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ABSTRACT BOOK

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ORAL PRESENTATIONS

A HIERARCHICAL APPROACH TO CLIMATE SENSITIVITY

Cathy Hohenegger, Max Planck Institute for Meteorology, Germany
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Radiative convective equilibrium has been applied in past studies to various models given its simplicity and analogy to the tropical climate. At convection-permitting resolution focus has been on the organization of convection that appears when using fixed sea surface temperature (SST). Here the SST is allowed to freely respond to the surface energy. The goal is to examine and understand the resulting equilibrium state and perturbations thereof, as well as to compare these results to a global simulation integrated with parameterized cloud and convection.

Analysis shows that the convection-permitting simulation self-aggregates. The occurrence of self-aggregation is found to be necessary for reaching a stationary climate and avoiding a greenhouse-like state. In contrast, strong shortwave cloud radiative effects, much stronger than at convection-permitting resolution, prevents the global simulation with parameterized cloud and convection to fall into a greenhouse state. The convection-permitting simulations also suggest that cloud feedbacks, as arising when perturbing the equilibrium state, may be very different, and in our case less negative, than what emerges from global models.

Keywords: RCE, Convection, Coupled Models

CONSTRAINING THE OPTIMIZED RANDOM WALK OF CLOUD MODELING: IDEALIZED FRAMEWORKS IN THE COMMUNITY EARTH SYSTEM MODEL FOR PARAMETERIZATION DEVELOPMENT AND UNDERSTANDING.

Andrew Gettelman, NCAR, USA
& CESM Model Development Team, NCAR, USA

How do we develop physical parameterizations for Earth System Models (ESMs) that are valid across scales? The robustness of ESMs depends on evaluating and validating expected responses at the parameterization level, and using hierarchies to provide detailed comparisons to observations, and analysis of sensitivities. Examples of some of the key hierarchies used in recent Community Earth System Model (CESM) development of cloud schemes will be discussed, including how development of clouds can be analyzed from the microphysical and weather scale to the climate feedback scale. The goal is to develop robust parameterizations that are applicable across a range of scales. Different hierarchies in CESM for parameterization development include constraints on atmospheric dynamics to focus on atmospheric physics and clouds: including idealized forcing, single column, nudged and forecast mode experiments. Hierarchies also includes full model simulations with key feedbacks and processes constrained. Conclusions include a perspective on how hierarchies can improve the parameterization development process, as well as facilitate the sharing and inter-comparison of model representations of clouds.

Notes: This presentation could be in the climate sensitivity theme, but it is really broader than that, and focused on physical parameterizations (which I think is underserved in the structure). One of the NCAR abstracts could give an overview of the CESM model Hierarchies if that is desired.

Keywords: clouds, climate,

THE CLIMATE MODELLING TOOLKIT (CLiMT)

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The Climate Modelling Toolkit (CliMT) is a Python-based framework that is designed to facilitate the building of a hierarchy of climate models with minimal effort and greater reproducibility. Towards this end, CliMT provides a suite of plug-and-play components that can be combined together in a simple manner to build a climate model of "appropriate" complexity.

Building a suite of climate models of increasing complexity is essential for a systematic understanding of the climate system [Held, 2005]. However, such an effort is hampered by many factors

- Models are often written in low-level languages such as Fortran for efficiency.
- The dynamics and physics packages are developed together and are often difficult to disentangle.
- Models aim for high fidelity of simulated climates rather than ease of building them

CliMT aims to address some of these issues by providing a standard set of components and an elegant way to combine them to build a model. Building climate models using these components is done entirely in Python, a language that is becoming the de-facto choice for data analysis in climate science and has a strong presence in the computational science community. Python provides a clean and understandable syntax, which makes the development of the model clear and reproducible; It also easily interfaces with libraries written in Fortran or C, making it possible to access the large amount of model code already available to climate scientists in these languages.

CliMT's suite of components includes a dynamical core which solves the primitive equations, a large suite of radiative codes ranging from grey gas radiation to a full complexity radiative transfer code from the Community Atmosphere Model (CAM) and parameterizations for insolation, convection, boundary layer and sea ice.

By combining the efficiency of Fortran and C with the elegance and clarity of Python, CliMT allows scientists to quickly build models in a hierarchical manner, with greater ease and reproducibility.

Keywords: Model Hierarchies, Python, Reproducibility

INVESTIGATING THE ROLE OF CLOUDS IN THE CLIMATE SYSTEM THROUGH THE CESM MODELING HIERARCHY

Brian Medeiros, National Center for Atmospheric Research, USA

Clouds are crucial components of the climate system because they are intricately tied to the thermodynamic equation, and thereby coupled to the circulation through the pressure gradient force that results from latent and radiative heating. Because clouds strongly impact the diabatic heating, climate model estimates of climate sensitivity depend on the details of the cloud representation, which is achieved through a network of prognostic and parameterized processes. The complexity of the problem, even in a single climate model, is daunting, and provides clear motivation for abstraction through simplified approaches that can be organized into a hierarchy of model complexity. In this presentation, I will describe some aspects of the hierarchy available in the Community Earth System Model's atmospheric component. Particular emphasis will be given to the aquaplanet configurations -- including radiative-convective equilibrium configurations -- with both fixed and interactive sea-surface temperature. The connections between clouds, circulation, and climate sensitivity will be explored through idealized experiments that focus on different aspects of the model including resolution, dynamical core, and parameterized physics. As has been shown for many climate models, the CESM's climate sensitivity is strongly connected to low-level tropical clouds, and we further explore the processes associated with these clouds across the hierarchy with detailed diagnostics from individual parameterizations.

Keywords: CESM, aquaplanet, radiative-convective equilibrium, cloud feedback

PHYSICAL PROCESS REALISM AND MODEL HIERARCHIES

Leo Donner, GFDL/NOAA, USA

Complexity within the model hierarchy varies greatly, with the merits of simplified models often based on their ability to capture and explain or isolate important features of a system whose full realization is difficult to understand. Comprehensive simulation models, on the other hand, are frequently assessed by their ability to accurately reproduce or predict observations.

A case is made here for augmenting the hierarchy of models with"metrics" for comprehensive models that assess the physicalrealism of the key processes on which the model's emergent behaviors depend. These processes primarily involve turbulence and boundary layers, along with cloud microphysics and macrophysics. The goal is to loosen the deadlock on key questions, like climate sensitivity and aerosol climate forcing, that have resisted resolution even as metrics based on circulation and hydrological cycle in climate models have become increasingly available. Ultimately, comprehensive models are based on these physical processes, and a great deal of knowledge constraining these processes exists which could be used to evaluate their representation in earth system models. Specific approaches for doing so could include suites of single-column tests for cloud regimes whose importance has been identified, in part by simplified models in the hierarchy. Though more difficult, microphysical and aerosol process representations should also be assessed. These are frequently used for model tuning with major consequences for model simulation realism, climate forcing, and climate sensitivity. Although it may be argued that not all models are formulated to be easily compared against such observational or theoretically robust results, that information alone has important implications. These metrics could become part of standard model inter-comparisons, addressing not only models' ability to simulate the earth system but also whether they have done so in accordance with understanding of the processes which are their building blocks.

Keywords: climate feedbacks, climate sensitivity, model evaluation, atmospheric physics

TRAC-MIP: TROPICAL RAIN BANDS WITH AN ANNUAL CYCLE AND CONTINENT - MODEL INTERCOMPARISON PROJECT.

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The "Tropical Rain belts with an Annual cycle and Continent - Model Intercomparison Project." TRAC-MIP involves five experiments using idealized aquaplanet and land setups to explore the dynamics of tropical rainfall. By using interactive sea-surface temperatures and seasonally-varying insolation TRAC-MIP fills the gap between idealized aquaplanet simulations with prescribed SSTs and the fully-coupled realistic model simulations of CMIP5. By including both key forcings of the future (greenhouse gases) and of the Holocene (orbital changes in insolation), TRAC-MIP wants to contribute to the "past to future (P2F)" efforts to connect the climate response to different forcings via a basic understanding of the mechanisms at play. TRAC-MIP includes the participation of 13 state-of-the art comprehensive climate models, and it also includes a simplified model that neglects cloud and water-vapor radiative feedbacks, thus allowing a more direct connection between the results from the TRAC-MIP comprehensive models and the theoretical studies of tropical rain belt dynamics.

We will present preliminary results from the ensemble, aiming to examine the mechanisms control- ling tropical precipitation in the context of forced variability. First and foremost, we are interested in the largest forced variation: the annual cycle. We will draw out the similarities and the distinctions between oceanic and continental rain bands, study the ways in which the two interact with each other, and investigate the extent to which established zonal-mean ITCZ frameworks contain information about regional rainfall characteristics. Second, we will investigate the response of both surface temperature and precipitation to quadrupling the CO2 concentration, comparing the multi- model mean response and the inter-model scatter to what was observed in models up and down the CMIP5 hierarchy, namely the CFMIP fixed-SST aquaplanets and the fully coupled Abrupt4xCO2 simulations.

Keywords: ITCZ monsoon aquaplanet

THERMODYNAMIC CONTROL OF ANVIL-CLOUD AMOUNT

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Brian Medeiros, NCAR, USA
Kevin Reed, Stony Brook University, USA
Aiko Voigt, Columbia University, USA

A hierarchy of numerical models, including CMIP General Circulation Models used in a range of configurations and Cloud Resolving Models, show that as the surface temperature increases, the convective anvil clouds shrink. By analyzing radiative-convective equilibrium simulations, we show that this behavior is rooted in basic energetic and thermodynamic properties of the atmosphere: as the climate warms, the clouds rise and remain at nearly the same temperature, but find themselves in a more stable atmosphere; this reduces the convective outflow in the upper troposphere and decreases the anvil cloud fraction. By warming the troposphere and increasing the upper-tropospheric stability, the clustering of deep convection also reduces the convective outflow and the anvil cloud fraction. When clouds are radiatively active, this robust coupling between temperature, high-clouds and circulation exerts a positive feedback on convective aggregation and favors the maintenance of strongly aggregated atmospheric states at high temperatures. The implications of this "stability-iris" mechanism for climate sensitivity and for the behavior of rainy areas in a warming climate will be discussed.

Keywords: RCE, anvil clouds, convective aggregation, climate sensitivity

THE MADDEN-JULIAN OSCILLATION IN IDEALIZED AND COMPREHENSIVE MODELS

Adam Sobel, Columbia University

I will review results on simulation of the Madden-Julian oscillation (MJO) in models over the full range of complexity: global climate and weather models, with both parameterized and explicit convection; limited area models, including small-domain cloud-resolving models with periodic boundary conditions and either imposed or interactive large-scale forcings as well as larger-domain regional models with realistic geography and forcing at lateral boundaries; and idealized models ("theories") of various sorts.

As recently as a decade ago, one commonly heard that we didn't understand the MJO, nor could we simulate it well. The latter statement is no longer true, as some models simulate the MJO quite faithfully by any reasonable standard (if not without some remaining biases), and numerical weather forecasts of the MJO now roundly beat statistical forecasts. We are now in the situation where theory can learn from simulation: understanding what makes models simulate the MJO well (or not) informs our improving understanding of how the real MJO works.

Keywords: MJO, tropical, intraseasonal, Madden-Julian

CARBON DIOXIDE'S DIRECT WEAKENING OF THE TROPICAL CIRCULATION: FROM COMPREHENSIVE COUPLED CLIMATE MODELS TO AXISYMMETRIC HADLEY CELL THEORY

Timothy M. Merlis, McGill University, Canada

Model hierarchies are critical to exposing the factors underlying robust climate changes in comprehensive climate change simulations. I will present the results of an examination of the mechanism underlying the robust "direct" CO_2-forced weakening of the tropical circulation of the atmosphere found in Coupled Model Intercomparison Project simulations. The proposed mechanism relies on spatially varying radiative forcing, which arises from CO_2 perturbing the radiative balance more weakly in regions of climatological deep convective clouds than in climatologically clear regions. This spatially varying radiative forcing reduces the atmospheric circulation's required energy transport and this will weaken the mass overturning. In simulations with atmospheric general circulation models with altered formulations of radiative transfer, this mechanism can be deactivated and the associated tropical circulation weakening can be eliminated. As the mechanism is based on energy transport requirements, I also show that it acts in single-layer, angular momentum-conserving models of the Hadley circulation.

Keywords: climate change, tropical circulation, radiative forcing

UNDERSTANDING MJO DYNAMICS USING A HIERARCHY OF MODELS AND REANALYSIS

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A growing recent body of evidence suggests that the Madden-Julian oscillation (MJO) is a moisture mode existing under weak temperature gradient (WTG) balance, where processes regulating the tropospheric moisture budget are responsible for propagation and destabilization of the disturbance. Novel MJO diagnostics based on WTG theory that diagnose the moistening processes regulating MJO propagation and destabilization are applied to reanalysis fields and the superparameterized Community Earth System Model (SP-CESM). In particular, these diagnostics derive a moisture-advecting vertical velocity that results from the dominant tropical WTG thermodynamic balance of adiabatic cooling and diabatic heating. These diagnostics support the view that the MJO is destabilized by radiative feedbacks and propagated eastward through horizontal moisture advection. Application of these diagnostics to 4xCO2 simulations of SP-CESM demonstrate the importance of increased vertical moisture gradients for stronger MJO precipitation variance in a warmer climate.

The simple linear MJO model of Sobel and Maloney (2013), extended by Adames and Kim (2016), is modified to include explicit representation of vertical moisture and temperature structure guided by results of the WTG diagnostics analysis applied to SP-CESM and reanalysis. These modifications allow the impacts of diabatic heating anomalies (including in radiative heating) on moisture to be more directly represented. Sensitivity of this idealized model to various parameter settings is explored, including those relevant to climate change.

Keywords: Convection, MJO, moistening, radiative feedbacks

GLOBAL RADIATIVE-CONVECTIVE EQUILIBRIUM FRAMEWORKS IN CAM

Kevin A. Reed, Stony Brook University, USA
Brian Medeiros, National Center for Atmospheric Research, USA
Dan R. Chavas, Purdue University, USA
Adam R. Herrington, Stony Brook University, USA

Global radiative-convective equilibrium (RCE) setups in atmospheric general circulation models (AGCMs) are becoming increasingly powerful for understanding model sensitivities, as well as diagnosing robust behaviors of cloud and precipitation processes. The role of convective parameterizations at high horizontal resolution and their impacts on clouds, circulation, and precipitation processes represent large uncertainties in current-generation AGCMs. RCE offers a reduced complexity framework to investigate such uncertainties. In particular, this work presents a hierarchy of RCE configurations spanning various rotation effects and horizontal grid-spacings to explore sensitivities of model physics parameterizations at reduced computational expense. Results with both non-rotating and rotating RCE with two versions of National Center for Atmospheric Research's Community Atmosphere Model (i.e., CAM5 and CAM6) will investigate organized convection and extreme precipitation as horizontal resolution approach cloud-system-resolving scales.

Keywords: RCE, high-resolution, reduced complexity

ITCZ WIDTH AND ITS SENSITIVITY TO CHANGES IN CLIMATE: THEORY AND A HIERARCHY OF SIMULATIONS

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The intertropical convergence zone (ITCZ) has received considerable attention in recent years, with much research focusing on how the latitude of maximum tropical precipitation responds to natural climate variability and to radiative forcing. The width of the ITCZ, however, has received little attention despite its importance for regulating the tropical climate and for our understanding of atmospheric dynamics.

We investigate the width of the ITCZ using theory and a hierarchy of simulations. In simulations with an idealised general circulation model over a wide range of climates, the ITCZ displays rich behaviour as the climate is varied, widening with warming in cool climates, narrowing in temperate climates, and maintaining a relatively constant width in hot climates. Theoretical scalings for (a) the width of the ITCZ relative to that of the neighbouring descent region and (b) the sensitivity of the ITCZ width to changes in climate are derived. The ITCZ width is found to depend on four quantities: the net energy input to the tropical atmosphere, the gross moist stability, the advection of moist static energy by the Hadley circulation, and the transport of moist static energy by transient eddies. Different processes are important for the ITCZ width in different climates, with changes in gross moist stability generally having a weak influence relative to the other processes. We use the theoretical scalings and idealised simulations to understand the ITCZ width in state-of-the-art simulations of future climates and find that cloud-radiative feedbacks, via their influence on the net energy input to the tropical atmosphere, play a central role in the robust narrowing of the ITCZ with warming.

