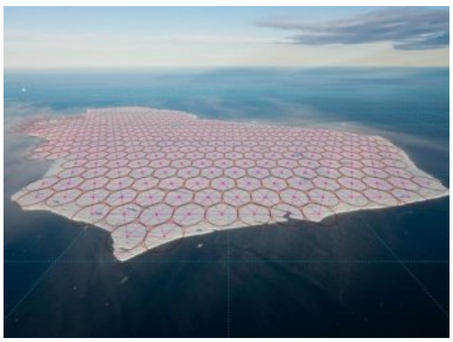
CIMES

Cooperative Institute for Modeling the Earth System



Annual Progress Report

July 1, 2018 – March 31, 2019

Cooperative Institute for Modeling the Earth System
at Princeton University
NOAA Cooperative Agreement
NA18OAR4320123

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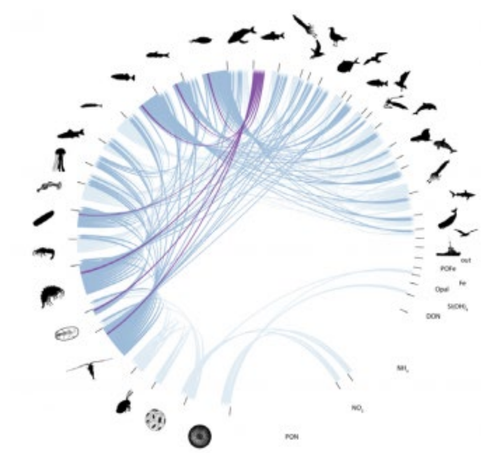

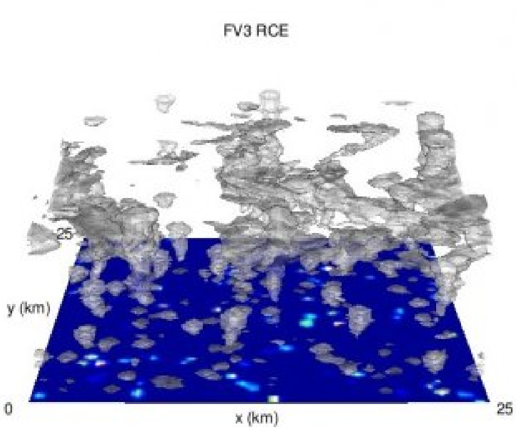

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Cooperative Institute for Modeling the Earth System
Princeton University

Annual Progress Report under cooperative agreement NA18OAR4320123

For the period July 1, 2018 – March 31, 2019

Introduction

In 2018, the Cooperative Institute for Modeling the Earth System (CIMES) succeeded the Cooperative Institute for Climate Science, which was established in 2003 to foster collaborations between Princeton University and the Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration (NOAA). The research conducted is in support of NOAA's mission and strategic goals in areas related to earth system science. CIMES builds on the collective knowledge and complementary resources that have been developed over the past five decades of close collaboration between Princeton University and NOAA's Geophysical Fluid Dynamics Laboratory (GFDL).

The CIMES vision is to:

Be a world leader in understanding and predicting the earth system, across time-scales from days to decades, and from the local to global spatial scales, with particular emphasis on extreme events, integrating physical, chemical and biological components.

The mission of CIMES is to contribute to achieving this vision principally by drawing on the three linchpins of the GFDL/Princeton relationship to focus the scientific talent of Princeton University at all levels from graduate students, through postdocs, and faculty, to address key questions related to climate science and earth system modeling, providing a bridge between NOAA-GFDL and Princeton University and the wider academic community.

The three linchpins of the GFDL/Princeton relationship on which CICS was built and which we propose to continue through CIMES, are: First, the outstanding graduate academic program in Atmospheric and Oceanic Sciences, which has trained many eminent scientists working today in climate and earth system science; Second, the academic expertise of Princeton faculty and investigators; Third, the flexibility of the academic enterprise at Princeton University to respond to new initiatives and opportunities.

The goals of CIMES, that is, the specific activities that CIMES will carry forward in order to make progress in accomplishing our vision together with GFDL, namely:

1. To develop the world leading earth system model, in collaboration with GFDL, by providing expertise in key processes, physical and biological components, and software development.

2. To apply this model to the problem of prediction across time and space scales, from high resolution simulations of extreme events, to prediction of climate phenomena from seasons to centuries.

3. To apply this model to understand impacts of a changing climate on societally-relevant problems, including marine ecosystems, weather extremes, droughts and air quality.

4. To train the next generation of leaders in earth system science, through the world-leading graduate Atmospheric and Oceanic Sciences Program, and the AOS postdoctoral program.

5. To develop a more diverse workforce by broadening participation in earth system science training, through summer internships, visiting faculty exchange fellowships and increasing research collaborations with diverse institutions.

