High-resolution global ocean simulations in the SWOT era: introducing ECCO llc4320v2

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Physics

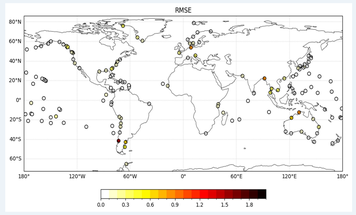
Global MITgcm ocean/sea-ice on 1/48° (llc4320) grid with 173 levels
Spanning SWOT and PACE missions: year 2023 is complete
Hydrostatic primitive equations with non-linear free surface
Forcing from hourly ERA5 atmosphere and full lunisolar tidal potential with online self attraction and loading
GEBCO2025 bathymetry including updates from SWOT
JRA55do river runoff with dynamic river temperatures
Spin-up from GLORYS12 at 1/12°

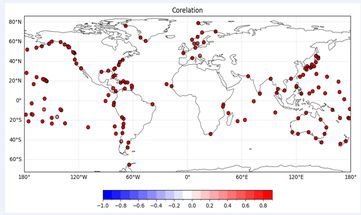
Engineering

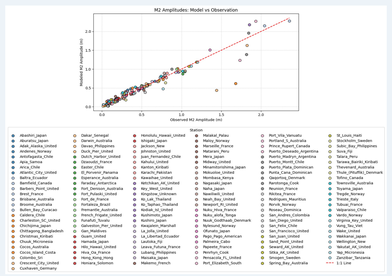
0.065 simulated hours per node hour on dual socket 128 core EPYC 9745 Turin processors.
Time step = 20 seconds.
Typical throughput of 8 days per wall clock day on 128 nodes; scales to 470 nodes.
Asynchronous I/O at 10s of GB/s with on-the-fly compression enables efficient output at 70GB per 3-D field per snapshot.
Hourly snapshots yield ~4PB per simulated year of data resolving high-frequency and submesoscale processes globally.

Coastal

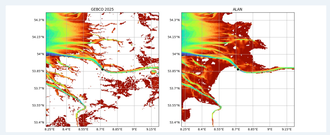
Modeled sea-level variability is similar to observations at coastal tide gauges, with few exceptions at sites with known difficulties.





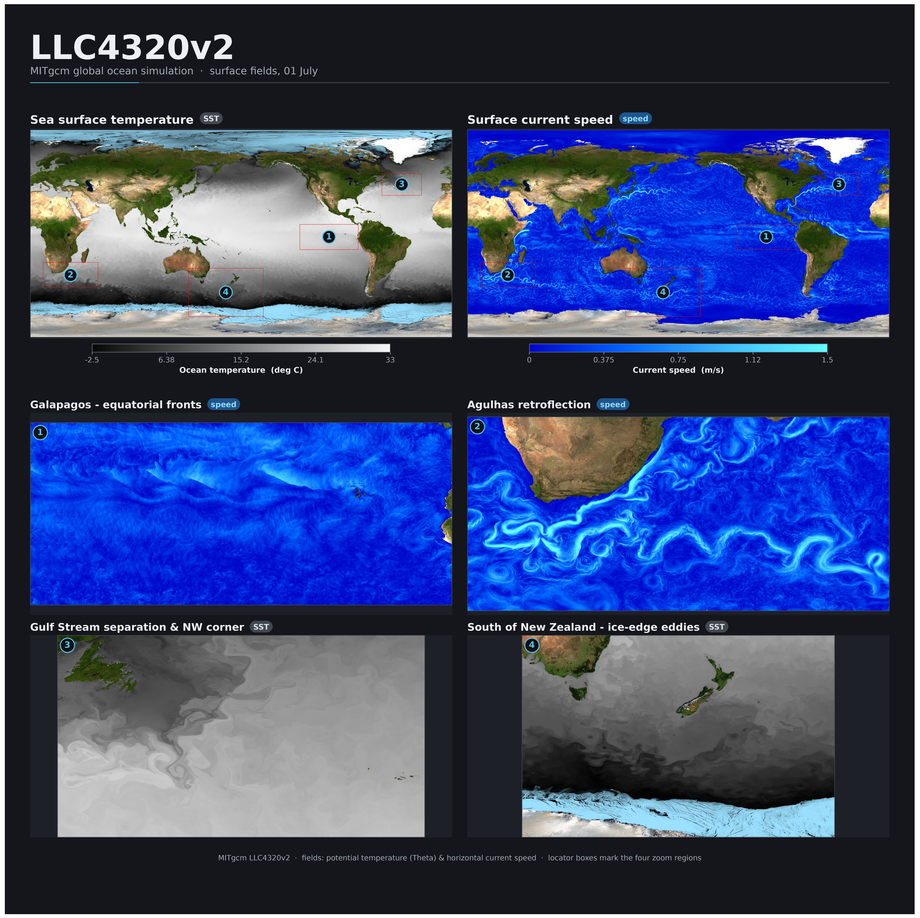


Example: Issues with GEBCO2025 bathymetry identified by Alan Wallcraft cause problems near Cuxhaven



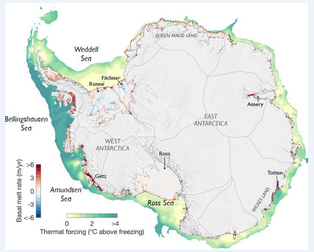
Access the output

Model output is immediately available to anyone who has access to NASA Ames Supercomputers and is being transferred to the public facing NAS (https://data.nas.nasa.gov) and Johns Hopkins (https://www.sciserver.org/) data servers for universal access. Please contact Dan Whitt (daniel.b.whitt@nasa.gov) or Dimitris Menemenlis (dimitris.menemenlis@sjsu.edu) for help getting access to model output.

