Process-Oriented Diagnostics for the Western Boundary Current Variability and Midlatitude Air-Sea Interaction

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Abstract

Western boundary currents (WBCs), such as the Kuroshio-Oyashio Extension in the North Pacific and the Gulf Stream in the North Atlantic, are the regions of largest ocean variability and intense air-sea interaction. In particular at interannual and longer time scales, the WBC variability generates strong ocean-to-atmosphere heat fluxes, resulting in anomalous diabatic heating that can impact the large-scale atmospheric circulation and the poleward heat transport in both the ocean and atmosphere. Therefore, variability in the WBCs and associated air-sea interaction play fundamental roles in regulating our climate. In addition, the WBCs variability have significant impact on extreme weather, coastal ecosystem, and sea-level.

Despite the importance of WBC variability and associated midlatitude air-sea interaction, the WBCs are the regions with some of the largest and longstanding ocean biases in the state-of-the- art coupled climate models. There have been numerous studies on the mean state biases in global climate models, in particular in WBC regions, and on the impact of improved spatial resolution. However, the influence of climate model spatial resolution on the biases of the WBC variability and associated air-sea interaction is yet to be systematically examined, despite their strong climate impacts. Here we propose to investigate the nature and impacts of the main biases of the WBC variability in state-of-the-art climate models based on a set of process-oriented model diagnostics, and establish their dependence on model resolution, as well as their links to main large-scale circulation biases. Our process-oriented diagnostics would lead to: (1) a systematic quantification of the model biases for the oceanic and atmospheric variability in the WBCs and resulting air-sea interaction, (2) identification of the key processes responsible for the model biases, and their sensitivity to the horizontal resolution of the model, and (3) improved understanding of the links between the WBC biases and the simulated large-scale atmospheric and oceanic circulations. The diagnostics will be first developed based on various state-of-the-art observational and reanalysis datasets. Then, they will be applied to the state-of-the-art climate model simulations at standard resolution as well as higher resolution to investigate the role of model resolutions in the biases and the representation of the associated processes.

This proposal targets the FY 2021 NOAA Modeling, Analysis, Predictions, and Projections (MAPP) Program solicitation Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications by proposing to better understand and benchmark process-level deficiencies related to the WBC ocean variability and associated air-sea interaction in the CMIP6 and HighResMIP simulations, with additional in-depth analyses of the GFDL and NCAR models using the proposed set of process-oriented diagnostics. Our proposed work is also directly relevant to NOAA's long-term climate goal of advancing scientific understanding, monitoring, and prediction of climate and its impacts, to enable effective decisions, especially

since the improvement in the climate model processes related to the WBC variability and associated air-sea interaction has significant implications for the prediction of our climate and its impacts.

Process-oriented diagnostics of dynamical coupling between the troposphere and stratosphere in Earth System Models

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Abstract

Dynamic coupling between the extratropical tropospheric and stratospheric circulations during boreal winter and austral spring are primarily mediated on short timescales via vertically propagating waves generated in the troposphere and their interaction with the stratospheric flow, but can also be modulated by phenomena that vary on sub-seasonal to decadal timescales. As a result, stratosphere-troposphere coupling processes need to be taken into account to fully understand, for example, the occurrence of extreme climate events linked to shifts in the extratropical storm tracks; climate variability on seasonal time scales such as teleconnections related to the El Niño-Southern Oscillation (ENSO) and stratospheric Quasi-Biennial Oscillation (QBO); and the response of the climate system to natural (e.g., solar, and volcanic aerosols) and anthropogenic (greenhouse gas increase, changes in ozone depleting substances) forcings.

Yet climate models (including those part of CMIP5/6) often lack a proper representation of stratospheric processes and realistic dynamic stratosphere-troposphere interactions, which can be related to model-specific configurations and parameterized (e.g., small-scale waves) or absent (e.g., interactive stratospheric chemistry) processes. These biases are tied to further model biases in the positions and variability of the tropospheric jets and their connection to extreme events.

