Impact of Arctic Mesh Refinement on Global Sea Ice State in E3SM

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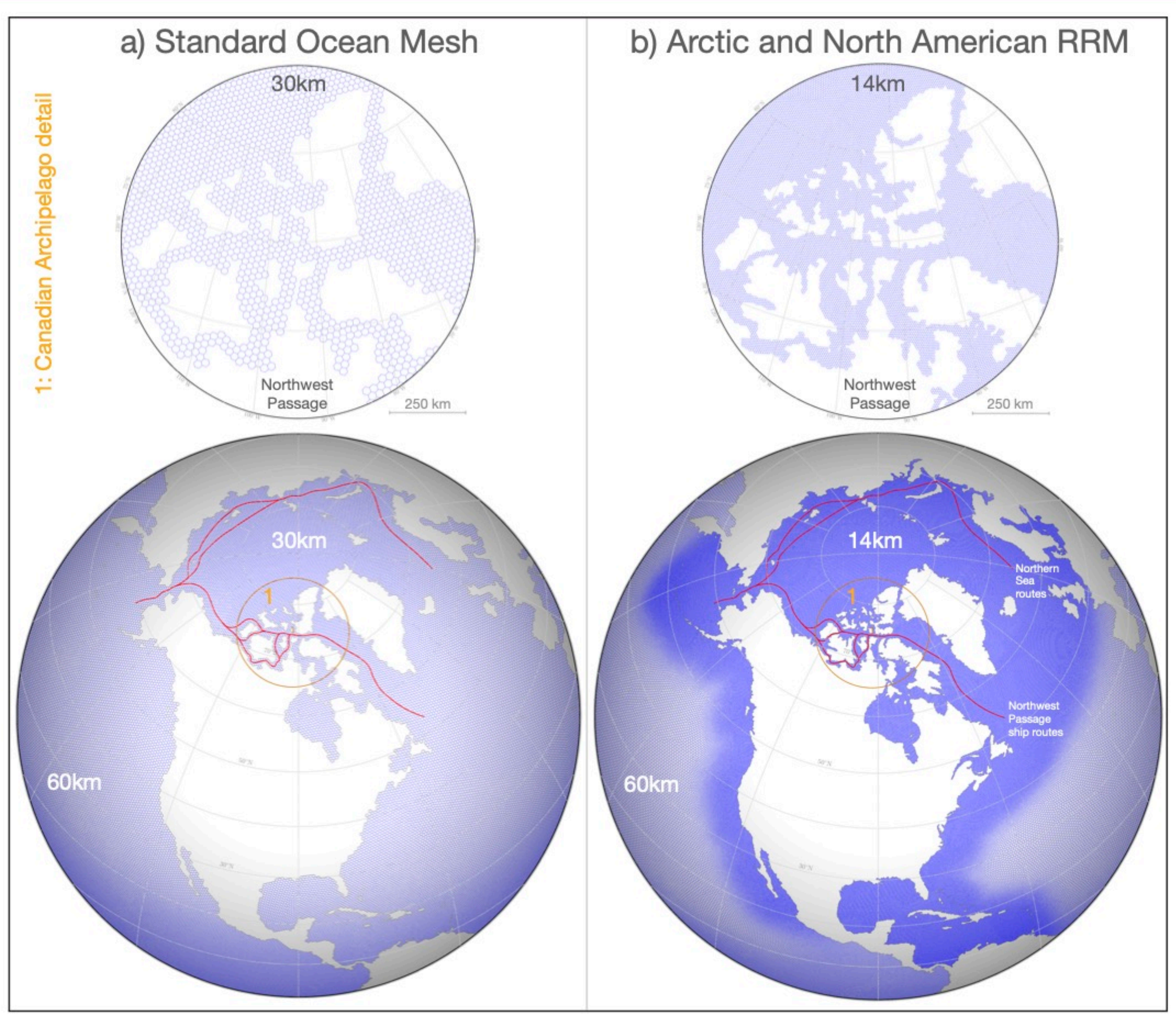
Summary

