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Evaluation of the Sensitivity of the Amazonian Diurnal Cycle to Convective Intensity in Reanalyses

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Abstract. Model parameterizations of tropical deep convection are unable to reproduce the observed diurnal and spatial variability of convection in the Amazon, which contributes to climatological biases in the water cycle and energy budget. Convective intensity regimes are defined using percentiles of daily minimum 3-hourly averaged outgoing longwave radiation (OLR) from Clouds and the Earth's Radiant Energy System (CERES). This study compares the observed spatial variability of convective diurnal cycle statistics for each regime to MERRA-2 and ERA-Interim (ERA) reanalysis data sets. Composite diurnal cycle statistics are computed for daytime hours (06:00-21:00 local time) in the wet season (December-January-February). MERRA-2 matches observations more closely than ERA for domain averaged composite diurnal statistics—specifically precipitation. However, ERA reproduces mesoscale features of OLR and precipitation phase associated with topography and the propagation of the coastal squall line. Both reanalysis models are shown to underestimate extreme convection.

INTRODUCTION

The diurnal cycle (DC) is an important mode of variability in the Amazonian climatology due to frequent and intense convection. Convective parameterizations in models fail to capture the diurnal and spatial variability of tropical deep convection (Betts and Jakob 2002), leading to considerable biases in the simulated climatological water cycle and energy budget in the Amazon, especially in the wet season (Itterly and Taylor 2014).

Field campaigns have provided key insights on the complex variations in convective processes across the Amazon region (Machado et al. 2002; Machado et al. 2014). Convection in the Northeast portion of the Amazon is primarily influenced by the position and structure of the Intertropical Convergence Zone (ITCZ) affecting the formation of a coastal squall line, which is an important mechanism for transporting oceanic moisture inland. Convection in the Western Amazon occurs frequently and is strongly modulated by the Andes Mountains, wind direction and moisture convergence (Machado et al. 2014).

DATA & METHODOLOGY

The CERES SYN1DEG Ed3a product provides 3-hourly, 1°x1° observations of TOA fluxes—outgoing longwave radiation (OLR), longwave cloud forcing (LWCF), and shortwave cloud forcing (SWCF)—by fusing Terra and Aqua sun-synchronous fluxes with geostationary observed radiances (Loeb et al. 2009; Doelling et al. 2013). The TRMM 3B42 product provides 3-hourly 0.25°x0.25° observations of tropical precipitation rates by combining VIRS infrared and microwave retrievals (Kummerow et al. 1998). MERRA-2 (Bosilovich et al. 2015) and ERA-Interim (Dee et al. 2011) output are interpolated to 3-hourly, 1°x1° resolution to match the observations.

We then apply averaging and compositing techniques to examine the spatial variability of daytime (06:00-21:00 LST) convective DC statistics, with a focus on the diurnal phase in this paper. Precipitation DC statistics are defined only when the 3-hourly average rainrate exceed an experimentally determined convective precipitation threshold defined as 10 mm day^{-1} (Itterly et al. 2016).

Convective regimes are defined using percentiles of daily minimum OLR, a proxy for deep (cold) convective cloud tops where lower values indicate more intense convection (Gray and Jacobson 1977). The very convective (VC) regime is defined as days below the 20th percentile of minimum OLR and the stable (S) regime is defined as days above the 80th percentile. Only model days within 10 W m^{2} of the observed daily minimum OLR are included in the analysis to ensure we are comparing days where models agree with the observed convective intensity.

Probability density functions (PDFs) of daily minimum OLR and daily maximum precipitation rate are shown in Figure 1. Models underestimate the occurrence of minimum OLR below 150 W m^{-2} (Fig. 1a), overestimate moderate precipitation rates between 5-20 mm day^{-1} and underestimate precipitation rates exceeding ~30 mm day^{-1} (Fig. 1b).

