Preliminary comparisons of high-resolution ECCO and GEOS/ECCO simulations with SWOT data

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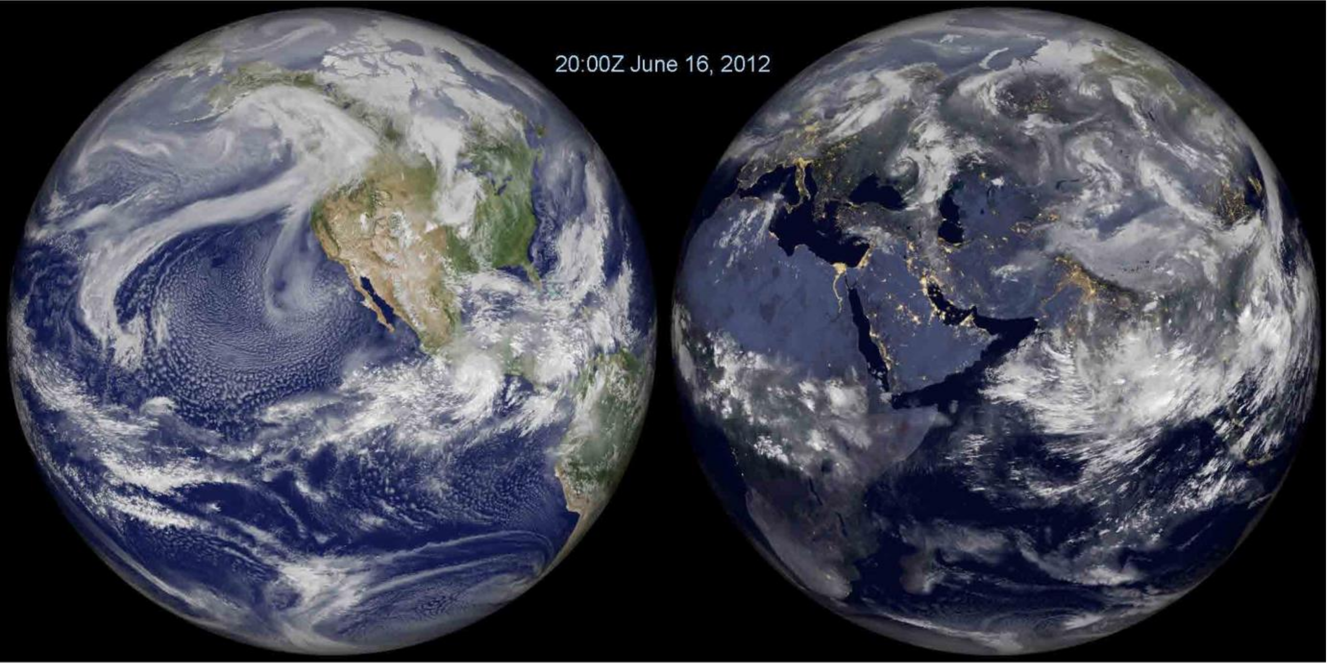
With: Andrea Molod, Chris Hill, Jean-Michel Campin, Patrick Heimbach, An Nguyen, Gaël Forget, Hong Zhang, Ehud Strobach, Abdullah Fahad, Atanas Trayanov, Chris Henze, Bron Nelson, David Ellsworth, Nina McCurdy, Brian Arbic, Dick Peltier, Kayhan Momeni, Yuchen Ma, Arin Nelson, Joe Skitka, Ritabrata Thakur, Yulin Pan, Patrice Klein, Hector Torres, Ian Fenty, Mike Wood, Dustin Carroll, Tom Haine, Ryan Abernathey, Martin Losch, and many others

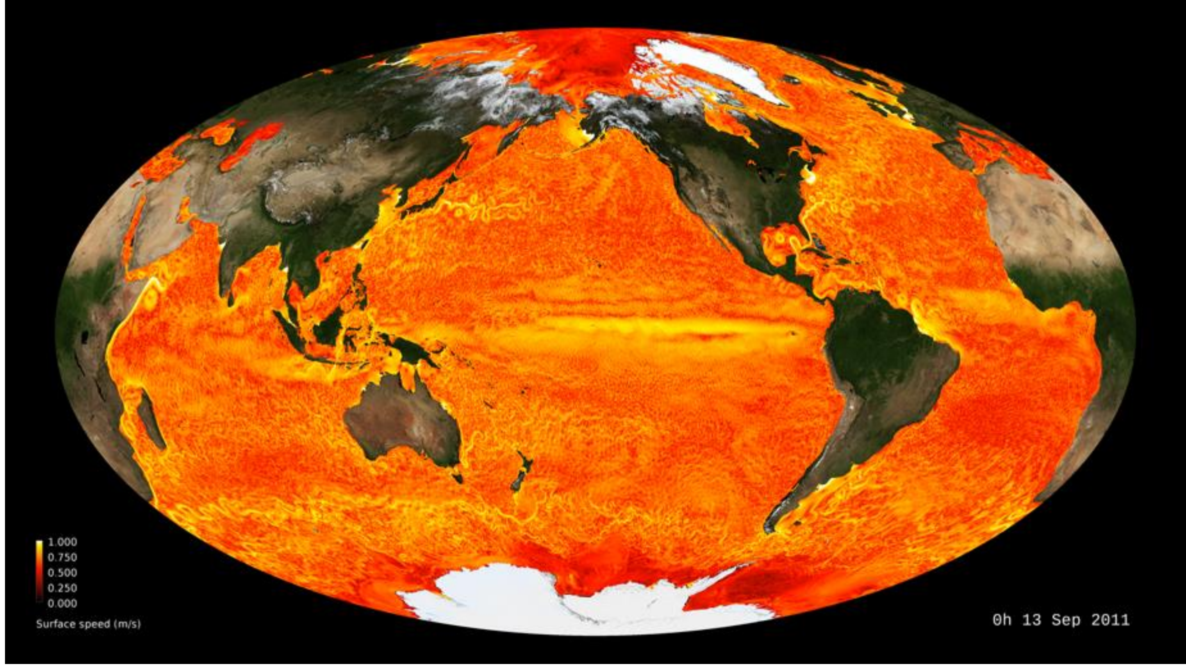
Presented at 2024 ECCO Annual Meeting
March 20-22, 2024
University of Texas at Austin



GEOS cloud-resolving simulation carried out with horizontal grid spacing of 1.5-km (courtesy of Bill Putman and GSFC/GMAO colleagues). Up to a few years ago, this was the highest resolution atmospheric simulation carried out with any US global model.

Explicit cloud-resolving simulations provide valuable insight on the 'grey-zone' of physics parameterizations, where sub-grid scale processes are partially resolved.

This engineering demonstration led to rapid development of the infrastructure of GEOS to support high-resolution global downscaling applications for climate and weather.



ECCO surface current speed from a 1/48° global-ocean and sea ice simulation carried out using the MITgcm. Importantly this simulation includes both atmospheric and tidal forcing and it admits submesoscale eddies and internal waves.

Preliminary work started in October 2012 and successful integration of the1/48-deg simulation started in January 2014.

Over 155 science publications make use of output from this simulation, especially for SWOT pre-launch studies.

