Summer 2021

GFDL BULLETIN

Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

Advancing the Modeling, Understanding, and Prediction of Weather and Climate

HORIZONTAL CIRCULATION ACROSS DENSITY SURFACES CONTRIBUTES SUBSTANTIALLY TO THE LONG-TERM MEAN NORTHERN ATLANTIC MERIDIONAL OVERTURNING CIRCULATION

Communications Earth & Environment (a Nature journal)

R. Zhang[1] and M. Thomas[1,2]

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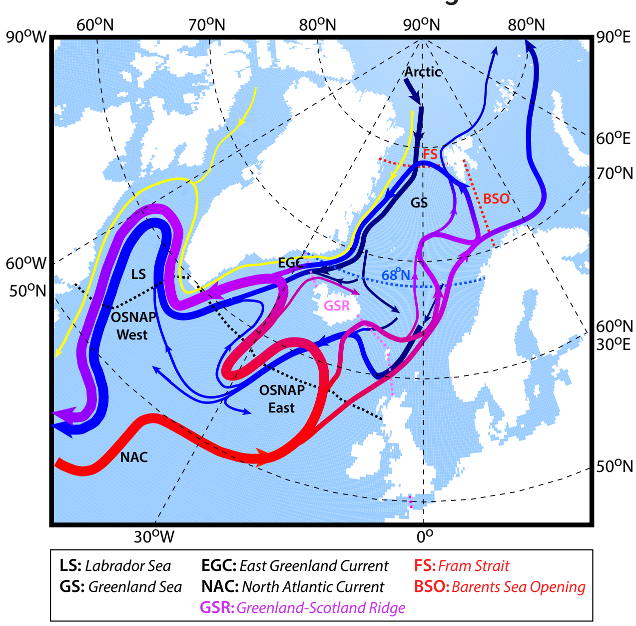
The Atlantic Meridional Overturning Circulation (AMOC) has profound impacts on temperature and precipitation, and other aspects of climate. The Greenland Sea is often viewed as the northern terminus of the AMOC and it has been suggested that the shutdown of open-ocean deep convection in the Labrador or Greenland Seas would substantially weaken the AMOC. In contrast to the traditional view, this study suggests that the Arctic Ocean, not the Greenland Sea, is the northern terminus of the mean AMOC. Open-ocean deep convection, in either the Labrador or Greenland Seas, contributes minimally to the mean AMOC. Meanwhile, horizontal circulation contributes more than 40% to the maximum mean northeastern subpolar AMOC.



Unlike many other climate variables, there is no established long-term mean of directly observed AMOC over the past several decades, so it is difficult to know whether the current observed AMOC is different from its long-term mean state. This study used GFDL's high-resolution global coupled climate model CM2.5, in conjunction with the observed hydrographic climatology, to provide a holistic picture of the long-term mean AMOC structure at northern high latitudes, which could be used to calibrate AMOC in models.

The results show that the deep AMOC branch across the Arctic outflow provides the densest source water to the mean AMOC. The Arctic Ocean, not the Greenland Sea, is the northern terminus of the mean AMOC. Understanding the mechanisms for the AMOC is crucial for predicting future AMOC changes and associated climatic, ecological, and economic impacts.

OAR Goals: Drive Innovative Science

Schematic (above): *Long-term mean AMOC pathways overlapped with sections (dotted lines). Colors of arrows indicate seawater density (light to dense: yellow-red-purple-violet-blue-dark blue). The density of Atlantic inflow increases along the pathways of the northeastern subpolar gyre, the gyre extended into Nordic Seas, and the branches entering the Arctic through Barents Sea Opening (BSO) and east Fram Strait (FS). Dark blue arrows: dense outflow through the Nordic Seas. The overflows become lighter after passing through the Denmark Strait and the Faroe Bank Channel due to entrainments. Yellow arrows: light (cold fresh) surface currents. In addition to the non-Ekman depth-space AMOC component linked to the density contrast across a section, the northeastern subpolar gyre and the gyre extended into the Nordic Seas moving with changing densities also contribute to the density-space AMOC. The density contrast across OSNAP East is much larger than that across OSNAP West, sustaining a much stronger AMOC across OSNAP East.*

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NEXT-GENERATION REGIONAL OCEAN PROJECTIONS FOR LIVING MARINE RESOURCE MANAGEMENT IN A CHANGING CLIMATE

