WINTER 2020-2021

GFDL BULLETIN

Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

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

THE GFDL EARTH SYSTEM MODEL VERSION 4.1 (GFDL-ESM4.1): OVERALL COUPLED MODEL DESCRIPTION AND SIMULATION CHARACTERISTICS

Journal of Advances in Modeling Earth Systems

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DOI: 10.1029/2019MS002015

GFDL's fourth generation Earth system model, ESM4.1, unifies advances across several past development efforts and highlights chemistry, carbon, and ecosystem comprehensiveness. The new model features vastly improved climate mean patterns and variability from previous chemistry and carbon coupled models. Because of the added complexity, this model is 30 times more computationally expensive than GFDL's previous Earth system models.

This model development effort included comprehensive revisions of atmospheric dynamics, physics, and chemistry; ocean, land and sea ice physics; and ocean and land biogeochemistry and ecosystems, to create NOAA's first coupled carbon-chemistry-climate model with state-of-the-art component representation and dynamic interaction. This effort builds on GFDL's laboratory-wide model development effort over 2014-2018 that resulted in the AM4.0 atmosphere, OM4.0 ocean, and CM4.0 coupled models, and includes additional comprehensiveness in atmospheric chemistry, land and ocean biogeochemistry and ecosystems, and the CO_2, dust, iron and nitrogen interactions between these components.

Over 50 simulations from ESM4.1 have been made publicly available. Analyses of these simulations will serve as the basis for research in years to come, helping to improve our understanding of coupled carbon-chemistry-climate interactions, and reducing uncertainty in projections of future climate change and its impacts and feedbacks. ESM4.1 represents a key part of NOAA's contribution to the World Climate Research Program's 6th Coupled Model Intercomparison Project.

OAR Goals: Drive Innovative Science

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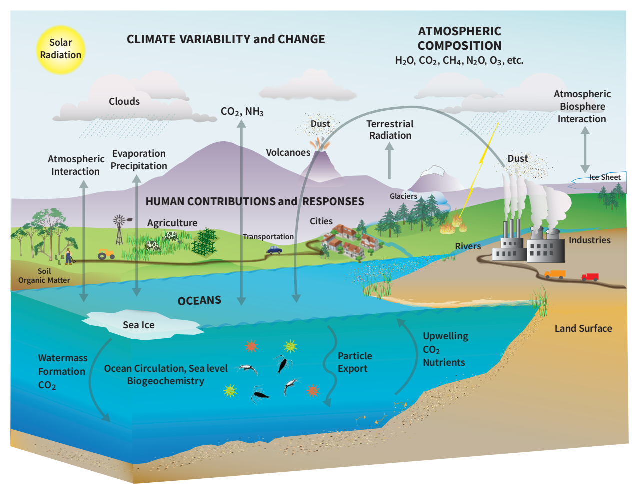
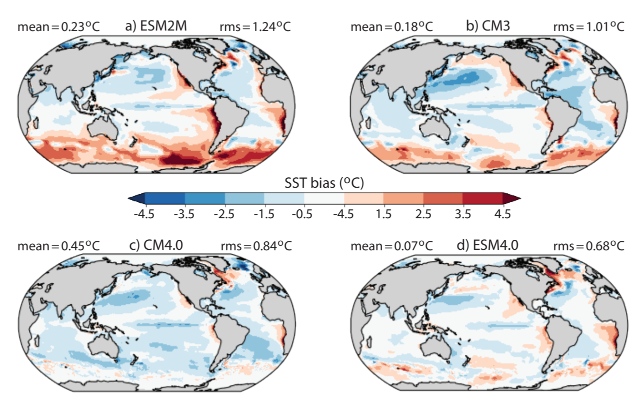


Major natural and anthropogenic processes and influences

Schematic of major natural and anthropogenic processes and influences on the climate system including CO_2, dust, iron, and nitrogen interactions between Earth system components (atmosphere, oceans, biosphere, cryosphere, terrestrial, and marine ecosystem.)



Bias in sea surface temperature, ESM4.1 compared to predecessors

Surface ocean patterns of bias in sea surface temperature compared to World Ocean Atlas 13 (Locarnini et al., 2013, WOA13) are shown for ESM2M (2013), CM3.0 (2011), CM4.0 (2019), and ESM4.1 highlighting the substantial improvement in root mean square error (RMS) across each model generation with ESM4.1 (RMS = 0.68°C) exhibiting a 45% reduction in root mean square error relative to ESM2M (RMS = 1.24°C). While CM4.0 exhibits a moderate cold bias of approximately −0.45°C compared to WOA13, ESM4.1 exhibits only a slight cold bias of −0.07°C leading to an overall smaller error (RMS = 0.68°C) compared to CM4.0 (RMS = 0.84°C).