We propose to develop process-oriented diagnostics (PODs) to measure the fidelity of key dynamical stratosphere-troposphere coupling processes and to inform actionable pathways to future model improvement. Our specific objectives of the proposed project are as follows:

1. Develop PODs that systematically evaluate the two-way stratosphere-troposphere coupling processes in Earth System Models, and make these PODs publicly available through implementation in the Model Diagnostics Task Force (MDTF) framework,

2. Apply PODS to CMIP6 simulations (both pre-industrial control and historical) and simulations of relevant CMIP-Endorsed Model Intercomparison Projects (MIPs) to diagnose and benchmark how different model configurations impact the representation of two-way stratosphere-troposphere coupling processes.

This Type 1 proposed project addresses the MAPP competition “Process-Oriented Diagnostics for Climate Model Improvement and Applications” by developing PODs to benchmark process-level deficiencies in stratosphere-troposphere coupling in Earth System models. This work would close a gap in the Model Diagnostics Task Force framework, which currently does not

include PODs that examine these processes and their linkages to related climate phenomena. The stratosphere-troposphere coupling processes we seek to address are relevant to the Climate Program Office's high-priority climate risk areas because they are closely connected with surface climate extremes driven by changes to the storm tracks and/or teleconnections; and to NOAA's mission to advance our understanding of the Earth's climate system and to use this knowledge to advance resilience of our Nation. We anticipate our diagnostics and their evaluation to have broad impacts for better understanding uncertainties in model simulations associated with large-scale atmospheric dynamics, and for improved representation of coupling processes linked to climate extremes.

Development of a hydrologic metrics evaluation package to understand and reduce hydrologic sensitivity biases in coupled Earth System Models

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Abstract

Increased resolution, complexity, and accuracy of Earth System Models (ESMs) has led to direct use of model projections to inform regional climate change impact assessments, including studies on changes in hydrology, water resources, and water security at sub-continental scales. However, ESMs often exhibit substantial regional biases in hydroclimate mean states, fluxes and - importantly - sensitivities. Biases in land model sensitivity project onto hydroclimate change signals under warming, undermining their accuracy and adding uncertainty to the already broad spread in climate change projections from model experiments.

It is therefore necessary to understand and reduce not just absolute biases, but also sensitivity biases, in order to increase the credibility and robustness of climate change impact assessments based on ESMs. Recent research on runoff sensitivity - the change in runoff as a function of changes in precipitation and temperature - showed a large potential for uncertainty reduction in model projections through the use of observational constraints. However, sensitivity biases remain inadequately measured and their causes poorly understood, thereby impeding model improvement, because process-oriented diagnostics (PODs) that target hydroclimate sensitivities and important features of their climatology, rather than simply mean states and fluxes, are missing from major diagnostics packages.

We propose to develop and refine a suite of PODs characterizing the fidelity of the hydrologic components - primarily runoff - of land surface models, to be applicable to models in the Coupled Model Intercomparison Project 5 and 6 (CMIP5/6). For the development of the PODs we will leverage several observational products and a range of existing and forthcoming simulations with the Community Earth System Model 2 (CESM2) and Community Land Model 5 (CLM5), including a Perturbed Parameter Ensemble, as well as Land Surface, Snow and Soil moisture MIP (LS3MIP) simulations as part of CMIP6. We will conduct additional sensitivity experiments with CLM5 to reveal model parameters relevant for runoff sensitivity and to refine the PODs.

The outcomes of this research will be a suite of PODs that provide process-based understanding of the origin of hydrologic sensitivity biases in ESMs, which will uncover opportunities for targeted model improvement. We will implement the new PODs in the NOAA Model Diagnostics Task Force (MDTF) Diagnostics Package and, with potential additional support from the Department of Energy, in the International Land Model Benchmarking (ILAMB) package (see Section 4.6 for more details).

