Spring 2021

GFDL BULLETIN

Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

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

CLIMATE CHANGE IS PROBABLY INCREASING THE INTENSITY OF TROPICAL CYCLONES

ScienceBrief Review by ScienceBrief.org

Thomas R. Knutson[1], Maya V. Chung[2], Gabriel Vecchi[2,3,4], Jingru Sun[4], Tsung-Lin Hsieh[3] and Adam J.P. Smith[5]

https://news.sciencebrief.org/cyclones-mar2021

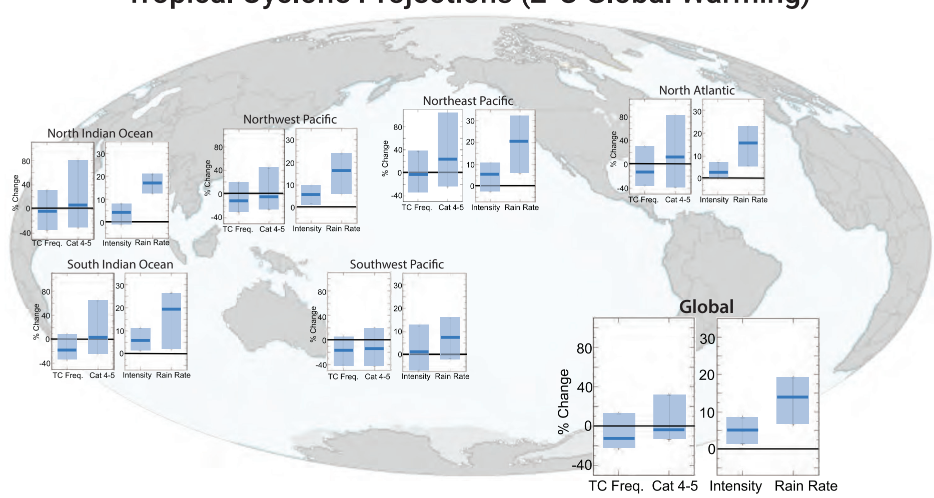
Since 2013, models can simulate observed tropical cyclone (TC) activity with greater skill, utilizing higher resolution climate models and improved downscaling techniques. State-of-the-art models and multi-decadal satellite observation records suggest that in some cases, the signal of human–caused influence on TCs may be beginning to emerge from natural variability.

Warming of the surface ocean from anthropogenic climate change is likely fueling more powerful TCs. The destructive power of individual TCs through flooding is amplified by rising sea level, which very likely has a substantial contribution from anthropogenic climate change. In addition, TC precipitation rates are projected to increase due to enhanced atmospheric moisture associated with anthropogenic global warming. The proportion of all hurricane observations that are at Category 3-5 has increased, possibly due to anthropogenic climate change. The proportion of TCs reaching Category 4-5 intensity is projected to increase, bringing a greater proportion of storms having more damaging wind speeds, higher storm surges, and more extreme rainfall rates. Most climate model studies project a corresponding reduction in the proportion of low-intensity cyclones, so the total number of TCs each year is projected to decrease or remain approximately the same. Models project that some regions will experience increases in rapid intensification, slowing of the forward motion of TCs, or a poleward migration of the latitude of maximum intensity, in coming decades.

This assessment was based on more than 90 peer-reviewed scientific articles describing observations of, or projected future changes to, the frequency and intensity of TCs, as well as changes in tropical cyclone-related rainfall and storm surge. Reliable scientific information on possible future changes in tropical cyclone activity will help inform climate change mitigation decision-making and adaptation efforts in hurricane-prone regions.

OAR Goals: Drive Innovative Science

Tropical Cyclone Projections (2°C Global Warming)



Summary of regional and global TC projections assuming a 2°C global anthropogenic warming scenario. Each inset panel shows the median and percentile ranges for projected percentage changes in TC frequency, category 4–5 TC frequency, TC intensity, and TC near-storm rain rate derived from published studies. For TC frequency, the 5th–95th-percentile range across the studies is shown. For category 4–5 TC frequency, TC intensity, and TC near-storm rain rates the 10th–90th-percentile range is shown. Note the different vertical-axis scales used for the two halves of each panel.