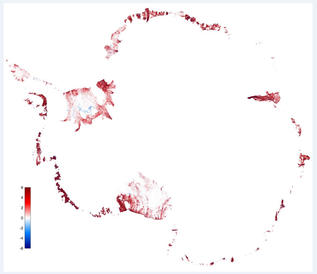


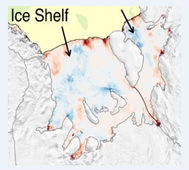
High-latitude

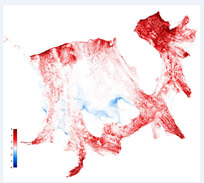
Coupling to thermodynamically active ice shelves



Adusumilli et al., *Nat Geosci.*, 2020.





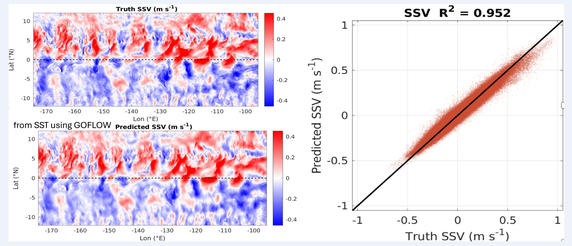


April 15, 2023 basal melt rate in m/yr for llc4320v2.

- Ice shelf cavities initialized January 1, 2023 from ECCOv4r5 + 2 years of spin-up @ llc1080.
- Ice shelf bed data from BedMachine Antarctica, Version 3.

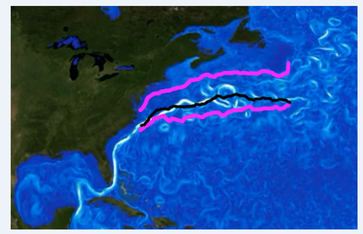
Machine learning

llc4320v2 has been used to train GOFLOW, which uses machine learning to estimate ocean currents from sequences of (nominally geostationary) SST images following the methods of Lenain et al. (2026) Nat. Geosci. We trained and tested GOFLOW in the tropical Pacific in addition to the North Atlantic. Preliminary results indicate that the high-resolution llc4320v2 nature simulation may prove valuable for training machine learning models.



Simulated northward velocity in the equatorial Pacific on January 24, 2023, can be predicted remarkably well from simulated SST using GOFLOW machine learning.

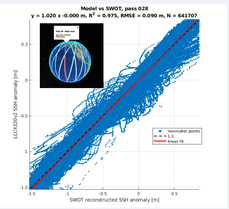
Gulf Stream

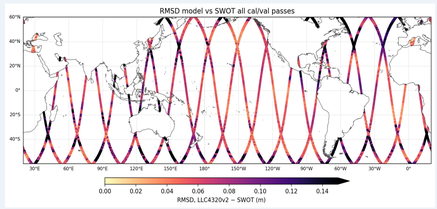


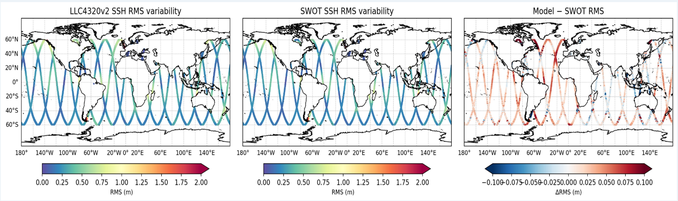
In llc4320 classic, the Gulf Stream separates prematurely from the North American continental margin, causing the entire modeled current path to sit too far south (~250 km at 70°W). This is fixed in llc4320v2. The figure at left shows llc4320v2 sea surface speed on May 29, 2023: black line is mean Gulf Stream location from OSCAR surface current analysis and magenta lines are a Gulf Stream envelope from Lee and Cornillon (JPO, 1996).

Surface Water and Ocean Topography

Modeled fields are interpolated to SWOT swaths with cubic-in-time+linear-in-space accuracy during the daily cal/val orbit between March 26 and July 10 2023.
https://nasa-ext.box.com/s/pa31ouihhkyckez9ojelpm74os92dd5m
After barotropic + baroclinic tide, dry atmosphere, and mean dynamic topography are added to convert L2SSHA -> SSH, the observations are highly correlated with the model (r^2 ≳ 0.9)







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