Process-oriented analysis of organized convection and synoptic disturbances in the tropics

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Abstract

In recent years, global models have improved such that they exhibit some skill in seasonal tropical cyclone (TC) forecasting and are a useful source of both near-term TC activity forecast guidance and long-term climate projections. However, many challenges remain, particularly with regards to TC genesis prediction. Models exhibit a wide spread in their ability to reproduce the observed TC frequency, with most models typically producing too few TCs in certain regions, such as the North Atlantic, while producing too many in other regions, such as the Indian Ocean during monsoon season. These biases contribute to uncertainty in future projections of TC frequency. While the impacts of mean state biases on the TC frequency biases have been extensively studied, less attention has been paid to how well the models represent the synoptic scale disturbances that lead to the formation of TCs. In particular, it is largely unknown whether and to what extent the degree of synoptic-scale convective organization affects the probability of synoptic disturbances developing into TCs and whether the models correctly represent the effect of convective organization. Addressing this question requires examining how deep convection becomes organized in those disturbances and how it interacts with circulation, moisture, and radiation, in both observations and climate models.

Our project will aim to evaluate climate model simulation of synoptic-scale tropical disturbances, the organization of tropical convection within them, and associated interactions among convection, moisture, and radiation. We will develop and apply a new set of diagnostics for synoptic-scale tropical disturbances and convective organization within them, filling a gap in the MDTF framework, in which no diagnostic currently exists for tropical disturbances. After developing them with reanalysis datasets and applying them to high-resolution CMIP6 historical simulations (from HighResMIP), we will use the new diagnostics to answer questions such as “Is a greater degree of convective organization associated with developing disturbances?” and “Do models capture observed differences between developing and non-developing disturbances?” The new diagnostics for tropical disturbances will be implemented into the NOAA Model Diagnostics Task Force (MDTF) software package.

The proposed research fits well within the MAPP - Process-Oriented Diagnostics for Climate Model Improvement and Applications (2864458) competition, as it develops and applies process-oriented diagnostics to a clearly-identified gap in the existing MDTF software package synoptic disturbances and associated organized convection that may serve as precursors for TCs. The application of the new diagnostics will identify key physical processes responsible for skillful simulation of synoptic-scale tropical disturbances and TC formation and target areas for model improvement. This will advance our understanding of model biases, and could lead to improvement in model simulation of TC genesis and frequency and eventually enhance our

ability to evaluate the current and future risk of coastal storms. It will also improve our understanding of and ability to simulate the disturbances themselves, which are important sources of tropical weather variability in addition to their role as TC precursors.

Atmospheric and oceanic BL processes over the eastern equatorial Pacific: development of process-oriented diagnostics to identify errors in climate models with implications to ENSO teleconnections over the United States Affiliated Pacific Islands

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Abstract

Climate models' limitations in representing the bottom-heavy vertical circulation over the eastern equatorial Pacific result in erroneously simulated ENSO–induced teleconnections. Over Hawaii and USAPI, direct impacts of this weakness include errors in representing multi-seasonal persistence of droughts/floods. Our overarching hypothesis is: The eastern equatorial Pacific cause and effect relationship for variations in convection can be determined from a comprehensive process-based diagnosis (down to the individual parameterization level) of systematic changes in vertical structure in response to changes in ocean-atmosphere surface characteristics. This includes meridional SST gradient-induced surface convergence.

Our objective, towards identifying the initial source(s) of model errors in climatological mean states, is to develop process-oriented diagnostics (PODs) that: (i) Assess "co-occurring parameterized processes in models; (ii) Include heterogeneous observational sources; (iii) Can be applied to daily and shorter timescales (model time steps at 30 minutes) to identify errors due to fast processes; and (iv) Quantify model development progress in CAM7/AM5. The proposed PODs target processes related to: (a) Atmospheric boundary layer and near surface interactions; (b) Vertical distributions in the troposphere and (c) Upper-ocean mixing. Crucially PODs developed here will be used interactively during CAM7/AM5 development, where each successive prototype simulation can be objectively assessed. This analysis workflow will improve the model development processes considerably, in that performance changes can be linked directly to parameterization improvements.