This poster summarizes key attributes of the global sea ice solution in the E3SMv2 North American Regionally Refined Model (NARRM) relative to the standard coupled model. We compare 500-year preindustrial simulations of the two models as well as historical ensembles to understand the impact of 14km marine regional refinement over the entire Arctic Ocean and North American coastal regions. This is coupled to 25km atmospheric refinement extending to abyssal areas off North American coasts. The refinement is compared to the standard model with 30-60km and 100km respective standard resolution ocean and atmosphere meshes. Using daily sea ice means from E3SM, our analysis indicates there is a marked increase in northern hemisphere sea ice volume with regional refinement, but little improvement in Arctic and Antarctic winter sea ice extent. For the industrial period, we inter-compare 5-member ensembles against the latest version of the NOAA Climate Data Record of ice concentration and the Pathfinder dataset of sea ice drift. These comparisons indicate there is little improvement in E3SM as compared to the observed winter ice edge even with Atlantic regional refinement, and that the NARRM model configuration does not resolve a chronic ice-edge bias in the model. The end-of-melt-season trend in northern hemisphere extent, as measured on the equinox, is similar and largely unbiased as compared to observations, while the southern hemisphere is biased and the trend has the wrong sign in E3SM. Both models produce markedly different circulation patterns in the Arctic relative to the Pathfinder drift dataset, however results from that dataset draw into question its veracity, and we are investigating this further by comparing with independent buoy drift datasets.

Observational datasets courtesy National Snow and Ice Data Center

Arctic Mesh Refinement



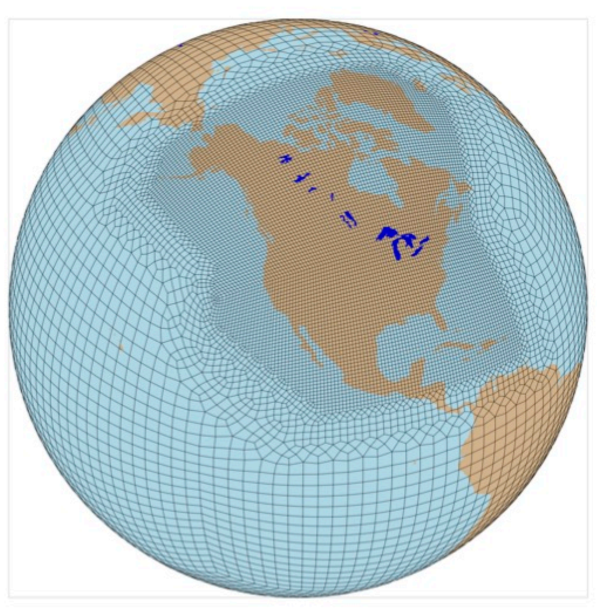


Figure 1 (above): Standard E3SMv2(a, LR) and regionally-refined (b, NARRM) sea ice mesh with scaled close-ups of the Canadian Archipelago illustrating refinement relative to the standard mesh. All configurations resolve Arctic coastal shipping routes (red).
Figure 2 (right): The NARRM atmospheric mesh refines the American Arctic to 25km.

	Resolution	Columns
Ocean and Sea Ice		
Standard Resolution (LR)	30–60 km	236,853
North American Refinement (NARRM)	14–60 km	407,420
Atmosphere and Land		
Standard Resolution (LR)	110 km	21,600
North American Refinement (NARRM)	25–110 km	57,816

Table 1: Mesh details: columns indicate the orthographic count of grid points on which scalars such as sea ice volume are calculated.

