Improving Fidelity of Arctic and Global Ocean Dynamics Using the E3SM Arctic Eddy-Resolving Ocean and Sea Ice (E3SM-AEROSI) Model

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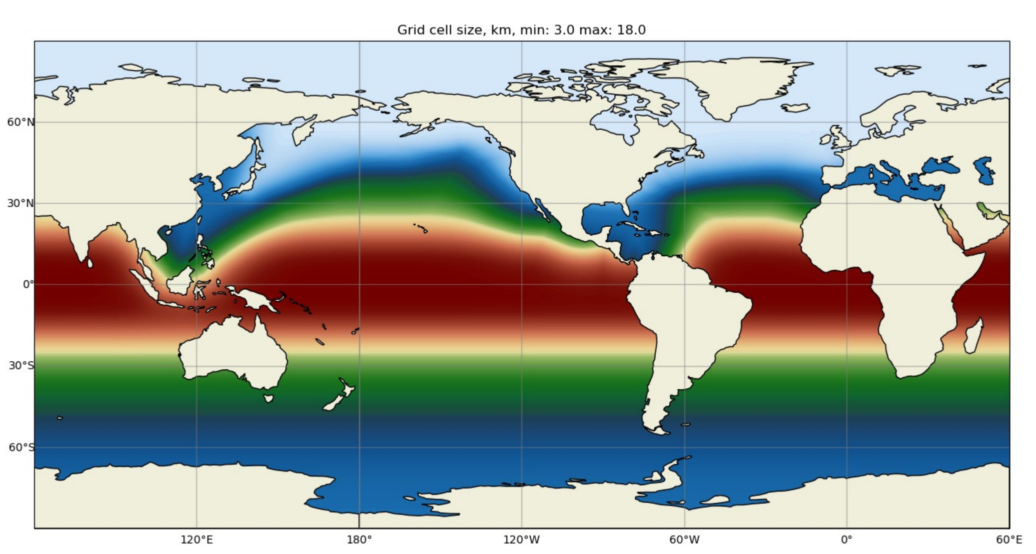
1. Abstract