Keywords: ITCZ, tropical circulation, idealised simulations

IDEALIZED MODELLING OF THE EAST ASIAN MONSOON

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The monsoon is an important feature of Asia's climate, with variability linked to floods and droughts affecting a large fraction of the world's population. Understanding monsoon circulations, and the mechanisms involved in future changes, is therefore essential for anticipating risks and adapting to the changing climate.

Many features of East Asian monsoon behaviour in the present climate are still unclear, such as the controls on onset, interannual and interdecadal variability, and links to the wider climate system such as the North Atlantic. While high resolution and complex regional models may help understand specific events, simpler models provide a useful tool to study the fundamental processes involved. From a dynamical perspective, monsoon circulations have been thought of as large-scale sea breezes, governed by land-sea heating contrasts, or as seasonally reversing winds related to shifts in the latitude of the ITCZ, apparent even in an aquaplanet configuration.

Numerical experiments have been performed using a model with a configurable level of idealization in order to investigate the relative roles of land-sea contrast, topography, and seasonal changes in ITCZ location and Hadley cell regime. By analysing the momentum budget over the monsoon onset for a range of combinations of land and topography, ranging from aquaplanet to near-realistic geometries, the dominant drivers of the observed wind reversal are identified. Experiments in which the moisture availability over land is controlled via changing an evaporative resistance parameter and/or using a simple bucket model, and where the convective parametrisation is varied, allow controls on the monsoonal precipitation to be investigated. Whereas some of the dynamics at work in more realistic set-ups is shared with aquaplanet simulations, topography in particular is found to play a key role in the monsoon onset.

Keywords: Monsoon, Dynamical regime, Momentum budget

TROPICAL CYCLONE SIZE AND STRUCTURE IN A HIERARCHY OF RADIATIVE-CONVECTIVE EQUILIBRIUM SIMULATIONS

Daniel Chavas, Purdue University, USA
Kevin Reed, Stony Brook University, USA

In idealized rotating radiative-convective equilibrium simulations, global convection tends to aggregate into a statistical equilibrium state characterized principally by a world of tropical cyclones. Beyond the study of the equilibrium climate state, these simulated worlds offer convenient experimental testing grounds for investigating the characteristics of the storms themselves in a tightly-controlled setting with a very large sample size. Here we employ a hierarchy of atmospheric models spanning limited-area axisymmetric and three-dimensional simulations as well as global simulations under uniform and spherical rotation to examine tropical cyclone size and structure and their evolution. Results and implications for understanding real-world storms are evaluated in the context of the simplifying assumptions implicit in each rung of the hierarchy.

Keywords: tropical cyclone, RCE, hurricane, size, structure

MODEL HIERARCHICAL APPROACHES WITH NICAM AND SOME IDEAS FOR AMIP/APE/RCE INTER-COMPARISONS

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The Nonhydrostatic Icosahedral Atmospheric Model (NICAM) has proven that tropical convective systems in various horizontal scales from meso-scale convective systems to Madden-Julian oscillations are represented by high-resolution simulations with explicit cloud microphysics calculation without convective parameterization (Satoh et al. 2014). The model hierarchical approaches using aqua-planet experiments (APE; Tomita et al. 2005) and radiative convective equilibrium experiments (RCE; Satoh and Matsuda 2009) in addition to the AMIP-type experiment (Kodama et al. 2015) are extensively taken with NICAM to study basic understandings of the convective systems and their sensitivities to forcing such as sea surface temperature. In this talk, we review these experiments with NICAM and propose a framework for inter-comparison experiments of AMIP/APE/RCE.

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Keywords: NICAM, RCE, tropical convective systems, Madden Julian oscillations

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WHAT MODELS OF DIFFERENT COMPLEXITY HAVE TAUGHT ABOUT STRATOSPHERE-TROPOSPHERE INTERACTIONS

Alan Plumb, MIT, USA

Forty years ago, conventional wisdom about stratosphere-troposphere interactions was straightforward: the troposphere was seen as largely independent of stratospheric behavior (to the extent that resolving the stratosphere was not seen as a priority in weather and climate modeling), while the stratosphere was seen as a slave to whatever wave activity was launched into it from the troposphere. The picture has changed, on both counts, over the intervening decades. We now recognize that stratospheric perturbations – e.g., warming events or polar ozone depletion – have significant surface manifestations, while it has also become clear that stratospheric variability can be produced through internal stratospheric dynamics, and not just as a response to tropospheric variability. In both respects, simplified models (such as severely truncated, or dynamical core models with simplified "physics") have played a major role in this evolving understanding. I will review past work, present some recent relevant results, and discuss what remains unresolved (and how it might become resolved).

USING SIMPLE MODELS TO UNDERSTAND PERIODIC VARIABILITY IN THE EXTRATROPICAL CIRCULATION

David WJ Thompson

Dept of Atmospheric Science, CSU

Various measures of the amplitude of the Southern Hemisphere storm track indicate robust periodicity on timescales of ~20-25 days. The periodicity is clear not only in hemispheric averages, but also in the context of individual wave packets as they propagate to the east in the storm track region. Here we will explore the physical processes that give rise to the periodicity in the extratropical circulation in simulations run on a range of numerical models with varying representations of the atmospheric flow, including fully-coupled IPCC-class GCMs, AMIP-style simulations run with and without cloud radiative effects, aquaplanet models, a dry dynamical core, and a simple zonally-varying model of the two-way interactions between baroclinicity and eddy activity. Together, the results suggest that the observed periodicity in the SH storm track is consistent with two-way interactions between 1) eddy activity advected eastward at the Rossby group velocity, and 2) baroclinicity advected eastward at a rate consistent with flow speeds in the lower troposphere.

MOIST FORMULATIONS OF THE ELIASSEN-PALM FLUX AND THEIR CONNECTION TO THE SURFACE WESTERLIES IN IDEALIZED AND COMPREHENSIVE GCM SIMULATIONS

Paul A. O'Gorman, Massachusetts Institute of Technology, USA
Dwyer, John G., Massachusetts Institute of Technology, USA

The amount of water vapor in the atmosphere increases as the climate warms, and this suggests a need for theories of the general circulation that include the effects of latent heat release. The use of both idealized and comprehensive general circulation models (GCMs) allows us to generate a wide range of different climate states in which to test such moist dynamical theories. In this presentation, I will discuss moist formulations of the Eliassen-Palm (EP) flux, and I will show that they are helpful in the analysis of meridional shifts of the surface westerlies. The EP flux is an important diagnostic for wave propagation and wave-mean flow interaction in the atmosphere.

Over the seasonal cycle in simulations with a comprehensive GCM, the upward EP flux is more closely linked to the surface westerlies when moisture is taken into account. In simulations over a wide range of climates with an idealized GCM, the surface westerlies do not track with the upward dry EP flux, and an anomalous source of dry wave activity near the subtropical jet becomes important for the surface westerlies in hot climates. The surface westerlies in the idealized GCM simulations exhibit both equatorward and poleward shifts with warming, and their behavior becomes easier to understand when moist EP fluxes are considered.

Keywords: shifts of the westerlies, latent heat release, climate change

THE TROPICAL TROPOPAUSE LAYER IN AN IDEALIZED MOIST MODEL: TROPICAL VS. EXTRATROPICAL CONTROL

Edwin P. Gerber, New York University, USA
Martin Jucker, University of Melbourne, Australia

The tropical cold point regulates the water vapor content of the stratosphere, with implications for both decadal temperature variations and the climate sensitivity of the Earth. The mechanisms setting the mean state and annual variation of the cold point and tropical tropopause layer (TTL), however, are not fully understood. Three main drivers have been identified: equatorial waves excited by tropical convection, extratropical planetary scale waves associated with the deep Brewer-Dobson Circulation, and synoptic scale waves associated with the midlatitude storm tracks. In both observations and comprehensive General Circulation Models (GCMs), all of these drivers coexist, and it is difficult to separate their individual contributions. In this work, a new intermediate-complexity GCM is developed to separate these three players.

Building on the work of Frierson et al. (2006) and Merlis et al. (2013), we model an idealized atmosphere where moisture fully interacts with the circulation through convection, large scale latent heat transport, and radiative transfer, but where the impacts of clouds and aerosols are explicitly neglected. This allows us to capture the essential characteristics of tropical convection and wave generation, midlatitude synoptic variability, and the planetary scale waves driving the deep Brewer-Dobson Circulation within the model, but still retain significant control of the climatology. This allows us to more cleanly investigate each process in isolation, in addition to simulating their mutual interactions. We find that tropical convection plays the most critical role in setting the overall mean structure of the TTL, but that asymmetries in the annual cycle of synoptic variability in the two hemispheres plays a key role in the annual cycle of the TTL. Nonlinear interactions between the three mechanisms, however, imply that all waves play an important role in the variability of the TTL.

Keywords: tropical-extratropical coupling, TTL, idealized modeling

TROPICAL TROPOPAUSE TEMPERATURE CONTROL IN A HIERARCHY OF MODELS

Thomas Birner, Department of Atmospheric Science, Colorado State University, USA

Tropical tropopause temperatures control stratospheric water vapor amounts, which are important for climate. But climate models notoriously struggle to simulate a realistic temperature structure near the tropical tropopause — inter-model spread in this region is of the order of 10 K with associated uncertainty in stratospheric water vapor concentrations. Climate change near the tropical tropopause is likewise uncertain — the transition from tropospheric warming to stratospheric cooling is necessarily located near the tropopause, but both warming and cooling are in principle possible at the tropopause. Most climate models predict slight tropical tropopause warming, while observational estimates of past trends are more uncertain. Here, we study controls on tropical tropopause temperature using a hierarchy of models: stand-alone single-column radiative-convective equilibrium (RCE) simulations with a radiative transfer model, two and three dimensional cloud-permitting simulations in RCE, and analyses of climate models and observational data. We compare the relative roles of radiatively driven feedbacks due to water vapor and ozone, upwelling-induced adiabatic cooling, and convectively-induced tropopause level cooling.

Keywords: RCE, tropical tropopause

BEYOND DOWNSCALING: THE UTILITY OF REGIONAL CLIMATE MODELS FOR MECHANISTIC STUDIES

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Xiaohui Ma, Texas A&M University, USA
Jesse Steinweg-Woods, Texas A&M University, USA
Raffaele Montuoso, Texas A&M University, USA
Ping Chang, Texas A&M University, USA

Regional climate models are widely used for studying the impacts of climate change, through downscaling of climate projections from global climate model simulations. In addition to this practical application, regional models can also play a role in addressing fundamental questions relating to mechanisms of weather and climate phenomena. Using a regional modeling approach as part of a modeling hierarchy has several pros and cons. The most obvious advantage is the ability to simulate certain processes at a much higher spatial resolution than is possible in a global model, such as explicitly resolving moist convection in the atmosphere. Another advantage is the ability to choose the location and the nature of the lateral boundary conditions, which allows for additional flexibility in designing mechanistic experiments. Spatial and temporal filtering can be applied at the lateral boundaries to suppress selected phenomena. Prescribing the lateral boundary condition can also increase the effective degrees of freedom in an ensemble experiment. The presentation will discuss mechanistic studies that have been carried out using a regional coupled ocean-atmosphere modeling framework to address the following questions:

i) What is the role of upstream flow conditions in causing flooding in the Midwestern U.S.?
ii) How do mesoscale oceanic eddies affect the midlatitude stormtracks?
iii) How is seasonal hurricane activity affected by different flavors of ENSO?
iv) What is the role of easterly waves in triggering Atlantic hurricanes?

Keywords: regional modeling, mechanistic modeling

THE POLEWARD DEFLECTION OF MIDLATITUDE STROM TRACKS: FROM IDEALIZED GCMS TO COMPREHENSIVE CLIMATE MODEL PREDICTIONS

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A well-known feature of the northern hemisphere midlatitude storm tracks, namely the Atlantic and Pacific storm tracks, is their downstream poleward deflection with respect to the zonal direction. While this is a robust feature, which appears both in observations and comprehensive GCMs, understanding its underlying mechanism is complex as it involves zonal asymmetries due to orography, SST, diabatic effects and eddy-mean interactions. In this work we present an effort to simply this problem by building a hierarchy of models with increasing complexity. We first study an idealized zonally symmetric GCM, where a basic mechanism for the poleward motion of midlatitude cyclones is identified using cyclone tracking and PV composites. This shows that the poelward tendency of cyclones occurs even in the absence of zonal asymmetries, and is mainly due to nonlinear advection by the upper level PV and diabatic forcing due to latent heat release. We then turn to an idealized GCM with a localized asymmetry, using an oceanic heat flux to produce a localized storm track. This adds an additional player in the form of a stationary wave, which contributes to the poleward tendency by advecting the cyclones poleward in the downstream region of the storm track. We analyze the relative roles of the transient nonlinear advection, the stationary advection and latent heat release in controlling the shape of the storm track. We repeat the PV tendency analysis using NCEP reanalysis data, and find that these mechanisms may explain the spatial structure of the Pacific and Atlantic storm tracks, and highlight some important differences between them. Finally, the implications for how this poleward deflection will change under global warming and its relation to the expected poleward shift of storm tracks is studied, by comparing idealized GCM experiments with increased surface temperatures to cyclone tracking analysis of projected CMIP5 data.

Keywords: storm tracks, idealized GCM, midlatitude cyclones, jet, CMIP5

USING A HIERARCHY OF CLIMATE MODELS TO INVESTIGATE WAVE-MEAN FLOW INTERACTIONS

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A hierarchy of climate models is used to investigate the dynamics of how surface-forced quasi-stationary (QS) wave disturbances interact with the zonal mean circulation at high latitudes. This has enabled the development and verification of a useful dynamical framework for interpreting the sign and amplitude of the zonal mean circulation response to diverse forcings associated with midlatitude snow cover variability, Arctic sea ice, and tropical sea surface temperature perturbations. In order of increasing complexity, experiments have been conducted using (i) specified heating anomalies in a dry dynamical core; (ii) prescribed idealized and realistic boundary conditions in atmospheric general circulation models; (iii) pacemaker experiments using specified regional ocean temperature and salinity anomalies in a coupled general circulation model (CGCM); and (iv) freely running simulations with CGCMs. In each case we examine the seasonal mean, and temporal evolution, of the QS Rossby wave response to imposed forcing, its linear interference with the background climatological stationary waves, and the resulting change in the zonal mean circulation. The wave disturbances lead to classical wave-mean flow interaction in the polar stratosphere, which subsequently affects the extratropical tropospheric circulation during winter. Across all of these different experimental configurations, on seasonal, interannual and climate change timescales, we find robust links between the linear interference terms and changes in the zonal mean, indicating that this mechanism represents an important dynamical control over the variability of the high latitude circulation.

Keywords: linear interference, teleconnections, climate variability

ATMOSPHERIC RIVERS IN A HIERARCHY OF CLIMATE SIMULATIONS: RESOLUTION SENSITIVITY AND IMPACTS OF GLOBAL WARMING

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Yang Gao, Pacific Northwest National Laboratory
Jian Lu, Pacific Northwest National Laboratory
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The western U.S. receives precipitation predominantly during the cold season when storms approach from the Pacific Ocean. The snowpack that accumulates during winter storms provides about 70-90% of water supply for the region. Associated with the warm sector of extratropical cyclones over the Pacific Ocean, atmospheric rivers (ARs) provide enhanced water vapor transport from the tropics. Upon landfall in the mountainous terrain along the U.S. west coast, ARs produce heavy precipitation that accounts for 25 – 50% of annual precipitation in the western U.S. Due to the narrow structure of the ARs and the complex terrain along the west coast, simulations of ARs and the associated precipitation are sensitive to model resolution. Using a suite of idealized aqua-planet simulations and AMIP simulations at resolutions ranging from 30km to 240km, we investigate the sensitivity of simulated AR frequency to model resolution and dynamical core. The impacts of global warming on ARs are investigated using CMIP5 models to evaluate the thermodynamical and dynamical contributions to changes in the frequency of ARs making landfall in western North America and Europe. We identified an emergent constraint for AR frequency changes using the observed position of the jet stream that works particularly well for the North Atlantic ARs.