Impact on Sea Ice Mass and Energy

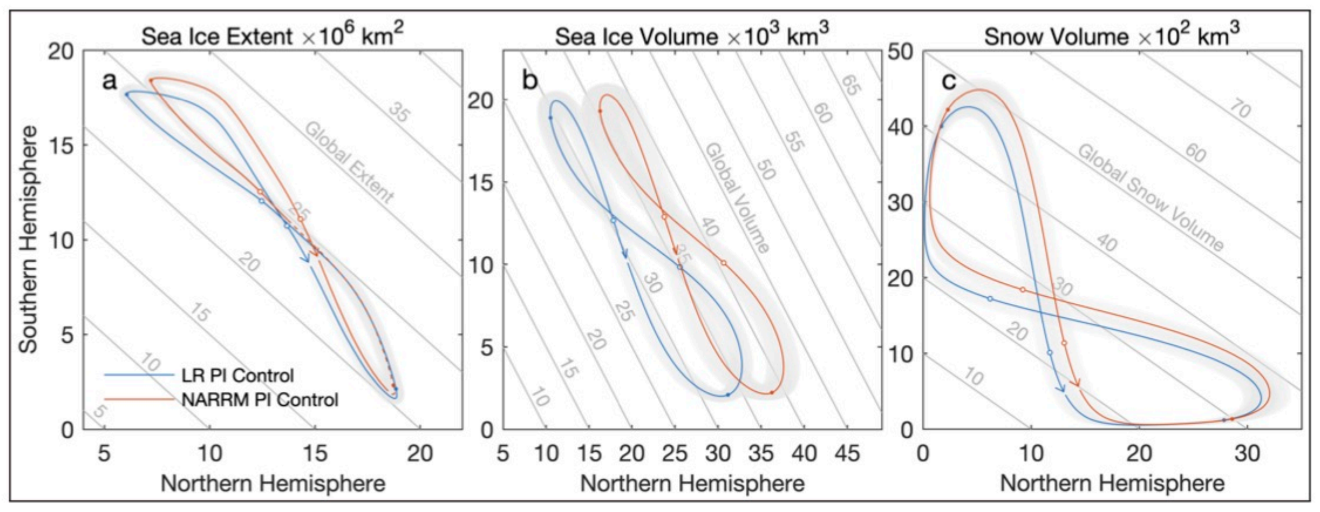


Figure 3 (above): Daily sea ice phase average (solid) and interquartile range (gray) illustrating that Arctic regional refinement (NARRM) results in an average 5000 to 6400 km^3 greater simulated ice volume in the Northern Hemisphere than is produced at standard resolution (LR), a ∼16% (winter) to 57% (summer) increase over the annual cycle of the 500-year preindustrial controls. Arctic refinement increases summer extent in the Arctic, and winter extent in the Antarctic. Snow volume on sea ice increases due to these changes. Dashed red lines indicate the null hypothesis for days of the year that NARRM is different from LR at the 99% compatibility interval. Traces start on January 1, passing the northward equinox (•), northern solstice (◦), southward equinox (•), and southern solstice (◦) to the end of December (→). Note that extent is a scale-dependent metric, but the comparison of total sea ice and snow volume is independent of resolved areas on a model or observational mesh.

Increased Arctic sea ice volume in NARRM simulations is in part attributable to increased convergence within the sea ice zone. Winter positive (negative) extent bias occurs in the northern (southern) hemisphere irrespective of model resolution (Figs. 3, 4, 6 and 7).