Research Themes Overview

Research in the Cooperative Institute for Modeling the Earth System addresses the following themes:

1. **Earth System Modeling:** Developing and improving Earth System Models (ESMs), numerical models which simulate the climate and earth system, and allow prediction of the future evolution of this system. These models include the dynamical, physical, chemical and biological components of the atmosphere-ocean-land system and the coupling between them.
2. **Seamless Prediction Across Time and Space Scales:** Applying the ESMs to predictions on time-scales from days to centuries, and over spatial scales from those of extreme events to global scales, making use of the same flexible code-base. We focus on two different aspects of prediction across time and space scales, the very high-resolution modeling necessary to resolve extreme weather phenomena, and the predictability of different weather and climate phenomena.
3. **Earth System Science: Analysis and Applications:** Using Earth System Models to understand the impacts of environmental variations and changes on pressing problems of relevance to society, including marine ecosystems, weather extremes, drought and air quality.

Earth System Modeling

The development of improved models for studying the earth system is an ongoing major focus of the collaboration between Princeton and NOAA-GFDL. Such models are continually improving to provide greater realism and credibility to simulations of the earth system by including more components of the earth system, by including better representation of physical, chemical and biological processes, and by increasing resolution. The major components of an Earth System Model are:

1. An ocean general circulation model, including a dynamical core to represent the fundamental fluid dynamics, and parameterizations of sub-grid-scale processes, such as mesoscale and submesoscale dynamics, and mixing.
2. Models for cryospheric processes, including ice-sheets, sea-ice and icebergs.
3. An atmospheric general circulation model, including a dynamical core to represent the resolved fluid dynamics, a radiation scheme, and parameterizations of sub-grid-scale processes such as clouds, convection, and turbulent transport in the planetary boundary layer.
4. An atmospheric chemistry model for predicting important chemical tracers.
5. A land model for surface hydrology and terrestrial biogeochemical processes.
6. An ocean biogeochemistry model enabling the prediction of the carbon cycle.

For each of these components, improvements continue to be made in creating faster and more accurate dynamical cores, more physically-based parameterizations, and including more active chemical tracers, e.g., the Nitrogen cycle. A common theme of these improvements is the use of greater understanding of important climate processes, gained through a combination of observations, process modeling and theoretical analysis, to advance the global model representations.

Seamless Prediction Across Time and through Space Scales

Earth System Models are increasingly being applied to prediction, in support of scientifically-based decision-making. Such predictions occur on a variety of spatial and temporal scales, dependent on the problem of interest. In order to make the best use of resources, increasingly the same code base is being applied to different prediction problems at different resolutions. Many of the model advances described in the Earth System Modeling research theme allow the same model to be applied to prediction at different scales, by incorporating scale-aware physically-based parameterizations, a choice of model formulation

with the appropriate physics for the scale of interest (e.g., nonhydrostatic v. hydrostatic), and varying degrees of comprehensiveness and complexity. CIMES focuses on two different aspects of prediction across time and space scales, the very high resolution modeling necessary to resolve extreme weather phenomena, and the predictability of different weather and climate phenomena.

High resolution modeling: the CIMES contribution to high-resolution modeling at NOAA-GFDL, focuses on the development of model components that accurately represent physical processes as model resolution is increased beyond the current norm of 25-100 km, and the computational and data issues associated with the development of high-resolution coupled models. The unique strengths of the NOAA-GFDL modeling system include the FV3 atmospheric dynamical core; the MOM6 ocean model; and the Flexible Modeling System (FMS) infrastructure underlying those, to which Princeton scientists have made substantial technical and scientific contributions.

Predictability: The next generation earth system modeling tools that have been and will be developed at CIMES and NOAA/GFDL present a rich opportunity for collaborative research aimed at understanding of the underlying predictability of the earth system, on timescales from hours to decades, and building systems that realize this predictive potential. Predictability on these timescales can arise from both the dynamical evolution of the earth system from its initial state ("initial value problem") and from changes in factors external to the system in question ("boundary value problem"). CIMES undertakes research into predictability, data assimilation and realizing prediction skill in close collaboration with scientists at NOAA/GFDL.

Earth System Science: Analysis and Applications

The earth system models that were developed in collaboration with GFDL are being applied to understanding a wide variety of societally-relevant climate problems. These include the impacts of climate change and natural climate variability on sea-level (an application of the ocean and cryospheric components of the modeling system), and the attribution of climate change to natural and anthropogenic forcing. Examples of the possible range of earth system model applications include air quality, extreme weather events and drought, and ecosystem impacts of climate change.

Air quality applications of earth system science studied by CIMES include: the impact of climate change and variability on air-quality via ecosystem-atmosphere feedbacks; the impact of nitrogen on air-quality; the seasonal prediction of extreme Ozone and particulate matter pollution.

CIMES research on extreme weather and drought events includes tropical cyclone modeling and storm-surge and flood hazards; extreme rainfall and flooding by warm season convection; seasonal and interannual forecasting and decadal changes in water availability; heat waves and urban climates.