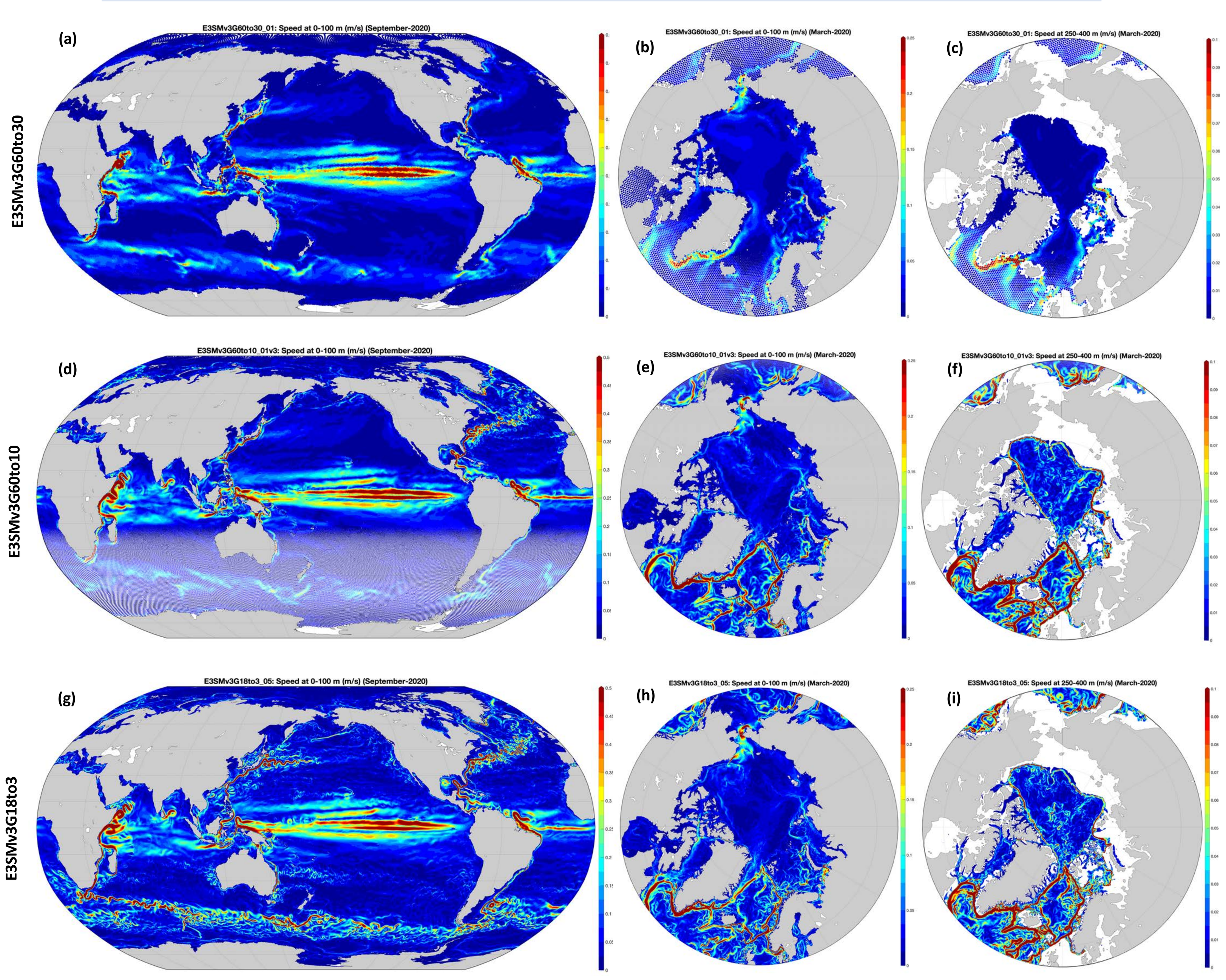
The E3SM Arctic Eddy Resolving Ocean and Sea Ice (E3SM-AEROSI) model aims to provide a process-level baseline of the Arctic Ocean and sea ice time-varying states not readily available from observations, connection to the lower latitude oceans, and a guidance for future observations and development of improved parameterizations of Arctic-relevant processes missing or under-represented in coarser resolution models. Its configuration is based on the standard E3SM high-resolution (6to18km) grid in the southern hemisphere, while it incorporates the Arctic regionally refined mesh with 3 km-width cells throughout the pan-Arctic region and along the western boundary currents, increasing to 6 km in the northern mid-latitudes, up to 18 km within the equatorial zone. The model has been forced at the surface with the Japanese 55-year atmospheric reanalysis (JRA55-do) and so far, has completed the full JRA55 cycle of 63 years. The approach of ultra-high and regionally refined ocean spatial resolution takes advantage and aims to demonstrate the benefits of the core E3SM capability and explores its readiness for coupling with cloud/convection resolving atmospheric models in the age of Exascale computing. Selected results are presented on the evolution of the Arctic sea ice, eddy kinetic energy field, Arctic-Subarctic exchanges, and potential impacts on the global ocean circulation, where possible comparing those to lower resolution forced ice-ocean E3SM simulations.