***Source:** Knutson, T. et al., 2020: Tropical Cyclones and Climate Change Assessment. Part II: Projected Response to Anthropogenic Warming. Bulletin of the American Meteorological Society, https://doi.org/10.1175/BAMS-D-18-0194.1*

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OCEAN BIOGEOCHEMISTRY IN GFDL'S EARTH SYSTEM MODEL 4.1 AND ITS RESPONSE TO INCREASING ATMOSPHERIC CO_2

Journal of Advances in Modeling Earth Systems

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DOI: 10.1029/2019MS002043

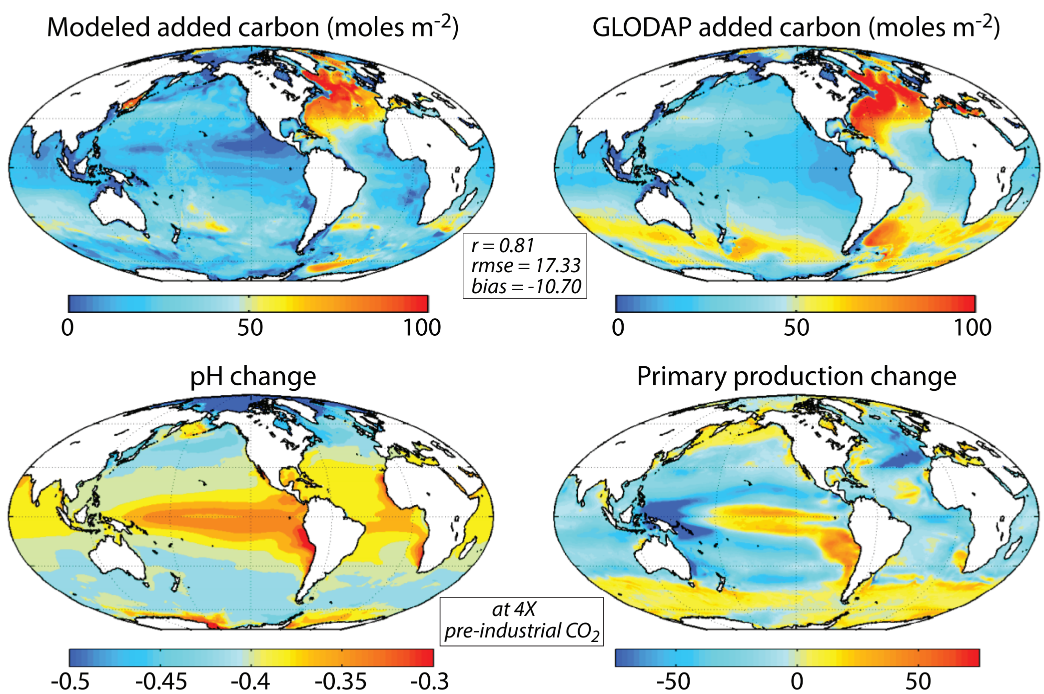
The ocean's capacity to absorb vast amounts of carbon dioxide and heat moderates the impact of greenhouse gas emissions on global warming. This service, however, can also put ocean environments and the marine resources they support at risk. The second version of GFDL's Carbon, Ocean Biogeochemistry and Lower Trophics model, or COBALTv2, was developed and integrated into GFDL's Earth System Model 4.1 to simulate the ocean carbon cycle and ocean ecosystem responses to climate change.

Amongst the most comprehensive ocean biogeochemical formulations used for global climate change simulations, COBALTv2 is distinguished by both its resolution of ocean carbon and nutrient cycling, and its comprehensive representation of plankton food web controlling the flow of energy from phytoplankton to fish. Advances in the model's "biological pump" represent sinking particles sequestering carbon in the deep ocean, and additional exchanges of nutrients with the land and atmosphere.

This paper documents the formulation of COBALTv2 and its capacity to capture diverse observed patterns in nutrients, carbon, and plankton once integrated with ESM4.1. Patterns captured include the enhanced oceanic uptake of CO_2 arising from historical greenhouse gas emissions, which has played a critical role in mitigating global warming (see figure, top panels). It also analyzes projected changes in marine ecosystem stressors, including ocean acidification and phytoplankton productivity trends at the base of marine food webs (see figure, bottom panels). These projected changes are currently being enlisted to drive global fisheries projections to assess economic and food security risks. COBALTv2 is also being deployed within high-resolution regional modeling systems to provide detailed risk assessments for U.S. Fisheries.

OAR Goals: Drive Innovative Science

COBALTv2 Captures Diverse Patterns in Nutrients, Carbon, and Acidification



Top panels compare the uptake of atmospheric carbon dioxide associated with anthropogenic emissions since 1850 estimated from COBALT compared with estimates based on in situ observations from version 2 of the Global Ocean Data Analysis Project (GLODAPv2). Bottom panels: Acidification and primary production changes associated with a 4X increase in atmospheric CO_2 relative to pre-industrial levels. These levels are comparable to those expected under high emissions scenarios during the latter third of the 21st century.