The impact of climate variability and climate change on marine ecosystems research in CIMES includes the application of seasonal to decadal prediction in real world management scenarios, fostering the use of ESMs to support NOAA's commitment to promote sustainable management strategies that lead to healthy and productive marine ecosystems; century-scale projections and simulations of marine ecosystems; novel observation systems and ecosystem diagnostics; continued development of ecosystem models; assessment of high-resolution earth system model simulations of key ecosystems. CIMES research also examines links between climate and infectious disease.

Education/Outreach

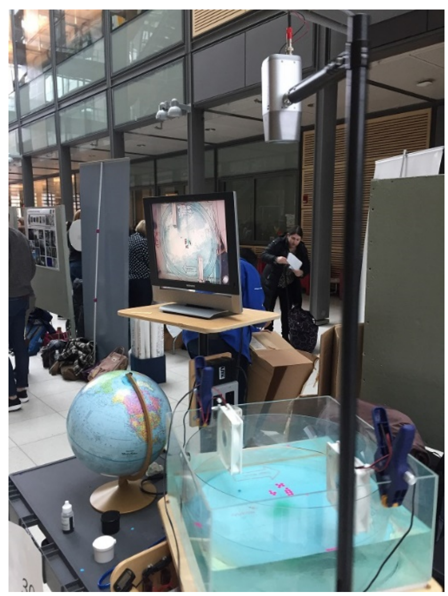
Many CIMES-funded scientists, students and postdocs take the initiative to participate in outreach and education activities, as described in the individual reports. Here we describe principal outreach activities sponsored by CIMES/AOS.

2019 Young Women's Conference in Science, Technology, Engineering, and Mathematics

Some 750 seventh-to-tenth-grade girls engaged in scientific experiments and a day of fun at the 2019 Princeton Plasma Physics Laboratory (PPPL) Young Women's Conference (YWC) in Science, Technology, Engineering, and Mathematics (STEM) on Friday March 22, 2019 at the Frick Chemistry Laboratory on the Princeton University campus. AOS/CIMES researchers were among the exhibitors who volunteered at the event with the goal of sparking interest in science that might lead girls to consider careers in STEM fields, a key first step in recruiting the most diverse and highly qualified next generation of New Jersey's scientists and engineers.

This year's conference featured more exhibitors than any previous year, including an exhibit on the brain by the Liberty Science Center, an exhibit by the New Jersey Department of Environmental Protection, and interactive demonstrations by several groups from Princeton University. Elizabeth Yankovsky (AOS/CIMES), who coordinated the outreach effort within the AOS Program and CIMES, Jane Smyth (AOS/CIMES), Jane Baldwin (PEI/formerly AOS/CICS), and Marion Alberty (AOS/CIMES), with the assistance of Danielle Schmitt (GEO), led the AOS/CIMES hands-on demonstrations.

CIMES Researcher Jane Smyth, an AOS graduate student, leading an ocean acidification experiment at PPPL's 2019 Young Women's Conference in STEM



Rotating tank demonstration at 2019 YWC in STEM

The first experiment explored the relationship between CO_2 and ocean acidification. The researchers discussed pH scale, using a pH indicator, tap water, and lemon juice, showing how the pH indicator turns color in the tap water with lemon juice since the lemon juice is an acid. The students were then asked to blow bubbles (releasing CO_2) into the third cup, also resulting in color changes in the acidic direction. A conversation ensued around what is happening as the ocean uptakes CO_2 from the atmosphere, and the resulting damage for the organisms that live in the oceans. The second experiment demonstrated how ice

melts differently in fresh water and salt water, based on the behavior of the meltwater from dyed ice cubes, leading to an engaging discussion about the ice cycle in the Arctic and the positive feedback of more melting creating fresher water and allowing for further melting.

For the final experiment, the researchers brought in a rotating tank to mimic the Pacific Ocean, placing a map underneath it. Using fans to simulate large-scale winds, the students were asked to place paper confetti along the edges of the tank (or off the coast of Japan and California). Due to gyre circulation that the tank simulated, the paper dots moved in a spiral towards the center of the tank where they all converged. The demonstration led to a dialogue about the Great Pacific Garbage Patch and how pollution deposited along the coast makes its way into the interior of the ocean and harms the ecosystems there.

Featured speakers at the conference, in addition to the exhibitors, included Tammy Ma, a plasma physicist at the U.S. Department of Energy's Lawrence Livermore's National Ignition Facility; Kamana Misra, M.D., founder of the companies ContraRx and BioThink LLC; Elahesadat Naghib, a final-year Ph.D. candidate in Princeton University's Operations Research and Financial Engineering Department; and Kathryn "Kitty" Wagner, a senior technical staff member in the Princeton University Chemistry Department.

The YWC conference has become more popular each year with registration for this year's event filling up within one month, according to the program manager for PPPL's Science Education Office. If enthusiasm and a spark in the eyes of the girls at the conference's more than 30 exhibits is any indication of what the future holds for STEM fields, New Jersey is in good hands.