2. E3SM-AEROSI Overview



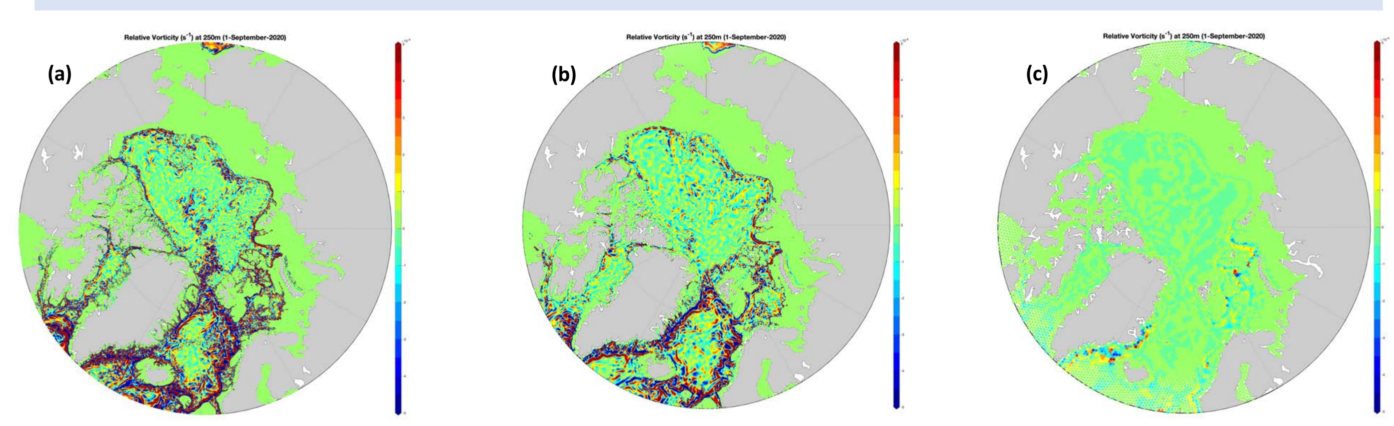
- Mean grid-cel size of the ocean and sea ice model components, ranging from 18 km in the equatorial zone up to 3 km in the northern high latitudes
- Southern Hemisphere grid as in the E3SMv3 HR (6to18km)

3. Intercomparison of the upper ocean dynamics



A monthly-mean September 2020 snapshot of global sea surface height and the upper ocean (0-100 m) currents (speed) (a,d,g). A monthly-mean March 2020 snapshot of the Pan-Arctic sea surface height and: the upper ocean (0-100 m) currents (speed) (b,d,h), the Atlantic layer (250-400m) speed (c,f,i).

4. Intercomparison of relative vorticity



Monthly-mean 'snapshots' of relative vorticity at 250 m for September 2020 from (a) E3SMv3G18to3, (b) E3SMv3G60to10, and (c) E3SMv3G60to30

9. Summary

1. E3SM-AEROSI simulation results represent improvements relative to the comparable coarser resolution E3SM ocean/sea ice configurations, and in comparison with observations.
2. Both the Arctic sea ice cover and AMOC strength are improved relative to the coarser E3SMv3 configurations.
3. E3SM-AEROSI allows a fully global and significantly improved representation of ocean mesoscale eddies and other ocean dynamics, including in the Arctic Ocean.
4. The completed and ongoing simulations constitute quality data for training AI/ML emulators and parameterizations.
5. Results from the first two loops of E3SM-Aerosi forced with JRA55-do atmospheric reanalysis provide encouragement for: (i) evaluation against observations, (ii) studies of mesoscale processes, (ii) further model optimization of scale aware parameterizations, and (iv) **coupling with high-resolution atmosphere / land E3SM configurations to advance modeling and predictive capabilities to address national science and operational objectives.**