Towards a submesoscale, internal-gravity-wave, and cloud admitting simulation

Simulation	Nominal horizontal grid spacing	Period of integration	Disk storage requirements
ECCO cs510 adjoint-method estimate	1/6°	January 2009 to December 2011 (3 years)	~25 TB
ECCO llc1080	1/12°	January 2010 to July 20, 2012 (30 months)	~250 TB
ECCO llc2160	1/24°	January 2011 to April 22, 2013 (28 months)	~1 PB
ECCO llc4320	1/48°	September 10, 2011 to November 15, 2012 (14 months)	~5 PB
GEOS/ECCO cs1440-llc2160	1/16° over 1/24°	Nominally: January 20, 2020 to March 25, 2021 (14 months)	~1 PB for GEOS ~1 PB for MITgcm
cs2880-llc4320	1/32° over 1/48°	TBD	TBD
llc8640	1/96°	TBD	TBD
TBD			

GEOS/ECCO Coupled Model Output - Atmosphere

Hourly “Instantaneous” 3D Prognostic/Diagnostic Fields on “native” horizontal and vertical grid:

U, V, W, H, DELP, P, T, QV, QL, QI RI, RL, FCLD, DTHDT, DTHDTCN, CO, CO2

15-minute “Instantaneous” Prognostic/Diagnostic Fields on “native” horizontal grid:

U10M, V10M, TS, QA, T2M, QS, Q2M, TQV, TQI, TQL, TQR, TQS, CWP, LWP, IWP, CAPE, INHB,
OMEGA, RH, ZLE at 800, 700, 500, 200 hPa

Hourly “Time Averaged” 3D Diagnostic Fields on “native” horizontal and vertical grid:

Convective Mass Fluxes, Turbulence Eddy Coefficients, “Tendency terms” from diabatic forcing

Hourly ”Time Averaged” 2D Diagnostic Fields on “native” horizontal grid:

TROPP_EPV, TROPP_THERMAL, TROPP_BLENDED, TROPT, TROPQ, TA, US, VS, SPEED, THAT, QHAT, PLS, PCU, CCWP, TAUTT, TAULO, TAUMD, TAUHI, CLDTT, CLDLO, CLDMD, CLDHI, RUNSURF, BASEFLOW, CT, CQ, CM, LAI, GRN, SNOMAS, ITY, WET1, WET2, WET3, TSOIL1, TSOIL2, FRACI, USTAR, Z0, Z0H, RHOS, U2M, V2M, T10M, Q10M, U50M, V50M, GUST, VENT, ASNOW, ALBVR, ALBVF, ALBNR, ALBNF

15-minute “Time Averaged” 2D Diagnostic Fields on “native” horizontal grid:

PRECANV, PRECCON, PRECLSC, PRECTOT, PRECSNO, ZPBL, RADSRF, FLNS, FLNSC, FLNSA, OLR, OLC, OLA, LWS, LCS, EMIS, LAS, SFCEM, CLDTMP, CLDPRS, OSR, OSRCLR, SWTNET, SWTNETC, SWTNETCNA, SWTNETNA, RADSWT, SWGDWN, SWGDWNC, SWGNET, SWGNETC, SWGNETNA, SWGNETCNA, ALBEDO, EFLUX, EVAP, HFLUX, TAUX, TAUY

http://data.nas.nasa.gov/geosecco
https://portal.nccs.nasa.gov/datashare/G5NR/DYAMONDv2/GEOS_6km_Atmosphere-MITgcm_4km_Ocean-Coupled/

GEOS/ECCO Coupled Model Output - Ocean

Hourly "Instantaneous" Prognostic/Diagnostic Fields on "native" horizontal and vertical grid:

Eta	sea surface height (m)
KPPhbl	mixing layer depth (m)
PhiBot	bottom pressure (m^2/s^2)
SIarea	fractional ice-covered area for 5 categories [0 to 1]
SIheff	effective ice thickness for 5 categories (m)
SIhsnow	effective snow thickness for 5 categories (m)
SItice	ice surface temperature for 5 categories (deg K)
SIuice	zonal (relative to grid) ice velocity, >0 from West to East (m/s)
SIvice	merid. (relative to grid) ice velocity, >0 from South to North (m/s)
Salt	salinity (g/kg)
Theta	potential temperature (deg C)
U.	zonal (relative to grid) velocity, >0 from West to East (m/s)
V.	merid. (relative to grid) velocity, >0 from South to North (m/s)
W.	vertical velocity (m/s)
oceFWflx	net upward freshwater flux, >0 increases salinity (kg/m^2/s)
oceQnet	net upward surface heat flux (including shortwave), >0 decreases theta (W/m^2)
oceQsw	net upward shortwave radiation, >0 decreases theta (W/m^2)
oceSflux	net upward salt flux, >0 decreases salinity (g/m^2/s)
oceTAUX	zonal (relative to grid) surface wind stress, >0 increases uVel (N/m^2)
oceTAUY	meridional (relative to grid) surf. wind stress, >0 increases vVel (N/m^2)

Please note that U, V, oceTAUX, oceTAUY, SIuice, and SIvice are aligned relative to model grid, not geographical coordinates, and that they are specified at the SouthWest C-grid velocity points. All other scalar fields are specified at the tracer point, i.e., the center of each grid box.

http://data.nas.nasa.gov/geosecco

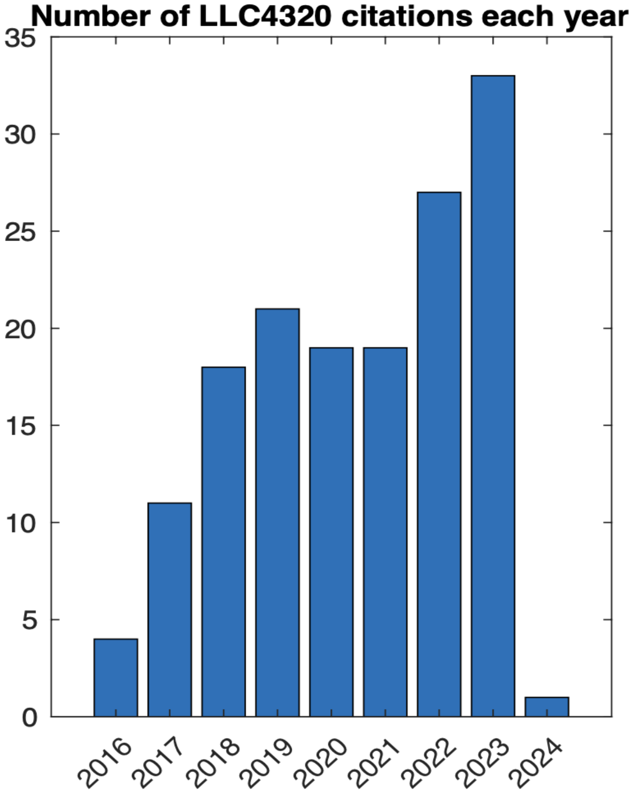
https://portal.nccs.nasa.gov/datashare/G5NR/DYAMONDv2/GEOS_6km_Atmosphere-MITgcm_4km_Ocean-Coupled/

