Observationally Constraining a Global Climate Model with Nudging: Methods, Challenges, and Applications

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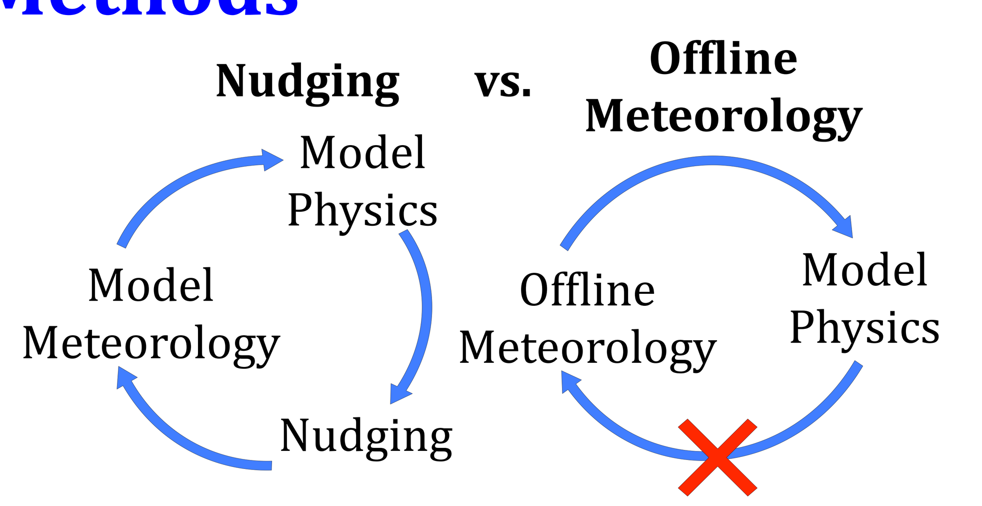
1. Introduction

Observationally constraining a global climate model (GCM) opens the door to validating the quality of its physics against intermittent high value datasets (e.g. CloudSAT, intense observing campaign data, in situ chemical data, etc.). It also potentially reduces the simulation length for model validation, which is increasingly important for expensive prototype climate models like MMFs. Observationally constraining an MMF further forces its embedded cloud resolving model to follow a reanalyzed trajectory, opening the door for forecast-mode experiments.

Nudging a model to reanalysis data is an attractive candidate strategy for constraining a GCM because a) it is simple to implement and b) it does not "kill" as many interesting feedbacks as the next simplest option of prescribing meteorological fields. This poster explores the "nudging" approach in practice during the U.S. summer. Section 3 demonstrates challenges of nudging, such as: How severe is the inconsistency between the reanalysis and climate model topography? How sensitive are remapped dynamical fields to the choice of interpolation algorithm? To what extent do remapping imperfections distort the nudged climate model trajectory, and are these distortions controllable? Section 4 demonstrates the validation benefits of a climate model in nudged mode.

2. Methods



The Community Atmosphere Model version 5 (CAM5 at 1.9x2.5 L30 resolution) is used here to explore the two main methods for constraining GCMs to observed weather, offline meteorology and nudging. The option for offline meteorology is built into CAM in which reanalyzed observations completely replace resolved scale fields. Physical parameterizations respond directly to an observed large scale state, but do not have any influence back on the large scale circulation. Nudging, however, relaxes the model calculations toward reanalysis on a prescribed time scale (τ), which maintains dynamical-convection feedbacks that operate in a free-running model. Maintaining such feedbacks in MMFs is especially important, given that they have more potential degrees of freedom for convection and large scale dynamics to interact. Nudging can include surface pressure, temperature, humidity, and horizontal winds, which are added to the prognostic equations as a forcing term given by:

$$\frac{\partial X_M}{\partial t} = \ldots - \left(\frac{X_M - X_R}{\tau} \right) \quad \text{(Eq. 1)}$$

3. Challenges

In order to apply Equation 1, reanalysis data must be remapped to the climate model grid, which can introduce systematic artifacts. How severe are the inconsistencies between reanalysis and climate model grids and topography? How important is the choice of algorithm in remapping from reanalysis to model?