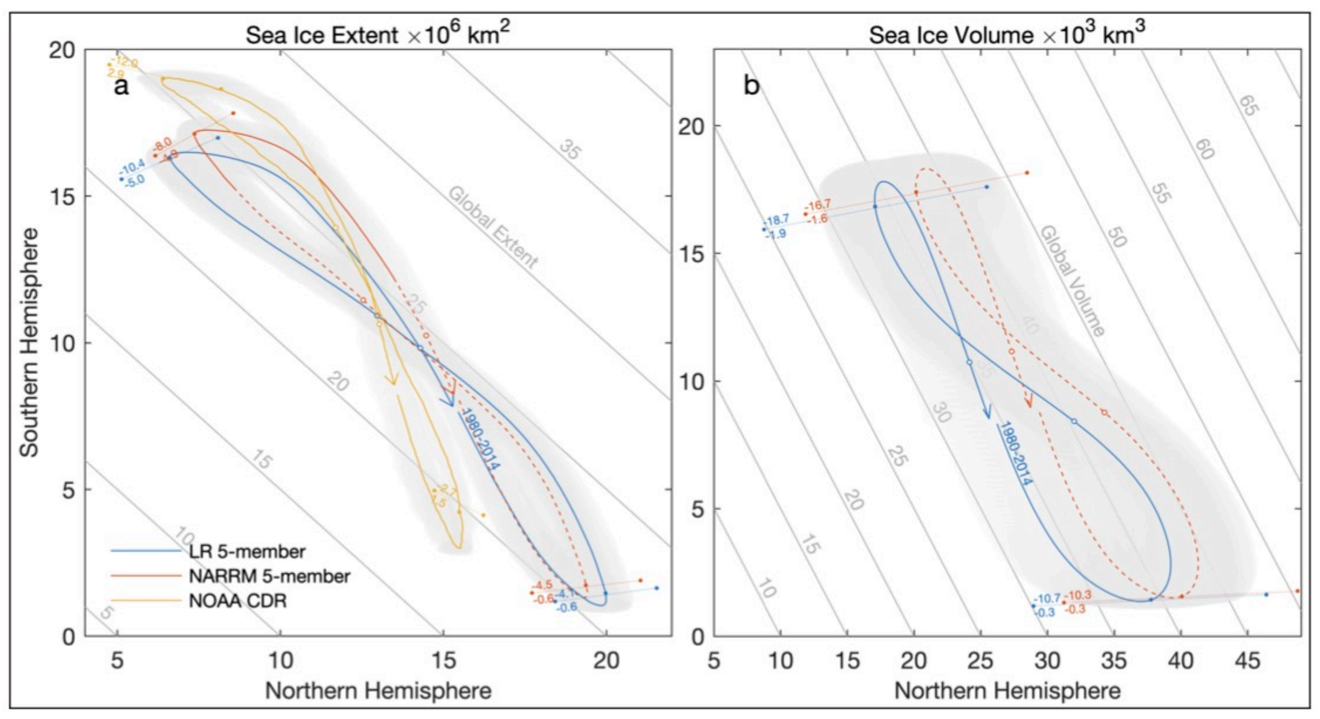


Figure 4 (above): Ensemble average (colored) and interquartile range (gray) in sea ice extent (a) and volume (b) phase from 1980 to 2014 for 5 ensemble members each from NARRM and LR, as compared to the NOAA Climate Data Record of sea ice extent in (a). In addition to the •, ◦, and → annotations explained in the Figure 3 caption, dotted linear trend lines are also provided for equinoxes extending from 1980 to 2014. Associated trends are annotated in units of %/decade for the northern (upper number) and southern (bottom number) hemispheres, respectively. For example, the observed September 1980-2014 equinox trend in extent is -12.0 and +2.9 %/decade, respectively, for the northern and southern hemispheres. The comparable NARRM values are -10.4 and -5.0 %/decade, respectively; the model does not capture the observed sea ice cover increase in the Antarctic, but closely mimics observed summer sea ice loss in the Arctic with no discernible bias.