OCEAN SCIENCES MEETING | NEW ORLEANS LOUISIANA 18-23 FEBRUARY 2024

>19 presentations based on hi-res ECCO simulations at Ocean Sciences 2024

1. PS53A-07 **Mapping internal tides using LLC4320 and SWOT measurements in the Southern Ocean** *Youran Li*
2. DO24A-2520 **Enki: Reconstructing Masked Pixels in Sea Surface Temperature with a Large Language Model** *J. Xavier Prochaska*
3. HE43B-05 **Detections of Submesoscale Coherent Vortices in the Seasonally Sea Ice-Covered Southern Ocean** *Jennifer Kosty*
4. PS14B-2004 **Dynamical Decomposition of Multiscale Oceanic Motions** *Zhiyu Liu*
5. PS24B-2075 **Seasonal Features and Potential Mechanisms of Submesoscale Processes in the Southern Bay of Bengal** *Xuhua Cheng*
6. PS23A-02 **Understanding the Generation and Dynamics of Internal Tides in the Bay of Bengal using ECCO salinity and observations** *Subrahmanyam Bulusu*
7. PS41A-05 **Response of Submesoscale Variability Under Sea Ice to Wind Bursts and Mesoscale Strain** *Georgy E Manucharyan*
8. DO12A-06 **A Data-Driven Approach for a Submesoscale Parameterization** *Abigail S. Bodner*
9. PS34B-2093 **Characterising Submesoscale Statistics Globally in a High-Resolution Model using Pangeo Tools** *Thomas Nicholas*
10. PS11A-06 **Ocean Eddy Splitting and the Associated Vertical Transport: Insights from Numerical Modeling** *Weiguang Wu*
11. DS21A-02 **Assessing the Potential of SMART Subsea Cables for Monitoring Essential Ocean Variables** *Karen Renninger-Rojas*
12. PS13C-02 **Sub-mesoscale Wind-Front Interactions and Their Impact on Ocean Vertical Velocities** *Yue BAI*
13. PS23A-07 **Internal-Wave Dissipation Mechanisms and Vertical Structure in a High-Resolution Regional Ocean Model** *Joseph Skitka*
14. PS53A-03 **First look at computing spectral kinetic energy cascades from SWOT** *Brian Arbic*
15. CC44B-1345 **Simulated Sea Surface Salinity Data from a 1/48° Ocean Model** *Frederick Bingham*
16. PS44B-2162 **Separation of Balanced and Unbalanced Flow in the California Current System: Comparison of SWOT, High-Frequency Radar, and Model Output** *Luke Kachelein*
17. DO14A-2459 **Ongoing efforts towards an Ocean Observing System Simulation Experiment (OSSE) capability at NOAA** *Jakir Hossen*
18. DO21A-02 **Development of Observing Quantitative Assessment Capabilities for Ocean Applications at NOAA** *Lidia Cucurull*
19. TH43B **Democratize the Data: A New Way to Analyze Ocean Models** *Thomas W N Haine*

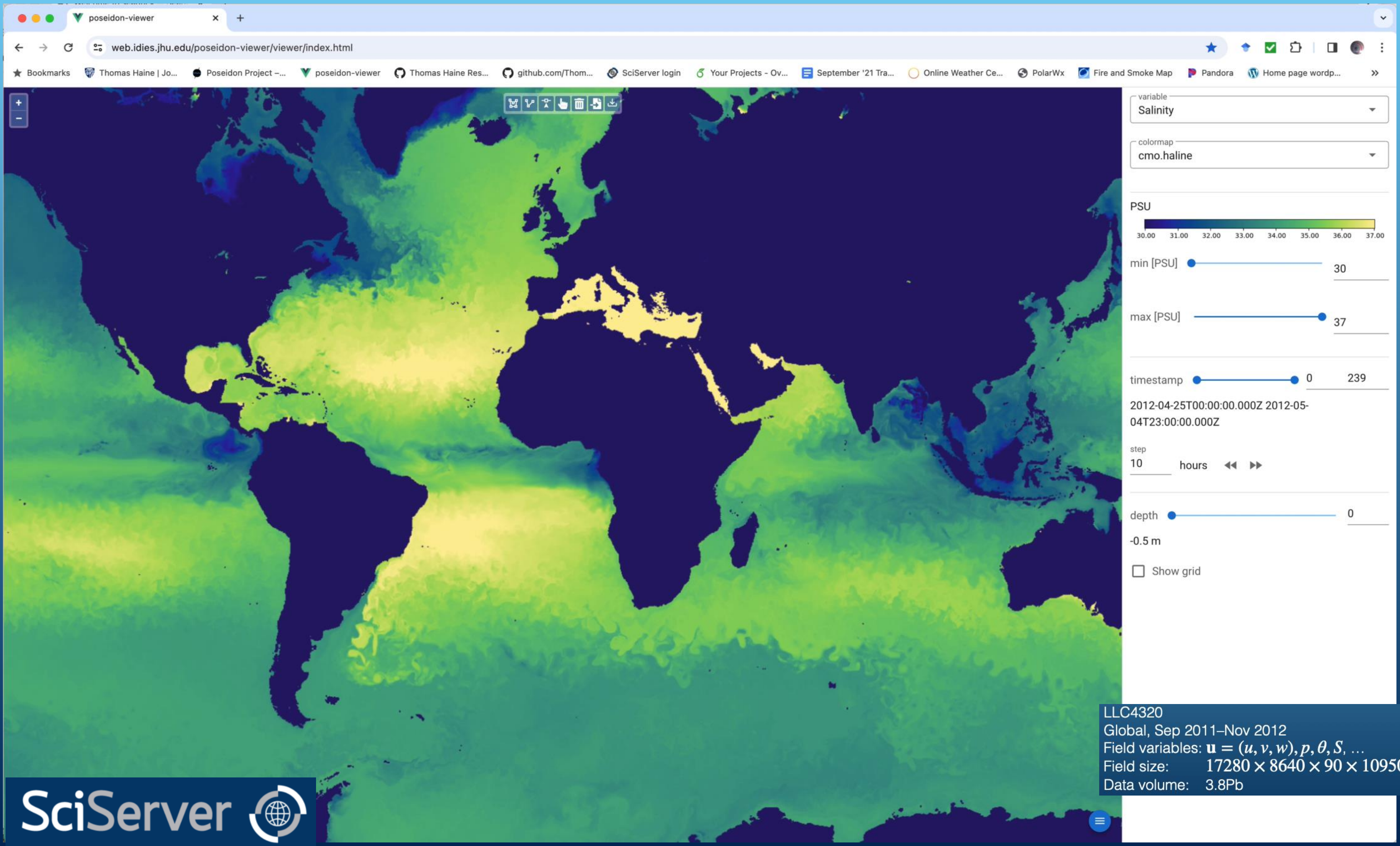
>155 publications based on hi-res ECCO simulations



LLC4320
Global, Sep 2011–Nov 2012
Field variables: $\mathbf{u} = (u, v, w), p, \theta, S, \ldots$
Field size: $17280 \times 8640 \times 90 \times 10950$
Data volume: 3.8Pb

(slide courtesy of Hong Zhang)

Democratize the data: Poseidon-viewer



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Data volume: 3.8Pb

Poseidon-Viewer

(Tom Haine, OSM24)

