Improved simulated diurnal hydrologic cycle in a global climate model with an embedded coud resolving model

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Introduction

The Multiscale Modeling Framework (MMF) approach to climate modeling (using embedded cloud resolving models instead of cloud parameterizations in a GCM) produces a large-scale climatological composite diurnal rainfall cycle in good agreement with satellite observations, which is a promising result. But can this prototype model also reproduce specific instances of diurnal convection when held to the higher standard of in situ ARM data?

As a first step to answering this question, physical process diagnostics are explored which isolate why the large-scale diurnal behavior of a MMF (SPCAM3.0) and a GCM (CAM3.0) differ. This is a crucial first step towards constructing meaningful statistical inter-comparisons of MMF and CAM simulated diurnal convection against ARM cloud and rainfall data at diurnally active field sites.

Improved diurnal rain statistics

Figure 1 shows that using an embedded cloud resolving model improves the simulated space-time statistics of the composite daily rainfall cycle in climate models. As in nature, the spatial pattern that statistically explains most composite diurnal rainfall variation in the MMF is a land-sea mask.

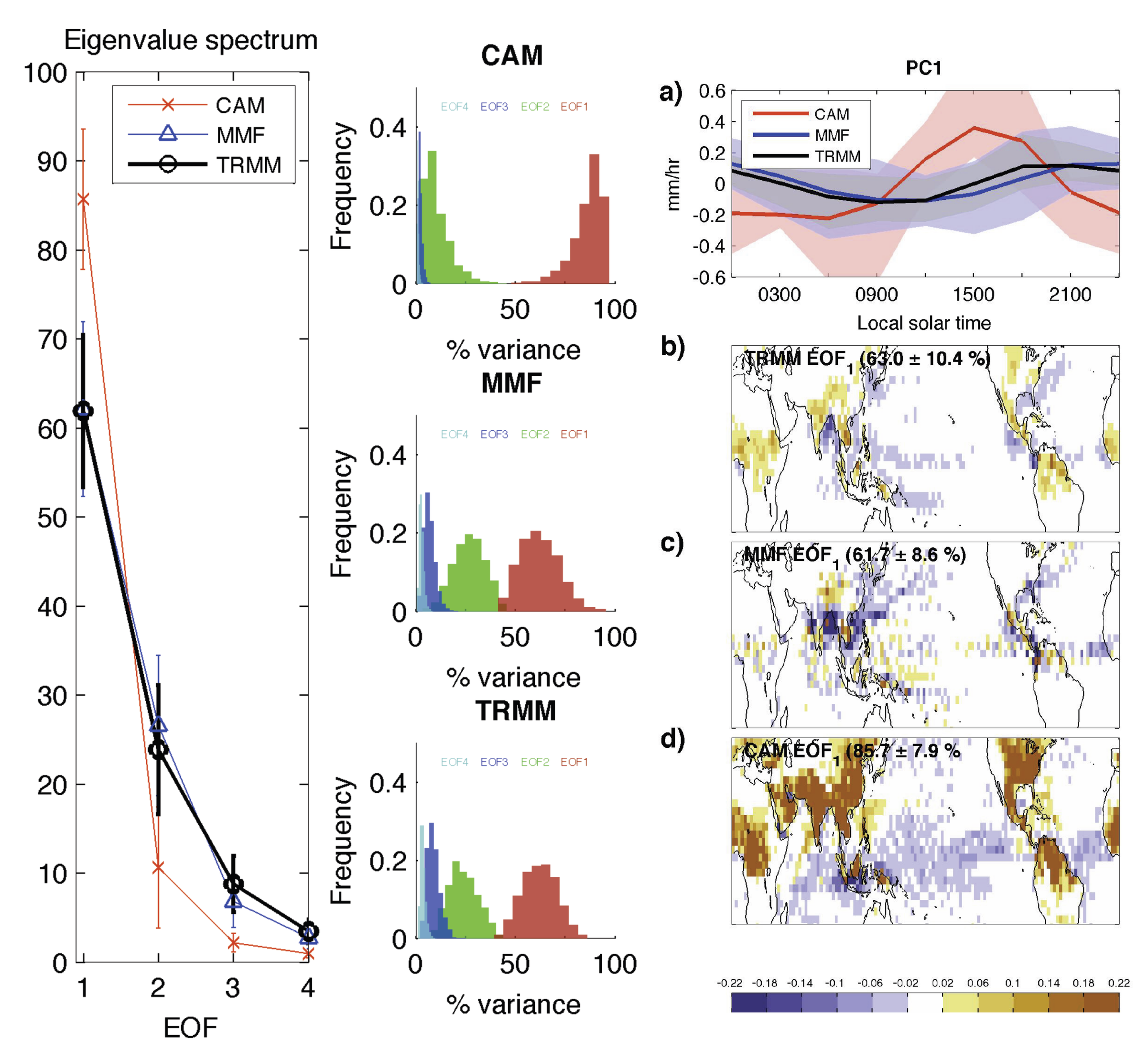