Our proposed research targets the MAPP competition that focuses on "key issues in the representation of Earth system processes in CMIP6-era and developmental models to improve model fidelity", with a particular focus on "clearly-identified gaps in the existing MDTF software package". Continuing assessment in moist convection processes, our proposed PODs branch-off from the ongoing efforts with primary focus on processes related to climatological basic-states, atmospheric and oceanic boundary layer, and co-located column processes. Recognizing that in data-sparse regions native model biases can dominate in reanalysis, we employ currently under-utilized in-situ, field, and radiosonde observations (taken and maintained by NOAA), to develop PODs based on ground observations. Process-based diagnosis of CFSv2 (NOAA operational model) is lacking, and the PODs developed here will be applied to forecasts. Our proposed work has close synergy with NOAA strategic plan for improved understanding and model applications relevant to high-priority climate risk areas.

Specific to CPO are extreme droughts and heat, and coastal flooding over Hawaii and USAPI. In their studies, the PIs have extensively employed most of the PODs. Implementing them into the MDTF framework will therefore be straightforward. Deliverables include a set of process-based metrics and post-processed data from models and observations that aid in assessing the improvements in recent model versions.

An Open Framework for Process-Oriented Diagnostics of Earth System Models (Type II proposal)

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Eric Maloney (Colorado State University) - Co-Principal Investigator
Paul Ullrich (UC Davis) - Co-Principal Investigator

Abstract

Problem addressed and rationale: Process-oriented diagnostics (PODs) aim to characterize physical processes in a manner that relates directly to mechanisms essential to their simulation, providing guidance for improvement of a climate/weather model or assessment of its ability to address a specific research question. The predecessor Team project (PIs of which form part of the current team) advanced an initial bare-bones framework into a community-based software framework that brings process-oriented diagnostics into the diagnostic suite for modeling centers at the Geophysical Fluid Dynamics Laboratory (GFDL) and the National Center for Atmospheric Research (NCAR). Experience with the recent development suggests multiple areas where refinement and expansion would be beneficial for both modeling centers and POD developers.

Work Summary: The proposed work will build on the previous Model Diagnostics Task Force (MDTF) framework and coordinate with the Type I individual proposals to expand the open framework to entrain PODs developed by multiple research teams into the development stream of the modeling centers. The framework developed over the previous two phases specifies POD protocols for the target model version and the comparison to observations and permits diagnostics to be placed in a multi-model context using results from the CMIP6 archive. The Type II framework team maintains consistency with the previous lead team while expanding the coordination with the diagnostic streams at GFDL and NCAR, and formalizing common standards with the Department of Energy (DOE) Coordinated Model Evaluation Capabilities (CMEC) effort to further coordinate US-based model evaluation efforts. The proposed work will include the following elements. (1) The current Team project has established GitHub-based documentation, setup and configuration protocols. With the successful incorporation of a substantial number of PODs, developments on the software side proposed for the next phase expand on this process, emphasizing maintainability, interoperability, portability, provenance and usability. (2) PODs targeting related phenomena and on similar timescales will be identified and grouped to coordinate development teams and assist navigation of the results. This organization will also help model developers assess the output frequency requirements for PODs targeting phenomena on different climate timescales. (3) A task force will be led by the Type II team, modeled on the current MDTF with regular teleconferences, facilitated scientific conference sessions, and coordinated publications. New community-building activities planned by the Type II team include “Developer days” to facilitate communication between climate model and POD developers and tutorials to familiarize diagnostic developers with coding best practices in the context

of the framework. (4) The Type II team will explore ways to include mean-state and variability diagnostics as context for PODs. Both GFDL and NCAR have expressed the need to modernize their legacy diagnostic suites and the MDTF Framework can help prevent redundancy. Enhancements to the framework will be implemented to handle common functions, such as atmospheric pressure-level sub-setting and ocean depth range integrals. (5) Similar to the previous Team Proposal, the team will develop tools and additional prototype PODs in key areas.