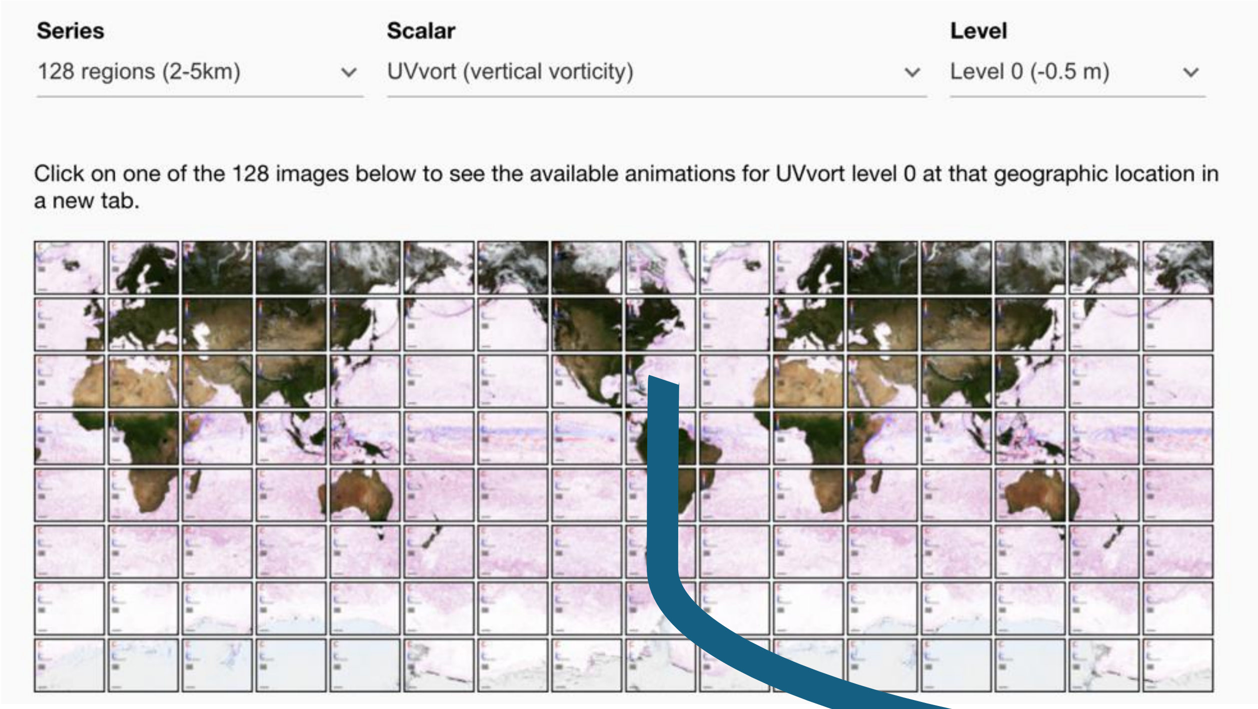
The NASA Advanced Supercomputing (NAS) Hyperwall enables interactive visualization of multi-petabyte, time-varying, multivariate data.

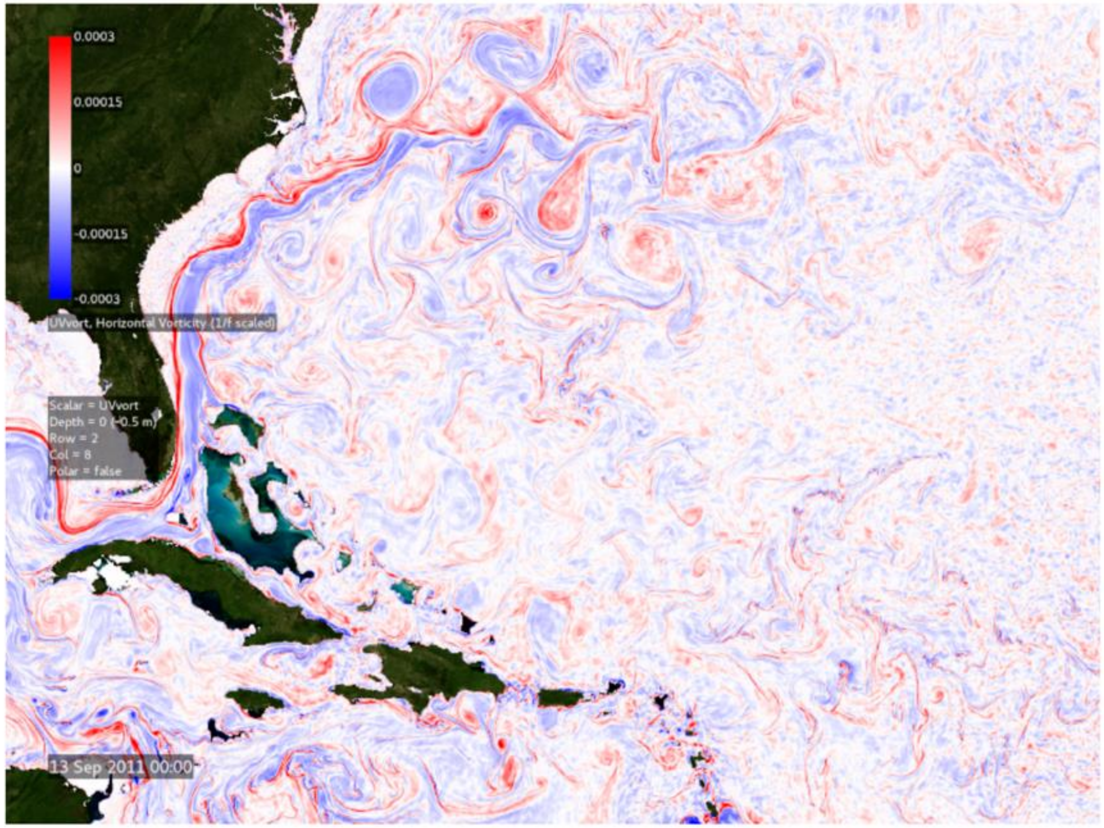
(Chris Henze,
Bron Nelson,
David Ellsworth,
Nina MacCurdy,
and others)

A new hyperwall is being assembled at NAS (image above sent by Chris Henze last week)
It has ~4 times as many pixels as previous generation NAS hyperwall
Which would allow global global SWOT maps with ~500-m posting
Or pixel-by-pixel visualizations of a hypothetical llc8640 (1/96°) ECCO simulation
Importantly, each display is driven by a 48-core Cascade Lake node

Hyperwall at home (created by David Ellsworth)