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GFDL BULLETIN

ASSIMILATION OF SATELLITE-RETRIEVED SEA ICE CONCENTRATION AND PROSPECTS FOR SEPTEMBER PREDICTIONS OF ARCTIC SEA ICE

Journal of Climate

Yong-Fei Zhang[1,2], Mitchell Bushuk[1], Michael Winton[1], Bill Hurlin[1], Xiaosong Yang[1], Tom Delworth[1], Liwei Jia[1,3]

DOI: 10.1175/JCLI-D-20-0469.1

Predicting Arctic sea ice, especially in the summertime, has great implications for environmental protection, industry regulations, and stakeholder decision making. The lack of knowledge of sea ice initial conditions is one of the major limitations of current summer Arctic sea ice forecasting. To maximize the utility of sea ice concentration (SIC) observations and explore the benefits of improved sea ice initial conditions for summertime Arctic sea ice predictions at short lead times, the authors pioneered a sea ice data assimilation (DA) framework within a GFDL sea-ice/ocean model (SIS2/MOM6).

Daily satellite-retrieved SIC observations were assimilated through an ensemble Kalman filter, then evaluated in a series of experiments. Climatology, inter-annual variability, and trends of SIC and sea ice extent (SIE) are largely improved in the authors' best DA experiment (DActr in the plot). The persistence of SIE anomalies is shown to be essential to accurate summertime predictions of Arctic sea ice at lead times of zero to one month in all Arctic regions, so the improved initial condition of SIE from the DA experiment shows prospects for superior September predictions of Arctic sea ice at short lead times. Additionally, the authors found that performance is influenced by DA frequency, observation error, and localization to different extents, offering design choices for future DA systems.

This first effort to assimilate SIC into the GFDL sea ice-ocean model was accomplished as part of the Data Assimilation Research Testbed (a community project to improve data assimilation in climate models). This work will also lay the foundation for DA of other observation types in the future.

OAR Goals: Make Forecasts Better

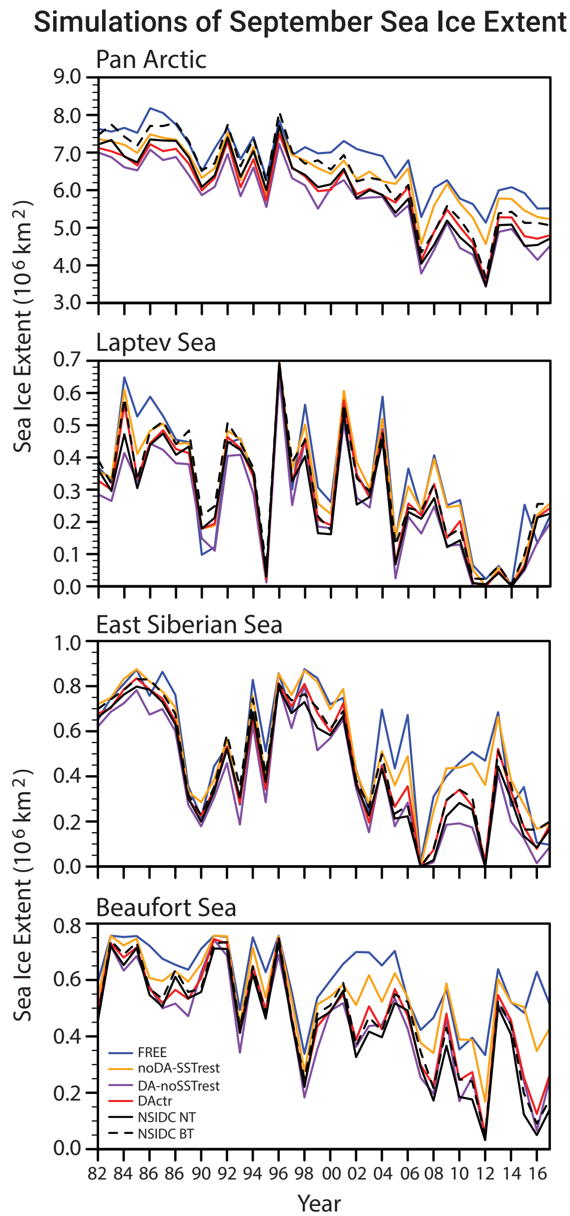

Figure (right): *Time series of regional and pan-Arctic September sea ice extent from 1982 to 2017 for different model experiments (colored lines) and two observation data sets from the National Snow and Ice Data Center, or NSIDC (black lines). The red line represents our best DA experiment.*