Relevance to competition: This proposal addresses the call for the “Modeling, Analysis, Predictions, and Projections (MAPP) Competition 2: Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications” for a Type II proposal that advances the model diagnostics software package led by the MDTF and a synergetic process for integrating results of individual projects on process-oriented diagnostics. It proposes infrastructure for code and data sharing that engages researchers in model evaluation and facilitates integration of their research products into the diagnostics packages used by modeling centers, as well as dissemination of this information. It addresses NOAA's long-term climate goals by strengthening foundational capabilities, combining observations with modeling and prediction, and communication of scientific understanding.

Process-oriented evaluation of oceanic equatorial waves in the Indian and west Pacific Ocean forced by intraseasonal westerly wind events

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Abstract

Equatorial shallow water ocean wave modes (OWMs), such as eastward-propagating Kelvin waves and westward-propagating equatorial Rossby (ER) waves, help regulate the depth of the thermocline, ocean heat content (OHC), ocean currents, sea surface height (SSH), and sea surface temperature (SST). Their modification of upper-ocean thermal characteristics influences the evolution of important coupled air-sea phenomena including the Madden-Julian oscillation (MJO), the Indian Ocean dipole (IOD), and the El Niño Southern Oscillation (ENSO). In the tropical Indian and Pacific Oceans, OWMs are frequently forced by strong, but short lived intraseasonal westerly wind events (WWEs; occurring every 30-70 days and lasting 3-21 days) acting on the ocean surface. The strength and meridional structure of the WWE forcing and the ocean mean state (including the depth of the thermocline and the stability of the upper ocean) help determine the amplitude and propagation characteristics of the OWMs.

For the first time, diagnosis of intraseasonal WWE-forced OWMs in CMIP models is possible with daily output of the depth of the thermocline in several CMIP6-member models, which was not available in previous CMIP archives. Our main goal is to diagnose the fidelity of intraseasonal WWE-forced OWMs in CMIP6 and other model databases relative to observations and link OWM biases to biases in the WWE forcing, or to biases in the ocean mean state. We will also examine changes to WWEs, tropical OWMs, and the ocean mean state under climate change. Our work plan is to:

1. Diagnose the fidelity of tropical OWM spectra and spatial variance patterns in CMIP6 models and other climate model databases relative to observations.

2. Characterize the frequency, intensity, and meridional structure of intraseasonal WWEs in models and observations.

3. Assess the realism of intraseasonal WWE-forced OWMs as a function of WWE intensity and meridional structure in models relative to observations.

4. Evaluate the stability of the ocean mean state in models relative to observations and its relationship to OWM amplitude and phase speed.

5. Quantify changes in OWM climatology, WWE statistics, and ocean stability under climate change and relate OWM changes to changes in WWE characteristics and ocean stability.

This work will result in a tropical OWM process-oriented diagnostic (POD) with several diagnostic components that will be added to the Model Diagnostic Task Force software package.

The OWM POD fills “clearly-identified gaps in the existing MDTF software package” including “open- and coastal ocean systems'' and advances the evaluation of coupled processes in climate models. Our objectives are highly relevant to one of the main goals of the MAPP Process-Oriented Diagnostics call to “better understand and benchmark process-level deficiencies that result in model performance biases for simulated Earth system and climate phenomena.” More broadly, this work advances NOAA’s long-term goal to “advance [the] understanding of the Earth’s climate system.” Ultimately, understanding the processes that lead to OWM biases is needed to improve OWM representation in models and obtain better predictions of climate modes influenced by OWMs, such as the MJO, the IOD, and ENSO.