THE GFDL GLOBAL ATMOSPHERIC CHEMISTRY-CLIMATE MODEL AM4.1: MODEL DESCRIPTION AND SIMULATION CHARACTERISTICS

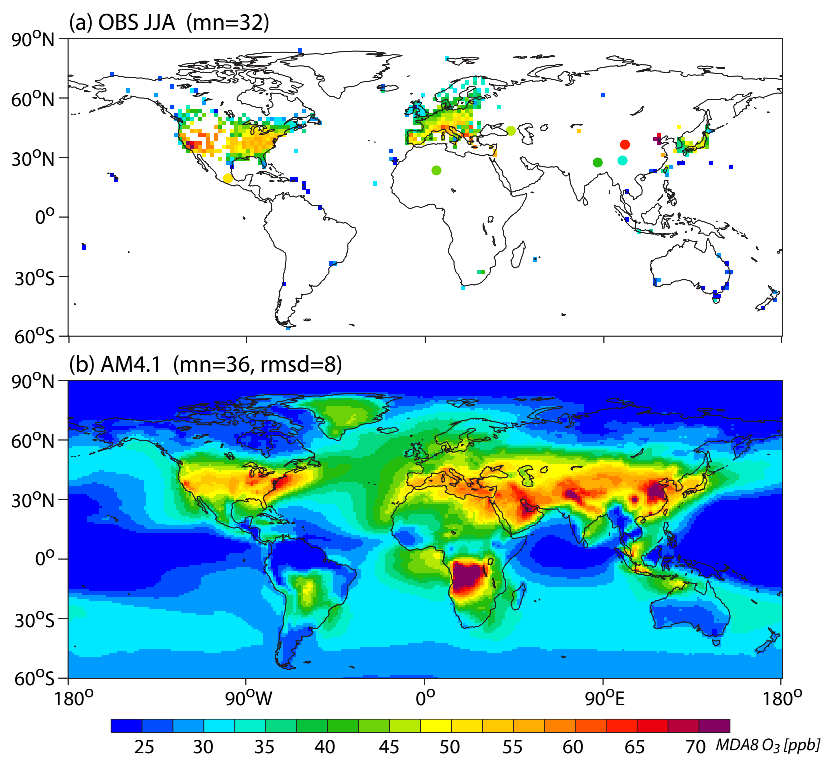
Journal of Advances in Modeling Earth Systems *L.W. Horowitz[1], V. Naik[1], F. Paulot[1], P.A. Ginoux[1], J.P. Dunne[1], J. Mao[2], J. Schnell[3], X. Chen[4], J. He[4], J.G. John[1], M. Lin[4], P. Lin[5], S. Malyshev[1], D. Paynter[1], E. Shevliakova[1], M. Zhao[1]*

DOI: 10.1029/2019MS002032

A new atmospheric chemistry-climate model, AM4.1, has been developed as part of GFDL's fourth generation model suite. AM4.1 includes an advanced dynamical core and physical parameterizations, with enhanced vertical resolution and revised aerosol and chemistry interactions. AM4.1 will help reduce uncertainty in coupled chemistry-climate interactions, historical climate-chemistry interactions in the atmosphere-only configuration discussed in this paper, and projected future climate change and its impacts and feedbacks. Compared to the previous-generation AM3.0 model, AM4.1 includes advances in the representation of atmospheric aerosols, chemistry, and physics, and accounts for biogeochemical exchanges of CO_2, dust, iron, and reactive nitrogen with the land and ocean.

AM4.1 provides vast improvements in fidelity over AM3.0, including substantially reduced biases in mean ozone for both spring and summer (figure below) over the eastern U.S. and Europe. AM4.1 captures most of AM4.0's baseline simulation characteristics and notably improves on AM4.0 in representation of the stratosphere and the ability to simulate interactive chemistry including ozone and methane. It also offers improved fidelity of aerosols over India, China, and the Southern Ocean and better representation of sudden stratospheric warming events in the coldest months. AM4.1 incorporates improved representations of climate feedbacks on "natural" emissions of aerosols and ozone precursors. Given its higher horizontal resolution (1° versus 2°), AM4.1 is more computationally expensive than GFDL's previous-generation atmospheric model.

OAR Goals: Drive Innovative Science



Surface ozone, AM4.1 vs. Obs

June–August (JJA) mean maximum daily 8-hour average (MDA8) surface ozone mixing ratios (ppbv) for 2000–2008 from: (a) observations from the Tropospheric Ozone Assessment Report database, regridded to the same 1° x 1° grid as AM4.1, and (b) AM4.1 Atmospheric Model Intercomparison Project simulation. Here, mn is the mean and rmsd is the root-mean-square deviation between observations and simulations.

