Improving the simulation of diurnal and sub-diurnal precipitation over different climate regimes

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1. Motivation

General Circulation Models (GCMs) for weather forecasts and climate simulations continue having difficulties in modeling the diurnal and sub-diurnal precipitation particularly over land. The issue is related to inappropriate representation of the processes that control sub-diurnal phenomenon like convection, and phenomena with timescales around the order of diurnal, like mesoscale systems. Over mid-latitude lands, such as warm seasons at the Southern Great Plains (SGP), there are two diurnal peaks of precipitation from observations: a predominant nocturnal peak of precipitation associated with eastward propagating mesoscale convective systems which usually originate over the Rocky Mountains and are often elevated and decoupled from the local surface, and a secondary late-afternoon peak associated with the transition from shallow to deep convection which is strongly coupled with the local surface forcing. Most GCMs often fail to capture the observed nocturnal peak and instead tend to simulate a diurnal peak of precipitation around noon, much earlier than the observed late-afternoon peak. Over tropical lands, such as over the Amazon and Darwin, Australia regions, the diurnal and sub-diurnal variability of precipitation are strongly influenced by different large-scale environments (e.g., dry versus wet seasons over the Amazon, or active versus break periods of monsoon at Darwin), adding difficulty for GCMs to capture the distinguishable behaviors. Moreover, difficulties facing the modeling of diurnal and sub-diurnal convection are also some of the key issues related to the skill of modeling convectively coupled process at longer time scales. Understanding and improving the modeling of diurnal and sub-diurnal precipitation processes can therefore have broader impact on the fidelity of climate simulations.

Problems in simulating the diurnal cycle of precipitation are primarily due to shortcomings and deficiencies in representing convection initiation, evolution, and propagation, as well as the interaction between convection and its large-scale atmospheric environment and the underlying land surface. For example, the failure of capturing night-time convection may be due to the lack of convective memory and/or poor treatment of elevated convection initiation in cumulus parameterizations. It is also highly likely that certain biases in the diurnal cycle arise from errors in how convection onsets as a function of the diurnal cycle of large-scale radiative effects, including dependence on lower free tropospheric water vapor, and mesoscale organization. It has been suggested that the interaction between water vapor in the lower free troposphere and moisture convection, mainly by way of entrainment processes (Holloway and Neelin 2009), is a primary control on the onset of deep convection. Systematically evaluating the model capability in capturing statistical relationships that describe the interaction between convection and moisture fields under various synoptic conditions against available observations would yield important insights into parameterizations of moist convection.

The highly time-resolved field data collected by the US DOE Atmospheric Radiation Measurement (ARM) program over its permanent research sites or during its major field campaigns located at different climate regimes provide crucial and comprehensive observational basis for studying diurnal and sub-diurnal precipitation. Moreover, advances in measurement techniques, data analysis approaches, and model evaluation and diagnosis tools and methods in recent years have provided more detailed and reliable observations and efficient modeling tools to facilitate process studies.

2. A potential GASS project

This white paper proposes a potential GASS project focusing on improving the model capability to simulate diurnal and sub-diurnal precipitation phenomena through multimodel intercomparison studies against observations. The overall goal is to understand what processes control the diurnal and sub-diurnal variation of precipitation over different climate regimes in observations and in models and identify the deficiencies and missing physics in current GCMs to gain insights for further improving the parameterization of convection in GCMs.

2.1 Potential research themes

1) **Interaction between convection and water vapor**: Identify the processes that primarily control the diurnal and sub-diurnal variability in precipitation over different climate regimes and evaluate how well current GCMs represent these processes, and in particular the statistical relationships that describe the interaction between convection and moisture fields under various synoptic conditions against observations (e.g., GoAmazon). A brainstorming thought on this research theme is
    - -- which sub-diurnal processes are most essential for the simulation of the diurnal cycle and sub-diurnal extreme events, and how can these be improved in weather and climate models?

2) **Nocturnal convection over land**: Identify the processes that primarily control nocturnal elevated convection at SGP and evaluate how well current GCMs represent these processes. The MC3E (Xie et al. 2014), PECAN (Greets et al. 2016) field campaigns, as well as ARM long-term observations will provide observational insights into this issue, and support for modeling investigations.
    - -- What is the role of convective memory (advection)?
    - -- What is the role of the night-time boundary-layer and elevated convection initiation?
    - -- What maintains the convection? (Is spatial separation of up- and downdraughts important or is it upper level heating and interaction with dynamics?)

3) **Diurnal cycle of convection over ocean**: Identify the processes that primarily control diurnal cycle of convection over ocean and evaluate how well current GCMs represent these processes.

The DYNAMO field campaign (Yoneyama et al. 2013; Zhang et al. 2013) can be used to study diurnal cycle of convection over ocean. The mechanisms tested in Ruppert and Hohenegger (2018) could be examined with participating models

- -- What is the role of the “direct radiation–convection interaction” (or lapse-rate) mechanism on diurnal cycle of convection over ocean?
- -- What is the role of the “dynamic cloudy–clear differential radiation” mechanism?
- -- What maintains the convection?

4) **Convection transition**: Identify the processes that primarily control the transition from shallow to deep convection at SGP and evaluate how well current GCMs represent these processes. A few cases can be selected from those identified in Zhang and Klein (2010 and 2013) and Zhang et al. (2017), which also provided the observational basis for modeling studies.