Identifying processes controlling the representation of coastal sea level in climate models

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Abstract

Statement of the problem: As climate models improve in resolution, and their output is increasingly integrated into risk assessment, planning, and adaptation efforts, it is critical to assess their ability to represent coastal processes. In particular, the representation of dynamic sea level (DSL) is of considerable societal interest, due to the substantial vulnerability of economic, cultural, and ecological resources to sea level change and variability. Preliminary analysis indicates that time-mean dynamic sea level (MDSL) gradients are often poorly represented at the coast in current-generation climate models, calling into question their ability to robustly project future changes and variability.

Rationale: Emerging models, especially those with higher horizontal resolution (≤0.25o), show an improved representation of coastal ocean dynamics. Simultaneously, new observational products are becoming available that better resolve DSL near coastlines, and recent theoretical advances permit a physical interpretation of DSL gradients. These elements provide a strong basis for: 1) development of coastal sea level diagnostics; and 2) interpretation of the processes underlying model-data differences.

Summary of Work: This project will develop mean dynamic sea level (MDSL) diagnostics near coastlines that allow the representation of key underlying processes to be assessed, prioritized, and improved in the next generation of climate models. Four activities will be pursued:

(1) Regional MDSL reference products, with improved representation near coastlines, will be developed by merging altimeter and tide gauge datasets in key boundary current regions;

(2) Biases in modeled MDSL fields (relative to reference products) will be analyzed and interpreted, using output from a hierarchy of GFDL ocean and climate models spanning a range of horizontal resolutions;

(3) Key processes underlying GFDL model MDSL biases will be identified using alongshore and area-integrated momentum balances;

(4) Targeted, process-oriented, MDSL diagnostics will be integrated into the MDTF framework and applied to the modern ocean state of CMIP6 simulations, providing context for ongoing ocean model development at GFDL.

Relevance to NOAA, MAPP, the competition, and society:
The improved understanding of processes influencing MDSL, and their representation in a hierarchy of climate models, will: 1) inform priorities for model development efforts at GFDL and

NCAR (through the MOM6 ocean model) and 2) lead to an improved basis for assessments of coastal flooding in a changing climate (a CPO high-priority climate risk). The proposed model area of open- and coastal ocean systems within the MDTF software package. For the larger scientific community, these diagnostics will be integrated into the MTDF and applied across a wide range of CMIP6 models, allowing a broad understanding of the processes responsible for climate model biases in different regions of the global ocean. The project will also develop improved MDSL products along the coastlines near boundary currents. In total, this project extends NOAA's core capabilities of understanding and modeling the changing climate system, developing projections of impacts, and providing decision support to meet the broad societal challenge of coastal and climate resilience.

Subtropical to Subpolar Atlantic Model Biases Addressed through Process-Level Diagnostics (Sub2Sub)

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Abstract

The proposed work is a collaborative project between the University of Wisconsin Madison and the National Center for Atmospheric Research (NCAR) to understand how the North Atlantic Current (NAC) path influences the Atlantic meridional overturning circulation (AMOC) in climate models of varying configurations and resolutions. The goal of this project is a thorough model comparison of NAC pathway biases – a longstanding issue in ocean and climate models – and their relationship with thermohaline biases from the subtropics into the subpolar North Atlantic. As part of this proposal, a set of process oriented diagnostics (PODs) will be applied to output from the Coupled Model Intercomparison Project version 6 (CMIP6), Ocean Model Intercomparison Project (OMIP), High Resolution Model Intercomparison Project (HiResMIP), and to experiments from an in-development version of the Community Earth System Model (CESM) coupled to the Modular Ocean Model version 6 (MOM6). The most novel of the PODs to be implemented are two NAC pathway identification algorithms, one applying image processing techniques on currents and the other drawing from the atmospheric thermal front identification literature. Analysis will focus on combining the NAC pathway POD with surface-forced water mass formation, allowing for a dynamically-defined decomposition of surface formation between subtropical and subpolar regions, as delineated by the NAC. Decomposing formation further by individual surface fluxes and by the overlap of density classes with surface fluxes will allow process-based characterization of ocean and climate model biases. Sources of pathway-related models from the multimodel ensembles described above, focusing on the effect of horizontal resolution in models with MOM. An expected outcome of this project is a clearer understanding of sources of NAC pathway and subtropical-to-subpolar formation model biases, identifying potential directions for ocean model development.