ICES Journal of Marine Science

E. Drenkard[1], C. Stock[1], A. Ross[1], K. Dixon[1], A. Adcroft[1], M. Alexander[1], V. Balaji[1], S. Bograd[2], M. Butenschön[3], W. Cheng[4,5], E. Curchitser[1,6], E. Di Lorenzo[7], R. Dussin[1], A. Haynie[8], M. Harrison[1], A. Hermann[4,5], A. Hollowed[8], K. Holsman[8], J. Holt[9], M. Jacox[2,10], C. Joo Jang[11], K. Kearney[4,8], B. Muhling[12,13], M. Pozo Buil[2,12], V. Saba[1], A. Britt Sandø[14,15], D. Tommasi[12,13], M. Wang[4,5]

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Management of living marine resources under climate change requires information about the range of possible future ecosystem conditions. However, most global climate models do not represent coastal oceans well. Downscaling these models is a means of translating global climate change information to relevant regional scales. GFDL scientists and their colleagues distill best practices and potential pitfalls from past ocean climate change downscaling studies and recommend a protocol for future studies to robustly support living marine resource science and management under climate change.

The authors identify the need to refine horizontal resolution judiciously and to downscale projections across the range of potential futures, using simulations that are long enough to capture climate change signals. Computationally-cheaper statistical downscaling methods can help in generating large ensembles with limited resources. Additionally, inconsistent use of bias correction indicates a need for objective best practices. This protocol, with effective dissemination and translation of model results, can enable conservation of valuable living marine resources in support of resilient and healthy oceans under climate change. This research facilitates seafood and economic security through support of better marine management.

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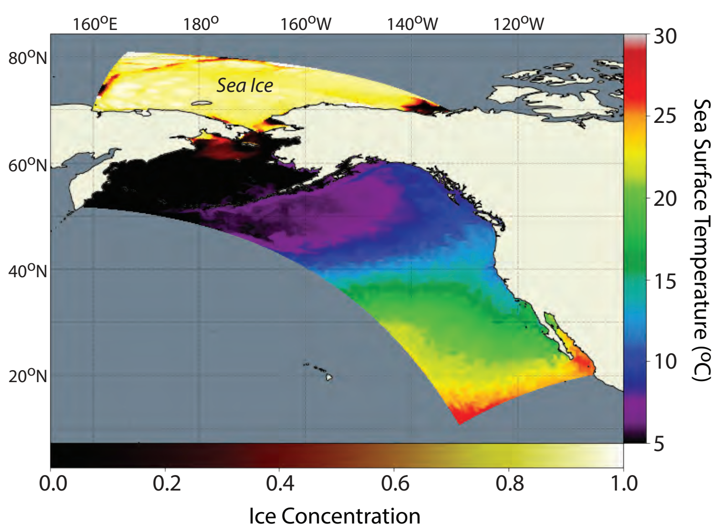
Northeast Pacific Regional MOM6 Model, Sea Surface Temp and Ice Concentration



A snapshot of spring 1981 sea surface temperature and ice concentration simulated by GFDL's 10km Northeast Pacific regional MOM6 model.

Climate change applications of this model and other regional high-resolution configurations of MOM6, such as the Arctic and Northwest Atlantic, will be guided by the protocol developed in Drenkard et al., 2021.

This regional version of MOM6 was developed at GFDL in collaboration with CIMES, Rutgers University, University of Alaska, Fairbanks, NOAA's Climate Program Office, and NOAA's Climate Portfolio.

[1]NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ; [2]NOAA Southwest Fisheries Science Center, Monterey, CA; [3]CMCC, Ocean Modeling & Data Assimilation Division, Bologna, BO, IT [4]University of Washington, Seattle, WA; [5]NOAA Pacific Marine Environmental Laboratory, Seattle, WA; [6]Rutgers University, Dept. of Environmental Science, New Brunswick, NJ [7]Georgia Institute of Technology, School of Earth & Atmospheric Sciences, Atlanta, GA; [8]NOAA Alaska Fisheries Science Center, Seattle, WA; [9]NOC Marine Systems Modeling, Liverpool, UK [10]NOAA Physical Sciences Center Laboratory, Boulder, CO; [11]KOIST Ocean Circulation Research Center, Youngdo-gu, Busan, ROK; [12]UCSC Institute of Marine Sciences, Santa Cruz, CA [13]NOAA Southwest Fisheries Science Center, La Jolla, CA; [14]IMR, Oceanography and Climate, Bergen, Norway; [15]Bjerknes Centre for Climate Research, Bergen, Norway

TWO-MOMENT BULK CLOUD MICROPHYSICS WITH PROGNOSTIC PRECIPITATION IN GFDL'S ATMOSPHERE MODEL AM4.0: CONFIGURATION AND PERFORMANCE