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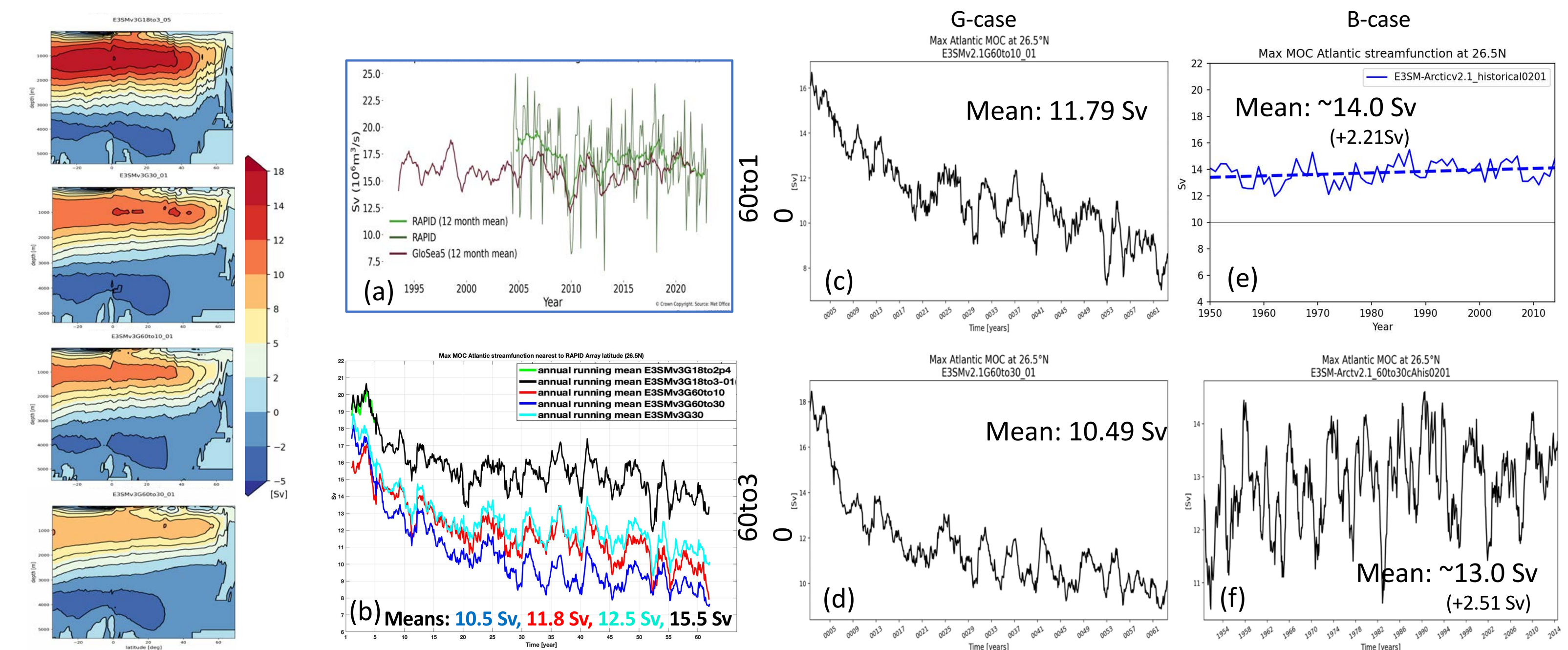