Keywords: Atmospheric Rivers, Jet Stream, Global Warming

PACIFIC ENSO-LIKE VARIABILITY: THE TIMESCALE-DEPENDENT ROLE OF OCEAN DYNAMICS

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Here we use a hierarchy of climate models to assess the role of the ocean in climate variability in the Pacific basin on a range of timescales. Our definition of the hierarchy is that it includes a state-of-the-art climate or Earth system model (in this case CESM), as well as simplified versions of that model in which individual processes are 'turned off' in order to test their impact. In this case, we use a slab ocean model, a fixed ocean (prescribed SST), and a zonally symmetric ocean (an aquaplanet model). Results show that on decadal and longer timescales, the fully coupled and slab ocean models produce similar ENSO-like variability that is in good agreement with observations. There are elements of this variability in the fixed ocean and aquaplanet simulations, suggesting that decadal ENSO-like variability arises from atmospheric processes, with some amplification by thermal coupling with the ocean. We provide diagnostics to demonstrate the ocean dynamical mechanisms that operate over a range of timescales, and how cancellation among different processes can lead to little net role for ocean dynamics on decadal timescales in the tropical Pacific. Implications of results for detection and attribution of forced climate variations are discussed

THE AMO IN VERY COMPLEX MODELS AND A VERY SIMPLE MODEL

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Clement et al (2015, Science) showed that the Atlantic Multi-Decadal Oscillation (AMO) in atmospheric GCMs coupled to slab oceans has the same temporal and spatial characteristics as one produced by GCMs coupled to a dynamically active ocean. This establishes that ocean circulation is not needed for the AMO, but leaves open the possibility that ocean circulation is sufficient for an AMO. Indeed, the prevailing view in the literature is that the Atlantic Meridional Overturning Circulation (AMOC) is essential for the AMO in coupled models and in nature. Here we re-examine the mechanisms of the AMO in the context of both atmospheric GCMs coupled to slab oceans and the one dimensional noise driven model, $dT/dt = -T + Qa + Qo$, where the first term on the right damps temperature anomalies and the last two terms represent white noise forcing by the atmosphere and ocean, respectively. We show that this simple model reproduces observed and simulated relationships among temperature, rate of change of temperature, surface heat flux, and ocean heat flux that have been previously interpreted in the literature as showing that the ocean circulation is necessary for the AMO. We demonstrate that some of these interpretations are artifacts of low pass filtering; others result from imputing causality based on relationships in what is actually an equilibrium state. We finish by noting what surviving evidence remains for the ocean's role in the AMO.

Keywords: AMO, Atlantic Multidecadal Oscillation, AMOC, low-pass filter

PACIFIC INTERDECADAL VARIABILITY DRIVEN BY TROPICAL-EXTRATROPICAL INTERACTIONS

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Interactions between the tropical and subtropical Pacific at decadal time scales are examined using uncoupled oceanic and atmospheric simulations. An atmospheric model is forced with observed Pacific sea surface temperatures (SSTs) and decadal anomalies, computed as the difference between the 2000-2009 and the 1990-1999 period, are sought. Negative decadal SST anomalies are found at the equator, with a global pattern reminiscent of the Interdecadal Pacific Oscillation (IPO). The tropical SST anomalies are responsible for driving a weakening of the Hadley cell and atmospheric meridional heat transport. The atmosphere is shown to produce a significant response in the subtropics, consistent with a weakening of the oceanic subtropical gyre (STG). A global ocean model is then forced with the atmospheric decadal anomalies. Subtropical cells (STC) spin down and the meridional heat transport is reduced, resulting in positive tropical SST anomalies. The resulting Ekman pumping anomaly alters the STC and oceanic heat transport, providing a negative feedback on the SST and giving rise to a mechanism for interdecadal ocean-atmosphere coupled variability. We further explore the connection between STG, STC and tropical SST with the help of an idealized model and show that SST decadal variability stems from the forcing of the Pacific STG through the atmospheric response to ENSO. Finally, we analysis a suite of CMIP5 models and assess their ability to reproduce the low-frequency variability in STC and equatorial SST.

Keywords: Interdecadal climate variability, tropical-extratropical interactions, teleconnections, ENSO

UNDERSTANDING OBSERVED CLIMATE VARIABILITY BY UNIFYING CGCM DYNAMICS, IDEALIZED STOCHASTIC MODELS, AND OBSERVED DATA USING THE INTERACTIVE ENSEMBLE CGCM.

Edwin K. Schneider, George Mason University, USA

An Interactive Ensemble CGCM (IE-CGCM) is constructed by coupling an ensemble of AGCMs to an OGCM, land model, and sea ice model. This model eliminates SST variability due to forcing by atmospheric noise, but preserves coupled variability mechanisms. The IE-CGCM provides an accurate and realistic algorithmic parameterization (without the necessity for closure assumptions) of the response of the atmospheric eddy fluxes of heat and momentum to SST and external forcing. The IE-CGCM has much reduced low frequency SST variability than the parent CGCM, proving that coupled SST variability in the CGCM is forced primarily by the noise in the atmospheric surface fluxes. The SST variability in a CGCM simulation can be recovered and its mechanisms diagnosed by forcing the IE-CGCM with the noise diagnosed, with the aid of AMIP-type simulations, from the CGCM simulation . The noise-forced IE-CGCM thus unifies the dynamics of the complex CGCM with the mechanistic understanding of idealized stochastic models and can be applied to the diagnosis of observed low frequency simulated or observed climate variability, event by event.

Keywords: climate variability, stochastic models

ENERGETICS OF THE OCEAN SURFACE AT LOW FREQUENCIES IN GFDL'S CM2-O MODEL HIERARCHY

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Low frequency variability within the ocean surface can be excited by both external forcing, such as atmospheric exchanges of heat and momentum, as well as the nonlinear transfer of energy between ocean eddies. Recent studies have shown that nonlinear eddy interactions at short timescales can excite an energy transfer from high to low frequencies similar to the transfer of energy between spatial scales in two dimensional turbulence. As this energy exchange is sensitive to the existence of oceanic eddies, the process of energy exchange across frequencies may be sensitive to ocean resolution. We use GFDL's CM2-O hierarchy of fully coupled ocean-atmosphere models to address the transfer of surface kinetic energy and temperature variance between synoptic and decadal timescales utilizing a cross-spectrum diagnostic. One question related to this research is whether low frequency modes are primarily driven from internal mechanisms, such as nonlinearity, or external forces from the atmosphere. Diagnostics of energy flux and transfer within the frequency domain will be compared between three models at 1, 1/4th, and 1/10th degree ocean resolution to address the importance of eddy resolution in the driving of energy to low frequencies.

Keywords: frequency interaction energy resolution

HIERARCHICAL APPROACHES TO INTERPRETING AND MODELING THE GLOBAL CARBON CYCLE

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Hierarchies of models are used to interpret and describe the global carbon cycle. We seek to understand and quantify the magnitudes and rates of exchange between the Earth's major carbon reservoirs; oceanic, terrestrial, geologic and atmospheric often with an emphasis on the latter due to its climatic significance. The organization of the system reflects a complex interplay between physical, chemical and biological processes and interactions across a vast range of space and time scales.

With a focus on the interaction of ocean and atmospheric reservoirs I will illustrate a hierarchical approach to global carbon cycle modeling which spans from highly idealized, globally integrated perpsectives to numerical simulations that attempt to resolve key physical and ecological processes. The former provide a transparent, yet still quantitative perspective on the global-scale controls of atmospheric CO_2. The latter provide a platform for investigating interactions in the complex system, the development of parameterizations, and quantitative support for the insights from idealized frameworks.

HOW TO BUILD A TRACEABLE MODEL HIERARCHY

Robin Tokmakian, Naval Postgraduate School, USA
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Various kinds of model hierarchies allow us, to some degree, to explain model responses in complex models with simpler models and hence get clarity on the physics involved. A question one can ask is how can we map the simple model response onto the solution space of the complex model in a rigorous way so that we have confidence in our explanations and can distinguish different possible simpler models or explanations. We propose an experimental design that allows for both models of the same species (e.g. CESM at different resolutions) as well as models within the same family (e.g. conceptual models of ocean circulation and general circulation models - GCMs) to be traceable from the the simpler model to the more complex model. Using modern statistical machinery we relate the response of the complex model to the response of the simpler model (with uncertainty). This allows us to test whether the response of the simple model, where we understand the physical mechanisms, is being reproduced in the complex model. The key to success is the design of the experiment defined by a correct set of inputs to explain the outputs. Two simple examples are used to explain this idea of traceable model hierarchies. The first is an abstraction. Our complex model is a simple set of PDEs and the simple model the family of analytical solutions. We use this to illustrate the methodology. The second example is more realistic and uses a QG model of the ocean at two resolutions (same species example). Finally, we consider how this idea might be applied to hierarchies involving CMIP class climate GCMs.

Keywords: Ocean, Hierarchies, traceable, statistics

GFDL'S HIERARCHY OF OCEAN BIOGEOCHEMICAL COMPREHENSIVENESS FOR EARTH SYSTEM MODELING

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As Earth System Models mature towards more quantitative explanations of ocean carbon cycle interactions and are applied to an increasingly diverse array of living marine resource communities, the draw towards biogeochemical and ecological comprehensiveness intensifies. However, this draw to comprehensiveness must also be balanced with the added cost of handling additional tracers. One way that GFDL has addressed this constraint is by developing a series of biogeochemical modules based on the 30 tracer TOPAZ formulation used in GFDL's CMIP5 contribution in both simplifying the biogeochemistry down to the 6 tracer BLING formulation and 3 tracer mini-BLING formulation, and in the other direction improving on ecosystem comprehensiveness with the 33 tracer COBALT formulation. We discuss the comparative advantages and disadvantages along this continuum of complexity in terms of both biogeochemical and ecological fidelity and applicability. We also discuss a related approach to separate out other modules for ideal age, 14C, CFCs, SF6, Argon and other tracer suites, allowing use to run an array of experimental designs to suite different needs.

Keywords: Ocean biogeochemistry ecosystem

OCEAN HEAT UPTAKE PROCESSES AND UNCERTAINTY

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The ocean absorbs a large portion of the anthropogenic heat released in the climate system. The magnitude and rate of ocean heat uptake are affected by several key ocean processes such as Southern Ocean Ekman and eddy transports, North Atlantic Deep Water formation and diapycnal mixing. The differences in the simulation of these processes in coupled climate models impact ocean heat uptake, therefore potentially leading to the multi-model spread in surface warming. We will introduce a hierarchy of models to investigate the key processes controlling ocean heat uptake. The models include a conceptual model of the ocean pycnocline, a novel ocean-ensemble driven by pre-industrial and RCPs CMIP5 fluxes with perturbed ocean physics and the output of CMIP5 models. We will quantify the uncertainty in surface fluxes and ocean physics in estimates of ocean heat uptake with a focus on high-latitude ocean dynamics.

Keywords: heat uptate, uncertainty, Southern Ocean

CONCLUSION INCONSISTENCIES WHEN TESTING PHYSICS SETTINGS IN MULTIPLE MODEL CONFIGURATIONS

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The performance of new and improved parameterizations in climate models can relate both to the processes being represented and the performance of the emergent phenomena ultimately being simulated. While the inherent processes can, for the most part, be consistently evaluated across a hierarchy of models the evaluation of the emergent phenomena is often unclear. With a clear mandate for including a new process not always apparent.

A particular example shown here is the simulation of the Madden Julian Oscillation (MJO) in variants of the NCAR Community Earth System Model (CESM). From either initialized, aqua-planet, AMIP or fully coupled simulations it is possible to get an inconsistent view of model performance of the MJO. In all three configurations it is clear that the basic state of the underlying model has a significant role to play in the skill of the model's MJO. AMIP-type experiments reveal a weak simulation of the MJO; near the bottom of similar CMIP5 model performances. As always this raises the obvious question of whether deficiencies are inherently due to the physics packages being used or whether more abstract mean systemic biases are to blame.

CESM1 hindcast experiments are not as polluted by the same systemic AMIP-type biases and the MJO performance is at the top of similar CMIP5 model performances, and arguably is right for the the right reasons. However, in free running fully coupled simulations the configuration of the underlying biases are in many ways worse than the AMIP configuration and yet they conspire to also give MJO characteristics superior to the AMIP configuration. In this talk we will present case studies of these apparent paradoxes, how the sensitivities are not the same in different models, and how development decisions can be improved.

Keywords: Climate MJO Convection Coupled Hindcast

INVESTIGATING ANTARCTIC SEA ICE CHANGE USING EXPERIMENTS WITH A HIERARCHY OF MODEL COUPLING

Marika Holland, NCAR, USA

Total Antarctic sea ice extent has increased over the modern satellite era since 1979. This trend is a result of large regional changes that are partly compensating. The observed total extent trend is generally outside that simulated by climate models for the 20th century. Additionally, aspects of the seasonal and spatial distribution of the trends are difficult to reconcile with the influence of internal variability as diagnosed from climate models. Here we explore factors affecting simulated Antarctic sea ice variability using experiments with the Community Earth System Model that have a hierarchy of model coupling. This allows us to isolate the role of different coupled feedbacks and interactions for simulated sea ice variability and trends. This also provides information on potential model biases that affect projected Antarctic change.

REPRESENTING MODEL UNCERTAINTY – HIERARCHY OR HETERARCHY?

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Models are always simplified constructs of reality and as such contain elements that are not represented correctly. As a consequence this introduces model uncertainties which can affect the model simulation outcomes substantially. A popular approach in Earth System modelling is to neglect model uncertainty. However, over the recent years, more emphasis has been put on exploring options to include estimates of model uncertainties in our models. The main methodologies in climate modelling to explicitly represent such uncertainties are the combination of quasi-independent models into multi-model ensembles, the perturbation of physical model parameters and stochastic parametrization schemes. Often applied to the same hierarchy of models, these three approaches can be seen as complementary in their implementation of model uncertainty. This contribution discusses how model uncertainty representations are used in comprehensive coupled global circulation models for climate forecasts and what their relative advantages and disadvantages are.

Keywords: model uncertainty; climate forecasting, model error

CLIMATE RESPONSE TO CHANGES IN THE MERIDIONAL ENERGY TRANSPORT : ROLE OF OCEAN DYNAMICS.

Francis Codron, LOCEAN-UPMC, France

The climate response to inter-hemispheric unbalances in the energy budget has been the object of many recent studies. In particular, it has been repeatedly shown that the ITCZ shifts towards the hemisphere gaining energy, as the Hadley cells have to transport energy in the opposite direction.

Most of these studies, whether in aqua-planet or more realistic settings, use a slab model for the ocean, which allows to prescribe the ocean heat transport.

In this study, we try to include progressively more complex (in terms of the included dynamical mechanisms) ocean models. Starting with a simple representation of Ekman transports in a slab ocean model, we show that changes in heat transport by the shallow ocean tropical cells can significantly change the response compared to cases when the atmosphere is "doing all the work".

Keywords: Energy Transport Ocean Climate

ROBUST NON-LOCAL EFFECTS OF OCEAN HEAT UPTAKE ON RADIATIVE FEEDBACK AND SUBTROPICAL CLOUD COVER

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The radiative feedback governing relationships between surface temperature and top-of-atmosphere (TOA) energy imbalance is not a one-size-fits-all parameter, but depends sensitively on timescale, spatial pattern and nature of the climate forcing. Progress has been made by treating the slowly-evolving, spatially complex pattern of ocean heat uptake as a quasi-equilibrium forcing on the "fast" atmospheric radiative-dynamical processes that link air-sea heat exchange to the TOA energy budget. Differences between these feedbacks and those on CO2 radiative forcing can be expressed as an "efficacy" of ocean heat uptake. We use idealized slab ocean GCMs forced by prescribed steady energy sinks limited to specific latitude bands to quantify how and why the efficacy depends on spatial pattern of ocean heat uptake. A multi-model approach is used to identify robust and non-robust aspects of the response. Efficacy of sub-polar heat uptake is 3 to 4 times larger than the efficacy of tropical heat uptake. Radiative kernel analysis allows an accurate partition into feedbacks due to temperature, water vapor and clouds. We find large and robust differences in clear-sky lapse rate feedbacks, associated with large-scale atmospheric circulation and thermal stratification changes driven by ocean heat uptake. A more novel and surprising result is the robustness across several GCMs of differences in subtropical low cloud feedback (positive under high-latitude uptake, strongly negative under tropical uptake). We trace these robust differences to thermodynamic constraints associated with lower-tropospheric stability and boundary layer moisture. Our results suggest that cloud feedback under transient climate change is partly modulated by ocean heat uptake through robust but non-local atmospheric processes, and has implications on a timescales ranging from inter-annual to multi-centennial. This study is a clear example of gleaning new insights into climate sensitivity by studying reduced complexity models.