Journal of Advances in Modeling Earth Systems *H. Guo[1], Y. Ming[1], S. Fan[1], L. Zhou[1,2], L. Harris[1], M. Zhao[1]*

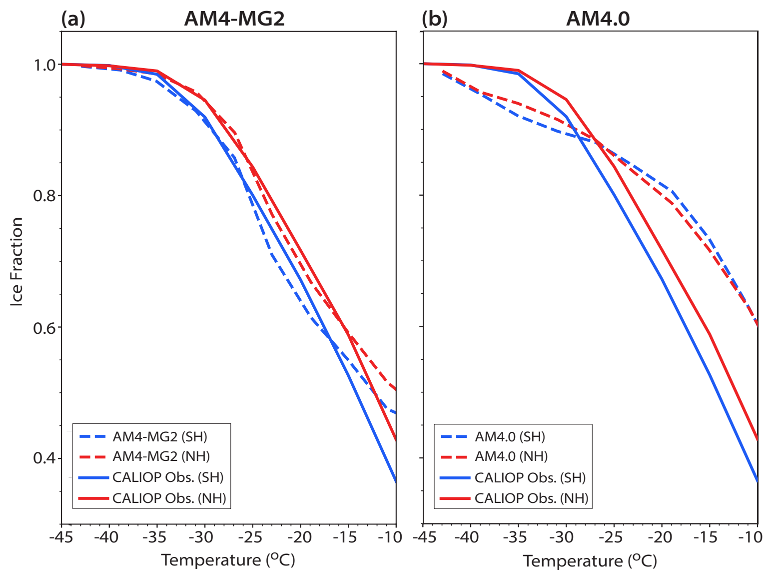
DOI: 10.1029/2020MS002453

To improve the cloud and aerosol representation in GFDL models, and narrow down the uncertainties of aerosol-cloud interactions in the context of climate change, an improved physics formulation was implemented in the Geophysical Fluid Dynamics Laboratory's Atmosphere Model AM4.0. The result of this effort is more accurate simulation of cloud physics and precipitation, in turn leading to improved prediction of weather and climate.

This paper describes those changes and shows that the new configuration, called AM4-MG2, compares favorably with observations and re-analyses. Compared to AM4.0, notable improvements include better coastal marine strato-cumulus and seasonal cycles, a more realistic cloud water phase, and more realistic dependence of rain production on cloud droplet size – important parameters that govern climate change impacts.

The prognostic precipitation treatment introduced with MG2 is more appropriate for high resolution simulations with shorter time steps, such as for weather forecasts. In addition, the new liquid cloud microphysics is similar to that in NOAA's Weather Research and Forecasting (WRF) Model, driving towards the NOAA objective of unified weather-climate modeling. Finally, MG2 is readily extended to include graupel and hail, important hydrometeors for weather forecasts. Therefore, it is feasible to apply MG2 in weather forecast models, as well as in climate models.

AM4-MG2 Compared to AM4.0 and Satellite Observations



Comparison of ice fraction versus temperature over the Northern Hemisphere (NH, red) and Southern Hemisphere (SH, blue) for (a) AM4-MG2 and for (b) AM4.0 against NASA's Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) satellite observations.

OAR Goals: Make Forecasts Better; Drive Innovative Science

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SCIENTISTS IN THE SPOTLIGHT

V. "Ram" Ramaswamy

GFDL's Director

has been selected for the

American Meteorological Society's 2022 Carl-Gustaf Rossby Research Medal

for his "original and highly influential leadership providing fundamental insight into radiative-climate interactions among greenhouse gases, aerosols & clouds."

The Rossby Medal is the highest award the Society bestows upon an atmospheric scientist.

GFDL Makes Notable Contributions to the IPCC AR6

For the recently published IPCC AR6, Working Group I report, **Vaishali Naik** was a Co-Author of the Summary for Policymakers and Technical Summary; Coordinating Lead Author of the chapter on short-lived climate forcers; and she participated in the plenary session, where the Summary for Policymakers was reviewed and approved by all participating countries. **John Dunne** was a Lead Author of the Working Group I report chapter, "Future global climate: scenario-based projections and near-term information", and **Ram Ramaswamy** was a Review Editor of the chapter, "The Earth's energy budget, climate feedbacks, and climate sensitivity."