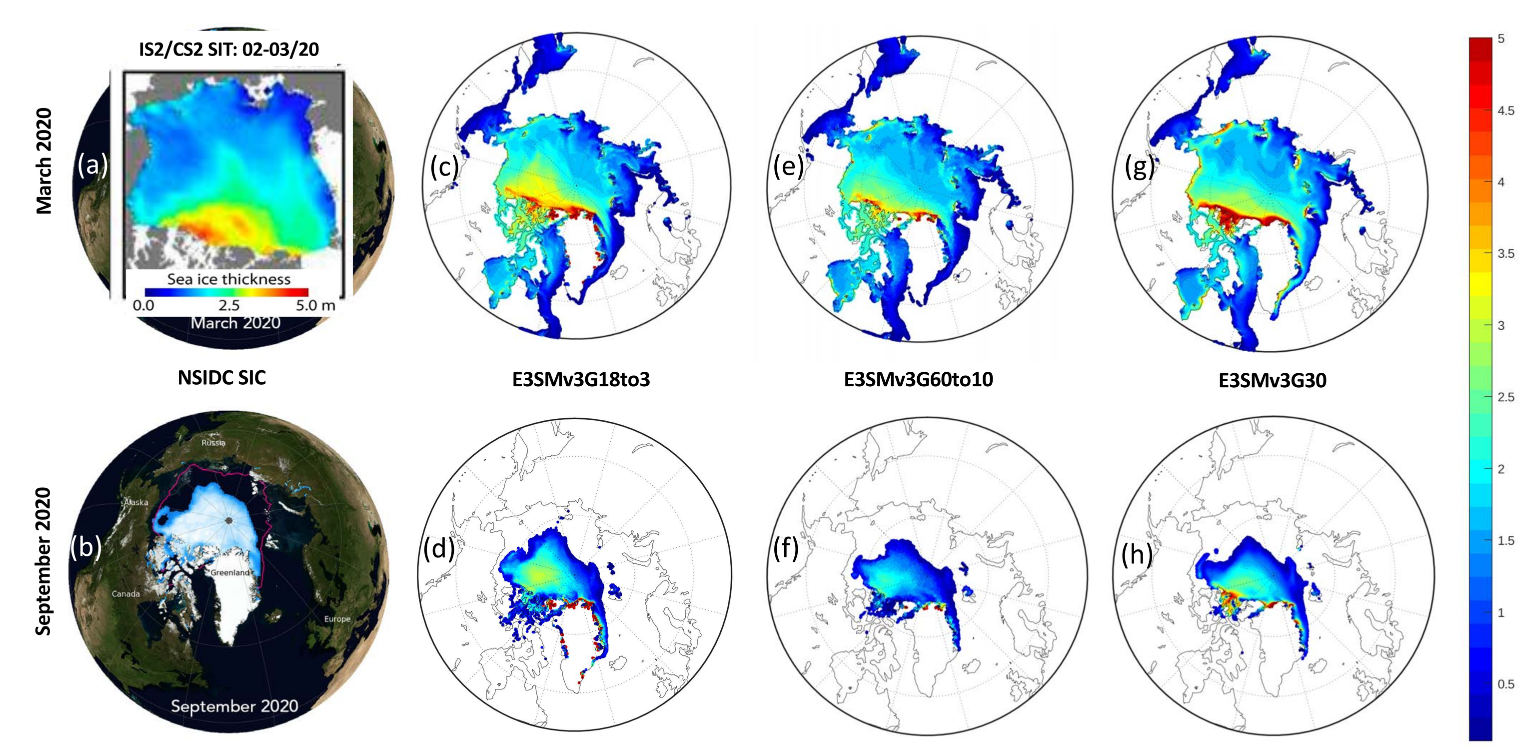
6. AMOC stream functions at 26.5ºW