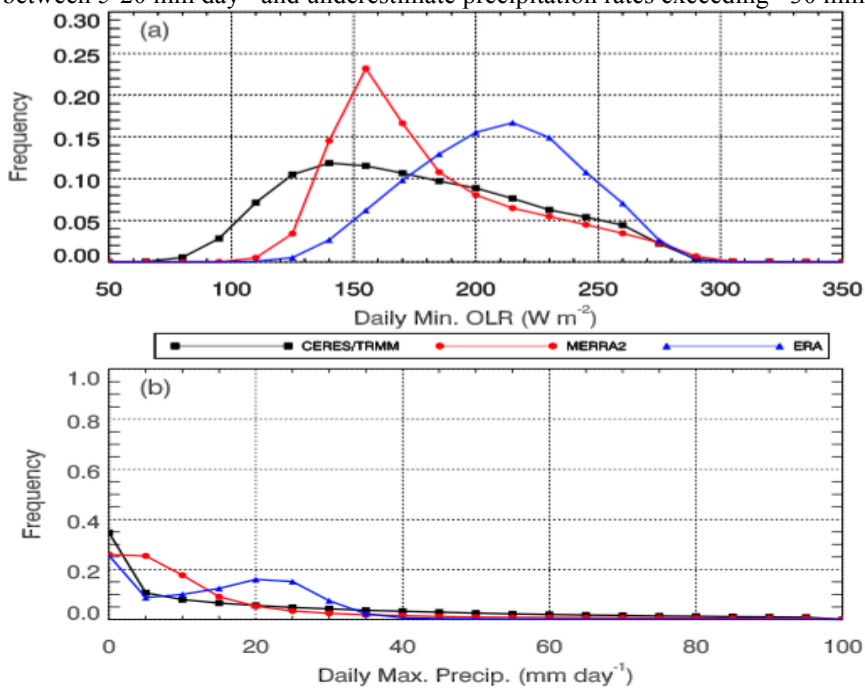

FIGURE 1. Probability Density Functions of daily minimum OLR for CERES, MERRA-2 and ERA (a) and daily maximum precipitation rate for TRMM, MERRA-2 and ERA (b).

RESULTS

The reanalysis models simulate the domain-averaged OLR phase fairly well, however they do not reproduce the observed composite spatial patterns. Figure 2a reveals a complex spatial pattern of OLR phase related to the propagation of mesoscale features and local topography. OLR phase values occur after noon several hundred kilometers inland from the coast, in southwest Brazil and in the higher terrain of Bolivia (Fig. 2a-c). MERRA-2 spatial composites of OLR phase capture the influence of the coastal front propagating inland on VC days (Fig. 2c) but S and All days lack variability (Fig. 2d,e). For ERA VC days, the coastal front influence on OLR phase is simulated well in the northeastern domain, however OLR phase occurs 1-3 hours too late in the southwest (Fig 2g-i).

Spatial composites of TRMM precipitation phase occur between 14:00-18:00 for nearly all grid points (Fig. 3a-c). The earliest observed precipitation phase occurs shortly after noon on VC days along the extreme northeastern coast, further inland (related to the overnight propagation of the coastal front) and in the mountains of Central Bolivia. On S days, domain-averaged precipitation phase occurs a half hour later and exhibits less spatial variability inland (Fig. 3b). ERA fails to capture the observed spatial variability of precipitation phase on VC days except for the relatively later precipitation phase associated with the coastal front and higher terrain. Domain averaged precipitation phase is 1-2 hours too early for MERRA (Fig. 3d-f) and 3-4 hours too early in ERA (Fig. 3g-i).