Keywords: feedback, ocean, clouds, efficacy

A MECHANISM FOR THE RESPONSE OF THE ZONALLY ASYMMETRIC SUBTROPICAL HYDROLOGIC CYCLE TO GLOBAL WARMING IN IDEALIZED AND COMPREHENSIVE CLIMATE MODELS

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Zonally asymmetric circulations maintain an intense hydrologic contrast between monsoon regions and subtropical drylands in Earth's present climate. Simulations of 21st century global warming scenarios suggest that zonal contrasts in subtropical precipitation and surface evapotranspiration will increase during local summer, with part of this projected change associated with variations in the zonally asymmetric vertical mass flux. Yet despite the importance of zonally asymmetric circulations in the hydrological cycle and its variations, existing theories for hydrological change are focused on the zonal mean. Here, we propose a novel mechanism to explain projected changes in the strength of zonally asymmetric circulations with global warming. Using an analytical convective quasiequilibrium, first-baroclinic mode framework, we relate changes in the circulation to tropopause height and to the land-ocean contrast in near-surface moist entropy. In this framework, an increase in tropopause height strengthens zonally asymmetric circulations as climate warms, while the land-ocean contrast in entropy may weaken or strengthen those circulations depending on surface properties. We demonstrate the relevance of this mechanism over a wide range of climates using an idealized moist GCM. Then we use this mechanism to quantify the influence of changes in tropopause height and near-surface thermal properties on changes in zonally asymmetric circulations in CMIP5 simulations of present-day and next-century climate.

Keywords: Stationary circulation, monsoons, global warming, hydrologic cycle

CLOUDS AND THE ATMOSPHERIC CIRCULATION RESPONSE TO WARMING

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We study the effect of clouds on the atmospheric circulation response to CO2 forcing in three coupled global climate models. The cloud effect is isolated by locking the clouds to either the control or high CO2 state in the radiation scheme only. In our models, cloud-radiative changes force a marked poleward expansion of the Hadley cells, midlatitude jets, and storm tracks under CO2 increase, even though they only cause modest global-mean surface warming. Cloud-radiative changes are shown to strongly enhance the Equator-to-pole temperature gradient at all levels in the troposphere, favouring stronger and poleward-shifted midlatitude eddies. By contrast, increasing CO2 while holding the clouds fixed causes strong polar amplification and weakened midlatitude baroclinicity at lower levels, yielding little or no poleward expansion of the circulation. Our results show that (a) the atmospheric circulation responds sensitively to cloud-driven changes in meridional and vertical temperature distribution, and (b) the spatial structure of cloud feedbacks likely plays a dominant role in the circulation response to greenhouse gas forcing. While the magnitude and spatial structure of the cloud feedback are expected to be highly model-dependent, an analysis of 4xCO2 simulations of CMIP5 models shows that the cloud feedback likely forces a poleward expansion of the tropospheric circulation in most climate models.

Keywords: Climate feedbacks, atmospheric circulation, clouds

THE IMPACT OF INTERACTIVE STRATOSPHERIC CHEMISTRY ON CLIMATE MODEL SENSITIVITY

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Due to computational constraints, interactive stratospheric chemistry is commonly neglected in many GCMs participating in inter-comparison projects, and the impact of this simplification on the modeled response to external forcings is still unclear. Inter-model differences in the treatment of radiative-dynamical interactions between stratospheric ozone and the circulation could be partly responsible for some of the existing spread in future projections. By carrying out model simulations from the Community Earth System Model (CESM), we carefully quantify the effect of coupling the stratospheric ozone chemistry onto the model's sensitivity to solar and anthropogenic greenhouse gases. We accomplish this by using a version of the Whole Atmosphere Community Climate (WACCM) model, which allows coupling and de-coupling stratospheric ozone chemistry, without altering the dynamical core and physical parameterizations. Thus, WACCM offers the unprecedented opportunity of quantifying the effects of adding complexity to a GCM (i.e., the stratospheric chemistry feedbacks), improving our understanding of the step in the model's hierarchy between GCMs and chemistry-climate models (CCMs). We show that the inclusion of a coupled stratospheric chemistry significantly reduces the model response to both greenhouse gases and solar forcing, albeit through two different mechanisms. According to our findings, stratospheric ozone responses yield an important, and yet undocumented, negative feedback in the climate system.

Keywords: Climate modeling, Climate Sensitivity, Chemistry-Climate interactions

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CS-F-01

THE INFLUENCE OF CLOUD FEEDBACKS ON EQUATORIAL ATLANTIC VARIABILITY

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Gaby Radel, Max Planck Institute for Meteorology, Germany
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Observations show that cloud feedback over the Namibian stratocumulus region is positive because cloud cover is anticorrelated with local sea surface temperature (SST) anomalies. Moreover, regressions of observed atmospheric fields on equatorial Atlantic SST anomalies indicate that cloud feedbacks over the Namibian stratocumulus region covary with Atlantic Niño. However, from observations alone, it is not possible to quantify the influence of regional cloud feedbacks on equatorial climate variability. To address this question, a set of sensitivity experiments are conducted using an atmospheric general circulation model (ECHAM6) coupled to a slab ocean in which the strength of positive cloud feedback is enhanced over several regions in the South Atlantic basin. Enhanced positive cloud feedback over the Namibian stratocumulus region increases local as well as equatorial SST variability, whereas enhanced cloud feedback over other regions in the South Atlantic increases local SST variability but exhibits negligible responses at the equator. These results indicate that the Namibian region plays a central role in enhancing equatorial SST variability because it is located where the SST anomalies associated with the simulated Atlantic Niño in the slab-ocean model develop. These results highlight the important role of the regional coupling of cloud cover over the Namibian region with local SSTs and its effects on equatorial Atlantic climate variability.

Keywords: cloud feedback, Atlantic Nino, internal variability

CS-F-02

ENERGY BUDGET AS QUALITY INDICATOR IN CLIMATE MODELS OF DIFFERENT DEGREES OF COMPLEXITY

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A valuable approach to study the climate system and the nonlinear interactions between its components (ocean, atmosphere, sea ice, etc.) is based on using a single numerical model where the degree of complexity is progressively increased by adding one component at a time.

The advantage of many present-day climate codes is that components are coded in different modules that can be added at run time. We use the MIT general circulation model (MITgcm) in our study since it is open-access and modular programmed.

In general the correctness of numerical simulations is guaranteed by the conservation of mass and energy at the global scale. We show that the global annual energy budget is a strong indicator of the quality of the numerical simulation at any level of complexity for the chosen climate model. In particular, from the energy budget at the top of the atmosphere and at the surface, useful information can be inferred on sink/source properties of the code and on the way such energy sinks/sources can be minimized. This optimization procedure, which is valid at any level of complexity of the model, allows one to obtain good control runs that reach quasi-steady state equilibrium over long time scale. Moreover, since the energy balance at the surface is the result of the energy gained/lost in each module activated in the climate model (ocean, land, sea ice, etc.), the balance can be used to estimate the limitations of the parameterizations in each component and to understand how they influence the global dynamics. We will discuss a series of examples using different degrees of complexity in MITgcm.

Keywords: Energy budget, quality of simulations, modular programming, MITgcm

CS-F-03

THE ROLE OF WATER VAPOR IN THE ITCZ RESPONSE TO HEMISPHERICALLY ASYMMETRIC FORCINGS

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Studies using both comprehensive and simplified models have shown that changes to the inter-hemispheric energy budget can lead to changes in the position of the ITCZ. In these studies, the mean position of the ITCZ tends to shift toward the hemisphere receiving more energy. While included in many studies using comprehensive models, the role of the water vapor-radiation feedback in influencing ITCZ shifts has not been focused on in isolation in an idealized setting. Here we use an aquaplanet idealized moist general circulation model initially developed by Dargan Frierson, without clouds, newly coupled to a full radiative transfer code to investigate the role of water vapor in the ITCZ response to hemispherically asymmetric forcings. We induce a southward ITCZ shift by reducing the incoming solar radiation in the northern hemisphere. To isolate the radiative impact of water vapor, we run simulations where the radiation code sees the prognostic water vapor field, which responds dynamically to temperature, parameterized convection, and the circulation and also run simulations where the radiation code sees a prescribed static climatological water vapor field. We find that under Earth-like climate conditions, a shifting water vapor distribution's interaction with longwave radiation amplifies the latitudinal displacement of the ITCZ in response to a given hemispherically asymmetric forcing roughly by a factor of two; this effect appears robust to the convection scheme used. We argue that this amplifying effect can be explained using the energy flux equator theory for the position of the ITCZ. Finally, assuming that the energy flux equator accurately predicts the position of the ITCZ we attempt to modify a one-dimensional energy balance model to include a crude representation water vapor's impact on outgoing longwave radiation to illustrate an analogous amplifying effect to that seen in the GCM simulations.

Keywords: ITCZ, water vapor feedback

CS-F-04

SIMPLIFIED PARAMETERIZATION OF ANTHROPOGENIC AEROSOL FOR BETTER UNDERSTANDING UNCERTAINTY IN RADIATIVE FORCING

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Estimating the radiative forcing of anthropogenic aerosol remains a challenge in understanding Earth climate. Shortage of observations with sufficient detail and coverage as well as uncertainties in atmospheric models hinder the advancement of understanding aerosol processes and their effect on climate. Particularly, the representation of clouds and circulation in complex climate models is believed to be major reason for model diversity and can adversely affect forcing estimates. To better understand the multi-model spread in radiative forcing, a systematic investigation of the relative importance of different uncertainties is needed. An approach that is (1) flexible enough to be used in different models and (2) easy enough to define idealised settings would herein be useful to facilitate both experimentation with and systematic inter-comparison of models capturing processes with different degree of abstraction. Such studies are now feasible with the simplified MACv2.0-SP parameterization for optical properties of anthropogenic aerosol. MACv2.0-SP has been developed for usage in models participating in CMIP6, i.e., can be applied in complex climate and Earth system models but also in stand-alone radiative transfer programs. The parameterization uses mathematical functions to generate spatio-temporal patterns in anthropogenic aerosol optical depth that globally mimic the present-day observation climatology. Using MACv2.0-SP enables computationally efficient experiments to study aerosol effects on climate. Here, perturbed parameter ensembles with MPI-ESM are used to study the sensitivity of the radiative forcing to aerosol specifications and atmospheric variability for present-day climate. Prescribing different but likewise plausible Twomey effects in ensemble simulations allows an evaluation of the relative importance compared to atmospheric variability. Future model inter-comparison with the same aerosol settings can relate potential differences in radiative forcing to model uncertainty other than the aerosol parameterization, e.g., clouds and circulation.

CS-F-05

MODELING WATER VAPOR AND CLOUDS IN AN IDEALIZED GCM

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This paper introduces an idealized global model in which water vapor and clouds are tracked as tracers, but are not allowed to affect circulation either through latent heat release or cloud radiative effects. The cloud scheme includes an explicit treatment of cloud microphysics and diagnoses cloud fraction from a prescribed sub-grid distribution of total water. The model is capable of capturing many large-scale features of water vapor and cloud distributions outside of the boundary layer and deep tropics. The subtropical dry zones, mid-latitude storm tracks, and upper-tropospheric cirrus are simulated reasonably well. The inclusion of cloud microphysics (namely re-evaporation of raindrops) has a significant effect of moistening the lower troposphere in this model.

When being subjected to a uniform fractional increase of saturated water vapor pressure, the model produces little change in cloud fraction. A more realistic perturbation, which considers the non-linearity of the Clausius-Clapeyron relation and spatial structure of CO2-induced warming, results in a substantial reduction in free-tropospheric cloud fraction. This is reconciled with an increase of relative humidity by analyzing the probability distributions of both quantities. Further perturbation experiments focus on understanding what controls mid-latitude cloud fraction and condensate, and how circulation changes associated with weaker meridional temperature gradient may alter them. The implications of these results and the utility of the idealized model for understanding cloud feedback are discussed.

Keywords: idealized model, clouds, water vapor

CLIMATE SENSITIVITY AND FEEDBACKS

CS-F-06

INVESTIGATION OF OCEAN CLIMATE CHANGE IN RESPONSE TO CO2 FORCING

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The magnitude and geographical patterns of changes in ocean heat content, salinity, circulation and sea-level in CO2-forced AOGCM experiments are strongly model-dependent, but we do not know what aspects of this uncertainty can be attributed to the ocean model formulation and state. The Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP) of CMIP6 aims to investigate the spread in the ocean response by applying model-independent perturbations (technically like flux adjustment, but with a different purpose) to the surface fluxes of momentum, heat and freshwater to the ocean in a range of AOGCMs. The imposed flux perturbations are the CMIP5 ensemble-mean changes in these fluxes at the time of 2xCO2 in 1pctCO2 experiments, and are thus typical of CO2-forced climate change. The aim is to reveal and analyse the diversity of ocean response to common flux forcing; the FAFMIP experiments are otherwise the same as the pre-industrial control (with 1xCO2 in particular). The design is the ocean analogue of AGCM experiments in which model-independent SST and sea-ice changes are prescribed that are typical of CO2-forced climate change, except for the important difference that the FAFMIP experiments use AOGCMs, not OGCMs. This is so that the unperturbed state for comparison is the AOGCM pre-industrial control, including unforced coupled variability on all timescales, which affects the mean state, and feedbacks that involve the atmospheric response to ocean surface conditions.

Keywords: ocean climate change feedback

CS-F-07

EXPLORING THE RESPONSE OF THE OCEAN AND THE COUPLED CLIMATE SYSTEM TO VOLCANIC ERUPTIONS IN A HIERARCHY OF MODELS

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A hierarchy of idealized models - ranging from a 1-d diffusion model, a 2-box model and a fully coupled GCM - are used to study the role of the ocean in the response of the climate system to a volcanic eruption. We find that an active ocean sequesters surface temperature anomalies induced by an eruption in to its interior, increasing the initial damping rate, relative to a slab ocean. However, shielded from damping to the atmosphere, the effect of the volcano persists on decadal timescales. This favors accumulation of the response from a succession of volcanic eruptions over time and may in part explain the multiple centuries of cold temperatures experienced during, for example, the Little Ice Age.

The role of the deeper ocean, and the physical processes involved in this prolonged response, are explored further in a coupled model consisting of an atmosphere coupled to a passive mixed layer as well as in a fully coupled GCM. Of particular interest are the responses of the Atlantic Meridional Overturning Circulation, the ITCZ and Sub-Tropical Cells to a volcanic eruption.

Finally Linear response function theory is used to explore the connection between the impulsive response (volcano) to the step-function response (e.g. 4xCO2 radiative perturbation)

Keywords: climate, sensitivity, volcano

CS-F-08

TURNING OFF CLOUDS IN RADIATIVE FORCING EXPERIMENTS: A CASE STUDY OF STRATOSPHERIC OZONE

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Numerical experiments show that stratospheric ozone increase may result slight cooling in surface temperature. This result is especially interesting in that the stratosphere-adjusted radiative forcing of stratospheric ozone is positive. We use a set of experiments, in which clouds and other climatic components are turned on and off respectively, to investigate their roles in the climate response to stratospheric ozone recovery. These experiments show that the surface cooling is mainly due to a strong radiative effect resulting from significant reduction of global high clouds and, to a lesser extent, from an increase in high-latitude sea ice. The results suggest clouds and sea ice are sensitive to stratospheric ozone perturbation, which constitutes a significant radiative adjustment that influences the sign and magnitude of the global surface temperature change.

Keywords: stratospheric ozone, radiative forcing, cloud adjustment, clouds-off

CS-F-09

UNDERSTANDING THE BEHAVIOR OF CLIMATE MODELS USING DRY AND MOIST 2D MODELS OF THE WEST AFRICAN MONSOON

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The West African monsoon, like other monsoon systems, is not accurately represented in CMIP5 models regarding the summer mean rainfall pattern or its variability. Cloud-radiation feedback seems significant in the biases found in CMIP5 models intensity and location of rainfall (Roehrig et al. 2013) but subgrid paramerized physics is also a source of dispersion (Martin et al. 2016, submitted). Given the large number of systems interacting with monsoon or ITCZ within a climate model, it is difficult to separate the global and large-scale drivers from those acting at the regional or smaller scales. Two different two-dimensional models of the WAM are used here to drive some idealized test with the scope of identifying the key process at play at the regional scale that may lead to the CMIP5 spread.

A two-dimensional dry model is first used. It does not account for any moist physics so that diabatic heating is prescribed to the model like in many previous theoretical studies of the Hadley cell (Held and Hou, 1988, Plum and Hou 1992, Fang and Tung 1994). Forcing the 2D model with the total diabatic heating for CMIP5 models that participated to the EMBRACE project allows reproducing some of the biases found in the full climate models. It suggests that the drivers of those biases are already at play in the simple framework. Each heating is then decomposed into the different physical processes (convection, turbulence, mycrophysics) which are then used to force the 2D dry model.

