproduce realistic intersection angles of conjugate faults. Here, the authors show that this is not the case. They discuss the potential reasons for this negative result compared to the more idealized study and suggest (with some supporting arguments) that these intersection angles may be largely constrained to follow the model grid axes, resulting in intersection angles often close to  $90^\circ$  in the case of the grid used here. Despite this negative result, they show that using a non-normal flow rule has other effects on LKF properties, which could make its use a convenient way to tune LKF characteristics in large-scale sea ice models.

The manuscript is well-written and clear. The scope is well-defined, and the analysis is sound and well-supported. The topic is perhaps a bit niche, but it aligns with previous studies published in the journal and is of interest to the sea ice modelling community targeted by The Cryosphere. The suggestion that the peak at  $90^\circ$  partly results from the alignments of LKFs with the grid axes is sound. It may not be fully demonstrated here (as mentionned), but the authors have gathered enough elements to point to this cause in their results and discussion. The argument is strong enough to motivate the community interested in sea ice deformations to investigate the numerics instead of only focusing on the physics. Additionally, the fact that the non-normal flow rule can be “tweaked” to tune sea ice deformations properties is an interesting result for the sea ice modelling community. Therefore, I support the publication of this manuscript

in The Cryosphere. I do not have comments that I consider major, but I would recommend the minor revisions below:

We thank the reviewer for these positive comments.

General comments:

Given that one of the main results is that using a non-normal flow rule can be a convenient way to tune certain LKF properties independently, the authors may consider commenting on the implementation in CICE. Does it require substantial modification to the code? Does it significantly impact computational time?

This is a very good suggestion. We will comment in the revised manuscript on what is required to implement the non-normal flow rule. The implementation is actually incredibly simple. Indeed, only small modifications to the calculation of the shear ( $\eta$ ) and bulk ( $\zeta$ ) viscosities are required. With the standard VP rheology,  $\eta = e^{-2}\zeta$  where  $e$  is the ellipse ratio and  $\zeta = P/2\Delta$  with  $\Delta = [D_d^2 + e^{-2}(D_t^2 + D_s^2)^2]^{1/2}$ . For the non-normal flow rule,  $e^{-2}$  is simply replaced by  $e_G^{-2}$  for computing  $\eta$  while  $e^{-2}$  in  $\Delta$  is replaced by  $e_F^2/e_G^4$ . There is therefore no impact on the computational time.

I sometimes found the order in which the figures are referenced a bit confusing. For example, it appears that Figure 4 is referred to after Figures 5 and 7, and Figure 2 before Figure 1. This has little impact in the preprint, since all figures are at the end, but the authors may consider reordering the figures for the final version.

Thank you for pointing this out. We will reorder the figures in the revised manuscript.

Specific comments:

L213: I think “of” is missing (or something else)

This will be corrected.

L337/338: I find this sentence a bit unclear.

This will be rephrased in the revised manuscript.

L340/350: I find the ideas in this paragraph a bit hard to follow, I think it would benefit from a bit of rewriting (especially the sentence starting with “But clearly..”)

We will carefully rephrase these sentences.

Jean-Francois Lemieux