https://ecco-group.org/world-of-ecco.htm



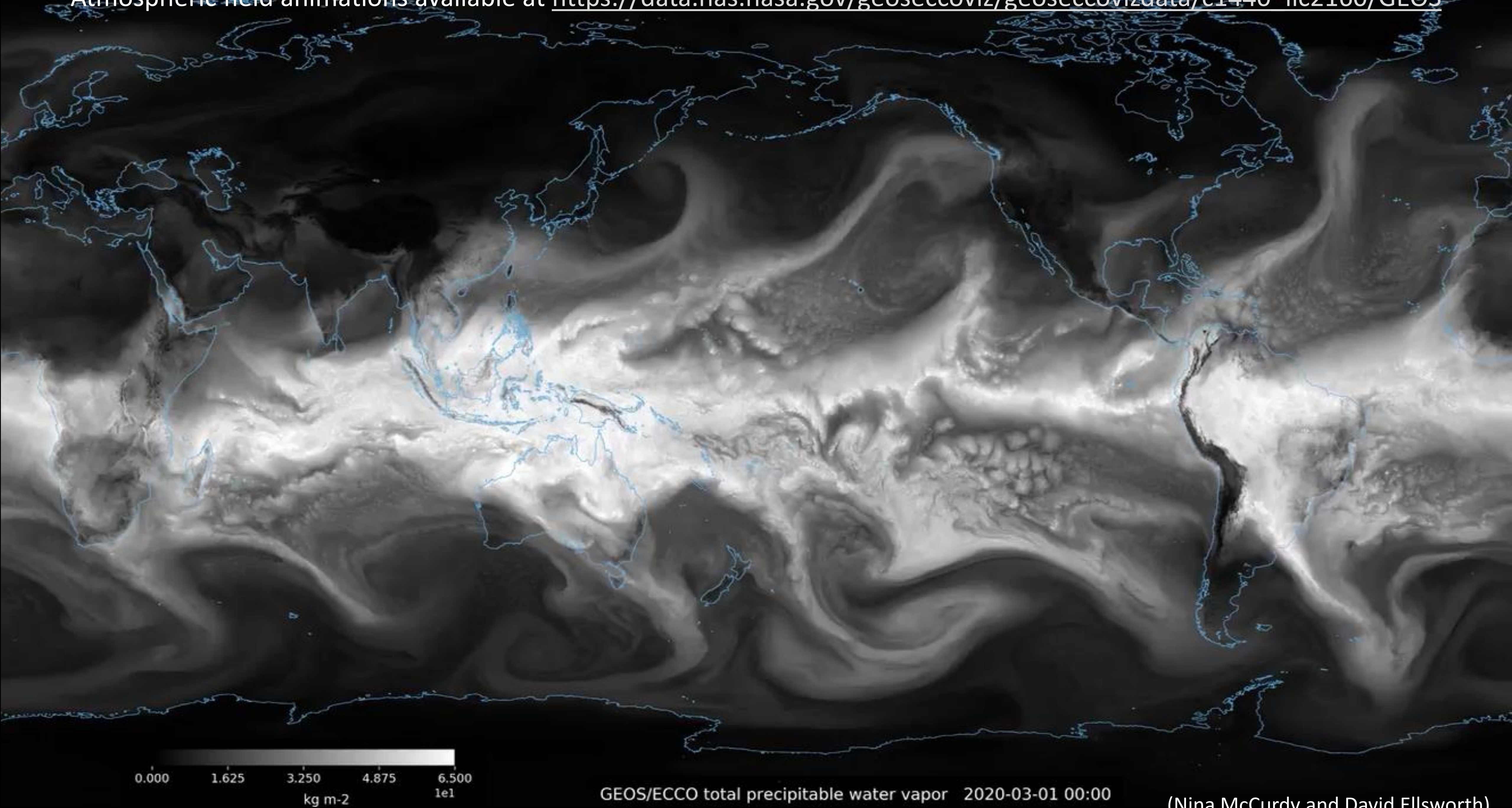


The buttons below will select a visualization of UVvort (horizontal vorticity) level 0 (depth -0.5 m) located at row 2 column 8 in the 128-region series of animations. The different buttons are for either a MP4 animation or a full size image. Animations are available for different resolutions and image sizes, and for a range of time steps. The sizes listed are for the MP4.

Timestep	Animation Pixel Resolution and File Size							
	5.4 km / 800x600				2.7 km / 1600x1200			
1 hour	172 MB	Play MP4	Download MP4	Image	788 MB	Play MP4	Download MP4	Image
3 hours	58 MB	Play MP4	Download MP4	Image	313 MB	Play MP4	Download MP4	Image
6 hours	39 MB	Play MP4	Download MP4	Image	199 MB	Play MP4	Download MP4	Image
12 hours	22 MB	Play MP4	Download MP4	Image	110 MB	Play MP4	Download MP4	Image
24 hours	14 MB	Play MP4	Download MP4	Image	65 MB	Play MP4	Download MP4	Image

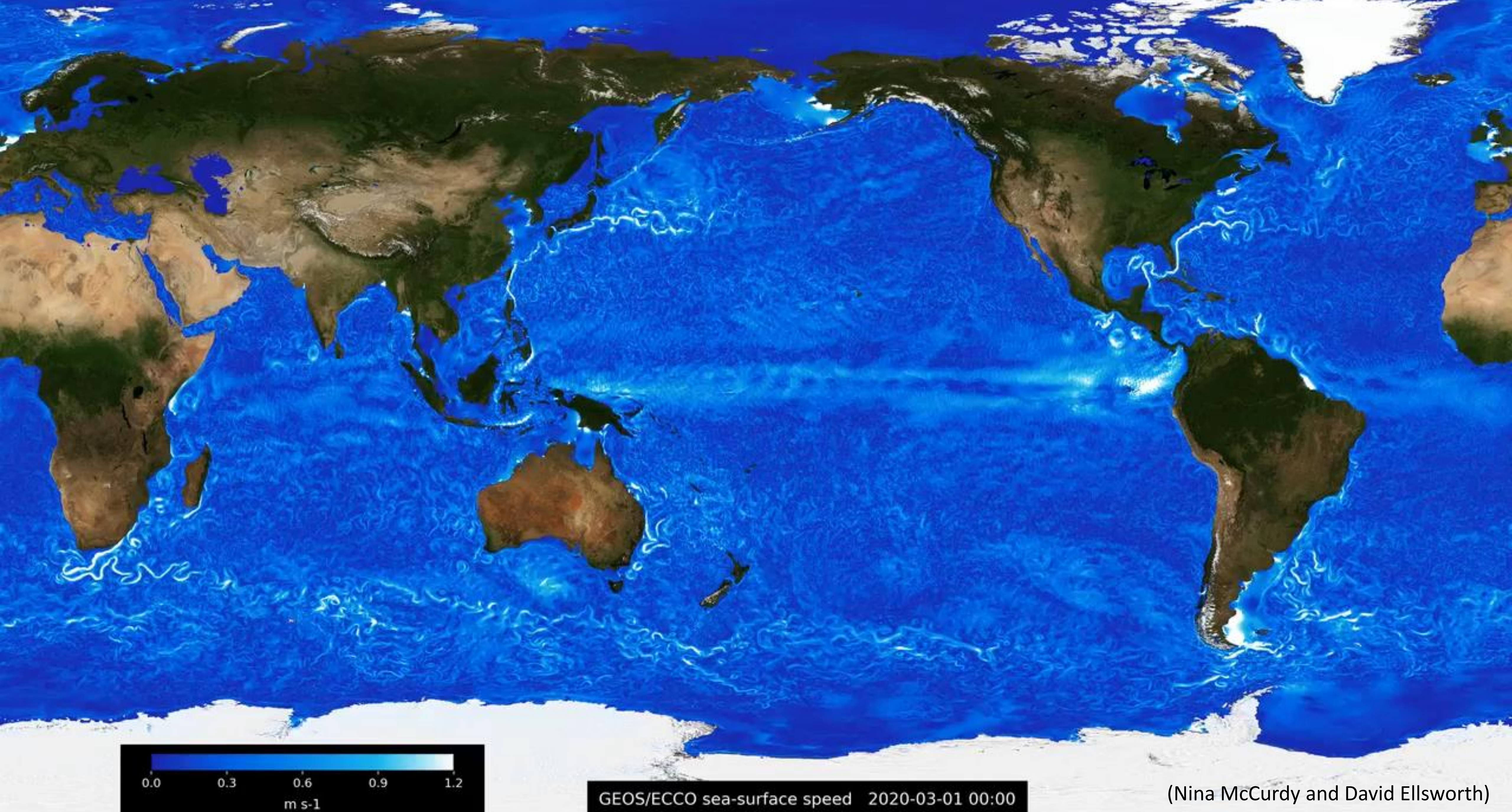
Hyperwall at home capability allows visual exploration of the hi-res simulation from a remote workstation.