A second two-dimensional model is used that includes moist processes. It possesses a complete physical package including an interactive continent. Results coming from Peyrillé et al. (2016) will be presented showing that modulating the water cycle component within the single 2D model (precipitation efficiency, evaporation and advection) is sufficient to reproduce the CMIP5 spread. The model currently accounts for the large scale environment through a forcing derived from reanalysis but a natural next step is to derive it from climate model experiments.

Keywords: monsoon, ITCZ, cloud feedback, water cycle

CS-F-10

A HYBRID-RESOLUTION CLIMATE MODEL

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The UK Earth System Model (UKESM) consists of the HadGEM3 coupled physical climate model plus earth system components including a terrestrial carbon cycle, an ocean biogeochemical model, an advanced representation of atmospheric chemistry and aerosols, and an interactive ice-sheet model. Adding these components results in a significant increase in model computational cost and concomitant reduction in throughput which, for example, make it difficult to use the planned high-resolution version (60 km in the atmosphere, 0.25 degree in the ocean) of UKESM for centennial timescale simulations such as those required in CMIP6.

Accordingly, we are developing a hybrid-resolution version of the model that retains the benefits of high model resolution and advanced process complexity whilst remaining computationally viable. With respect to the atmosphere, we split the model in two, running all the physics and dynamics at 60 km, and the aerosols, chemistry and tracer advection at a lower resolution (140 km). The two parts of the model are kept in step by exchanging fields which are interpolated onto the different grids using the OASIS-MCT coupler. More specifically, the dynamical core fields in the low-resolution part are hourly overwritten by those from the high-resolution part, ensuring the meteorological trajectory of the former is locked to follow the latter. All trace gas chemistry and aerosol processes are calculated at low resolution and the required outputs are passed to the high-resolution part to be used in the parameterization schemes for cloud microphysics, precipitation and radiation.

Initial comparison of results from the hybrid-resolution version against the full high-resolution version (running the atmosphere, aerosols, chemistry and tracer advection all at 60 km) are promising. The hybrid currently runs around three times faster than the full version; we are still exploring the greater flexibility in load balancing that the splitting of the model into two executables provides.

Keywords: hybrid, performance, throughput, chemistry, sensitivity

TC-RCE-01

MOIST TO DRY ROTATING RADIATIVE-CONVECTIVE EQUILIBRIUM: A MODEL HIERARCHY FOR TROPICAL CYCLONES?

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Our understanding of many aspects of dynamics in our real moist atmosphere has been strongly informed by idealized dry analog models. It is widely believed that tropical cyclones (TCs) are a fundamentally moist phenomenon – relying on evaporation and latent heat release – yet recent work has actually shown that dry axisymmetric tropical cyclones can form in a state of dry radiative-convective equilibrium. What can such “dry hurricanes” teach us about intensity, structure, and size of real moist tropical cyclones in nature? What does the moist-dry transition look like? And what place should dry radiative-convective equilibrium – rotating and non-rotating – occupy in our model hierarchies?

To address these questions, we use the SAM cloud-system resolving model to simulate radiative-convective equilibrium on a rapidly rotating f-plane, subject to constant tropospheric radiative cooling. We use a homogeneous surface with fixed temperature and with surface saturation vapor pressure scaled by a factor 0-1 relative to that over pure water – allowing for continuous variation between moist and dry limits.

A perfectly moist surface yields a classic TC-world where multiple vortices form spontaneously and persist for tens of days. A completely dry surface can also yield an analogous dry TC-world with stable persistent vortices – but if the rotation rate is too large, vortices become unstable. Over a large range of the semi-dry parameter space, however, spontaneous cyclogenesis fails to occur at all. We discuss the mechanisms behind the discontinuous moist-dry dynamical transition, and its implications for a model hierarchy. We also interpret our findings of an upper bound on rotation rate for a TC-world with stable vortices in terms of a free-convective Rossby number, which has been shown to lead to regime transitions in rotating Rayleigh-Benard convection.

Keywords: Tropical Cyclones, Radiative-Convective Equilibrium, Dry Convection

TC-RCE-02

UNDERSTANDING MONSOON ONSET USING A NORMALIZED GROSS MOIST STABILITY FRAMEWORK IN AN IDEALIZED MODEL

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L. Ruby Leung, PNNL, USA

Accurately modelling monsoon onset remains a challenge. We aim to improve understanding of the coupling between the transition from the dry to rainy seasons and the divergence of moisture and moist entropy by the large-scale circulation through a gross moist stability framework. Isentropic mass transport is calculated in a series of idealized aqua planet simulations with a seasonal cycle using the Model for Prediction Across Scales (MPAS). Fluxes of moist and dry entropy are then used to compute Normalized Gross Moist Stability (NGMS) and moist stratification. The onset of the rainy season owing to the ITCZ movement is analyzed in terms of NGMS and moist stratification. We find that there is a rapid transition between the dry and rainy seasons during a period of near-zero NGMS followed by another rapid transition from the rainy season to the dry season where NGMS becomes unstable and grows towards infinity before switching sign. NGMS and moist stratification are in quadrature with one another such that there is a maximum in moist stratification coincident with the near-zero NGMS and rapid transition from dry to rainy seasons. The dry season is characterized by negative NGMS owing to the predominant subsidence diverging both moist entropy and moisture from the atmosphere. These results are expanded across the suite of Tropical Rain belts with an Annual cycle and Continent Model Intercomparison (TRAC-MIP) models as well as additional simulations within MPAS where a zonally asymmetric q-flux is prescribed.

Keywords: Monsoon onset, NGMS, isentropic transport

TC-RCE-03

DYNAMICAL AND MIXING PROPERTIES OF THERMALS IN IDEALIZED LARGE EDDY SIMULATIONS OF TROPICAL CONVECTION

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Although most parameterizations of cumulus convection are based on the steady entraining plume conceptual model, we know that the building blocks of cumulus clouds are transient thermals rather than steady plumes. In order to explore the possibility of developing new convection parameterizations based on such transient thermals, we study the dynamical and mixing properties of thermals in idealized large eddy simulations of tropical convection using WRF. We have designed an alogorithm that identifies and tracks these thermals in a simple but physically consistent way, from which we can derive numerous properties such as the main forces acting on the thermals and their mixing rates. We find that thermals are relatively small (R<300 m), ascend at moderate rates (2-4 m/s), maintain an approximately constant size as they rise and have brief lifetimes (4-5 min). In general, as convection deepens thermals do not travel further, but rather initiate at higher altitudes. Drag seems unrelated to mixing, decreases with increasing convective intensity, and cannot be easily explained based on standard dissipative drag assumptions. Although most thermals mix vigorously with their environment, the few that travel the furthest tend to be relatively undiluted. Thus, entrainment rate and initial ascent rate are more important than the initial thermodynamic state for how far thermals rise.

Keywords: Tropical convection, large eddy simulation, cumulus thermals

TC-RCE-04

NON-CONVERGENCE OF THE COMMUNITY ATMOSPHERE MODEL WITH INCREASING HORIZONTAL RESOLUTION IN IDEALIZED FRAMEWORKS

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Variable and adaptive meshes represent a promising pathway towards improved regional climate projections in global models. However, global primitive equation models are notoriously non-convergent, resulting in diverging solutions across mesh transitions. It is generally thought that poorly formulated closure approximations are responsible for non-convergence in the models, however the specific mechanisms remains elusive. Reduced complexity test cases, ranging from more complex aqua-planet set-ups, to simplified non-rotating radiative-convective equilibrium frameworks, are used to explore the mechanisms leading to non-convergence in the Community Atmosphere Model. The experiments indicate that the removal of gravitational instability by the adiabatic dynamics results in increasing resolved vertical velocities with increasing resolution, consistent with linear theory. The implications of this result are discussed in the context of the closure problem, emphasizing the role of the physics-dynamics coupling method.

Keywords: GCM, convection, clouds

TROPICAL CONVECTION AND RCE

TC-RCE-05

A HIERARCHY OF PERTURBATION COMPLEXITIES: CASE STUDY OF RAINFALL IN THE SAHEL

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Several important outstanding problems in climate dynamics -- e.g. paleoclimate variations and anthropogenic climate change -- involve understanding the climate response to multi-faceted and complicated perturbations. For such problems, a complementary approach to a hierarchy of model complexities is a hierarchy of /perturbation/ complexities. We describe results using idealized perturbations to the sea surface temperature (SST) lower boundary condition and the convective parameterization in multiple comprehensive atmospheric general circulation models to understand the response of precipitation in the African Sahel to anthropogenic warming. This example illustrates the physical insight that targeted, simple perturbation experiments can engender. Despite a range in coupled model simulations of 21st century rainfall from severe drying to severe wettening, nearly all of seventeen models we analyze respond to uniform SST warming by drying the Sahel, and this drying is triggered largely by a shared set of straightforward physical mechanisms. Further idealized SST perturbation experiments -- varying the magnitude and sign of uniform warming, perturbing SSTs only in targeted regions, removing mean temperature change from a patterned signal -- further elucidate pertinent physical mechanisms. Simple alterations to models' convection schemes combined with simple perturbation experiments also yield new insights, an approach that likely extends to other model components. The implication of these successes is that researchers should take advantage of existing idealized perturbation experiments (including those partaken through CMIP) as well as design and use their own, in order to ring out more useful information from high complexity models.

TC-RCE-06

DEPENDENCE OF CONVECTIVELY COUPLED GRAVITY WAVES ON CONVECTIVE REPRESENTATION

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This study investigates the effects of selected parameters in either a single-column model or a cloud-resolving model on simulated convectively coupled gravity waves. All simulations are conducted within an idealized framework, in which the time-independent radiative forcing is prescribed and the large-scale dynamics are parameterized with the damped gravity wave method in a nonrotating atmospheric column. In the single-column model (single-column Community Atmosphere Model) simulations, experiments using various parameter values associated with the efficiency of convective adjustment and the sensitivity to the environmental moisture are implemented. Furthermore, alternative convection schemes that are designed to unify different cloud types are evaluated. In the cloud-resolving model (System for Atmospheric Modeling, SAM) simulations, an additional parameter controlling the ratio of horizontal resolution to horizontal domain size is explored.

TC-RCE-07

A SIMPLE PICTURE FOR RADIATIVE COOLING AND PRECIPITATION CHANGE WITH WARMING

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Radiative-Convective Equilibrium (RCE) is one of the lowest rungs of the model hierarchy. Nonetheless, the radiative cooling that drives convective overturning remains enigmatic, and we have little feel for how it should evolve with warming. In this talk we show that when temperature is used as the vertical coordinate, radiative cooling profiles are actually insensitive to surface temperature. We then leverage this simple behaviour to estimate, directly from a baseline RCE state, the ~3% per Kelvin increase of radiative cooling and precipitation with surface warming, without the need for a perturbed state calculation.

We hope that these results, which simplify our picture of RCE, will spark discussion and future work about the degree to which they hold further up the model hierarchy, e.g. in global climate models.

Keywords: radiation, convection, precipitation

TC-RCE-08

SENSITIVITY STUDIES OF CLOUD RESPONSES ON SSTS IN RCE EXPERIMENTS USING A HIGH-RESOLUTION GLOBAL NONHYDROSTATIC MODEL

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As the variation in climate sensitivity among global climate models is largely attributable to differences in cloud feedback, better understanding of the response of clouds to climate changes provides important insights into climate science. The radiative-convective equilibrium (RCE) is one of key ingredients in order to understand the role of moist convection in the atmosphere. To reduce the uncertainties of the response of clouds to climate changes, simulations with RCE configurations will be examined using a high-resolution nonhydrostatic global circulation model (the Nonhydrostatic Icosahedral Atmospheric Model; NICAM). The configurations with fixed SSTs, explicit microphysics parameterizations, and no cumulus parameterization will be used. Especially, the sensitivity of the high clouds, liquid water path, and ice water path to vertical grid spacings will be studied using fixed SST configurations, as previous studies showed high clouds responses are different between NICAM and other coarse resolution climate models. In addition, it was found that vertical grid spacings of 400 m or less are necessary to resolve the bulk structure of cirrus clouds, we also examine sensitivities to vertical resolutions.

Keywords: nonhydrostatic global circulation model, RCE

TC-RCE-09

THE ROLE OF EDDIES IN DETERMINING THE TROPICAL OVERTURNING CIRCULATION: ENERGETIC AND MOMENTUM-BASED PERSPECTIVES

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Large-scale eddies originating in midlatitudes have been shown to play an important role in determining the strength of the tropical overturning circulation. Previous work has focused on the atmospheric angular-momentum budget and the influence of eddies through their transports of momentum. But midlatitude eddies also transport significant amounts of energy meridionally, and examining the energy budget provides a different perspective on the potential effects of eddies on the mean circulation.

Here, we use idealized simulations on an equatorial beta-plane to explore the response of the tropical circulation to large-scale eddy fluxes of energy and momentum. We first consider the simple case of the equinoctial Hadley circulation under fixed-SST conditions before including the additional complexity of interactive surface temperatures, a simple representation of ocean heat transport and, finally, the seasonal cycle. We find that under fixed-SST conditions, the strength of the Hadley circulation is relatively insensitive to the presence of eddies, whereas in the interactive-SST case, the eddies act to amplify the Hadley circulation substantially. Our results suggest that one must consider both the energy and angular-momentum budgets in order to fully understand the role of eddies in determining the tropical overturning circulation and its seasonal evolution.

Keywords: Hadley circulation, eddies, momentum, energy

TC-RCE-10

EVALUATING THE INTERACTION OF CLIMATE MODEL BIAS AND CONVECTIVE CLOUD REPRESENTATION IN SIMULATING THE INTRASEASONAL VARIABILITY OF THE TROPICS

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Convection is central to tropical atmospheric dynamics. The dominant mode of variability in parts of the tropics is on the intraseasonal time scale. The poor representation of intraseasonal variability in global climate models (GCM) is well documented in the literature. Most GCMs have grid spacing of O(100 km). At this spatial scale, many subgrid scale phenomena remain unresolved. In particular, convection is parameterized at the grid scale of GCMs. Some recent efforts to improve the representation of convection in the Community Earth System Model (CESM), by embedding a cloud-resolving model (CRM) in each gridbox, the so-called super-parameterization (SP) of clouds, have improved the simulation of intraseasonal variability (Stan et al. 2010). In uncoupled mode, the SP version of the CESM atmospheric component (the Community Atmospheric Model, CAM) over-estimates the intensity of convection at the intraseasonal time scale (Benedict et. al. 2007). The simulated convective bias is likely due to unrealistic boundary layer interactions, the lack of weakening of simulated disturbances over the Maritime Continent and mean state errors. We test interactions of climate model biases, convective cloud representation and eastern Pacific sea surface temperature (SST) variability by running simulations with (a) CAM4 coupled with a slab ocean (SOM); (b) SP-CAM coupled with SOM; (c) SP-CAM coupled with SOM and bias-corrected by correcting Q-flux; and (d) SP-CAM coupled with SOM using bias-corrected Q-flux and specified SST in the eastern Pacific Ocean. This experimental setting makes it possible to evaluate the importance of air-sea interactions in simulations of intraseasonal variability and improve our understanding of the role of model mean state biases, interannual variability and cloud representation in simulation of intraseasonal variability.

Keywords: cloud-resolving model, intraseasonal variability, slab ocean model

TC-RCE-11

COEXISTING EQUATORIAL AND OFF-EQUATORIAL ITCZ IN AN AQUA PLANET MODEL

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On the seasonal time-scale, the ITCZ is known to migrate towards the differentially warm hemisphere such that more energy is transported to the colder hemisphere. During boreal summer, the Indian ocean has two coexisting ITCZs : a primary one at the off-equatorial location in response to the differential warming, and a secondary one near the equator. We investigate how the energetic constraints can be extended to explain the coexistence of these ITCZs.

We have used idealised aqua-planet simulations with zonally symmetric sea surface temperature forcing to simulate the coexisting ITCZ. The off-equatorial ITCZ exports moist static energy to the colder hemisphere due to the depth of the upper-tropospheric branch, while the equatorial ITCZ shows a complex vertical structure of energy exports. In particular, horizontal advection exports moist static energy while vertical advection imports MSE into the equatorial ITCZ due to the shallower vertical extent of the associated circulation. Consistent with this, the equatorial ITCZ has a negative Gross Moist Stability (GMS) while the off-equatorial ITCZ has a positive GMS. We further investigated the factors that affect the strength of the coexisting ITCZ. The ITCZ strength is sensitive to the net energy input in the column. The off-equatorial (equatorial) ITCZ strengthens (weakens) as the surface latent heat flux increases.