Figure 1: Left panels) Eigenvalue spectrum for the composite JJA diurnal cycle of precipitation as simulated by CAM and MMF, and as observed in TRMM 3B42 and normalized histograms of the percent variance attributable to the first four EOFs in a 2000-member bootstrapping ensemble of EOF calculations. (Right panels) (a) Principle component (PC) time series of the leading EOF of the composite boreal summer diurnal cycle of precipitation as simulated by CAM (red) and MMF (blue), compared to TRMM observations (black). Solid lines and shading denote the mean +- one standard deviation of the ensemble of EOF calculations. (b)-(d) Ensemble mean spatial structure of EOF1 for (b) TRMM data, (c) the MMF, and (d) CAM.

Convective heating & convective moistening over US

Figure 2 contrasts the daily cycle of heating and moistening due to convection in the two models along a coastal transect intercepting the Gulf Stream. Over land the daytime improvement of peak timing in the MMF may be partly a result of morning shallow convective diurnal entrainment humidification (DeMott et al., 2007) as has been seen in 3D CRM studies (Guichard et al. 2004; Bretherton 2007). This process is ubiquitous over MMF land surfaces and can be seen in Figure 2 (e.-g.) as convective humidification atop a thin shallow convective heating layer in Figure 3 (e.-g.). In contrast to the MMF, the CAM convection package almost exclusively acts to remove moisture.