Atmospheric field animations available at https://data.nas.nasa.gov/geoseccoviz/geoseccovizdata/c1440_llc2160/GEOS



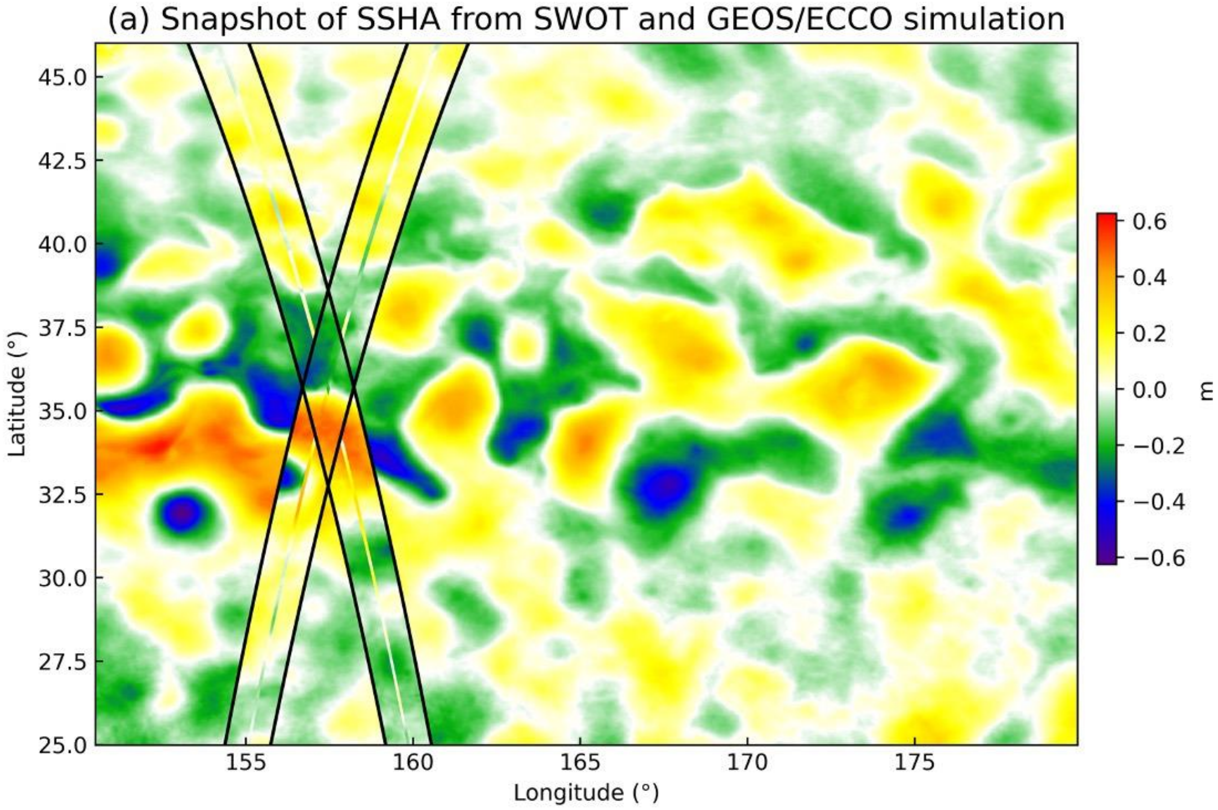
(Nina McCurdy and David Ellsworth)

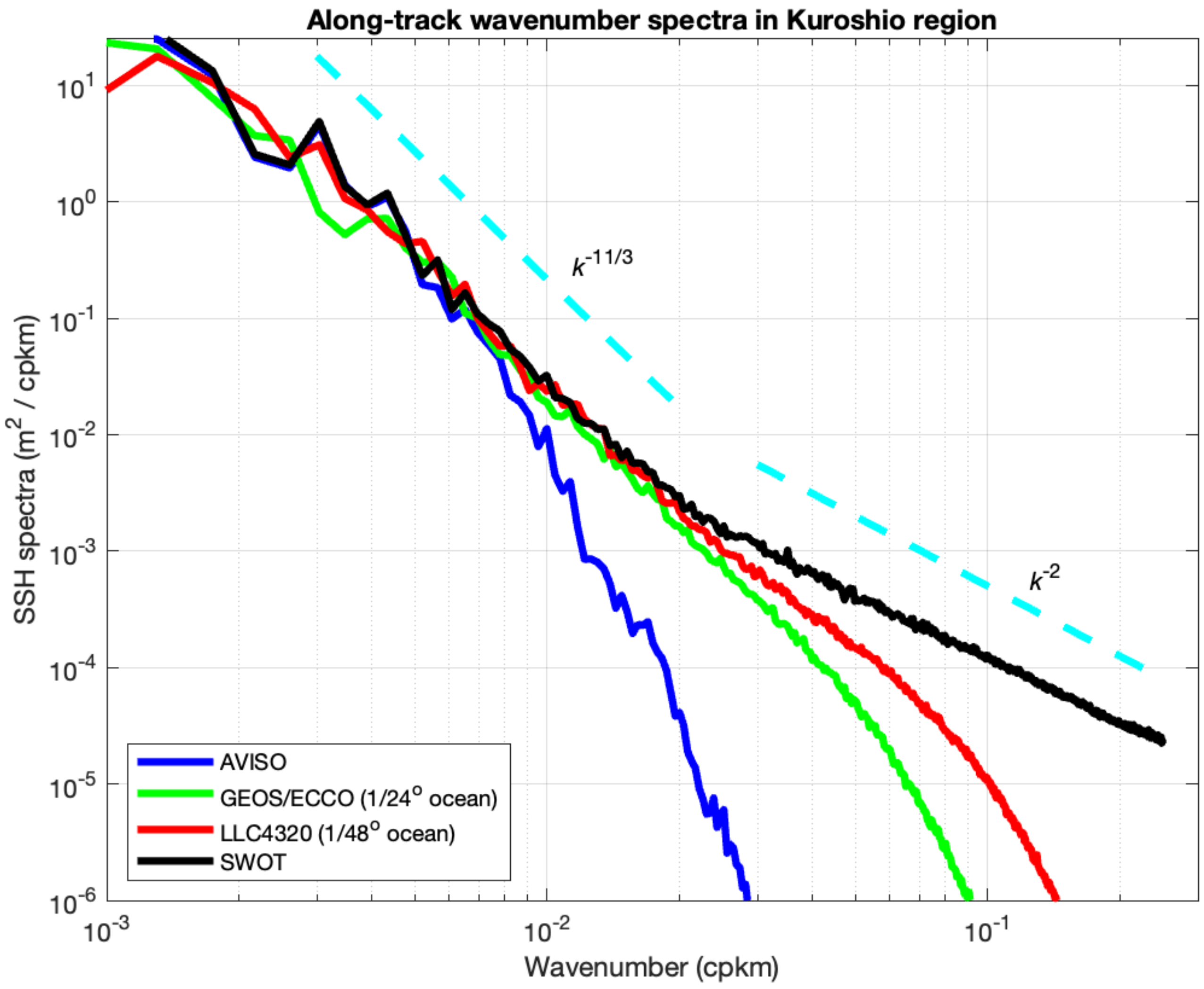
Oceanic field animations available at https://data.nas.nasa.gov/geoseccoviz/geoseccovizdata/c1440_llc2160/MITgcm/