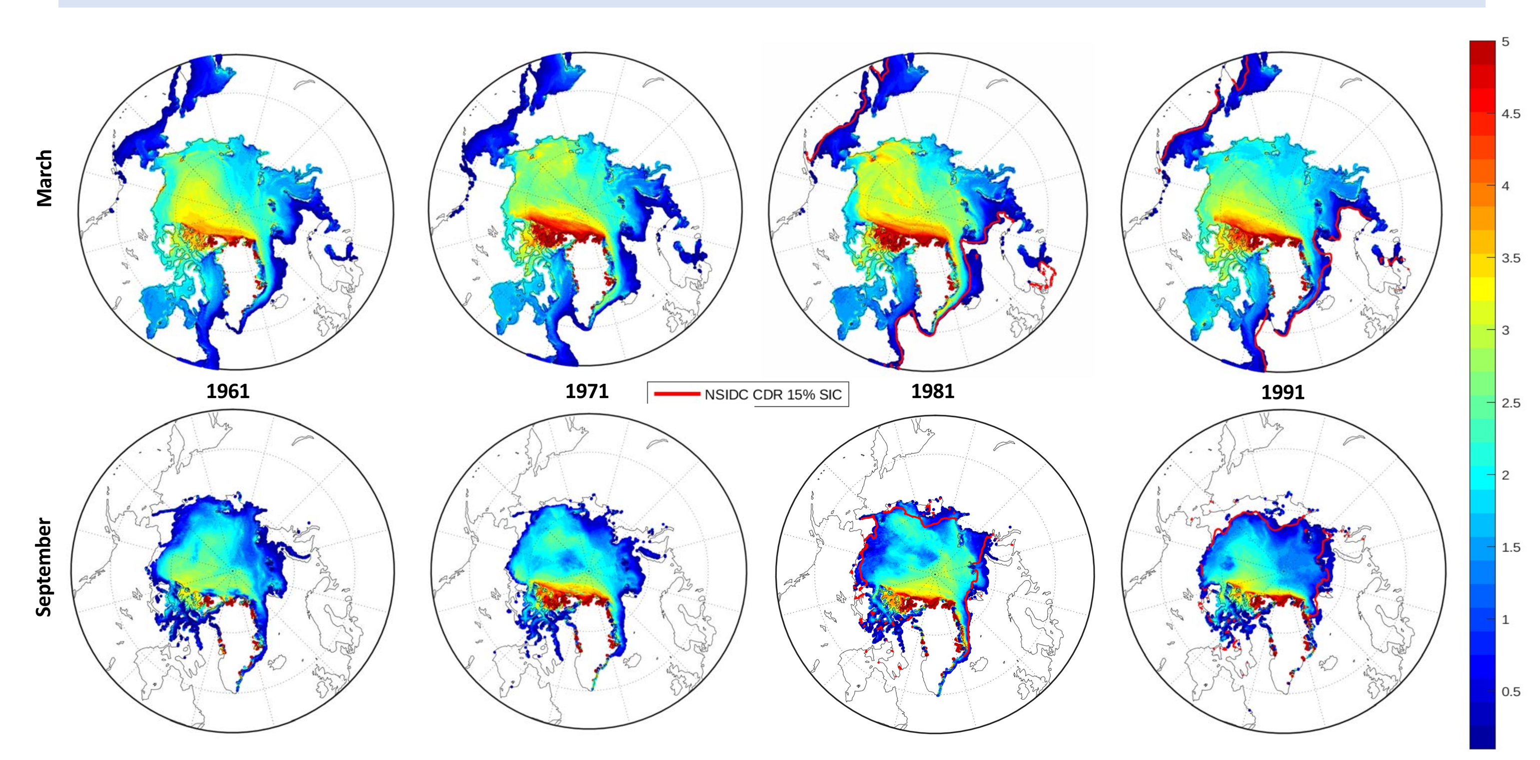
The AMOC mean (1982-2020) meridional overturning stream functions (Sv) from four E3SM configurations forced with JRA55-do (left column). (a) Intercomparison of AMOC stream functions timeseries at 26.5 from the RAPID array and GloSea5 ocean reanalysis, E3SMv3xx JRA-55-do forced (c & d) and fully coupled (e & f). Note that AMOC stream function is: (i) 2-3 Sv less in GloSea5 compared to the RAPID array, (ii) increasing in E3SMv3G configurations with increasing frid resolution, and (iii) increasing 2-3 Sv in E3SMv3B simulations compared to the respective E3SMv3G simulations.