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ENHANCED CLIMATE RESPONSE TO OZONE DEPLETION FROM OZONE-CIRCULATION COUPLING

JGR Atmospheres *Pu Lin[1,2] and Yi Ming[2]*

DOI: 10.1029/2020JD034286

Stratospheric ozone depletion is known to cause global-scale climate variations and affect weather in many ways, such as shifts in storm tracks and changes in ocean ventilation. Understanding how climate responds to ozone depletion is key to understanding past climate changes, as well as making reliable future projections. This study elucidates how to represent ozone depletion in climate models accurately and efficiently.

The ozone hole over Antarctica leads to a strong cooling in the stratosphere. However, when simulating this effect in climate models, the magnitude of the cooling depends on how ozone is represented in the model. This study identifies a new pathway for ozone to affect stratospheric temperature via the ozone-circulation interaction. Such interaction leads to a weaker dynamical heating following ozone depletion, and hence a stronger net cooling. The ozone-circulation interaction is largely suppressed when ozone concentration is prescribed as a monthly time series as in most leading models, leading to an underestimation of the climate responses to ozone depletion in these models.

Using GFDL's AM4 model, a new scheme representing the stratospheric ozone in climate models was developed, capable of representing the ozone-circulation interaction at much less computational cost than the conventional full chemistry. The stratospheric cooling resulting from this scheme is as strong as the full chemistry (as shown in panel b). For future model development this would allow more computational resources to be allocated to enhanced resolution or other key processes, such as convection.

OAR Goals: Drive Innovative Science

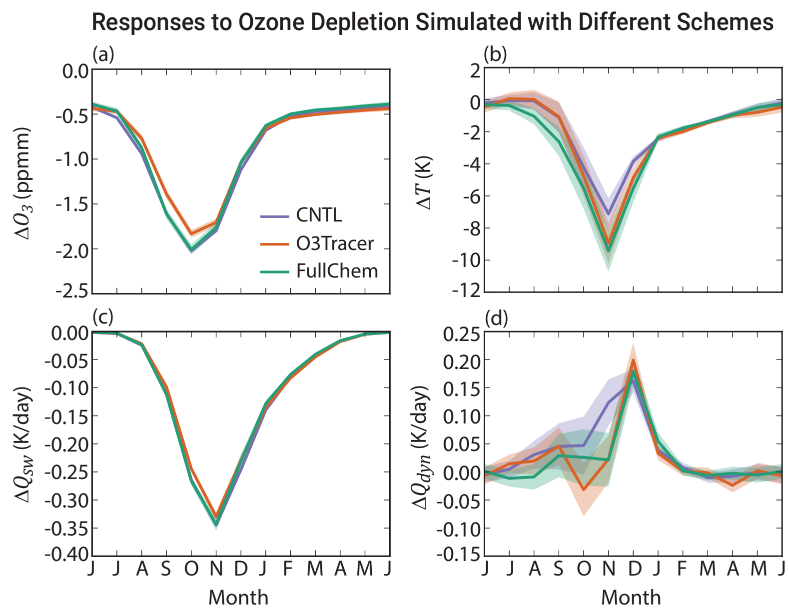

Figure (right): *Difference in (a) ozone concentration, (b) temperature, (c) shortwave (SW) heating rate, and (d) dynamical heating rate between the 2010O3 and the 1960O3 experiments using GFDL AM4. Purple lines are for the control (CNTL) simulation where ozone concentration is specified as monthly zonal mean time series, orange lines are for the simulations using the new O3Tracer scheme, and green lines are for the fully interactive chemistry (FullChem) simulations. Results are shown at 100 hPa averaged over 60°S-90°S. Shading indicates the 95% uncertainty range estimated based on the Student's t-test.*

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SPEAR Large Ensemble Prediction Data is now publicly available:

Visit: https://www.gfdl.noaa.gov/spear_large_ensembles/

GFDL has made output from a 30-member ensemble of climate change simulations using a high-resolution climate model (SPEAR) publicly available. These simulations cover the period of 1921 to the year 2100, and provide estimates of changes in climate, including extremes. This dataset may be valuable for climate risk assessment.

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