Structure of the Joint Institute

Building on the past five decades of shared experience between GFDL and Princeton University, CIMES continues to be managed within the AOS Program, with ties to the Department of Geosciences (AOS is an autonomous program within the GEO Department) and the Princeton Environmental Institute (PEI), which shares many of the same interests. AOS was founded five decades ago as part of the collaboration between Princeton and GFDL, and has served its function extraordinarily well as judged by the success of our graduates, and past reviews of our predecessor, CICS. The CIMES research and education activities are organized around the three themes discussed previously in the Research Themes Overview. The following tasks and organizational structure have been established to achieve the objectives:

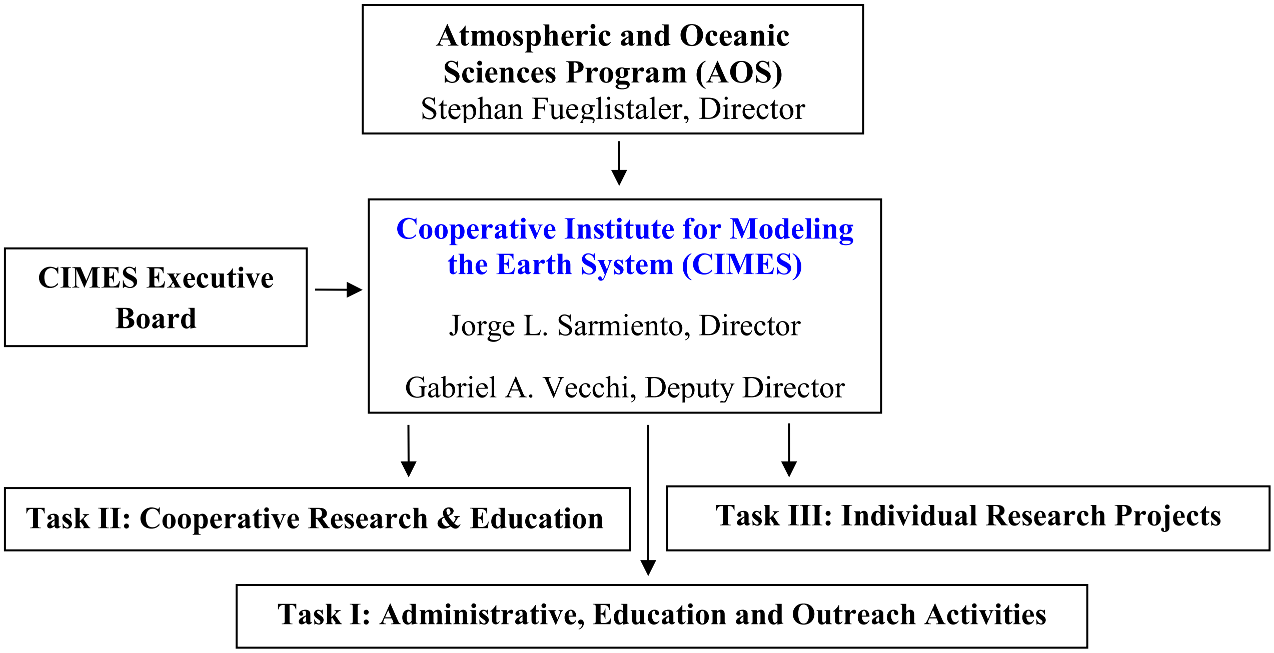
Task I. Administrative, Education and Outreach Activities are carried out by the AOS Program.

Task II: Cooperative Research Projects and Educational Activities usually involve on-going direct collaborations with NOAA/GFDL scientists and are carried out in the GFDL building. This continues to be accomplished largely through the AOS Program of Princeton University, an autonomous academic program within the Geosciences Department. One of the most important, and thus far, successful tasks of the cooperative institute has been the post-doctoral, research and visiting scientist program. Research projects are undertaken both by postdoctoral scientists and by research scientists in long-term positions. Projects involving research scientists are typically developed in both formal and informal discussions with GFDL scientists. Most major research projects are intertwined with GFDL projects (for example, the development of the next-generation ocean model), and there is two-way consultation and collaboration on a daily basis, as well as the more strategic and formal discussions. Appointments are made in the AOS Program on the recommendation of the Visiting Scientist Selection Committee, which includes both Princeton University and GFDL scientists as members. The committee is currently chaired by Sonya Legg and Leo Donner (GFDL Physical Scientist and AOS Faculty member). Students advised by GFDL scientists are usually funded by Cooperative Institute Task II research funds, although some students advised by Princeton University professors receive funding from Cooperative Institute Task III, following a competitive proposal review process. A strong connection between student Cooperative Institute-funded research and GFDL and NOAA goals is ensured by research guidance from GFDL advisors and/or committee members. Graduate students are formally admitted to the AOS Program by the Graduate School at Princeton University, based on a recommendation by the faculty of the AOS Program, which includes, approximately 10 employees of GFDL/NOAA, thus ensuring that the NOAA vision is fully represented.