Inconsistent orography in the reanalysis can distort surface pressure, and consequently all 3D fields via vertical interpolation to hybrid model coordinates (Fig. 1-a). Differences in horizontal interpolation schemes can distort areas with sharp temperature gradients (Fig. 1-b) and introduce unintended unbalanced circulation components. Vertical interpolation scheme differences depend largely on the specific field and vary widely according to the vertical derivative of that field (Fig. 1-c).

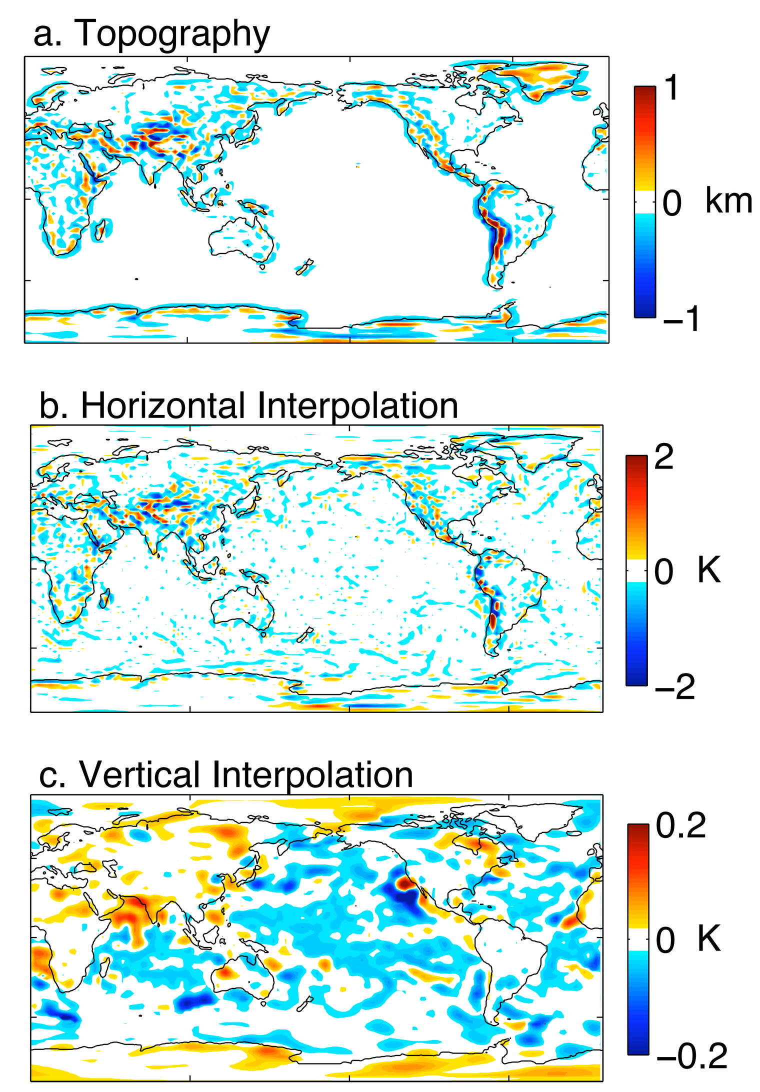


Fig. 1: a. Difference in topography between reanalysis and CAM5 grids. b. Difference in reanalysis temperature on a lower tropospheric model level due to horizontal interpolation (conservative - linear). c. Difference in reanalysis temperature on a lower tropospheric model level due to vertical interpolation (quadratic in ln(p) - linear).