(Note: The current priority is on the diurnal cycle of convection over land, which represents a much larger problem in current weather/climate models than it over ocean. We would encourage volunteers to lead studies on the diurnal cycle of convection over ocean if there is a large group interest.)

2.2 A hierarchy modeling approach

A hierarchy of models including single column models (SCMs)/Cloud-Resolving Models (CRMs), Cloud Permitting Models (CPMs), and GCMs is proposed to be used in the multimodel intercomparison study to diagnose and investigate the associated processes and model biases in depth. This modeling approach has been proven very useful to identify strengths and weaknesses of model parameterizations by comparing results among different models and with observations over different climate regimes in earlier GASS (GCSS) studies. SCMs/CRMs will be driven with the same large-scale forcing derived from the field campaign data. CPMs and GCMs can be run in hindcast mode with initial conditions from NWP analyses so that output can be directly compared to the observations. GCMs are also recommended to run at higher resolution over the selected regions if they can run at variable resolutions. GCMs in climate simulation mode are expected to have similar diurnal characteristics as that in short-term hindcast mode.

2.3 Suggested experiments

(Note: The experimental design and analysis will be iterated among the groups who will participate in the project once the project is approved)

- Multi-year hindcasts to build-up statistics and connection to climate errors. Series of short-range (3-5 day) hindcasts with GCMs and SCMs starting every day at 00Z for the warm season from 2004/01/01 to 2015/12/31. These set of experiments are to establish robust composites of mean diurnal cycles at selected locations as well as composites of different cloud regimes (e.g., Zhang and Klein 2010). Given the well constrained large-scale condition in the hindcasts, modelers can better identify problems in specific regimes related to parameterizations in a diurnal cycle, such as the transition from shallow to deep convection.

- Convection Permitting Modeling to provide benchmark for improving conventional cumulus parameterizations. CPM experiments will only focus on selected field campaigns periods. This could be done with other GASS related activities (See Section 4 – coordination part)
- Intensive Operational Periods to provide rich ground-based observations for process studies. List of possible field campaigns:
    - The SGP Midlatitude Continental Convective Clouds Experiment (MC3E) (22 April 2011 to 6 June 2011) (covered by the GASS CAUSES project)
    - The 2015 Plains Elevated Convection At Night (PECAN) (1 June 2015 – 15 July 2015)
    - The Green Ocean Amazon (GOAmazon) (January 2014 - December 2015).
    - The Dynamics of the MJO (DYNAMO) experiment was conducted during the period from October 2011 to March 2012 over the Indian Ocean.

2.4 Diagnostics

- Metrics for the diurnal cycle of precipitation (Covey et al. 2016)
- Convection onset diagnostics (Bretherton et al. 2004, Holloway and Neelin 2009)
- More to be developed during the pilot phase

3. Timelines, participants, and publication plan

This white paper covers a wide range of topics relevant to modeling diurnal and sub-diurnal cycle of precipitation. It will be a multi-year project that contains different phases and sub-projects. We propose a pilot study followed by the main project. The pilot study would be six-month to one-year long using existing simulations (e.g., GASS CAUSES project, Morcrette et al. 2018) or new simulations from initial participating groups. The focus would be on gathering available observations and developing diagnostics for the main intercomparison project phase. The scope of the study could be narrowed-down and detailed timelines will be determined through future iterations among participating groups. Both major weather prediction and climate modeling centers and individual groups are welcome to participate in the study by contributing model results, observational data, and/or analyses. Results can be summarized in papers in regular journals.

We plan to have a side meeting at a conference/meeting where most participants would be around to discuss detailed plan and some preliminary results. The targeted conferences/meetings could be the upcoming AGU, EGU, and GEWEX/GASS sponsored meetings. This will be further discussed among the groups who are interested in participating the project.

4. Coordination with other projects

- The recently-completed GASS CAUSES project (Morcrette et al. 2018). CAUSES involved 11 different models from 9 modeling centers around the world with the goal to improve our understanding of the role of clouds, radiation and precipitation processes in contribution to the surface temperature biases in the region of the central United States. The CAUSES models were initialized every day at 00Z and run freely for 5 days for the period between 1 April and 31 August 2011 covering the ARM MC3E period, thus producing 153 simulations, each 120 h in length. These data could be used for a pilot study for the current project.
- The LLNL, MetOffice, and PNNL modeling groups are currently planning a “Convection Permitting Model Intercomparison Project on the MCSs and surface air temperature

biases over the Central USA" following-up CAUSES. This is highly relevant to the currently proposed activity of modeling diurnal cycle of precipitation. A close collaboration between these two projects is expected.

- The DYAMOND runs (global convection permitting simulations) for Aug 2016 (https://www.esiwace.eu/services/dyamond).
- The RCEMIP project (http://myweb.fsu.edu/awing/rcemip.html)

5. Potential Participating Models

1) E3SM (confirmed)
2) CAM6 (confirmed)
3) ECMWF (confirmed)
4) WRF (confirmed)
5) UKMO (interested)
6) LMD/IPSL (?)
7) CNRM (interested)
8) TaiESM (interested)
9) CIESM (interested)
10) DWD (interested)

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6. Leadership

- Organizers: Shaocheng Xie (LLNL), David Neelin (UCLA), Peter Bechtold (ECMWF), and Hsi-Yen Ma (LLNL)
- A postdoc at LLNL is currently being planned to conduct some initial analysis of simulations available in the pilot study
- Volunteers needed to lead sub-projects and the analysis of model results (email to the co-chairs about your interest in this)

7. References

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