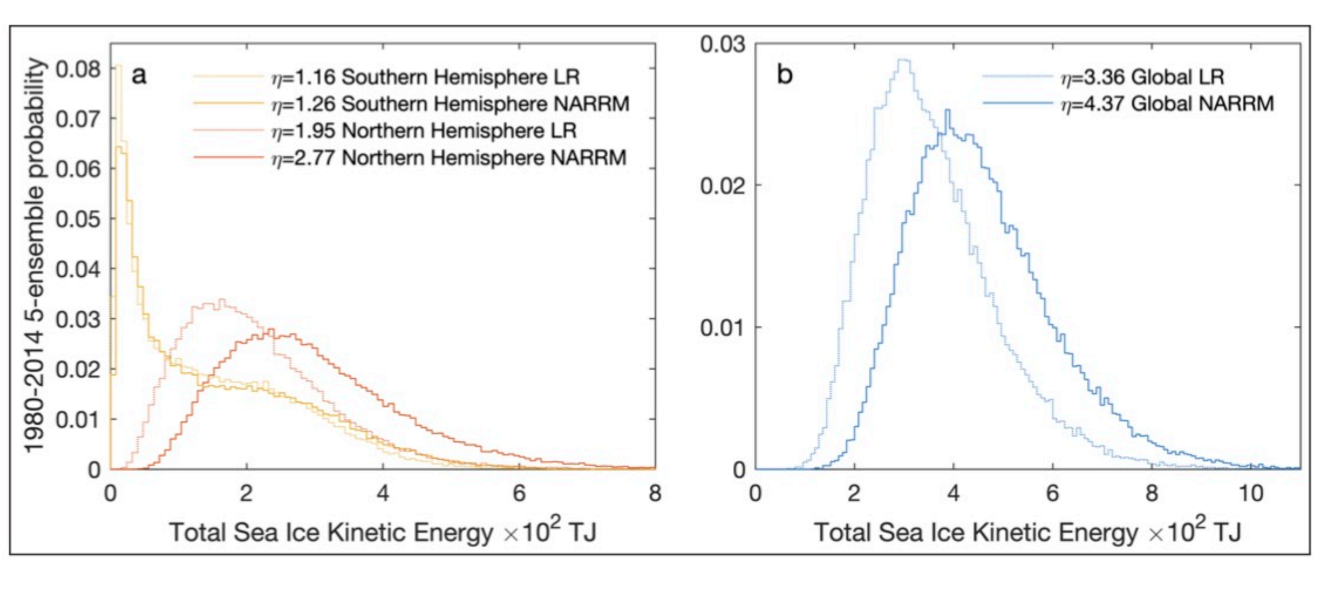


Figure 5 (above): Total kinetic energy (TKE) in the NARRM and LR 5-member ensembles for the 1980-2014 evaluation period. Increased TKE results from increased mass and eddying in NARRM versus LR.