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SIMULATIONS OF ATMOSPHERIC RIVERS, THEIR VARIABILITY AND RESPONSE TO GLOBAL WARMING USING GFDL'S NEW HIGH-RESOLUTION GENERAL CIRCULATION MODEL

Journal of Climate

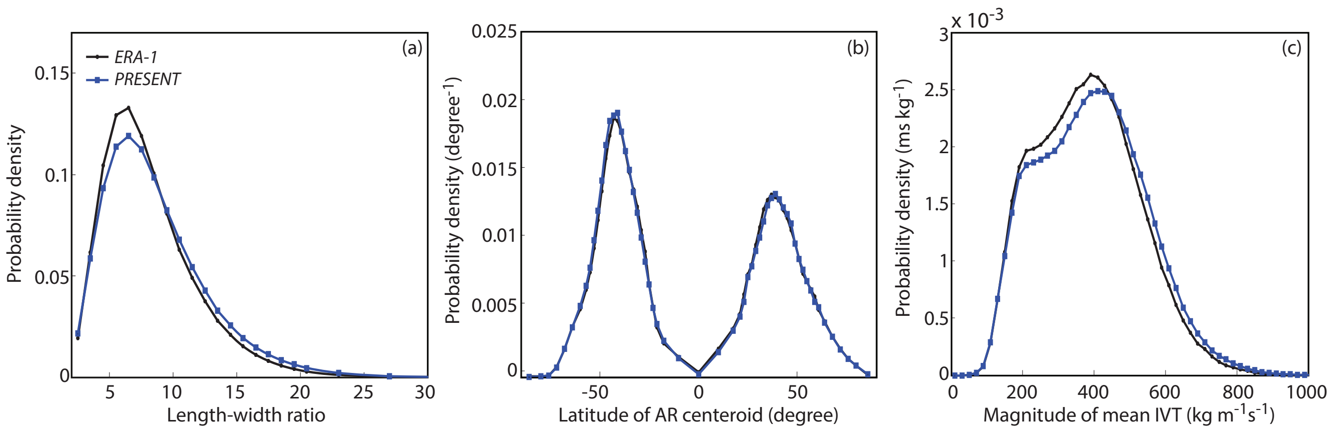
M. Zhao[1]

DOI: 10.1175/JCLI-D-20-0241.1

This study offers an assessment of GFDL's new 50km high-resolution version of the fourth generation atmospheric model, AM4.0 (100 km), for its ability to simulate and predict weather and climate extremes such as flood, drought and extreme winds. The paper describes a systematic evaluation of the model's ability to simulate atmospheric river (AR) characteristics including AR geometry, climatology, variability and future change. Despite significant regional biases, the high-resolution AM4.0 well reproduces the observed spatial distribution of AR frequency and variability in response to large-scale circulation patterns such as the El Nino - Southern Oscillation, the Northern/Southern Hemisphere Annular Mode, and the Pacific North American teleconnection pattern.

For global warming scenarios, this study shows only a very modest increase in the horizontal extent of ARs (i.e., length and width), and therefore the frequency of AR conditions, at a given location. This is different from most previous studies of AR response to warming, which show a very large increase. However, this model does produce a large increase in strong ARs, with the frequency of Category 3-5 ARs rising by roughly 100-300% per degree of global mean warming. The global mean AR intensity as well as AR intensity percentiles increase by 5-8% per degree of global mean warming, roughly consistent with the Clausius-Clapeyron scaling of increase in water vapor with surface warming. This study points out the importance of using appropriate vapor transport thresholds in detecting ARs in warmer climates. This paper was highlighted in the January 2021 issue of *BAMS* in the Papers of Note section, which is designed to deliver noteworthy topics to a wider audience.

OAR Goals: Make Forecasts Better



Simulating atmospheric river characteristics, high-resolution AM4.0 vs. Obs

GFDL's high-resolution version of AM4.0 captures the observational atmospheric river (AR) characteristics (i.e., geometry/location/strength) well, with the model typically producing stronger and narrower ARs than the observational estimates. This, and the model's ability to reproduce the observed AR frequency variability in response to large-scale circulation patterns, make it useful for investigating future AR changes in a global warming environment. This figure shows a comparison of observations (ERA-I, black) and the high-resolution version of AM4.0 (blue) simulated probability density functions for (a) the length–width ratio, (b) the centroid latitude, and (c) the mean magnitude of water vapor transport of the atmospheric rivers (AR) in present-day (1980-2014) climate.