Task III: Principal Investigator led research projects fall within the themes of CIMES, usually involving some collaboration with NOAA/GFDL scientists, and are investigated by the Princeton researchers. These projects generally occur within Princeton's departments, centers, institutes and programs, and may also include subcontracts to research groups at other institutions as needed. Task III is the main route for involvement of Princeton faculty in GFDL-relevant science. Funding is primarily through an annual call for proposals, with a review and evaluation process carefully designed to avoid conflicts of interest, promote engagement of a wide group of Princeton faculty in CI research, and involve GFDL scientists to ensure alignment of funded research with GFDL goals.

The Director is the principal investigator for the CIMES proposal. The Director is advised by an Executive Board consisting of Princeton University associated faculty.

Cooperative Institute for Modeling the Earth System (CIMES)



CIMES Executive Board

Board Members

Jorge L. Sarmiento – Director of CIMES, Professor of Geosciences
Gabriel A. Vecchi – Deputy Director of CIMES, Professor of Geosciences and Princeton Environmental Institute
Sonya A. Legg – Associate Director of CIMES, Senior Research Oceanographer in Atmospheric and Oceanic Sciences Program, Lecturer in Geosciences
Thomas Delworth – GFDL Physical Scientist, Lecturer in Geosciences
Stephan Fueglistaler –Director of the Atmospheric and Oceanic Sciences Program, Associate Professor of Geosciences
Isaac Held – GFDL Senior Research Scientist, Lecturer with rank of Professor in Geosciences
Michael Oppenheimer – Professor of Geosciences and Public and International Affairs, WWS
Stephen W. Pacala – Professor of Ecology and Evolutionary Biology
Venkatachalam (Ram) Ramaswamy – Director of GFDL and Senior Research Scientist

Executive Summary of Important Research Activities

EARTH SYSTEM SCIENCE: ANALYSIS AND APPLICATIONS

As we are transitioning from CICS (ending in June 2019) to CIMES (began in July 2018), only three newly hired postdocs are currently working as part of CIMES. These three postdoctoral researchers are all exploring applications of earth system science to societally important problems, from the climate impacts of the aerosol induced direct radiative forcing (**Gaurav Govardhan**), to the impacts of aerosol-cloud interactions on extreme rainfall (**Xiaoqiong Li**) to the impact of biosphere-atmosphere interactions on air pollution (**Yuanyu Xie**). For further information, refer to the individual reports.

Budget Amount and Milestones

During this current CIMES reporting period, July 1, 2018 – March 31, 2019, Princeton received funds in the amount of $5,070,131 for Task I, Task II and Task III research projects (see details in ***CIMES FY'19 List of Awards***). No dollar amount has been specified for a project, nor is spending tracked by CIMES on a project not given specific funding. Any milestone/project progress has been reported under ***Methods and Results/Accomplishments*** as we do not list specific milestones to be met in our proposal.

Project Titles

Cooperative Institute for Modeling the Earth System (CIMES)
NOAA Cooperative Award NA18OAR4320123

Education/Outreach Projects

- 2019 Young Women's Conference in Science, Technology, Engineering, and Mathematics

Earth System Science: Analysis and Applications

- Breaking Down the Aerosol Induced Direct Radiative Forcing and its Climatic Impacts (Gaurav Govardhan)
- Understanding Aerosol-Cloud Interactions and the Effects on Extreme Rainfall (Xiaoqiong Li)
- Biosphere-Atmosphere Interactions and Air Pollution Extremes (Yuanyu Xie)

Progress Reports:

Earth System Science: Analysis and Applications

Progress Report Title: **Breaking Down the Aerosol Induced Direct Radiative Forcing and its Climatic Impacts**

Principal Investigator: Gaurav Govardhan (Princeton Postdoctoral Research Associate)

CIMES/GFDL Collaborator: V. Ramaswamy (GFDL), David Paynter (GFDL), Fabien Paulot (Princeton), Paul Ginoux (GFDL)

Award Number: NA18OAR4320123

Task II: Cooperative Research Projects and Education

NOAA Sponsor: V. Ramaswamy (GFDL)

Theme: Earth System Science: Analysis and Applications

NOAA Goals:
Climate Adaptation and Mitigation Goal: An Informed Society Anticipating and Responding to Climate and its Impacts

Objectives: I would like to understand species-wise, sector-wise, region-wise, altitude-wise contribution of different aerosol species to the global aerosol induced direct radiative forcing and its climatic impacts using the GFDL AM4/CM4 models.

