

Following is my review of the manuscript entitled “Effects of including the adjoint sea ice rheology on estimating Arctic ocean–ice state” by Guokun Lyu, Armin Koehl, Xinrong Wu, Meng Zhou, and Detlef Stammer (egusphere-2022-1099).

General Comment

In this study, motivated by Toyoda *et al.* (2019), the adjoint sea-ice model with viscous–plastic rheology (adjoint-VP) is applied to a coupled ocean and sea-ice state estimation system for the Arctic Ocean, and compared with the previous version in which the simplified adjoint sea-ice model of free drift (adjoint-FD) is used to avoid numerical instability. One year of optimization experiment for 2012 shows that the adjoint-VP can produce better state of the ocean and sea-ice through more appropriate dynamic and thermodynamic processes than the adjoint-FD.

Such findings are important for a further development of global-scale ocean state estimation and data assimilation studies, and could be worth to be published in *Ocean Science*. However, the manuscript has many deficiencies listed below and needs to be substantially revised before acceptance.

Specific Comments

1. Line 44: ECCO should be defined here.
2. Figure 1: It might be better to indicate important seas and straits.
3. Line 86: Describe the bulk formulae and related parameters used in this study, or cite appropriate references.
4. Explain why the open boundary conditions and the river runoff are not included in control variables.
5. Line 101: Explain what “effective” thickness means.
6. Line 118: BGEP should be defined here.
7. There are no explanations for SIC, SIE, SIT, SLA, and SST.
8. Section 2.3: Briefly describe the treatment of snow on sea ice, which may affect surface albedo and thermodynamic processes, or cite appropriate references.
9. Line 191: It is better to write explicitly that satellite-observes SST (J_{SST}) and SIC (J_{SIC}).
10. Line 196: It is misleading to call “the adjoint of full sea ice dynamics”, because adjoint-VP still uses an approximated form of viscous–plastic rheology.
11. Section 3.1 and Table 2: The reviewer supposes that relative costs of individual constituents depend on their number of observations. If this is true, it might be better to indicate the total number of each measurement in Table 1.
12. Figure 3, caption: Explicitly mention that (a)–(c) are average of 2012.

13. Line 217: Explain what “sea ice extent regions” means.
14. Section 3.2.1: The normalized SIC errors of about 0.5 indicates that simulated SICs are overfitted to observations. Discuss this point.
15. Figure 4, caption: Describe the averaging period for (a)–(c).
16. Section 3.2.2: There are no description of Figure 5.
17. Figure 5, caption: Describe the averaging period.
18. Figures 3, 4, 5, and 6: It might be better to use the same colors among these figures for CTL, adjoint-FD, and adjoint-VP.
19. Line 337: Explain why April 10 and September 20 are chosen for this analysis.
20. Figure 9, caption: Explicitly mention that (a)–(e) are for the control run.
21. Figure 9: It seems that the red lines in (a), (f), and (k) are the September SIE from the control run, the black lines in (g)–(j) are from the adjoint-FD, and those in (k)–(o) are from adjoint-VP.
22. Line 369: It sounds strange that the SIC change through ice–albedo feedback is categorized as F_{oi} rather than F_{ai} .

Technical Corrections

1. Use the same terminology throughout the manuscript. There are variants, e.g., “coupled ocean and sea-ice model”, “coupled ocean and sea ice model”, or “coupled ocean–sea ice model”; “Barents and Kara Seas” or “Kara and Barents Seas”.
2. Lines 60 and 63: Dynamic should read dynamics.
3. Line 63: Zhang and Hibler Iii, 1997 should read Zhang and Hibler, 1997.
4. Line 108: Q^{-2} should read Q_a^{-2} .
5. Line 125: 0.25% should read > 25%.
6. Equation 3: $\varepsilon_{i,j}$ should read ε_{ij} .
7. Line 152: C^* should be 20.0 rather than -20.0 .
8. Line 163: 31 January 31 should read January 31.
9. Line 180: Dynamic should read dynamics.
10. Line 195: J_{sst} should read J_{SST} .
11. Line 207: Visual should read visible.
12. Line 274: Convert the second “In” to lowercase.
13. Line 374: Betterthan should read better than.
14. Line 374: Barent should read Barents.

15. Line 413: Incuded should read included.

16. Line 425: 20. September should read September 20.

17. Figures 1, 3, 4, and 7: Paint the Great Britain Island gray.