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ASSESSING THE INFLUENCE OF COVID-19 ON EARTH'S RADIATIVE BALANCE

Geophysical Research Letters

Y. Ming[1], N.G. Loeb[2], P.Lin[1], Z. Shen[3], V. Naik[1], C.E. Singer[3], R.X. Ward[3], F. Paulot[1], Z. Zhang[4], N. Bellouin[5], L.W. Horowitz[1], P.A. Ginoux[1], V. Ramaswamy[1]

DOI: 10.1029/2020GL091699

The authors investigated the impacts of the worldwide reduction in aerosol emissions resulting from the COVID-19 pandemic, using simulations with GFDL's AM4.0 model to separate the effects of meteorology and emissions. Pandemic-related emission reductions account for approximately one-third of the large, precipitous decrease in solar clear-sky reflection (when the sky is not covered by clouds) over the East Asian Marginal Seas in March 2020. The remainder of the observed decrease can be attributed to weather variability and long-term emission trends. By contrast, no robust signal is identified in the negative anomaly in solar all-sky reflection. The presence of clouds makes it harder to detect any signal from COVID.

This study looked at the underlying mechanisms of the large, precipitous decrease in solar clear-sky reflection over the East Asian Marginal Seas in March 2020, using satellite observations and model simulations. AM4.0 is skillful at reproducing the observed interannual variations in solar all-sky reflection, under both clear and cloudy-sky conditions. This allowed the scientists to distinguish forced signal from weather variability, a prerequisite for interpreting observations.

The COVID-19 pandemic provides an opportunity for evaluating the model representation of the aerosol-cloud-radiation interactions, a major source of uncertainty in global weather and climate modeling. Although the observational evidence for aerosol direct effects is unequivocal, and their model representation is satisfactory, it is more difficult to draw definitive conclusions about aerosol-cloud interactions from the observed shortwave all-sky flux. By leveraging the latest observational and modeling capabilities, the framework described in this study is ideal for studying the radiative impacts of the ongoing COVID-19 pandemic, and the resulting perturbations to the energy balance in other parts of the world, such as North America.

OAR Goals: Make Forecasts Better

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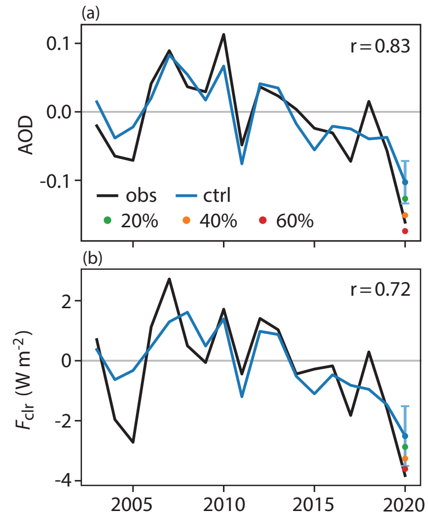

Variations in solar all-sky reflection

Time series of the anomaly in aerosol optical depth (AOD) over the East Asian Marginal Seas in March from 2003 to 2020. The black line is from MODIS satellite observations, and the blue line is from the control simulation. The vertical bar denotes the detection limit (one standard deviation of the differences between the observations and the control simulation from 2003-2019). The orange, green, and red dots denote the perturbation simulations of 20%, 40%, and 60% emissions reductions, respectively. "r" is the correlation coefficient between simulation and observation. (b) Same as (a), but for CERES satellite clear-sky shortwave radiative flux.

GFDL'S NEW MODELING SYSTEM FOR SEASONAL PREDICTIONS (SPEAR)

GFDL's newly developed SPEAR modeling system will be used to produce real-time experimental seasonal predictions each month. On Feb. 6, 2021, SPEAR became part of the North American Multi-Model Ensemble, an effort led by the National Weather Service's Climate Prediction Center to combine multiple global systems to generate seasonal predictions and support operational seasonal outlooks (temperature, precipitation, Atlantic hurricane outlook, winter outlook, etc.). At the beginning of each month, GFDL scientists use observations from around the world to be used as starting points for the SPEAR system, to make climate predictions for the following 12 months.

Predictions made with SPEAR have improved skill for many aspects of the Earth's climate system, including the El Niño-Southern Oscillation, precipitation and temperature over North America, and Arctic sea ice. SPEAR will also be used for ongoing research toward improving climate predictions and projections on timescales from one season to decades ahead, with a focus on climate extremes, including hurricanes, drought, heat waves, atmospheric rivers, and hydrologic extremes. In addition, decadal climate predictions from the SPEAR system are transmitted to the UK Meteorological Office as part of a World Meteorological Organization international collaborative activity. For more information, please visit: https://www.gfdl.noaa.gov/spear/

***Erratum**: In the Fall 2020 issue, in recognizing Andrew Wittenberg for being on the Web of Science Group's 2020 List of Highly Cited Researchers, his name was inadvertently misspelled.*