Methods and Results/Accomplishments:

I aim to understand the partitioning of the global aerosol induced direct radiative forcing into different species, sectors, altitude levels etc. using the GFDL model AM4. The first step towards that would be understanding the strength and weaknesses of the model simulated aerosol loading. This could be achieved by carrying model evaluation of the aerosol related parameters. Evaluation of model simulated global fields vis-a-vis the space or ground based measurements provide us guidelines about further improvements. With this motivation a few previous studies (Ginoux et al. (2006); Donner et al. (2011); Naik et al. (2013); Ocko and Ginoux (2017), Paulot et al., (2018)) have examined the performance of GFDLs models CM2.1, CM3 and AM3, in simulating global aerosol related parameters. Recently, Zhao et al., 2018, have briefly examined the performance of GFDL AM4 in simulating aerosol optical depth (AOD) globally. We, in this study, would like to study the performance of the GFDL AM4 model in simulating magnitude and variability of regional AOD and the other aerosol related parameters, over different regions of the world. We make use of two versions of the AM4 model i.e. free running version (AM4-F) and a version of the model with every six hourly meteorological nudging (AM4-N).

Upon examining the simulated aerosol fields we find that both the models successfully capture the strength and the variability of AOD over the global hot-spots for aerosol loading namely the regions like Eastern US, Western Europe and Eastern China (with slightly overestimating the AOD magnitudes over Eastern China), vis-a-vis the satellite retrieved AOD products (MODIS and MISR). However, the models fail to capture the overall trend and the magnitude of AOD over the North African region. Over the Indian region, the models successfully capture the trend in AOD while the magnitudes are underestimated especially during the boreal winter months vis-a-vis the satellite retrieved products and the measured AOD from ground-based AERONET (AErosol RObotic NETwork) stations. Further, it is found that, the models tend to overestimate Single Scattering Albedo (a measure of aerosol related absorption of radiation) vis-a-vis that retrieved by ground based station algorithms, over the Indian region. This could be related with the simulated black carbon aerosol fields or the assumed state of mixing of aerosols in the models. This will be examined further.

I would like to continue this study to understand species-wise, sector-wise, region-wise, and altitude-wise contribution of different aerosol species to the global aerosol induced direct radiative forcing and its climatic impacts.

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https://doi.org/10.1002/2017MS001208.

Progress Report Title: **Understanding Aerosol-Cloud Interactions and the Effects on Extreme Rainfall**

Principal Investigator: Xiaoqiong (Sage) Li (Princeton Postdoctoral Research Associate)

CIMES/GFDL Collaborator: Yi Ming (GFDL), Stephan Fueglistaler (Princeton)

Award Number: NA18OAR4320123

Task II: Cooperative Research Projects and Education

NOAA Sponsor: V. Ramaswamy (GFDL)

Theme: Earth System Science: Analysis and Applications

NOAA Goals:
Weather-Ready Nation Goal: Society is Prepared for and Responds to Weather-Related Events

Objectives: Improve the understanding of aerosol and cloud processes and the effects on monsoon low pressure systems and extreme rainfall

Methods and Results/Accomplishments:

Precipitation extremes are expected to significantly increase in the future (O'Gorman, 2012) due to both increasing greenhouse gases (GHGs) and declining aerosol emissions (Wang et al., 2016). Aerosols are likely to be more effective than GHGs in altering land rainfall extremes, particularly over eastern and southern Asia (Lin et al. 2016). Over the monsoon regions, rainfall extremes are largely related to synoptic scale low-pressure systems such as lows and depressions (Hurley and Boos, 2015). The response of monsoon depressions to external forcing, particularly aerosol and cloud processes, has not been fully explored. We have examined the changes of the Asian monsoon rainfall in GFDL-CM4 and GFDL-AM4 to quantify the effects of external forcing. Tracking algorithms have been utilized to analyze the characteristics of monsoon low pressure systems to explore the possible changes of synoptic scale activities contributing to intense rainfall. The new ERA5 reanalysis dataset with hourly data available from 1979-2019 from the European Centre for Medium-Range Weather Forecasts (ECWMF) is analyzed as a comparison.

Global climate models (GCMs) show significant biases in simulating global cloud and rain distribution, largely related to the lack of adequate representation of aerosol and cloud processes. This contributes to large uncertainties in anthropogenic aerosol effects on global climate such as monsoons, atmospheric circulation, and extreme events. In order to evaluate the representation of cloud and aerosol processes in GFDL-AM4 and obtain a direct comparison with *in situ* observations, GFDL-AM4 simulations are performed with a "nudged-meteorology" approach in which the wind field is constantly nudged toward reanalysis data. These simulations will be evaluated against the integrated datasets synthesized from The Southern Ocean Clouds Radiation Transport Aerosol Transport Experimental Study (SOCRATES) observations.