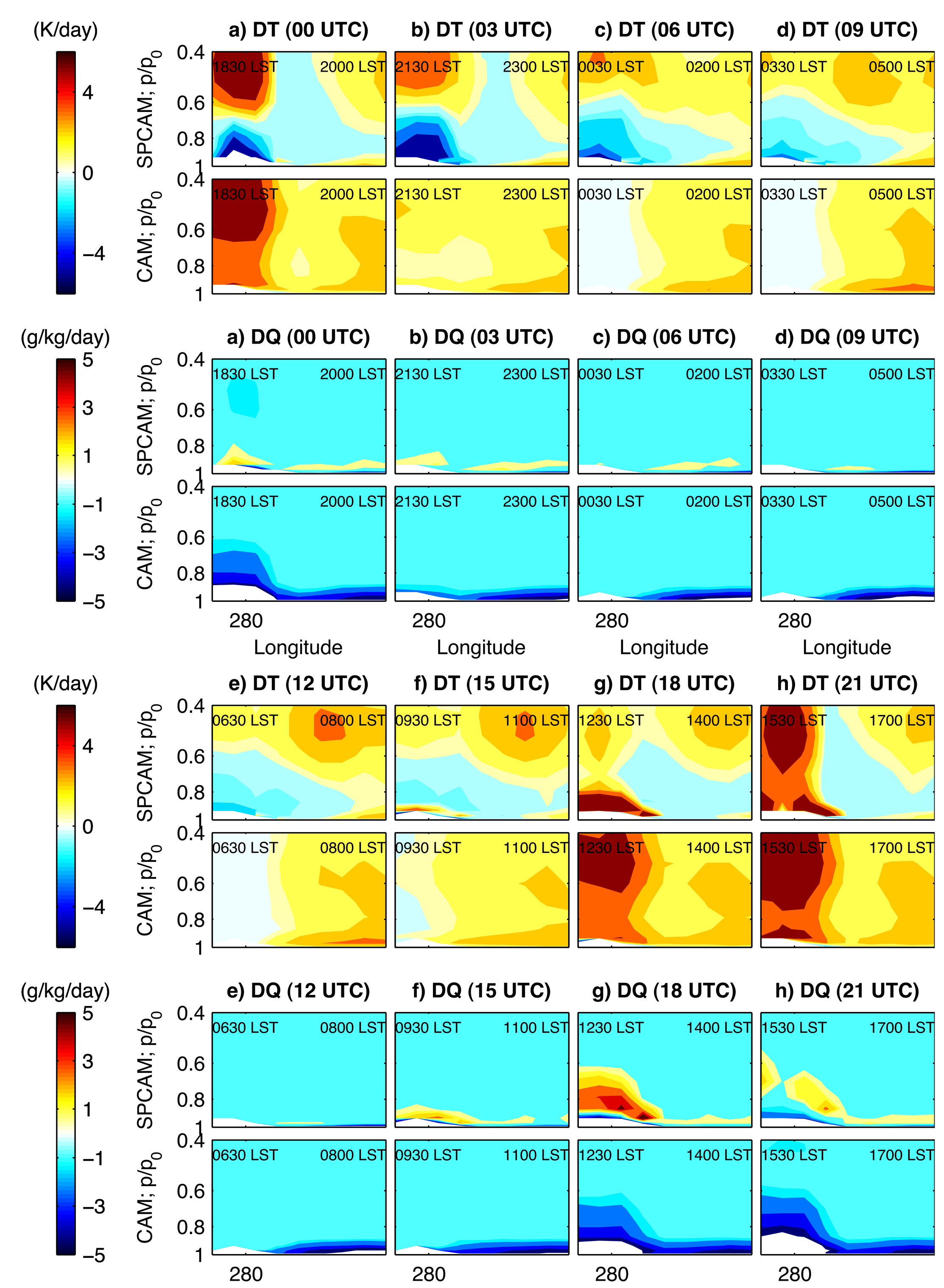

Figure 2: Height-longitude section contrasting the diurnal chronology of convective heating and convective moistening in the SP-CAM and the CAM, along a zonal transect straddling the Gulf Stream and eastern United States (275E to 300 E, averaged over 34 N to 40 N). The quantities shown are tendencies exerted by convection in the physics package, i.e. by nudging towards the nested CRM in the SP-CAM and as diagnosed by conventional parameterization in CAM. The vertical coordinate is normalized pressure (σ = p/1000 hPa), and the land component at the western edge of the transect is identifiable as a blanked out region at the base of the domain.

Figure 2 also shows that the low-level convective cooling layer in the MMF over land is much deeper than in CAM. This has important consequences for the model's capacity to propagate coherent orogenic organized convective events, and thus non-locally forced diurnal convection at the ARM SGP site.

Tropical column water budget diurnal analysis

To understand why the diurnal rainfall cycles are different in CAM and MMF it helps to look at additional terms in the simulated water budget. Focus on a tropical land-sea composite anticipates a future regional comparison of the MMF to ARM data at diurnally active TWP sites.

$$-\underbrace{\int \frac{\partial q}{\partial t} dz}_{-\text{DQDT}} - \underbrace{\int \nabla \cdot (q\mathbf{v})}_{\text{QCONV}} - \underbrace{PREC}_{\text{-PREC}} + \underbrace{QFLX}_{\text{QFLX}} = 0$$

depletion of stored vapor and cloud; convergence due to advection; removal by precipitation; addition by evapotranspiration