Keywords: ITCZ, MSE budget, GMS, Energetics

TC-RCE-12

CHANGES IN CLOUDS AND CIRCULATION WITH WARMING IN CLOUD-RESOLVING MODEL SIMULATIONS OF SELF-AGGREGATION OF CONVECTION

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Large-scale atmospheric circulation, and its interaction with organized moist convection across many scales, sets the patterns of tropical cloud cover and relative humidity and their sensitivity to climate change. Possible changes in the amount of organized convection with warming therefore may modulate climate sensitivity. We explore changes in clouds and circulation and the degree of self-aggregation of convection in response to uniform SST change in a set of radiative-convective equilibrium simulations with the System for Atmospheric Modeling (SAM) cloud resolving model. We use a non-rotating, highly elongated three-dimensional channel domain of length >104 km, with interactive radiation and surface fluxes and fixed sea-surface temperature varying from 280–310 K. Convection self-aggregates into multiple moist and dry bands across this full range of temperatures, but the length scale of the aggregation varies systematically with temperature. We find high cloud fraction is reduced as the convection aggregates and with warming, and decompose the cloud changes with warming into those related to changes in the degree of aggregation with warming and those simply a function of temperature. Simulations at 300 K show a surprisingly realistic distribution of large-scale vertical velocities at 500 hPa, despite homogeneous boundary conditions, and so we also discuss how large-scale overturning circulations change in response to warming. Finally, we discuss preliminary results from simulations with interactive surface temperature and the effect of this on the degree of aggregation and its associated cloud and humidity changes.

Keywords: rce, convection, self-aggregation, clouds, circulation

TC-RCE-13

SIMULATING THE MADDEN-JULIAN OSCILLATION IN 1D, 2D, AND 3D MODELS

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What is the nature of the Madden-Julian Oscillation (MJO)? What are the key recipes in simulating the MJO? I will present a simple MJO theory based on results from 1D and 2D shallow water models. This theory suggests that the MJO is a large-scale envelope of high-frequency gravity waves and predicts faster, bigger, and stronger MJOs in warmer climates. I test this theory by studying the MJO over a wide range of sea surface temperatures (SSTs) using the SuperParameterized Community Atmosphere Model (SPCAM). I demonstrate that the MJO can occur across a vast temperature range (1°C to 35°C SSTs) and exhibits robust and smooth changes with surface warming—faster propagation speed, bigger horizontal scale, and stronger rainfall variability. The relationship between the rates of each of these changes agrees with a power law scaling prediction from the gravity-wave theory of the MJO, which views the MJO as a large-scale envelope of convective events that are linked by high-frequency tropical waves. According to this view, faster MJOs result from high frequency tropical wave speedup, bigger MJOs result from a shift towards more intermittent rainstorms, and stronger MJOs result from more vigorous individual rainstorms in warmer climates. This study suggests that an accurate representation of individual rainstorms and high-frequency tropical waves are important for simulating the MJO.

Keywords: MJO, Convection, RCE, Climate change, gravity wave

TC-RCE-14

A SINGLE-COLUMN MODELING STUDY ON A SPURIOUS CLOUD OSCILLATION IN CAM5 WITH CLUBB-MG2 SCHEMES

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Based on ARM observations in the Azores, we identified a spurious cloud/PBL oscillation in the Community Atmosphere Model (CAM) version 5 with the Cloud Layers Unified By Binomials scheme (CLUBB) and new microphysics scheme (MG2). Global screening proves that the oscillation is a common phenomenon in trade cumulus regimes over the world. This study uses single-column model to fully understand the mechanism of how drizzle-cloud- turbulence interactions in CLUBB-MG2 causes the oscillation in AMIP simulations. A key factor triggering this type of cloud/boundary layer oscillation is found to be the location of the sub-cloud rain evaporation. The findings from this study can help us better understand the cloud-drizzle-turbulence interactions in CAM5 and guide the future improvement of the parameterization schemes.

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Keywords: Single column model, drizzle-cloud-turbulence interaction

ML-ST-01

THE DYNAMICS OF EXTREME NEGATIVE STRATOSPHERIC PLANETARY WAVE HEAT FLUX EVENTS IN AN IDEALIZED MODEL

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Recent work has shown robust stratosphere-troposphere coupling during extreme values of the stratospheric planetary wave heat flux in Northern Hemisphere winter in both reanalysis and CMIP5 models. Here an idealized AGCM is used to investigate the dynamics of extreme total (climatology plus anomaly) negative wave-1 stratospheric heat flux events. The evolution of the reanalysis events and their coupling to the troposphere is qualitatively reproduced with modifications to the standard Gerber and Polvani (2009) model setup linked to the stratospheric shear.

Ensemble spectral nudging experiments are performed to test whether planetary wave reflection can explain the dynamics of the events. The experiments isolate the components of the circulation that reproduce the free running events by nudging to the evolution of the circulation from the events themselves. The events are partially reproduced when simultaneously nudging the reflective layer via the stratospheric zonal-mean flow and the wave source via the tropospheric wave-1 whereas weak responses are found when nudging either independently. The events are almost entirely reproduced when nudging both the tropospheric wave-1 and higher planetary wavenumbers in the stratosphere.

Two possible pathways in which higher planetary wavenumbers could produce the events are investigated: 1) modification of the stratospheric zonal-mean flow producing wave reflection and 2) direct non-linear wave-wave interaction. Preliminary experiments separating the pathways suggest both may play a role. Evidence supporting the role of higher wavenumbers during reanalysis events is also shown. Finally cross-spectral correlation analysis is used to support the role of planetary wave reflection during the model and reanalysis events.

Keywords: stratosphere-troposphere coupling, planetary waves, negative heat flux, wave reflection

ML-ST-02

ACCURATE CALCULATION OF THE LINEAR RESPONSE FUNCTION OF AN IDEALIZED ATMOSPHERE: GREEN'S FUNCTIONS VERSUS FLUCTUATION-DISSIPATION THEOREM

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The linear response function (LRF), M, relates the response, x, of a nonlinear system, such as the atmosphere, to weak external forcings, f, and tendencies, x_t, via x_t= M x + f. Knowing the LRF of GCMs helps with better understanding their internal variability and climate-change response. However, even for simple GCMs, the LRF cannot be calculated from first principles due to the lack of a complete theory for eddy-mean flow feedbacks.

We have calculated the LRF of the dry dynamical core with Held-Suarez physics by applying a sufficiently complete set of localized weak forcings, one at a time, to the GCM and calculating the time-mean responses. The LRF is then computed through matrix inversion. Tests demonstrate that the LRF is sufficiently accurate for a number of applications, and its spectral analysis reveals interesting information about the model's internal variability. An eddy flux matrix (EFM), which determines the eddy flux responses to mean-flow changes, is also calculated. The LRF and EFM have been recently used to probe the causality in the relationship between blocking variability and Arctic Oscillation, and to quantify the eddy feedbacks in the annular mode dynamics. Furthermore, this Green's functions framework can be readily employed to compute the LRF of more complex GCMs.

Another common approach to calculating the LRF of GCMs is the Fluctuation-Dissipation Theorem (FDT), which has produced mixed results in the previous studies, while the reason(s) behind the poor performance of the FDT remains unclear. We have found that the FDT also produced mixed results when applied to the aforementioned GCM. The accurate LRF (calculated using Green's functions) is used to show that dimension-reduction by projecting the data onto leading EOFs, which is commonly used for FDT, can alone be a significant source of error. Further analysis demonstrates that this error arises because of the non-normality of the operator. These results suggest that errors caused by dimension-reduction are a major, if not the main, contributor to the poor performance of the LRFs calculated using FDT.

Keywords: dry dynamical core, linear response function, eddy-mean flow feedback, internal variability, Fluctuation-Dissipation Theorem

ML-ST-03

THE IMPACT OF TROPICAL HEATING ON THE TROPOSPHERIC RESPONSE TO STRATOSPHERIC SUDDEN WARMINGS

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Imposing large-scale tropical heating in a Polvani-Kushner-like setup of a dry-dynamical core is found to nearly double the amplitude of tropospheric wind anomalies in the aftermath of stratospheric sudden warmings, despite only weak changes in the strength of the stratospheric anomalies associated with the warmings.

In contrast to our expectations, further experiments reveal that the enhanced sensitivity is associated not with stationary wave field produced by the zonally asymmetric heating, but with the subtler basic state changes associated with the symmetric component of the heating. Moreover, the enhanced sensitivity is not a result of stronger tropospheric feedbacks. The sensitivity arises instead from the stronger effective forcing of the stratospheric anomalies on the tropospheric jet via the stationary wave field.

This supports the conclusions of a number of recent studies with models of varying degrees of complexity, which highlight the importance of the stationary wave field for coupling the stratosphere and troposphere. However, it also raises a more general challenge for such simplified modeling studies that the dynamical processes underlying stratosphere-troposphere coupling appear to be very sensitive to the basic state.

Keywords: Stratospheric sudden warmings, dry-dynamical core, stationary waves

ML-ST-04

HYPOHYDROSTATIC CONVECTION ON A BAROCLINIC F-PLANE

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The hypohydrostatic rescaling is implemented to better resolve convection in a limited-area model of moist baroclinic life cycles and evaluated against cloud-permitting simulations. Proposed as a computational method to reduce the scale separation between convection and the large-scale circulation, the hypohydrostatic rescaling has been used to replace convective parameterizations in several modeling studies of phenomena dominated by convection. In this study, the influence of the rescaling is examined in an f-plane channel model forced by a constant baroclinic sea surface temperature and fully interactive radiation. A suite of experiments is performed spanning a range of rescaling parameters and grid spacings such that convection is resolved to different degrees. As the rescaling parameter increases, the strongest convective cells are found to widen and slow down. The widened cells are better resolved and exhibit a similarity relationship to those in unscaled cloud-permitting simulations. The total precipitation is found to be independent of the rescaling parameter and is constrained by radiative cooling. For experiments having a grid spacing typical of global models, a large rescaling parameter, as predicted by the similarity theory, is required to resolve convection, but the severe slowdown of convection introduces a bias in the baroclinicity. The results suggest that the hypohydrostatic rescaling may not be useful on a coarse grid where convection is not the most important process.

Keywords: Hypohydrostatic rescaling, baroclinic life cycles, convective parameterization

ML-ST-05

IN-DEPTH ASSESSMENTS OF DYNAMICAL PHENOMENA VIA AN ENSEMBLE OF IDEALIZED DYNAMICAL CORES

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and the DCMIP-2016 organizers and modeling mentors

A broad spectrum of dynamical phenomena, such as tropical cyclones, gravity waves, baroclinic waves, Sudden Stratospheric Warmings (SSWs) or the Quasi-Biennial Oscillation (QBO) in the stratosphere, can already be simulated and analyzed in very idealized configurations of General Circulation Models (GCMs). In particular, dry and moist-idealized dynamical cores (the fluid dynamics component of GCMs) can already reveal the key interactions between waves and the mean flow, wave generation mechanisms, and the principles behind growing or propagating flow disturbances. These idealized model experiments capture the physical foundations of the more complex processes in nature, and thereby provide an in-depth assessment of their causes and effects. This gives an easier access to an improved understanding of the dynamical system which is a key motivation for the utilization of model hierarchies. Furthermore, idealized dynamical core configurations can also be used for model intercomparisons. This second aspect reveals the impact of the numerical GCM designs on the physical phenomena which is, most often, underappreciated.

The paper will highlight these two aspects. A variety of test cases from the recent Dynamical Core Model Intercomparison Project (DCMIP-2016) and a moist (aqua-planet) variant of the Held-Suarez test will be briefly introduced. In particular, these test cases demonstrate how ensembles of dry and moist-idealized dynamical core simulations can be used to inform the development of more complex modeling systems and provide information about the physics-dynamics coupling. Selected examples of tropical cyclone, baroclinic wave, SSW and QBO-like simulations from a broad range of models will be analyzed. This sheds light on the power of idealized GCMs and provides uncertainty estimates.

Keywords: Dynamical core intercomparisons, numerical designs, idealized test cases, dynamics, tropical cyclones

ML-ST-06

THE RESPONSE OF THE ARCTIC STRATOSPHERE TO FUTURE WARMING IN A SUPER-PARAMETERIZED MODEL

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Current models predict a wide range of future Sudden Stratospheric Warming (SSW) frequency trends and of lower stratosphere temperature trends over the Arctic in a future warming scenario. To understand the relevant dynamical feedbacks, a hierarchy of models, from models based on a dry dynamical core to fully coupled super-parameterized (SP) stratospheric-enabled GCM, is used to investigate the response of the Arctic stratosphere and of SSW to global warming. The use of an SP model which is able to better represent tropospheric convective variability, allows to study the interaction between such variability in a changing climate and the stratospheric circulation and variability that is indirectly affected by it.

Keywords: SSW, Simple model, SPCAM, MJO, global warming

ML-ST-07

EXPERIMENTAL SEASONAL FORECASTS OF MID-LATITUDE SNOWPACK

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Water resources in mountainous regions in the mid-latitudes rely heavily upon mountain snowpack for water storage and spring through fall water supply via snowmelt runoff when precipitation is otherwise scarce. Seasonal forecasts of snowpack would be extremely valuable to society, but have so far eluded us. We will explore the model hierarchies required to develop seasonal forecasts of mid-latitude snowpack. In particular, we will show the relative contributions of resolution, initialization and atmospheric state for improving prediction skill.

Keywords: snow, prediction, seasonal, resolution, water

ML-ST-08

EDDY ACTIVITY SENSITIVITY TO THE VERTICAL STRUCTURE OF BAROCLINICITY: FROM LINEAR THEORY TO IDEALIZED GCMS AND CLIMATE PREDICTIONS

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One of the most robust predictions of greenhouse warming simulations is that the equator-to-pole temperature difference will decrease at the lower levels of the troposphere, while it will increase at the higher levels. Linear theory of baroclinic instability predicts how the growth rate of instabilities is related to a meridional temperature gradient that is constant with height, but it does not predict how the growth rate is affected by a meridional temperature gradient that varies with height. Using a hierarchy of idealized GCM simulations with different methods to control the final mean temperature distribution, we investigate the effect of the meridional temperature gradient, at different levels, on eddy characteristics. We find that an increased upper tropospheric temperature gradient causes a significant increase in eddy kinetic energy (EKE), eddy fluxes and as a consequence also surface winds. It is suggested that the larger eddy sensitivity to the upper-tropospheric temperature gradient is a consequence of large baroclinicity concentrated in upper levels. This result is consistent with a 1D Eady-like model with nonuniform shear showing more sensitivity to shear changes in regions of larger baroclinicity. In some cases, an increased temperature gradient at lower-tropospheric levels might decrease the EKE, and it is demonstrated that this might be related to the midwinter minimum in EKE observed above the northern Pacific. Finally, through systematic variations of the vertical structure of the lapse rate and meridional temperature gradient we investigate the relations between the mean available potential energy, EKE and eddy fluxes. We find that the linear relationships between these quantities found when considering them vertically integrated are significantly altered when considering their vertical structure. These results might have significant implications in a global warming scenario when the vertical structure of baroclinicity is expected to vary.

Keywords: Eddy kinetic energy, Baroclinicity, global warming, storm tracks, idealized GCM

ML-ST-09

THE CONTRIBUTION OF OCEAN DYNAMICS TO INTER-ANNUAL NORTH ATLANTIC CLIMATE VARIABILITY

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Variability in the North Atlantic basin is a major feature of the global climate; oscillations in this region can influence weather across North America and Eurasia. Recent work suggests that multi-decadal variability in this basin may be an expression of atmospheric noise, rather a direct response to changing ocean currents. The North Atlantic Oscillation (NAO) describes one mode of variability in this basin. The literature considers the NAO to be primarily driven by dynamical processes inherent to the atmosphere. We will evaluate this hypothesis using a hierarchy of climate models, extending from a general circulation model (GCM) over a slab-ocean aquaplanet to a fully-coupled atmosphere-ocean GCM. This approach will allow us to identify and isolate the precise role the ocean plays, if any, in modulating the NAO. Further, this paper will demonstrate the utility of model hierarchies for understanding modes of climate variability.