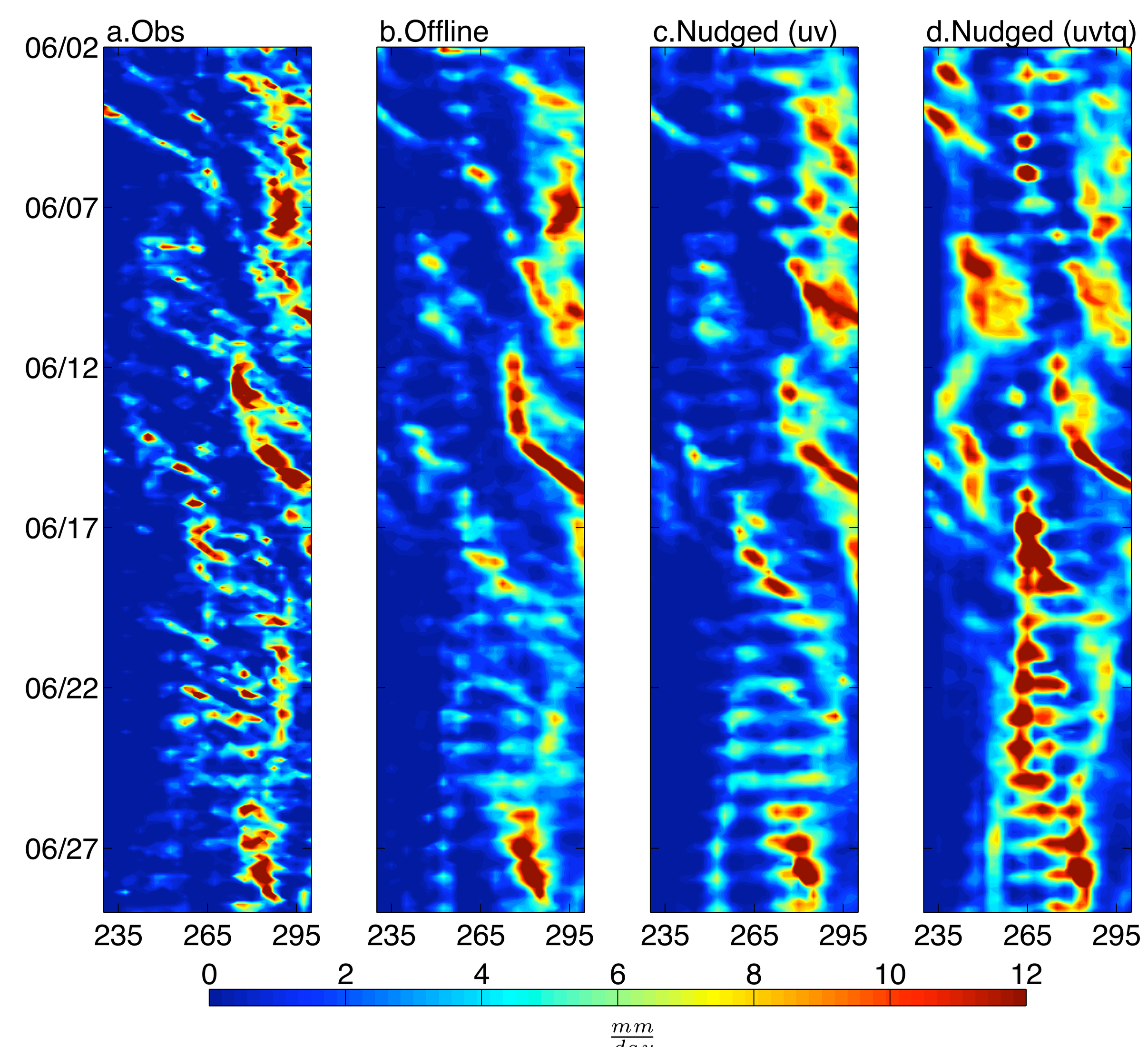


Fig. 2: June 2006 precipitation rate over the United states averaged over latitudes 25-50N. a. TRMM 3B42 observations, b. CAM5 with offline meteorology, c. CAM5 with U and V nudging, d. CAM5 with U, V, T, and Q nudging.

Figure 2 demonstrates how imperfect remapping from reanalysis to model can cause counter-intuitive results in a nudged run of CAM5. Surprisingly, the model skill deteriorates as the number of data fields it is nudged to is increased from two (U,V; Fig. 2c) to four (U,V,T,Q; Fig. 2d). The fact that the difference occurs near topographic features in the U.S. suggests interpolation issues play a role. One possible explanation is that dynamical inconsistencies introduced by interpolation amongst the full set (U,V,T) are mitigated when a subset (U,V) is prescribed and the remainder is allowed to respond within the model. The fact that the model produces a reasonable synoptic precipitation response to only U,V nudging may be a regionally specific result, related to dominant quasi-geostrophic dynamics.

4. Applications

Figure 3 demonstrates the advantage of nudging for validation purposes under computational constraints on simulation length. A single-season CAM5 run in free-running mode produces precipitation statistics that cannot be meaningfully compared to observations without significant temporal averaging. When nudged to a specific year, a more meaningful comparison is possible, particularly if nudging is used to initiate forecast simulations and evaluate model divergence from observations.