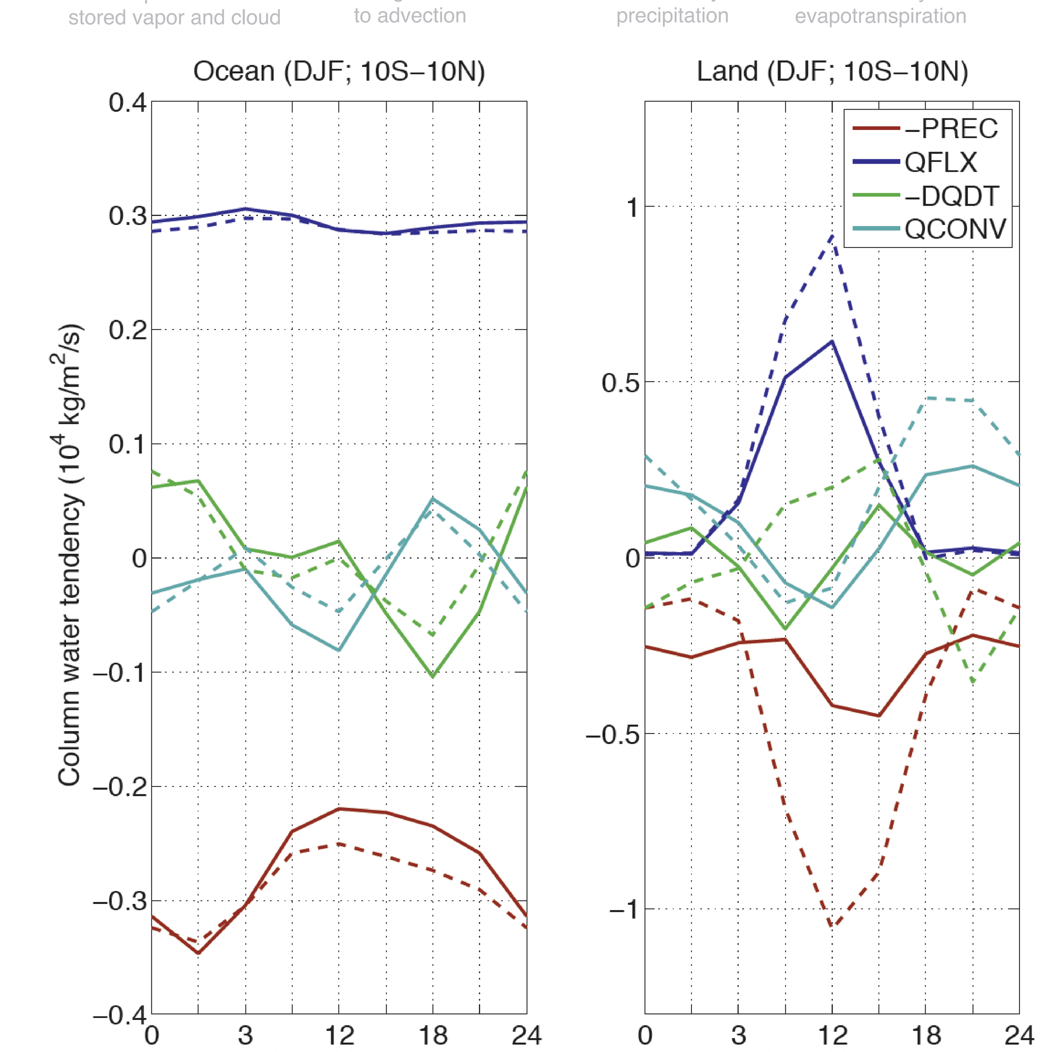

Figure 3: Composite DJF diurnal cycle of all components of the vertically integrated moisture budget, averaged over (left) ocean points and (right) land points within a latitude band from 10 S to 10 N, during DJF comparing CAM (dashed lines) to MMF (solid lines).

Figure 3 (right panel) shows that the differences in the tropical land diurnal rainfall cycle in the two models are mostly balanced by differences in their moisture storage (green). In contrast, the convergence (cyan) and evaporation (blue) diurnal cycles are qualitatively similar; both models converge water over land at night, and have sun-synchronous evaporation cycles. The MMF's embedded CRM evidently converts nocturnal convergence into rainfall more efficiently than CAM's cloud parameterization, storing up less nocturnal water, and tempering its precipitation diurnal cycle amplitude. In the MMF the shift in timing of peak rainfall from noon to mid-afternoon is supported by a morning storage signal again suggestive of local pre-conditioning by entrainment humidification.