5. Comparison of E3SM NH sea ice thickness distributions



(a) Intercomparison (top) March and (bottom) September 2020 sea ice thickness distributions from (a) IceSat2-CryoSat2, (c&d) E3SMv3G189to3, (e&f)) E3SMv3G60to10, (g&h) E3SMv3G60to30, and (b) sea ice area from NSIDC.

5. Snapshots of E3SMv3G18to3 sea ice thickness and area distributions

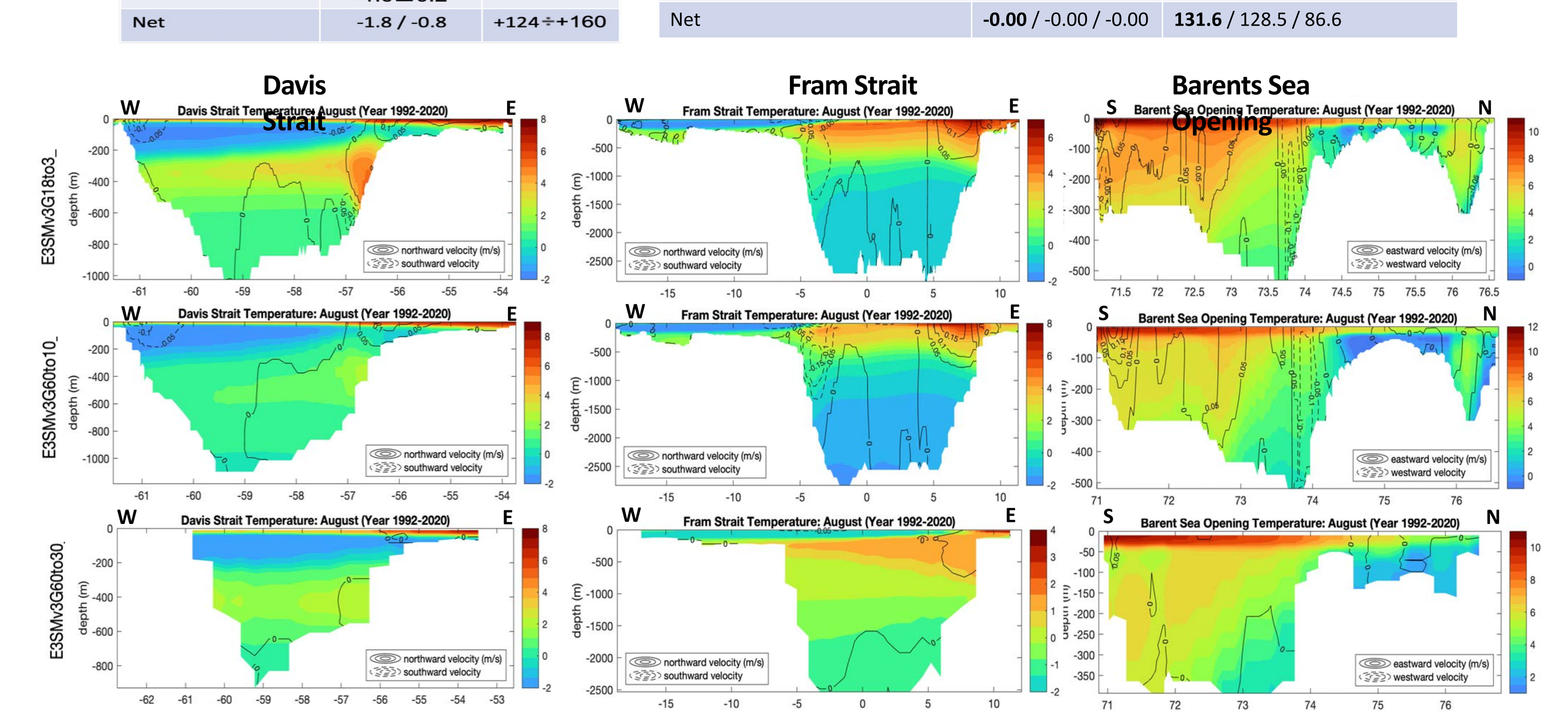


(a) Intercomparison (top) March and (bottom) September 2020 sea ice thickness distributions from (a) IceSat2-CryoSat2, (c&d) E3SMv3G189to3, (e&f)) E3SMv3G60to10, (g&h) E3SMv3G60to30, and (b) sea ice area from NSIDC.

8. Comparison of transport and structure at Arctic Ocean gateways

Observations	Volume (Sv)	Heat (TW)
Fram Strait	-2.0±2.7	+26÷+50
Barents Sea Opening	+2.0±0.8 / +2.3±2.9	+70
Bering Strait	+0.8±0.2	+10÷+20
Davis Strait	-2.6±1.0 / -1.6±0.2	+18÷+20
Net	-1.8 / -0.8	+124÷+160

E3SMv3G18to3 / 60to10 / 60to30	Volume (Sv)	Heat (TW)
Fram Strait	**-2.51** / -2.75 / 3.61	**18.1** / 18.8 / -11.3
Barents Sea Opening	**2.77** / 2.54 / 3.07	**102.1** / 94.9 / 89.9
Bering Strait	**1.10** / 0.99 / 0.96	**11.5** / 10.3 / 9.3
Davis Strait	**-1.39** / -0.78 / -0.87	**-0.2** / 4.5 / -1.3
Net	**-0.00** / -0.00 / -0.00	**131.6** / 128.5 / 86.6



The mean (1992-2020) August structure of temperature distribution across (left) Davis Strait, (middle) Fram Strait, and (right) Barents Sea Opening from (top) E3SMv3G18to3, (middle) E3SMv3G60to10, and (bottom) E3SMv3G60to30.