Relevance: Through its analysis of ocean and coupled model simulations of historical climate, this proposal supports both NOAA's mission to "advance our understanding of the Earth's climate system" and the CPO MAPP program's overall mission to "enhance the Nation's and NOAA's capability to understand, predict, and project variability and changes in Earth's climate system." The proposed work aligns with the MAPP program's primary objectives of "improving Earth System models", "supporting an integrated Earth System analysis capability" and "improving methodologies for global to regional scale climate analysis, predictions, and projections" by identifying sources of ocean model biases in the subtropical to subpolar North Atlantic. The current Model Development Task Force (MDTF) diagnostic software have a large gap in open ocean model diagnostics. The North Atlantic Current pathway identification and water mass transformation PODs described in this proposal would partly fill this gap. Through close collaboration with NCAR, opportunities for MOM6 improvement will be identified in CESM-MOM6 development simulations. Because MOM6 is also the ocean component model in NOAA

ESMs, the CESM-MOM6 diagnosis described here will indirectly contribute to the improvement of NOAA models. In collaboration with NCAR, POD software will be contributed to MDTF for further dissemination and to CESM community diagnostic packages.

Processed-Oriented Diagnostics of Aerosol-Cloud Interactions in CMP6 Models

Brian Soden (University of Miami) - Lead Principal Investigator

Abstract

Aerosols represent a key source of uncertainty in global climate models. Through the absorption and scattering of shortwave radiation, aerosols reduce the incoming solar radiation at the surface and thus offset part of the warming resulting from increases in anthropogenic greenhouse gases. In addition to this direct radiative effect, certain types of aerosols are known to act as cloud condensation nuclei, altering the cloud albedo and lifetime. Differences in modeling the effective radiative forcing from aerosol-cloud interactions (ERFaci) are a substantial source of uncertainty in predicting climate change.

Aerosol-climate interactions (ACI) play an important role in climate projections despite the limited ability of models to represent aerosol and cloud processes accurately. Indeed, climate models can disagree on both the sign and magnitude of the radiative effects from aerosol-cloud interactions. This disagreement reflects, in part, the absence of a consistent methodology to quantify their effects in models. Indeed, even the direct radiative effects of aerosols are rarely calculated explicitly. The lack of a coherent framework to quantify the radiative impact of aerosol-cloud interactions limits our ability to compare its importance across different models, or even between different versions of the same model. This is compounded by the lack of regionally-resolved observations of ACI on a global scale, that account for the presence of co-varying meteorological conditions on ACI. Thus, despite their fundamental role in determining both historical and future climate change, the magnitude of ACI remains poorly constrained in models.

This proposal aims to fill this gap by developing a set of diagnostics for evaluating aerosol-cloud interactions in models that can be derived from existing CMIP6 simulations, or from standard model performed by labs runs during the model development cycle, and can be applied to both historical and future emission scenarios. The model diagnostics will be compared to observationally-constrained estimates of ERFaci for low (warm) marine clouds which are the dominant source of uncertainty of ACI in models. These estimates use satellite measurements to provide observational constraints on the cloud susceptibility to aerosols within a framework that accounts for the role of varying environmental factors in modulating the strength of aerosol–cloud interactions.

Through these diagnostics, we aim to both quantify and better constrain the representation of aerosol-cloud processes in CMIP6 models. This will directly support the MAPP program goal to “advance understanding of biases generally affecting CMIP6-era and next-generation models and to identify targeted model improvements that can improve model fidelity.”