Keywords: NAO; Variability; Aquaplanet

ML-ST-10

EXPLORING CHANGES IN THE HYDROCLIMATE OF WESTERN NORTH AMERICA SINCE THE LAST GLACIAL MAXIMUM

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Paleoclimate reconstructions from western North America show that the region's hydroclimate was starkly different than the present during the last glacial maximum, and considerable changes occurred during the last deglaciation. The Pacific Northwest was largely dry, while southwestern North America, particularly in the Great Basin, supported large pluvial lakes that quickly disappeared around 15,000 years ago. These reconstructed changes have largely been attributed to changes in precipitation due to shifts in the positions of the polar jet stream and the storm track over the eastern North Pacific, forced at least in part by massive North American ice sheets. But the mechanisms that caused large changes in moisture transport and delivery to the continent, as well as the timing and pacing of changes, remain unresolved. We investigate the relationships between the westerly jet, the storm track, atmospheric moisture transport, and precipitiation relevant to the region in a suite of models. A principal complication for simulations of these mechanisms is the large span of timescales involved in these processes. In order to explore the millennial evolution of the climate, we analyze output from a transient forcing, synchronously coupled atmosphere-ocean model of the last 22,000 years (Trace21k) at modest resolution; we explore the robustness of simulated circulation changes at important intervals using the suite of coupled models participating in the Paleoclimate Model Intercomparison Project phase 3 (PMIP3) experiments; and we further explore differences in synoptic systems affecting moisture transport with high-frequency output from two sets of simulations using the atmospheric model LMDZ. In combination, and through detailed comparisons to proxy reconstructions, we aim to use this modeling suite to understand the dominant processes and changes that affect the hydroclimate of western North America in an evolving global climate.

Keywords: Paleoclimate

ML-ST-11

THE DYNAMICAL CONSTRAINT ON THE MID-LATITUDE HYDROLOGICAL EXTREMES IN AN AQUAPLANET AGCM AND THEIR RESPONSE TO GLOBAL WARMING

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A series of idealized aquaplanet simulations are conducted with the MPAS AGCM at different horizontal resolutions and under a uniform SST warming to investigate the response of the hydrological extremes and their meridional distribution to climate warming. A budget for a measure of the hydrological extremeness is constructed based on the finite-amplitude wave activity for the column water vapor. The resultant metrics for the hydrological extremes in a Lagrangian mean sense become normally distributed and more amenable to scaling. Within the budget framework, the eddy moisture flux across the water vapor isosurface can be mathematically expressed as a down-gradient diffusive flux with the diffusivity scaled as the product of the square root of eddy kinetic energy and the wave activity. It is found that the structure of the eddy stirring is the most dominant factor in determining the meridional distribution of the hydrological extremes, such as atmospheric rivers. Furthermore, the change in the normalized equivalent length, a measure for mixing efficiency, is the leading factor in determining where the hydrological extremes increase the most under the SST warming.

Keywords: hydrological extremes, atmospheric rivers, storm track, global warming, aquaplanet AGCM

ML-ST-12

THE RESPONSES OF IDEALIZED ATMOSPHERIC MODELS TO OROGRAPHIC FORCING

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Our understanding of stationary waves starts with linear theory and then passes through a sequence of increasingly more complex models on the way to the observed quasi-stationary wave patterns. An important step on this path is isolating the linear responses of general circulation models (GCMs) to zonally-asymmetric forcings and then understanding how these responses breaks down. Here we compare the linear and non-linear responses of an idealized, dry GCM to large-scale orographic forcing under two different settings: the standard Held-Suarez set-up and a second set-up that produces a climate similar to observed northern hemisphere winter conditions. These two model states produce very different responses, both in their linear regimes and in their non-linear regimes. In the linear regime the model's responses can generally be reproduced by a barotropic model on a sphere, and predicted by the barotropic index of refraction, suggesting that the linear response is mostly governed by linear barotropic dynamics. However, although the response of the barotropic model undergoes a similar transition to the GCM as the orographic forcing is increased, the underlying dynamics appear to be different. As such, the GCM responses are compared with a stationary wave model in an attempt to identify what is responsible for the breakdown of the linear response in the two cases.

Keywords: Stationary waves, linear response, barotropic dynamics

ML-ST-13

THE STRATOSPHERIC RESIDUAL CIRCULATION RESPONSE TO DIABATIC HEATING

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The residual circulation of the stratosphere is a meridional overturning circulation characterized by tropical upwelling and high latitude downwelling. The residual circulation is wave-driven, so its strength relates to mid-latitude baroclinic instability and the wintertime stratospheric polar vortices. The residual circulation can be represented in a range of modeling complexities, from simplified linear models to fully-coupled Earth system models. While fully-coupled climate model simulations agree on certain aspects of the residual circulation response to diabatic heating, such as its predicted strengthening with greenhouse gas warming, models and theory disagree on other aspects of the residual circulation response to diabatic heating, such as the response to diabatic heating following the eruption of Mt. Pinatubo. Here, we use a hierarchy of models to explore the response of the residual circulation to idealized diabatic heating perturbations. We investigate how changes in the background temperature and radiative damping affect the basic state and variability of the residual circulation in idealized simulations, and apply these insights to interpret fully-coupled model results and observations. We use the Newtonian cooling approximation, which parameterizes diabatic heating as a temperature relaxation to some equilibrium temperature, as a bridge to connect results from dry dynamical core simulations with results from fully-coupled model simulations.

Keywords: stratosphere, upwelling, residual circulation, aerosol

ML-ST-14

A FAMILY OF GCM OF INCREASING COMPLEXITY AND SOPHISTICATION

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The development of General Circulation Models has led in the last ten years to the emergence of a generation of models of increasing complexity and scope. The GCM have become component of Earth system models that include detailed mathematical models of chemical and biological processes, with the main thrust aimed at the inclusiveness of most of the processes that were thought to be relevant to climate and the determination of its impacts. However, the wide scope of the potential applications and the emerging pervasiveness of the climate variability as a main regulator of hugely important human activities has pointed to the the need for more nimble and flexible models. Such models could be more closely tailored to specific problems and investigations. We present here a family of NCAR atmospheric GCMs such that we take full advantage of the advances in dynamical cores and software engineering realised in the past years to design a hierarchy of models with coherent physical parameterisation of different complexity and completeness within the CESM infrastructure. Early results and performance are evaluated.

Keywords: GCM, CESM,

ML-ST-15

THE IMPACT OF HORIZONTAL RESOLUTION ON NORTH AMERICAN MONSOON GULF OF CALIFORNIA MOISTURE SURGES IN A SUITE OF COUPLED GLOBAL CLIMATE MODELS

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We explore the impact of atmosphere and ocean horizontal resolution on the climatology of North American Monsoon Gulf of California (GoC) moisture surges in a suite of global circulation models (CM2.1, FLOR, CM2.5, CM2.6, HiFLOR) developed at the Geophysical Fluid Dynamics Laboratory (GFDL). These models feature the same physical parameterizations, but differ in horizontal resolution in either the atmosphere (200, 50 and 25 km) or the ocean (1, 0.25, 0.1 degree). Increasing horizontal atmospheric resolution from 200 km to 50 km results in a drastic improvement in the model's capability of accurately simulating surge events. The climatological near-surface flow, moisture and precipitation anomalies associated with GoC surges are overall satisfactorily simulated in all higher-resolution models. The number of surge events agrees well with reanalyses but models tend to underestimate July-August surge-related precipitation and overestimate surge-related September rainfall in the southwestern United States. Large-scale controls supporting the development of GoC surges such as tropical easterly waves (TEWs), tropical cyclones (TCs) and trans-Pacific Rossby wave trains (RWTs), are also well captured, although models tend to underestimate the TEW/TC magnitude or number. Near-surface GoC surge features and their large-scale forcings (TEWs, TCs, RWTs) do not appear to be substantially affected by a finer representation of the GoC at higher ocean resolution. The substantial reduction of the warm eastern Pacific sea surface temperature bias through flux-adjustment in the FLOR model leads to an overall improvement of tropical-extratropical controls on the GoC moisture surges and the seasonal cycle of precipitation in the southwestern United States.

Keywords: Gulf surges, tropical-extratropical interaction, North American Monsoon

ML-ST-16

WHAT CANMOIST THERMODYNAMICS TELL US ABOUT CIRCULATION SHIFTS IN RESPONSE TO UNIFORM WARMING?

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Aquaplanet simulations exhibit a robust expansion of the Hadley cell and poleward jet shift in response to uniform warming of sea surface temperature. Here moist thermodynamic and dynamic frameworks are combined to make predictions of circulation responses to warming. We show Clausius-Clapeyron (CC) scaling of specific humidity with warming predicts an expansion of the Hadley circulation according to convective quasi-equilibrium dynamics. A poleward jet shift follows from the control climate relationship between the Hadley cell edge and jet stream position. CC scaling of specific humidity with warming also predicts decreased diffusivity and a poleward shift of the latitude of maximum latent and dry static energy transport according to mixing-length theory. Finally, atmospheric cloud radiative changes shift the latitude of maximum energy transport poleward in most models. Our results show moist thermodynamics can predict meridional shifts of the circulation when combined with dynamical frameworks; however, additional feedbacks are important for the simulated response. The connections across a range of Atmosphere General Circulation Models and Atmosphere-Ocean General Circulation Models will also be discussed.

Keywords: climate dynamics, moist thermodynamics

ML-ST-17

PROPAGATING ANNULAR MODES

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The leading "annular mode"— usually defined as the dominant EOF of surface pressure or of zonal mean zonal wind variability — appears as a dipolar structure straddling the mean midlatitude jet and thus seems to describe north-south wobbling of the jet latitude. However, it has long been recognized that extratropical zonal wind anomalies tend to migrate poleward, rather than simply rocking back and forth around the mean jet. Taken in isolation, EOF1 describes a north-south wobbling of the jet position, while EOF2 describes a strengthening and narrowing of the jet. However, despite the fact that they are spatially orthogonal, and their corresponding time series temporally orthogonal, EOFs1 and 2 are not independent, but show significant lag-correlations which reveal the poleward propagation.

The EOFs are not modes of the underlying dynamical system governing the zonal flow evolution. The true modes can be estimated using principal oscillation pattern (POP) analysis. We use a combination of idealized experiments and reanalysis to show that under certain circumstances, the leading POPs manifest themselves as a pair of complex conjugate structures with conjugate eigenvalues thus, in reality, constituting a single, complex, mode that describes poleward propagating anomalies.

If one interprets the annular modes as the modes of the system, then simple theory predicts that the response to steady forcing will usually be dominated by EOF1, typically the mode with the longest time scale. However, such arguments should really be applied to the true modes and, in situations where the leading POPs form a conjugate pair, there is only one relevant time scale. Idealized experiments show that climate responses can take the form of either EOF1 or 2, and more generally a combination of both.

Keywords: annular modes, idealized models, midlatitude jet and storm tracks

ML-ST-18

THE ROLE OF PLANETARY WAVES IN THE TROPOSPHERIC JET RESPONSE TO STRATOSPHERIC COOLING

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An idealized general circulation model is used to assess the importance of planetary-scale waves in determining the position of the tropospheric jet, specifically its tendency to shift poleward as winter stratospheric cooling is increased. Full model integrations are compared against integrations in which planetary waves are truncated in the zonal direction, and only synoptic-scale waves are retained. Two series of truncated integrations are considered, using (i) a modified radiative equilibrium temperature or (ii) a nudged-bias correction technique. Both produce tropospheric climatologies that are similar to the full model when stratospheric cooling is weak. When stratospheric cooling is increased, the results indicate that the interaction between planetary- and synoptic-scale waves plays a key role in determining the structure of the tropospheric mean flow response. In particular, the results appear to rule out the possibility that the jet shift results from the direct modification of the tropospheric synoptic waves by mean flow changes in the stratosphere, even though the latter would be expected to have a nonlocal effect on waves throughout the depth of the atmosphere.

Keywords: stratosphere-troposphere coupling, planetary waves, idealized modeling

ML-ST-19

THE IMPACT OF ANOMALOUS OCEAN HEAT TRANSPORT ON SEASONAL PREDICTABILITY IN AN IDEALIZED MODEL

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A high priority for many modelling centres is increasing predictability on seasonal timescales, and some progress is being made. However, identifying and understanding the key mechanisms that might give rise to increased seasonal predictability, and separating robust signals from the noise, can be difficult in comprehensive models because of their overwhelming complexity. In this study we investigate problems of seasonal predictability and teleconnections within an idealised modelling framework, focussing on the impact of anomalous ocean heat transport on the summer storm tracks.

To do this we use an idealized atmospheric model with simplified continents and a radiation scheme that includes the radiative feedback of water vapour but has no clouds. By including this radiation scheme, the stratosphere is reasonably well resolved. Anomalous ocean heat transport is created in the model's slab ocean using localised q-fluxes.

To address questions of seasonal predictability, the amplitude of the anomalous ocean heat transport is varied in time, being non-zero in one season per year. The impact of the anomalous transport on subsequent seasons is diagnosed by comparing results from these experiments with a control experiment. Preliminary results indicate that anomalous ocean heat transport in spring can impact the storm tracks in summer, but that changing the latitude and longitude of the anomalous transport changes its impact. The mechanisms behind these different impacts will be discussed, including both tropospheric and stratospheric processes.

Keywords: Storm tracks, Summer, SST

ML-ST-20

THE ROLE OF DIABATIC HEATING ON THE CO-VARIABILITY OF FINITE-AMPLITUDE WAVE ACTIVITY AND ZONAL INDEX

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Water vapor profoundly shapes our basic climate and its response to climate forcings. In mid-latitude troposphere, the radiative forcing from water vapor is roughly one third of the total solar radiation received at the ground. Idealized atmospheric dry models parameterize the radiation effects by linearly relaxing the temperature profile toward a "radiative equilibrium state" profile (Held and Surarez 1994). However, such a dry model lacks an important interactive diabatic heating that is due to the condensation of water vapor. On synoptic timescale, diabatic heatings in fact strongly interact with the dry dynamics, shaping up a very different co-variability of atmospheric waves and mean flow compared to that in a dry model. The co-variability's intrinsic timescale is an important indicator for estimating climate sensitivity. The observed decorrelation timescale of Annular Mode is substantially smaller than that in a dry atmosphere, hinting a possible negative feedback may exist in a moist atmosphere. In this presentation, we will introduce a new zonal momentum - finite-amplitude wave activity framework, in which the role of diabatic heating is explicitly incorporated and accurately quantified. We will demonstrate a robust negative diabatic eddy feedback to the zonal index in a hierarchy of idealized GCMs. This negative feedback is achieved through the changes in finite-amplitude wave activity. We will discuss this negative feedback's possible role in the magnitude of the jet shift in a warming climate by extracting the interactive diabatic eddy feedback from a grey-radiation AGCM (Frierson et al. 2006).

Keywords: Finite-amplitude Wave Activity; Water Vapor; Eddy Feedback; Grey-Radiation model; Annular Mode

ML-ST-21

RESPONSE OF NORTHERN HEMISPHERE MIDLATITUDE CIRCULATION TO ARCTIC AMPLIFICATION IN A SIMPLE ATMOSPHERIC GENERAL CIRCULATION MODEL

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There is an increasing body of observational and modeling evidence that Arctic Amplification (AA) might strongly impact both the weather and climate, not only in the Arctic region, but also remotely in Northern Hemisphere midlatitudes. However, discrepancies in atmospheric circulation response exist among different model integrations.

To investigate the robust circulation response in both the troposphere and stratosphere, we make use of a dry primitive equation model with a simple representation of the stratospheric polar vortex and a realistic topography. We find that, with an imposed heating over the Arctic, the tropospheric jet shifts equatorward and the stratospheric polar vortex weakens, which is in good agreement with previous studies. Despite the weakening of the stratospheric polar vortex, we find no statistically significant change in the frequency of sudden stratospheric warming events.

Furthermore, in addition to the tropospheric pathway, previous studies also suggest an important role of the stratospheric pathway in linking the AA to the midlatitude circulation that involves upward wave propagation from the surface into the stratosphere and later downward migration from the stratosphere back to the troposphere and surface. However, there has been no explicit quantification of the relative importance of the stratospheric pathway. In this study, to explicitly separate the tropospheric and stratospheric pathway, we isolate the tropospheric pathway by nudging the stratospheric zonal mean state towards the reference state. With the nudging method and thus an inactive stratosphere, in response to AA, the tropospheric jet is still found to shift equatorward, but by only about half the magnitude compared to that of an active stratosphere. The difference represents the stratospheric pathway and the downward influence from the stratosphere on the troposphere. This suggests that the stratospheric pathway, or stratosphere-troposphere coupling plays a non-negligible role in establishing the midlatitude circulation response to AA.