(Nina McCurdy and David Ellsworth)

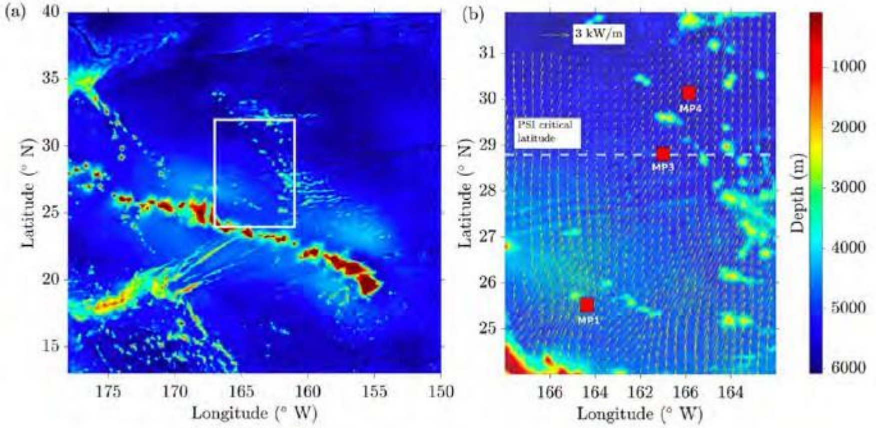
Preliminary comparison of high-resolution ECCO and GEOS/ECCO simulations with SWOT data

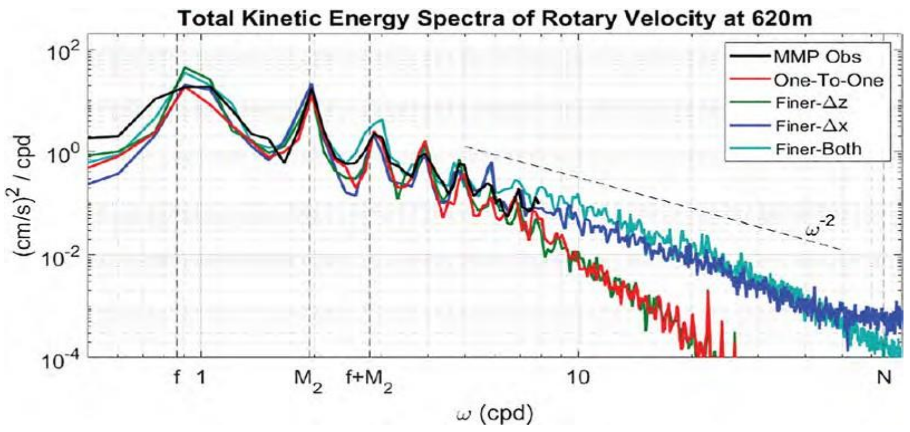




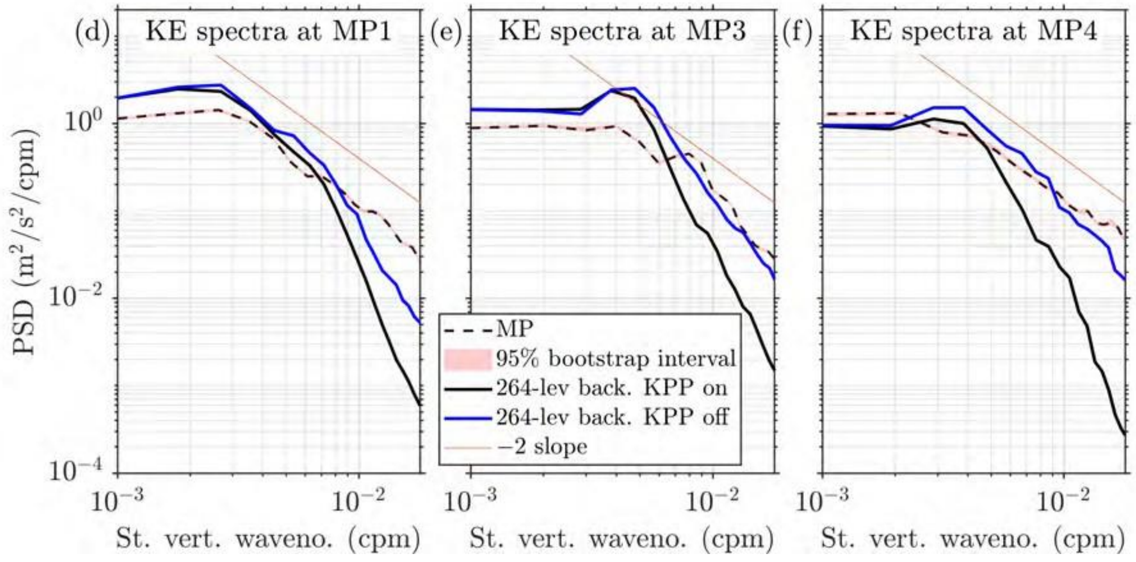
Downscaled regional simulations north of Hawaii with LLC4320 boundary conditions

Collaboration with: B. Arbic, D. Peltier, A. Nelson, J. Skitka, R. Thakur, Y. Pan, K. Momeni, Y. Ma, and N. Grisouard

