Review of the Paper: "Impact of Non-Normal Flow Rule on Linear Kinematic Features in Pan-Arctic Ice-Ocean Simulations"
Jean-François Lemieux, Mathieu Plante, Nils Hutter, Damien Ringeisen, Bruno Tremblay, François Roy, and Philippe Blain

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Summary:
This paper presents a detailed sensitivity study on the influence of a non-normal flow rule in the viscous-plastic (VP) sea-ice rheology on the simulation of linear kinematic features (LKFs) in Arctic sea ice. The authors implement the concept of a plastic potential and non-normal flow rule introduced by Ringeisen et al. (2021) into the CICE sea ice model and conduct a comprehensive series of pan-Arctic simulations based on this implementation.

However, the central result of the study is that the peak of the probability density function (PDF) of the simulated intersection angles between conjugate LKFs remains at 90°, whereas observational data show a peak around 45°. This finding is counterintuitive, as Ringeisen et al. (2021) demonstrated that using a non-normal flow rule enables the simulation of smaller intersection angles that align more closely with observations. This discrepancy raises a fundamental and scientifically important question: what is the underlying cause of this difference? Answering this question would be interesting and valuable for the community.

Instead of systematically addressing this question, the authors limit themselves to a purely parametric sensitivity analysis. As a result, parts of the paper take on the character of a technical documentation of the non-normal flow rule implementation in CICE, without achieving the intended effect, namely more realistic intersection angles. In my view, the innovative contribution of this paper is therefore limited.

Since the discrepancy between the idealized tests in Ringeisen et al. (2021) and the CICE implementation remains unresolved, the overall validity of the presented results is questionable. In my view, it is entirely possible that the peak in LKF intersection angles at 90 degrees arises from numerical details specific to the CICE implementation, and that a careful reproduction of the setup proposed by Ringeisen et al. could yield a peak at smaller angles.

The authors' explanation, that this discrepancy is due to a grid effect, appears vague and insufficiently analyzed. Moreover, this hypothesis is not in line with previous studies, such as Hutter et al. (2022) and Hutter and Losch (2020).

Recommendation:

I therefore recommend that the manuscript place greater emphasis on the core scientific question: Why does the CICE implementation yield different results from the idealized tests by Ringeisen et al.? A targeted and transparent validation of the implementation is essential in this regard. For these reasons, I recommend a **major revision**.

Main Points:

1. The authors write:
   "We don't think it is related to the use of a C-grid and a VP rheology by Ringeisen et

al. (2021) as opposed to the B-grid with EVP dynamics used here."
To validate this claim and, more importantly, to demonstrate that the implementation performs as intended, I suggest reproducing the idealized test case from Ringeisen et al. within CICE and first evaluating whether their results can be replicated. This would confirm that the basic implementation is correct and that differences in numerical treatment—such as C-grid vs. B-grid or the choice of solver—do not, as the authors suggest, contribute to the observed deviations in the results.

2. "For VP experiments with a normal flow rule, Hutter and Losch (2020) compared the mean orientation of LKFs with the grid axis and could not find a clear correlation. For the SIREx project, Hutter et al. (2022) made the qualitative argument that the peak of the PDF at 90° is not caused by LKFs aligned with the grid as models with an unstructured grid also lead to a peak at 90°. Our analysis, involving the computation of the intersection angle for all the conjugate pairs, clearly indicates a tendency of simulated LKFs to be aligned with the grid."
This is already the second aspect in which the results of this study seem to differ from existing work. To relate the observed behavior to a grid effect, a more in-depth investigation, as suggested in point 1, is required.
3. In line 351, the authors write:
"As demonstrated in other studies, we find that the elastic-viscous-plastic (EVP) rheology with a normal flow rule (i.e., $e_G = e_F$) leads to a PDF of intersection angles (for conjugate pairs) with a peak at 90°. Using a non-normal flow rule with the elliptical yield curve, as introduced by Ringeisen et al. (2021), does not remedy this problem. Either with $e_G < e_F$ or $e_G > e_F$, the peak is still at 90°."
In my opinion, this study cannot claim general validity of its findings, as it remains unclear what the cause of the observed failure is. In particular, it has not been convincingly ruled out that the observed effect may be due to details in the implementation. From my perspective, it is still possible that the effect observed by Ringeisen can also be reproduced in pan-Arctic simulations, provided that the setup is carefully implemented.

Minor Points:

Introduction:

- **Line 32**: "It is expressed with the use of a plastic potential: the post-failure deformations are normal to the plastic potential."
This sentence is extremely technical for an introduction and difficult to understand. Some readers may not know what it means that post-failure deformations are normal to the plastic potential. It should either be reworded and better explained or supplemented with a sketch or equation that clarifies the meaning.
- **Lines 31–40**: These are too technical and difficult to digest for an introduction. Please revise and invest more effort in explaining the technical terminology.

Section 2:

- Move Section 2 to the appendix. The presentation of the concepts is currently very isolated, making it completely unclear how they relate to the equations that describe the rheology.

- For example, in **line 60**: Which system of equations are you referring to? Please specify clearly.
- In addition to the equations describing the rheology or yield curve in the standard VP model and in Ringeisen's version, graphical representations would be helpful for better understanding the key parameters **eF, eG, and e**. In the current presentation, it is very difficult for readers from the Cryosphere community, who may not be familiar with all of Ringeisen's previous work, to follow the argument.
  - **Line 65**: Please explicitly state the constitutive equation.
  - **Line 77**: "With the non-normal flow rule, η is now equal to $e^{-2}\zeta$." – Why? Please explain.

Methodology:

- **Line 136**: Where does this choice come from? Why is eG set to ~ eF/1.5, eF, or ~ 1.5eF? Please justify.
- **Line 155**: "A kernel value of seven is used for the detection algorithm." – Why 7? What does it mean? Please explain.
- **Lines 168–173**: What is α? What does "morphological thinning" mean? Please include a sketch to make this clearer.
- **Line 176**: What do you mean by "conjugate fault lines"?
- **Line 177**: What exactly is the vorticity being analyzed?
- **Lines 177–182**: This section is extremely technical and hard to understand. Either explanatory sketches should be added, or the content should be moved to the appendix.

Figure 1a:

- To me, the structures shown look like numerical instabilities. It is possible that the modification proposed by Ringeisen increases the stiffness of the system of equations, making it harder to solve. While 900 iterations are considered sufficient in the standard EVP model, they may be inadequate for the modification investigated here. I therefore recommend conducting tests with smaller time steps and/or more iterations to check whether sharper structures can be resolved and whether the 900 EVP subcycles are indeed sufficient here.

Results:

- Line 366: "Note that our conclusions remain the same whether the implicit approach (VP) in CICE or the explicit one (EVP) is used."
  There are numerous publications, including some by Lemieux, that show that ten Picard steps are insufficient to achieve a convergent solution. Therefore, it is possible that the observed effect is due to the inadequate accuracy of the approximation solutions in both setups (EVP and Picard).