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Progress Report Title: **Biosphere-Atmosphere Interactions and Air Pollution Extremes**

Principal Investigator: Yuanyu Xie (Princeton Postdoctoral Research Associate)

CIMES/GFDL Collaborator: Meiyun Lin (GFDL), Larry Horowitz (GFDL)

Award Number: NA18OAR4320123

Task II: Cooperative Research Projects and Education

NOAA Sponsor: V. Ramaswamy (GFDL)

Theme: Earth System Science: Analysis and Applications

NOAA Goals:
Climate Adaptation and Mitigation Goal: An Informed Society Anticipating and Responding to Climate and its Impacts

Objectives: Understand how changes in vegetation dry deposition and wildfires in a warmer and drier world affect surface air pollution extremes

Methods and Results/Accomplishments:

The land biosphere plays a critical role in the emissions and the removals of key surface air pollutants. Extremely high ozone levels are found during hot and dry days, when dry depositions are largely reduced as plants close their stomata to conserve water [*Emberson et al.*, 2013; *Huang et al.,* 2015]. In this project, I performed comprehensive evaluations of the newly implemented interactive dry deposition scheme in GFDL LM4.0 [*Paulot et al.*, 2018; *Shevliakova et al.*, 2009; *Milly et al.*, 2014; *Zhao et al.*, 2018; *Lin et al.*, in review] in simulating ozone-temperature relationship (Figure 1). Compared to the surface observations, inclusion of interactive dry deposition scheme largely improves the linear regression correlation coefficient and the slope between ozone and temperature as compared to the simulations with fixed dry deposition. The results suggest an important role dry deposition plays in regulating surface ozone variability. The role of dry deposition may become more important for ozone extreme events in a warming climate.

Hot and dry weathers are also conducive of large wildfires. The thick smokes coming out from biomass burning is a significant threat to surface fine particulate ($PM_{2.5}$) air quality. Several studies found that the $PM_{2.5}$ pollution is largely reduced over the eastern US due to reduction of anthropogenic emissions over the past three decades, while the $PM_{2.5}$ levels over the western US did not decrease and even present an upward trend as a result of increasing wildfires [*McClure et al.*, 2018; *O'Dell et al.*, 2019]. I show using surface observation data and satellite retrievals that summer time surface $PM_{2.5}$ concentration and aerosol optical depth (AOD) are tightly correlated with fire $PM_{2.5}$ emissions. Among different species of $PM_{2.5}$, organic carbon and black carbon show strong correlations with fire $PM_{2.5}$ emissions while sulfate do not present a significant correlation.

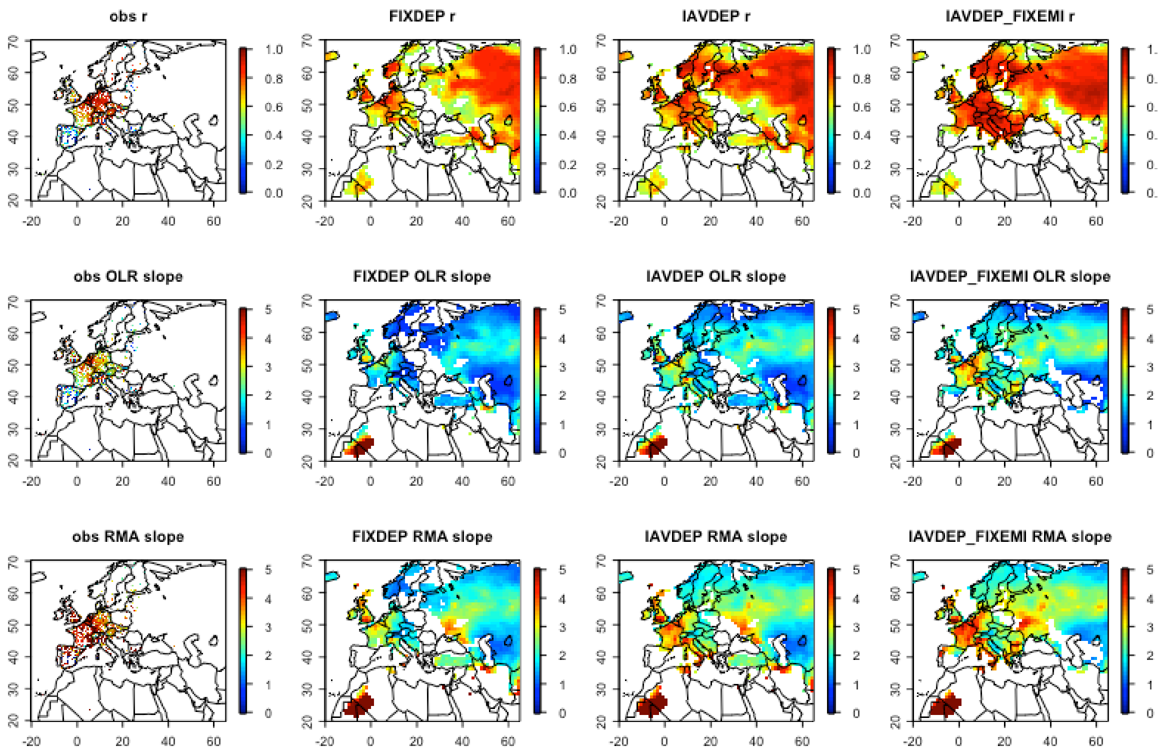

Figure 1. Improved simulations of ozone-temperature relationship with interactive dry deposition in GFDL AM4/LM4. The relationship between monthly mean MDA-8 ozone and maximum temperature for August during 2000 to 2014, shown as correlation coefficient (r, top panel), ordinary linear regression (OLR, middle panel) slope and reduced major axis (RMA, bottom panel) slope for observation, model with fixed dry deposition (FIXDEP), interactive dry deposition (IAVDEP) and interactive dry deposition with fixed anthropogenic emissions (IAVDEP_FIXEMI).