Impact on Sea Ice Drift

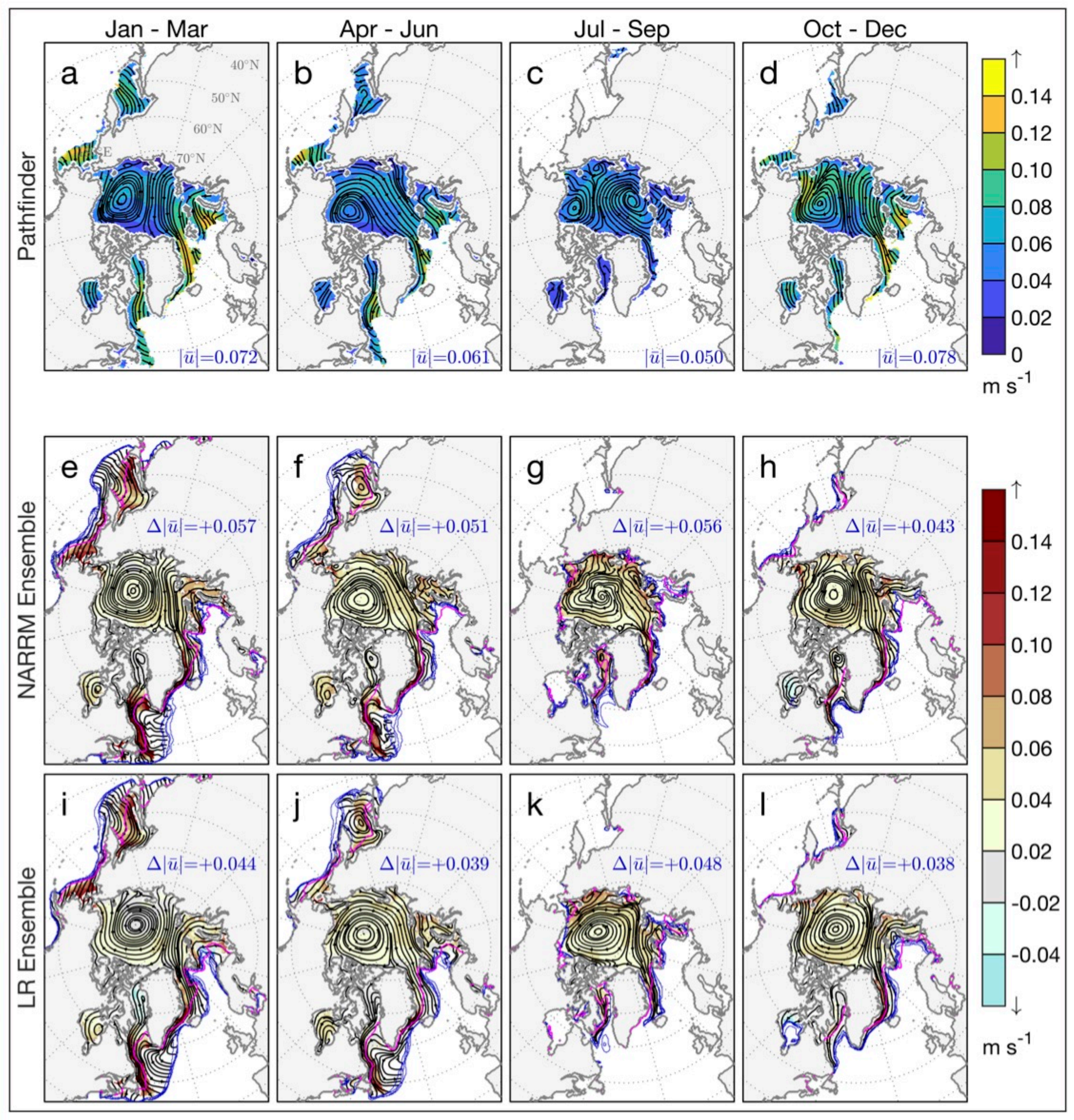


Figure 6 (above): 1980-2014 average northern seasonal sea ice drift (streamlines) and speed (shaded) constructed from daily Pathfinder V4 approximations fused from buoy, and orbital infrared and passive microwave observations, truncated at 15% concentration (a-d). The seasonal speed difference (shaded) between E3SM 5-member ensembles and Pathfinder drift is illustrated for NARRM (e-h) and the standard resolution E3SM (i-l). Overlaying streamlines for the model indicates ensemble mean drift. Sea ice extent for each respective ensemble member in E3SM is provided in blue in the two lower panels, and may be compared with the seasonal sea ice edge from the NOAA daily V4 Climate Data Record seasonal average (magenta). Blue numbers in the top row indicate mean drift speed across the sea ice zone ($|\bar{u}|$), and in the lower two rows indicate the difference between the ensemble mean and Pathfinder ($\Delta|\bar{u}|$), illustrating that modeled Arctic sea ice is on average nearly twice as fast as the Pathfinder observations.

Difference between individual ensemble members and Pathfinder drift is significant at the 99% compatibility interval across nearly all of the sea ice zone. Standard deviation in model drift often exceeds Pathfinder by a factor of two for individual ensemble members. Owing to the Pathfinder tracking method, it is likely E3SM is more realistic and agrees better with published buoy drift speeds. During summer months when feature tracking is difficult, NARRM simulated drift closely follows bathymetric contours, in contrast to Pathfinder and standard resolution E3SM.