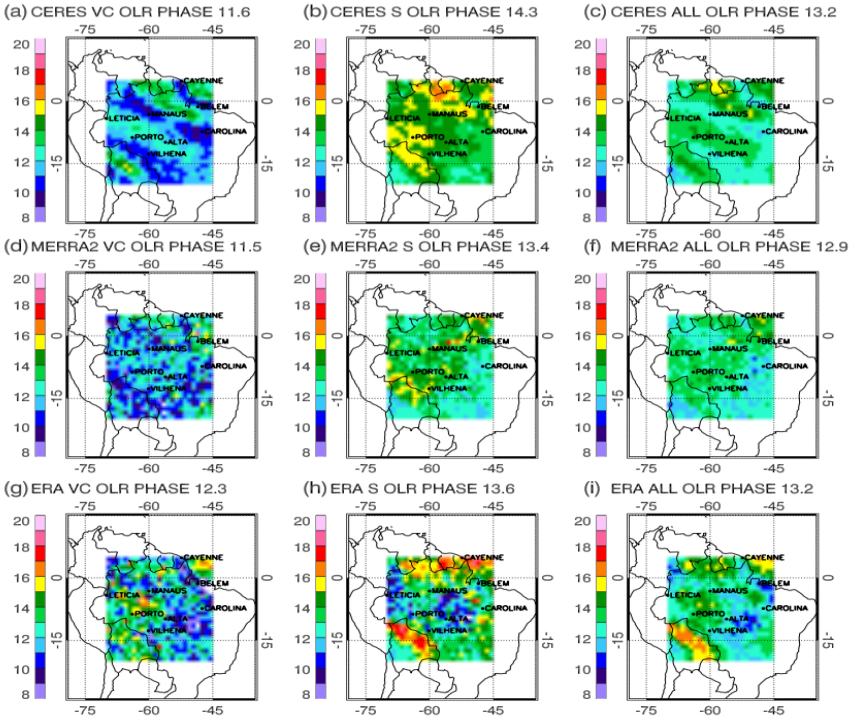

FIGURE 2. Spatial composites of OLR phase (units in local time) on very convective (VC), stable (S) and all days for CERES (a-c), MERRA-2 (d-f) and ERA (g-i). The numerical value in each panel title provides the domain average of each diurnal cycle statistic. Contour intervals are one hour.

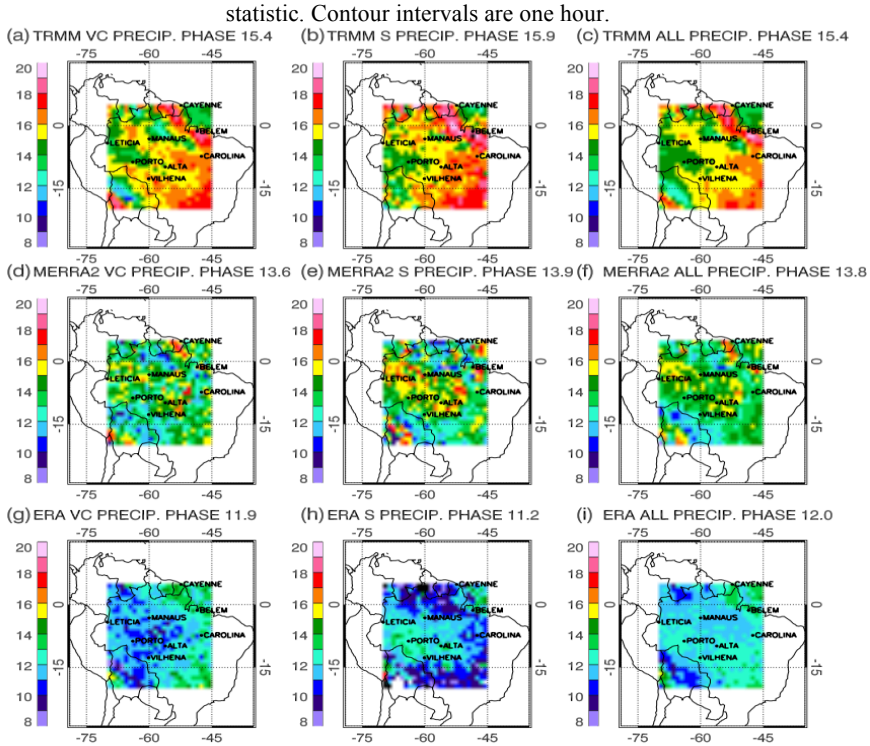

FIGURE 3. Spatial composites of precipitation phase (units in local time) on very convective (VC), stable (S) and all days for CERES (a-c), MERRA-2 (d-f) and ERA (g-i). The numerical value in each panel title provides the domain average of each diurnal cycle statistic. Contour intervals are one hour.

DISCUSSION & CONCLUSIONS

The spatial variability of DC statistics in reanalyses is evaluated with satellite observations for the Amazon wet season from 2002-2012. Sorting by regimes of convective intensity improves understanding of the temporal and spatial scales of the physical mechanisms that modulate various diurnal cycle shapes. The temporal and spatial characteristics of CERES OLR and TRMM precipitation daytime phase reveal a mesoscale feature propagating across the Amazon that appears to have been initiated by a coastal front fueled by temperature gradients along the northeast coast.

Reanalysis models do not consistently reproduce observed composite spatial DC characteristics, especially on convective days. ERA reproduces certain mesoscale features in the VC regime, however precipitation phase occurs 3-4 hours too early and convective intensity is too weak. MERRA-2 agrees more closely with the observed domain-average values and convective intensity PDF, but composite spatial variability is too weak and precipitation phase occurs 1-2 hours too early. Further work is needed to suggest specific improvements to the model parameterizations and to address the significant errors in the water cycle and energy budget.

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