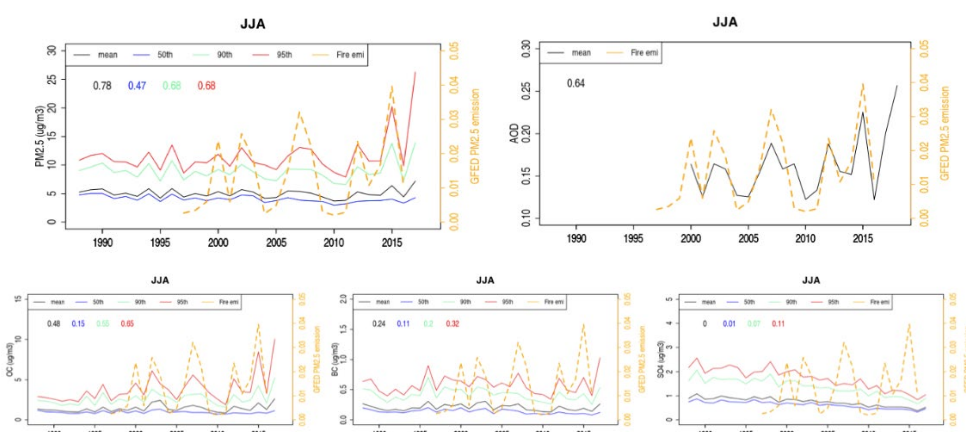

Figure 2. Tight correlations between $PM_{2.5}$, AOD and fire emissions over the western US. Interannual variations of the summertime (June, July, August) average fire $PM_{2.5}$ emissions (g/m^2/month) from Global Fire Emission Database (GFED) and $PM_{2.5}$ concentrations at different quantiles (top left), monthly mean AOD (top right), organic carbon (OC, bottom left), black carbon (BC, bottom middle) and sulfate (SO4, bottom right) over the western US. The numbers shown are coefficient of determination (R^2) between fire $PM_{2.5}$ emissions and each variable displayed.

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COOPERATIVE INSTITUTE FOR MODELING THE EARTH SYSTEM

Task I: Administrative Activities and Outreach Supported Personnel

Name	Rank
Vecchi, Gabriel	Deputy Director of CIMES

Task II: Cooperative Research Projects and Education Supported Personnel

Name	Rank	Host/Advisor
Govardhan, Gaurav	Postdoctoral Research Associate	Ramaswamy, V./Paynter, David
Li, Xiaoqiong (Sage)	Postdoctoral Research Associate	Fueglistaler, Stephan/Ming, Yi
Xie, Yuanyu	Postdoctoral Research Associate	Lin, Meiyun

Personnel				
Category	Number	B.S.	M.S.	Ph.D.
Faculty	1	-	-	1
Research Scientist	-	-	-	-
Visiting Scientist	-	-	-	-
Postdoctoral Research Associate	3	-	-	3
Professional Technical Staff	-	-	-	-
Associate Research Scholar	-	-	-	-
Administrative	-	-	-	-
Total (≥ 50% support)	**2**	**-**	**-**	**2**
Undergraduates	-	-	-	-
Graduate Students	-	-	-	-
Employees that receive < 50% NOAA funding (not including graduate students)	2	-	-	2
Located at the Lab (include name of lab)	GFDL-3			-
Obtained NOAA employment within the last year	-	-	-	-

CIMES FY'19 List of Awards for Institutional Award NA18OAR4320123

Amount	PI	Project Title
$2,937,924	Jorge L. Sarmiento	CIMES – YR 1 (Research/Education-Task II)
$ 122,209	Jorge L. Sarmiento	CIMES – YR 1 (Administration – Task I)
$ 10,000	Jorge L. Sarmiento	CIMES – YR 1 (Administration – Task I (conferences)
$ 86,124*1	Jorge L. Sarmiento	CIMES – YR 1 (Administration – Task I)
$1,413,874*1	Jorge L. Sarmiento	CIMES – YR 1 (Research/Education-Task II)
$ 500,000*1	Jorge L. Sarmiento	CIMES – YR 1 (Research/Education – Task III)

Amendment No. /PI	Amount	Project Title
Initial Award PI: Jorge L. Sarmiento	$3,070,133	Cooperative Institute for Modeling the Earth System (CIMES)
Amendment #1 PI: Jorge L. Sarmiento	$1,999,998	Cooperative Institute for Modeling the Earth System (CIMES)