ML-ST-22

SIMULATIONS AND PROJECTIONS OF EXTRATROPICAL STORMS IN COUPLED MODELS WITH DIFFERENT MODEL RESOLUTIONS

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Extratropical storms (ETS) play important roles in momentum and heat transports in climate system, and variations of ETS could drive extreme weather/climate events, thus ETS is essential for climate projections and climate predictions. We will explore the model fidelity of ETS in terms of climatology and variability in a suite of coupled models with different horizontal resolutions for the current climate. We will discuss the sensitivity of ETS response to global warming with respect to model resolutions.

Keywords: Extratropical storms, projection

MIDLATITUDES/STRAT-TROP INTERACTIONS

ML-ST-23

PACIFIC MIDWINTER MINIMUM IN A ZONALLY SYMMETRIC GCM

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Linear theories of baroclinic instability contributed significantly to the understanding of synoptic-scale storms in the midlatitudes. These linear theories, provided a scaling which relates between the mean climate state and climatological eddy magnitudes. Despite the success of linear theory to explain many phenomena in midlatitudes, the midwinter minimum of the Pacific storm tracks in the northern hemisphere remains a remarkable example of the failure of the linear theory to give a correct prediction to the relation between the mean state and eddies. We show that a zonally symmetric idealized dry GCM, has the sufficient complexity to reproduce a midwinter minimum, and zonal asymmetries or moisture are not a necessary ingredient for the presence of the minimum.

We use an idealized general circulation model with a modified Newtonian relaxation scheme. The scheme uses a short relaxation time for the zonal mean state, and a much longer relaxation time for eddies. This allows reproducing the mean temperature profile above the Pacific from reanalysis data in zonally symmetric simulations. Simulating the temperature distributions in different months above the Pacific along the year, we show that a zonal symmetric model with realistic temperature distribution can reproduce a minimum in the eddy kinetic energy which resembles the observations. Furthermore, we show that these results are consistent also when an iterative method to control the final mean temperature distribution of an idealized general circulation simulation is applied with same relaxation time for the mean and eddy fields. The results of this study imply that the mean temperature above the northern Pacific is a key factor in the presence of the midwinter minimum.

Keywords: Pacific midwinter minimum, eddies,

ENSO/COUPLED MODES OF VARIABILITY/OCEANS/CARBON CYCLE

ENSO-01

SENSITIVITY OF ENSO TO GLOBAL WARMING IN AN INTERMEDIATE COMPLEXITY OCEAN-ATMOSPHERE COUPLED MODEL.

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One of the main effects of global warming onto the tropical oceans consists in an increased vertical stratification owned to the stronger warming of the surface layer than the subthermocline particularly in the western-central Pacific. This has the potential to impact ENSO (El Niño Southern Oscillation) through both changes in wave dynamics and thermodynamical processes within the mixed-layer (i.e. thermocline and zonal advective feedbacks, thermal damping). Here we used a modified version of the Cane&Zebiak model that considers realistic mean thermocline profile to investigate the sensitivity of ENSO characteristics to mean stratification changes that mimic those of the multi-model ensemble of the Climate Model Intercomparison Project (CMIP) under anthropogenic forcing. Within realistic values of model parameters for which the model is unstable, the increased in stratification leads to a change in statistics of ENSO regimes, i.e. a tendency of the model to simulate more frequent central Pacific El Niño events with larger amplitude. A heat-budget analysis indicates that the change in ENSO diversity can be understood in terms of the increased contribution of both the thermocline and zonal advective feedbacks in the western Pacific, and the changes in the characteristics of the recharge-discharge process. Additional sensitivity experiments consist in further prescribing either the radiative heating due to the greenhouse effect as obtained from the multi-model ensemble of CMIP or the climatological sea surface temperature (SST) of the future climate. While the former tends to destabilise ENSO through increase in the zonal dipole pattern of SST, the latter is influential on the non-linear relationship between SST anomalies and surface winds (i.e. non-linear Bjerknes feedbacks), which also favors the strong El Niño regime. The results are discussed in light of recent ENSO studies from CMIP models.

Keywords: ENSO diversity, climate change, ICM

ENSO-02

ROLES FOR THE OCEAN MESOSCALE IN CLIMATE AND CLIMATE IMPACTS: INSIGHTS FROM A HIERARCHY OF CLIMATE MODELS

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A long-standing question in climate science concerns the role of mesoscale ocean currents in regional and global climate and climate impacts. This question is examined through analysis of the CM2-O suite of GFDL climate models, which includes 0.1, 0.25, and 1-degree ocean resolutions. We highlight questions related to (A) meridional and vertical transport of heat by mean and transient eddies, with relevance to climate model drift and ocean heat uptake; (B) role of ocean eddies for climate sensitivity; (C) boundary currents and their role in climate change impacts on fisheries and sea level; (D) the transfer of surface ocean energy through frequency space, with relevance to understanding time scales for climate variations; (E) the role of transient eddy variability on setting time scales for transport pathways in the ocean interior. We suggest that some aspects of ocean mesoscale features may be suitably parameterized at non-eddying or partially eddying resolutions, whereas other aspects may only be explicitly represented rather than parameterized.

Keywords: ocean mesoscale dynamics, climate

ENSO-03

OCEANIC CONTROL OF MULTIDECADAL VARIABILITY IN THE NORTH ATLANTIC

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The origin of multidecadal variability in the North Atlantic ("AMO, "AMV") has not yet been settled, and a wide range of hypothesis have been proposed in various coupled model simulations but none allow a straightforward comparison or validation with (maybe too short) observations.

On the other hand, multidecadal variability appears spontaneously in idealized ocean simulations forced by prescribed surface buoyancy flux, through baroclinically-unstable Rossby waves. Such mechanism was also found in more realistic North Atlantic configurations (OPA ORCA2°), with and without eddies, with and without atmospheric coupling. The signature of this mode in the more realistic simulations is comparable to the signature of the AMO in the observations, as far as it can be identified and distinguished from global warming.

We review several results from the most idealized studies to the more realistic in ocean and coupled GCMs to support the relevance of such a mechanism for the Atlantic Multidecadal Oscillation.

ENSO-04

ASSESSING THE LEGACY EFFECTS OF CLIMATE CHANGE WITH REVERSIBILITY SCENARIOS

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Our oceans are key regulators of the Earth's climate and marine ecosystems provide highly-valued socio-economic services. Anthropogenic climate change has already impacted the ocean and earth system models project continued alteration under future carbon emissions scenarios. This has spurred consideration of diverse climate change mitigation strategies. Very little is known, however, about what would happen to our ocean under mitigation.

The utility of idealized greenhouse gas reversibility scenarios to investigate processes driving responses under mitigation was demonstrated in a recent study by John et al. (2015), which showed that legacy effects of climate change continue even as mitigation is implemented under a reversal of the RCP8.5 scenario. Results will be presented from a multi-model reversibility intercomparison to assess and quantify the range of uncertainty in an idealized RCP8.5 mitigation projection. Results from an idealized 1% to 4xCO2 reversal will also be discussed to assess whether an even simpler model in the model hierarchy can produce comparable responses to the RCP8.5 reversal. As mitigation discussions come to the forefront, idealized reversibility model simulations will be useful for process understanding and impact studies.

Keywords: reversibility, mitigation, biogeochemical cycles, processes and modeling

ENSO-05

UNDERSTANDING AND REPRESENTING THE ROLE OF OCEAN MIXING IN THE CLIMATE SYSTEM THROUGH USE OF A HIERARCHY OF MODELS.

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Several recent climate process teams have brought together developers of CMIP models with observationalists, process modelers and theoreticians to develop improved parameterizations of ocean mixing processes, such as gravity current entrainment and internal wave breaking. Model hierarchies are an important component of these teams, bridging the gaps between observations and theory, and between observations and climate model simulations, and allowing parameterizations to be tested and calibrated in isolation. Simplified experiments with global models allow the sensitivity of the simulated flow to the parameterized process to be explored. We will present examples of successful use of model hierarchies for developing representations of ocean mixing in climate models, and understanding the impact of these processes on the large scale climate.

Keywords: ocean mixing

ENSO-06

DISENTANGLING NATURAL AND ANTHROPOGENIC CONTROLS ON VEGETATION GROWTH TRENDS

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We use multiple estimates from remote sensing-based datasets and simulations from earth system models, and one statistical framework to attribute the enhanced northern-extratropical latitudes vegetation growth during the past three decades. Our findings reveal that the observed vegetation activity is consistent with the simulations with anthropogenic forcings, where the greenhouse gases forcing plays a dominant role, but not with that expected from internal climate variability and natural forcings only. This study provides clear evidence of a discernible human fingerprint on large-scale terrestrial vegetation dynamics.

Keywords: detection and attribution, earth system models, human impacts, and vegetation growth

ENSO-07

A SIMPLE CONCEPTUAL MODEL TO INTERPRET THE 20TH CENTURY GLOBAL MEAN SEA LEVEL RISE IN COMPREHENSIVE CLIMATE MODELS

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In this study, we develop a simple conceptual model on the basis of Earth energy balance models to interpret the 20th century GMSL rise as modeled by comprehensive CMIP5 climate models . We show that climate models estimates of the 20th century GMSL rise is the sum of the GMTSL rise which linearly depends on the time-integrated radiative forcing F (under continuously increasing radiative forcing), and the Glaciers Mass Loss (GML) which shows both a long term response to the little ice age and a short term response to the time-integrated F . The constant of proportionality between the GMTSL rise and the time integrated F (nu) expresses the transient thermosteric sea level response of the climate system and the constant of proportionality between glaciers mass loss and the time integrated F (lambda) expresses the glaciers sensitivity to climate change. nu depends on the fraction of earth energy imbalance stored in the ocean, the expansion efficiency of heat, the climate feedback parameter and the ocean heat uptake efficiency. lambda depends on the fraction of the earth energy imbalance stored in glaciers, the climate feedback parameter and the ocean heat uptake efficiency.

An interesting outcome of this study is that we can quantify with the conceptual model the causes of the across CMIP5 model spread in GMSL rise. The across-model spread in climate feedback parameter and ocean heat uptake efficiency explains most of the across-model spread in GMSL rise over the 20th century, while the across-model spread in time-integrated F explains the rest. The comparison of climate models estimate of the 20th century GMSL rise with observations shows that the model-ensemble mean is within the uncertainty of observations but the model ensemble spread is much larger than the observations uncertainty. The conceptual model suggest that observations of the 20th century GMSL and GMTSL rise could give a constraint on climate model estimates of the GMSL and further give a constraint on the transient climate response of climate models.

Keywords: sea level earth energy balance

ENSO-08

SPATIAL PATTERNS AND FREQUENCY OF UNFORCED DECADAL-SCALE CHANGES IN GLOBAL MEAN SURFACE TEMPERATURE IN CLIMATE MODELS

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The causes of decadal time-scale variations in global mean temperature are currently under debate. Proposed mechanisms include both processes internal to the climate system as well as external forcing. Here, we examine the robustness of spatial and timescale characteristics of unforced (internal) decadal variability among Comparison Model Intercomparison Project Phase 5 (CMIP5) preindustrial control runs. We find that almost all CMIP5 models produce an Interdecadal Pacific Oscillation-like pattern associated with decadal variability, but the frequency of decadal-scale change is model-dependent. To assess the roles of atmosphere and ocean dynamics in producing decadal variability, we compare two preindustrial control Community Climate System model (version 4) configurations: one with coupling to a slab ocean and the other fully coupled to a dynamical ocean. Interactive ocean dynamics are not necessary to produce an IPO-like pattern, but do affect the magnitude and frequency of the decadal changes primarily by impacting the strength of El Nino Southern Oscillation. However, low frequency El Nino Southern Oscillation variability and skewness explains up to only 54% of the spread in frequency of decadal swings in global mean temperature among CMIP5 models, hence there may be other internal mechanisms that can produce such diversity. We conclude that the spatial pattern of decadal changes in surface temperature are robust and can be explained by atmospheric processes interacting with the upper ocean, while the frequency of these changes is not well-constrained by models.

Keywords: ENSO, Interdecadal Pacific Oscillation, thermal coupling, CMIP5, atmosphere-slab ocean model

ENSO/COUPLED MODES OF VARIABILITY/OCEANS/CARBON CYCLE

ENSO-09

PACIFIC RESPONSE TO THE ATLANTIC MULTIDECADAL VARIABILITY

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The Atlantic Multidecadal Variability (AMV) is associated with marked modulations of climate anomalies over many areas of the globe. This includes droughts in Africa and North America, decline in sea ice, changes of tropical cyclone activity in the Atlantic, and changes in the atmospheric large-scale circulation. However, the shortness of the historical observations compared to the AMV period (~60-80yr) makes it difficult to show that the AMV is a direct driver of these variations. To isolate the AMV climate response, we use a suite of global coupled models from GFDL and NCAR, in which the North Atlantic sea surface temperatures are restored to the observed AMV pattern, while the other ocean basins are left fully coupled. In order to explore and robustly isolate the AMV impacts, we use large ensemble simulations (between 30 and 100 members depending on the model) that are run for 10 years. All models show that during boreal summer the AMV alters the Walker Circulation and generates precipitation anomalies over the whole tropical belt. During boreal winter, the AMV warming is associated with large anomalies over the Pacific, with a response that projects onto a negative phase of the Pacific Decadal Oscillation (PDO). In this presentation, we use a set of experiments in which the ocean-atmosphere coupling is globally or regionally precluded to extract the physical mechanisms leading to the Pacific response. We show that the PDO response comes from a lagged adjustment of the tropical Pacific Ocean to the AMV forcing in summer, and it is reinforced by ocean-atmosphere coupling over the extratropical Pacific. It is then show that the PDO response is responsible for precipitation and temperature anomalies over North America. Therefore, our study highlights the importance of using a global coupled framework to investigate the climate impacts of the AMV.

Keywords: Decadal Variability, Atlantic, Pacific

ENSO-10

IS THE QUIRKINESS OF PROJECTED LAND HYDROLOGIC CHANGE CAUSED BY CLIMATE CHANGE, OR BY CO2 EFFECTS ON VEGETATION?

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Under CO2-forced warming, modern GCMs project large, widespread declines in topsoil moisture, boundary-layer relative humidity, and climatic wetness indices on land. Yet, their projections for deeper-layer soil moisture and river runoff are much more benign. To explain this unexpected contrast, CO2-driven plant stomatal closure and warming-driven increases in precipitation seasonality and/or intensity have both been invoked.

Here, we directly test these ideas using two matching multi-GCM warming experiments: one in which the vegetation submodel is allowed to "see" the CO2 increase, and one in which it is not. If CO2 effects on vegetation are the main cause of the above contrasts, they should largely collapse in the latter, simpler experiment. However, if the contrasts persist in both types of experiments, they are likely to be a basic property of greenhouse climate change. Simulations with very simple land models can then inform on the reasons for these contrasts.

Keywords: Mechanism denial; land eco-hydrology; CO2 & vegetation

ENSO-11

THERMODYNAMICALLY COUPLED VARIABILITY IN CAM4 COUPLED WITH AQUAPLANET SLAB OCEAN

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In a hierarchy of climate models ranging from standalone AGCMs to fully coupled earth system models, AGCM thermodynamically coupled with Aquaplanet Slab Ocean Model (AGCM-AquaSOM) is an important intermediate component that has been used to understand mean climate state and its response to anthropogenic forcing. Here, the thermodynamically coupled internal variability of this intermediate component is investigated using NCAR CAM4 with a goal to disentangle the role of ocean-atmosphere thermodynamical coupling in climate variability.

Internal variability of CAM4AquaSOM is found to be sensitive to its mean state. With zonally uniform mean climate of tropical mean temperature much warmer than observations, the SST variability is dominated by a mode of global scale zonal wavenumber-1 and interhemispherically symmetric pattern. Arising from tropical thermodynamical coupling, this global scale mode explains about 50% of the variance and features a prominent eastward propagation (crossing the globe every 2 years with a slab ocean depth of 50m) that is essentially attributed to the Wind-Evaporation-SST feedback. With zonally uniform but colder mean climate (tropical mean SST closer to observations), the variance explained by this global scale mode is reduced substantially, which suggests its sensitivity to the mean state. With an idealized zonal wavenumber-1 asymmetry of a realistic magnitude added to the mean climate, this mode is not detectable; instead, the SST variability is dominated by regional rather than global scale processes. Preliminary analysis shows evidence for the imprints of this global scale mode in atmospheric fields. These results highlight the dependence of internal variability on mean state and suggest that internal variability needs to be assessed within the context of mean state. This work has important implications for climate model development and paleoclimate studies.

Keywords: Aquaplanet, slab ocean, thermodynamics, global scale mode