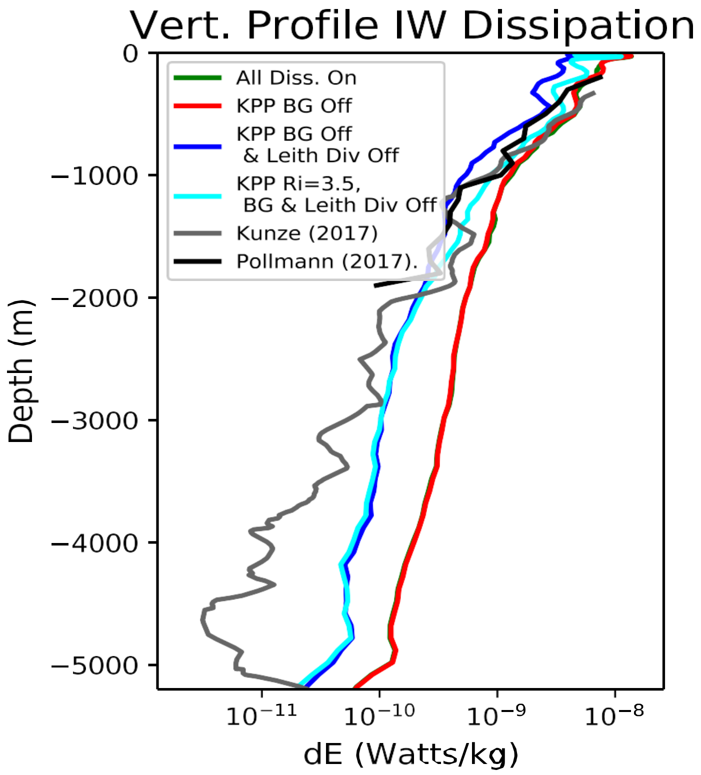




Nelson et al. 2020

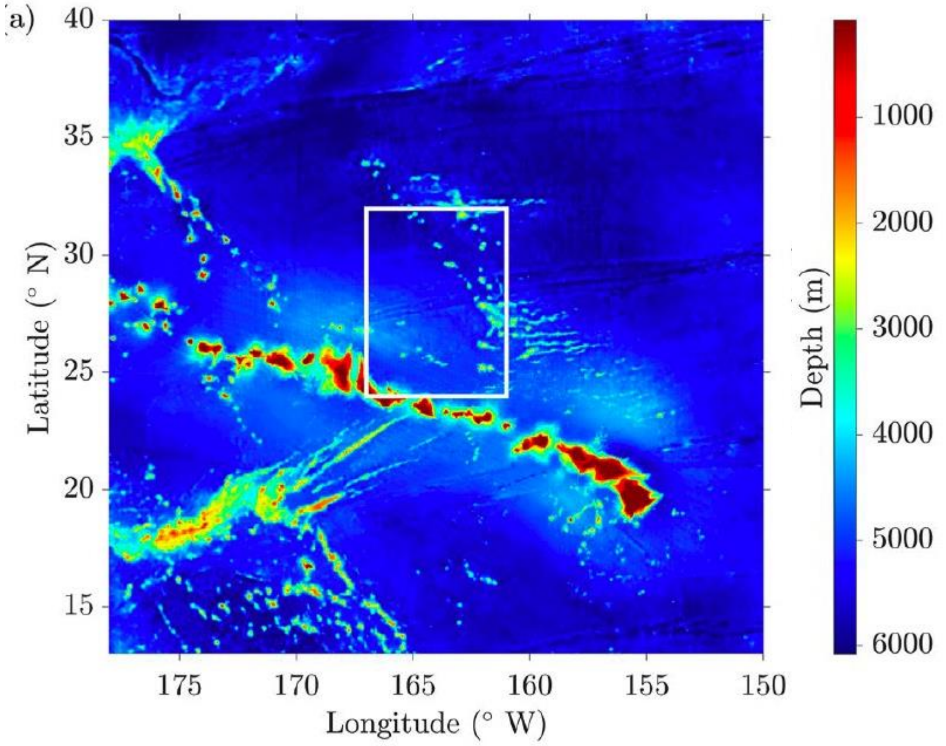


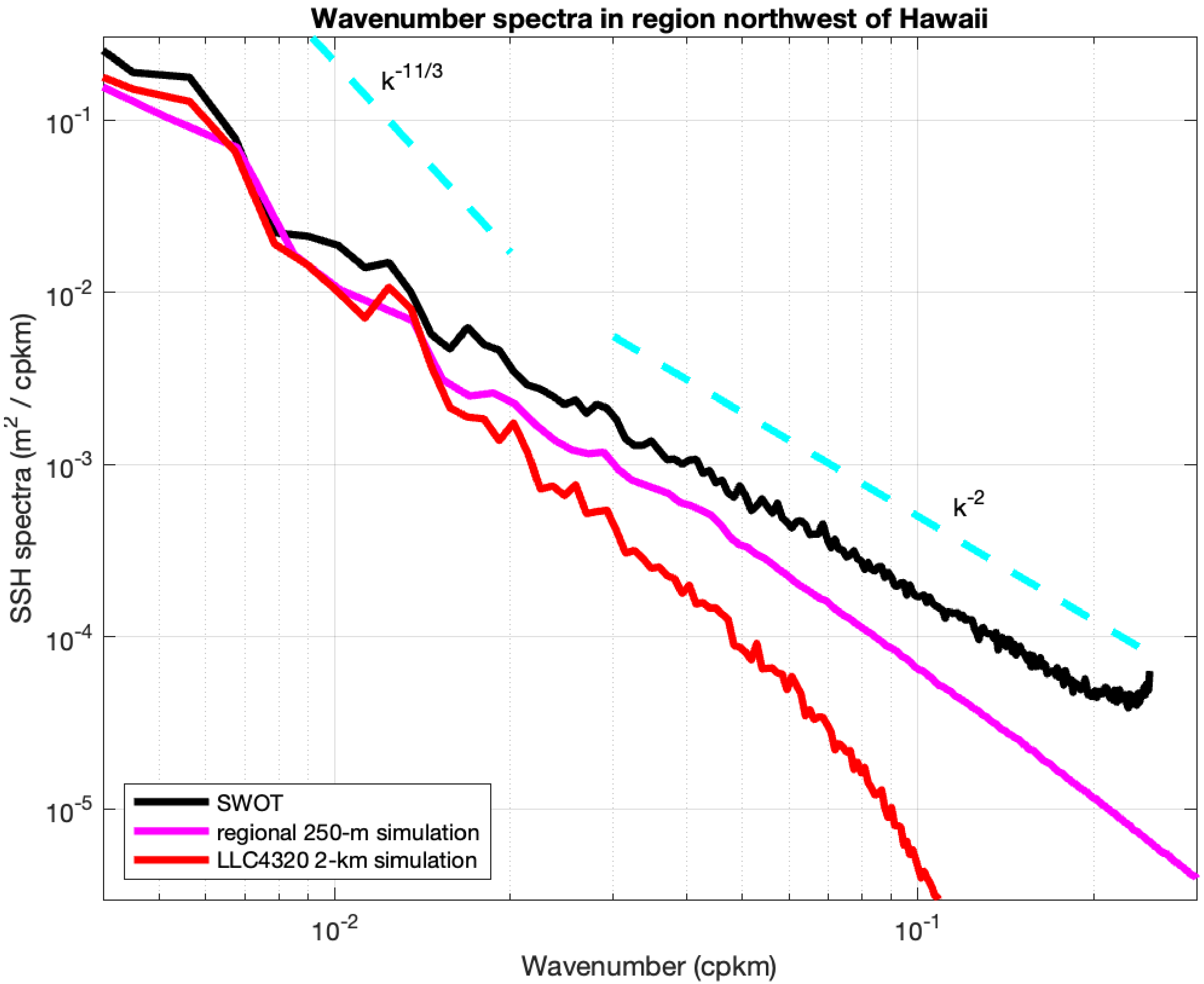
Thakur et al. 2022



Skitka et al. 2024

Comparison of SWOT data and model output northwest of Hawaii





Summary and concluding remarks

- **With the successful launch of the Surface Waves and Ocean Topography (SWOT) altimeter, physical oceanography, once again, finds itself at a fascinating crossroads of theory, computational capabilities, and observations!**

- **Global high-resolution simulations are not able to reproduce the high-wavenumber variability that is observed by the SWOT Ka-band Radar Interferometer (KaRIn).**

- **Regional, downscaled simulations can start to represent some of this observed variability, but they require higher-resolution forcing at the lateral boundaries than is currently available.**

- **A big impediment for running global, yet-higher-resolution simulations is the volume of model output produced, e.g., 5 PB for 14 months of hourly LLC4320 model output.**

- **A circa-2006 suggestion by Chris Hill of saving high-frequency lateral boundary conditions that can be used to reconstruct or downscale regional pieces of a global simulation has now become possible with software tools developed by Mike Wood and Ian Fenty.**