Over the ocean, what appear at first to be modest intermodel differences in the diurnal hydrologic cycle (Figure 3, left panel) are a misleading artifact of spatial compositing. Figure 4 unfolds the longitude dimension that went into the composite budget, showing that behind the zonal mean in CAM there is a large scale convergence/storage wave emanating from land hot spots into the ocean. Tempering the amplitude of the deep latent heating diurnal cycle over land in the MMF has removed this diurnally excited barotropic tropical gravity wave and as a result reduced the extent of non-local control of the marine hydrologic cycle by land. Care must be taken in interpreting such non-local effects in CAM's diurnal cycle when comparing to ARM TWP data.

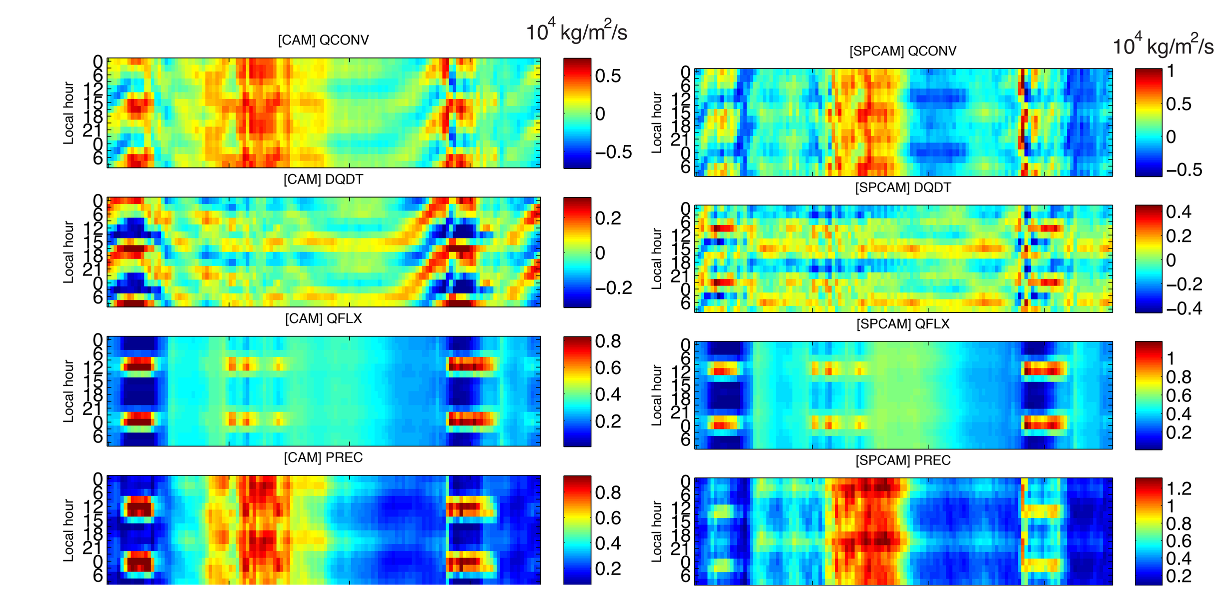

Figure 4: Local time - longitude section contrasting the composite DJF diurnal evolution of all components of the vertically integrated water budget in (left) CAM and (right) SPCAM, averaged from 10S to 10N. The daily cycle is repeated twice for clarity.

ARM evaluation implications

Physical processes differentiating the diurnal rainfall cycle in an MMF and a GCM were reviewed to inform the development of a meaningful model-model-observation intercomparison of the simulated diurnal hydrologic cycle against in situ data at the ARM SGP and TWP sites.

Non-local changes affecting convective forcing (e.g. coherent long-lived propagating convection in the MMF; unrealistic diurnal tropical subsidence wave radiation in CAM) are equally important to understanding the models' diurnal cycle differences in free-running mode as are local changes in convective forcing (e.g. entrainment humidification) .

The implications for ARM data - model comparison experiment design are clear. Forecast-mode global simulations of an MMF and GCM - not single column model simulations - will be necessary to meaningfully evaluate the effects of cloud parameterization vs. embedding cloud resolving models against in situ ARM observations of diurnal cloudiness and rainfall. The development of a forecast-ready version of the MMF used in this study is underway.

References:

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