ANTHROPOGENIC FORCING AND RESPONSE YIELD OBSERVED POSITIVE TREND IN EARTH'S ENERGY IMBALANCE

Nature Communications *S. P. Raghuraman[1], D. Paynter[2], V. Ramaswamy[1,2]*

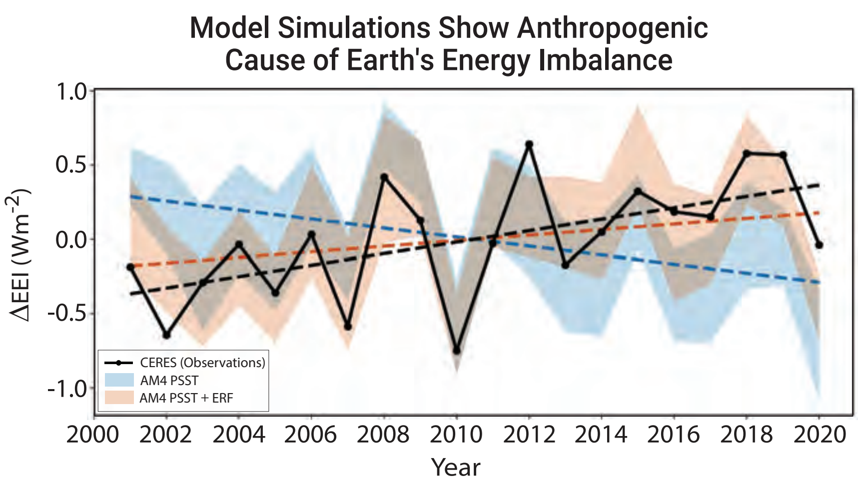
DOI: 10.1038/s41467-021-24544-4

The observed trend in Earth's energy imbalance, a measure of the acceleration of heat uptake by the planet, is a fundamental indicator of perturbations to climate. A positive energy imbalance manifests as many symptoms across the Earth system, such as increases in temperature, sea levels, flooding, droughts, and extreme events. This study increases confidence in the causes of the increase in Earth's energy imbalance: anthropogenic activities.

GFDL scientists found that it is exceptionally unlikely (<1% probability) that this observed trend can be explained by natural variations in the climate system alone. Using climate model simulations with GFDL's CM4.0, the authors estimated the anthropogenic and internal variability contributions to the satellite-observed trend during 2001-2020. The study concludes that the satellite record provides clear evidence of a human-influenced climate system.

The authors show that anthropogenic forcing and the associated climate response yield the significant positive globally-averaged observed trend. This trend is driven by a large decrease in reflected solar radiation and a small increase in emitted infrared radiation. This is because recent changes in forcing and feedbacks are additive in the solar spectrum, while being nearly offset by each other in the infrared.

OAR Goals: Drive Innovative Science



Global-mean Earth Radiation Budget time series. Interannual anomalies (denoted by Δ) in the Earth's Energy Imbalance (EEI) which is the net of the change in the reflected shortwave radiation and outgoing longwave radiation during 2001–2020. Blue and orange shading each represent the full range of time series realizations from model simulations. Positive values indicate more net energy in the Earth system. Blue and orange dashed lines represent ensemble mean trends from the simulations. CERES = Clouds and the Earth's Radiant Energy System satellite observations (black), AM4.0 PSST = Prescribed Sea Surface Temperatures (SSTs) and sea ice with climate forcing agents held fixed at 2014 levels in the Geophysical Fluid Dynamics Laboratory Atmosphere Model 4.0 (AM4.0) (blue). AM4.0 PSST+ERF = same as AM4.0 PSST, but with effective radiative forcing changes over the period (ERF; forcing agents varying with time) (orange).

[1]Program in Oceanic and Atmospheric Sciences, Princeton University, Princeton, NJ; [2]NOAA/GFDL, Princeton, NJ

LEADERSHIP ROLES FOR GFDL SCIENTISTS

Kirsten Findell

is co-chairing a **World Climate Research Programme** Lighthouse Activity initiative: "Explaining and Predicting Earth System Change", to design and begin implementing a system for quantitative observation, explanation, early warning and prediction of Earth System changes on global and regional scales, with a focus on multi-annual to decadal timescales.

Nat Johnson

is the only OAR scientist serving on **NOAA's ENSO Forecast Team** of 11 scientists. He has been a member of the team since July 2017 and he is also a primary contributor to the climate.gov ENSO Blog as a writer, editor, and moderator.

Elena Shevliakova

has been selected to serve on the new **Interagency Council on Advancing Meteorological Services,** created "to build bridges across all relevant entities to advance interagency collaboration around a holistic Earth system approach to advance meteorological services"; she is a member of the subcommittee on Earth System Modeling and Prediction.

See more GFDL awards and honors:
www.gfdl.noaa.gov/awards