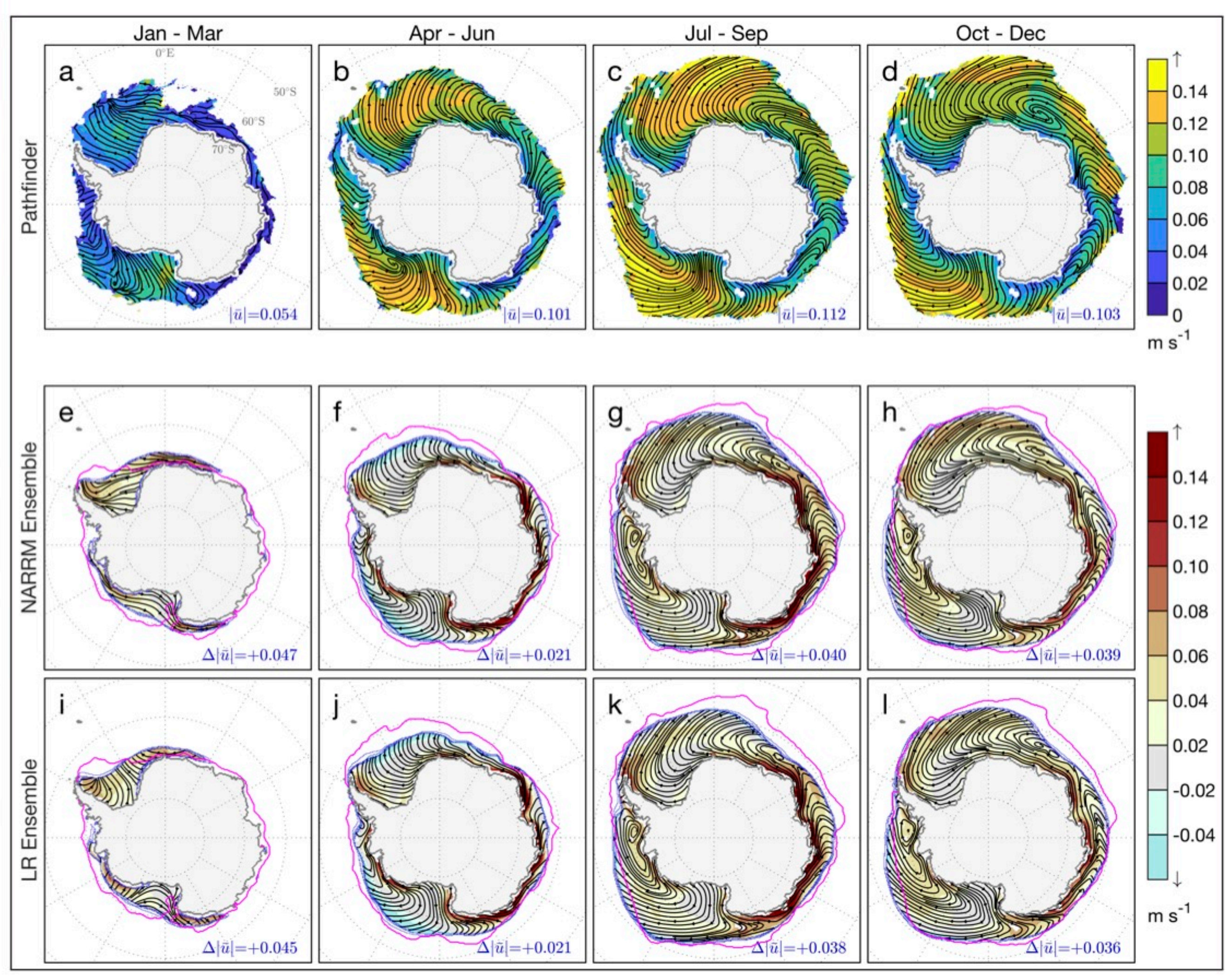


Figure 7 (above): As for Figure 6, but for the southern hemisphere.