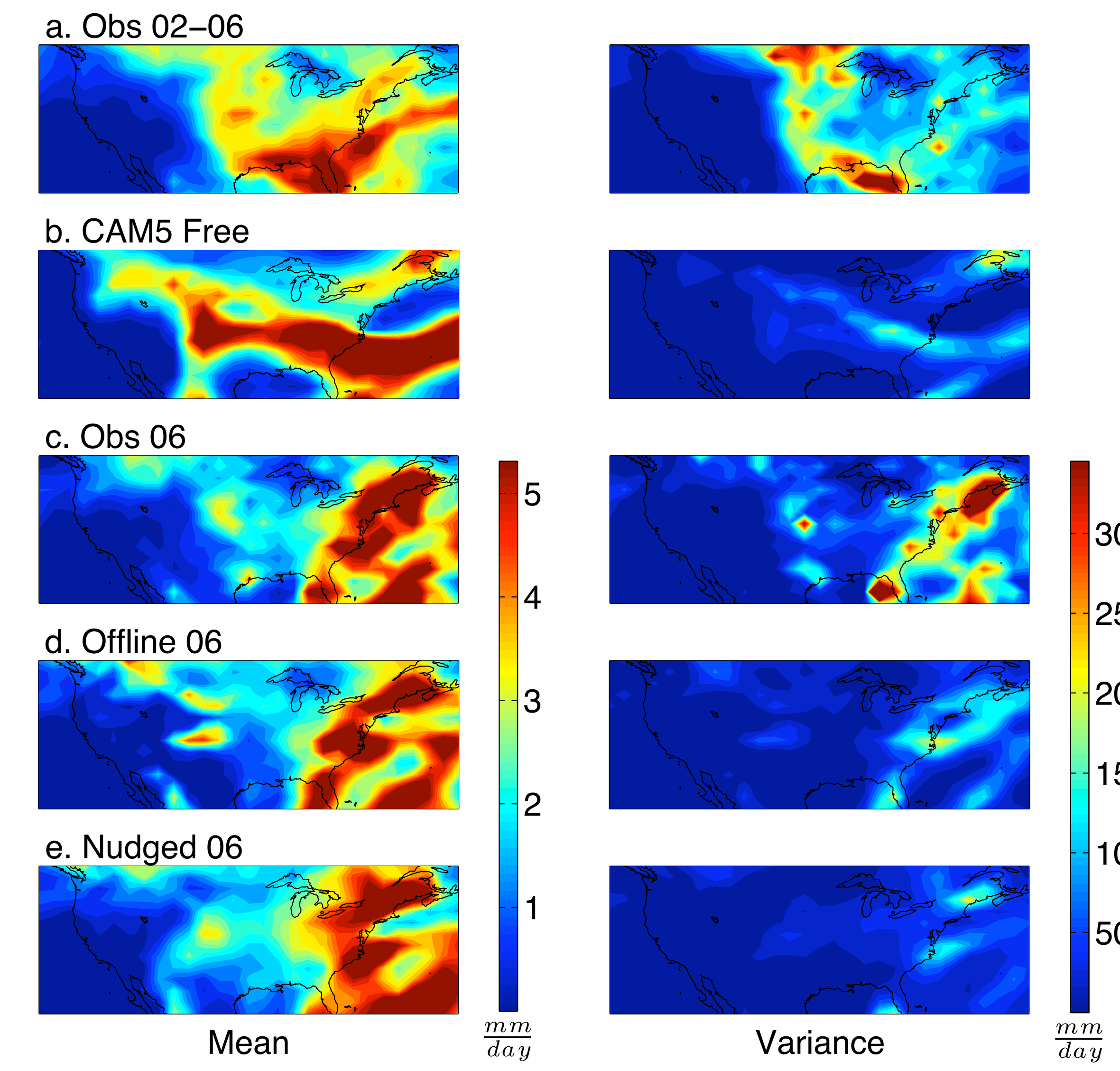


Fig. 3: Mean and 3-hourly variance of precipitation for June. a. TRMM 3B42 2002-2006, b. Free running CAM5, c. TRMM 3B42 2006, d. CAM5 with offline meteorology 2006, e. CAM5 with U and V nudging 2006.

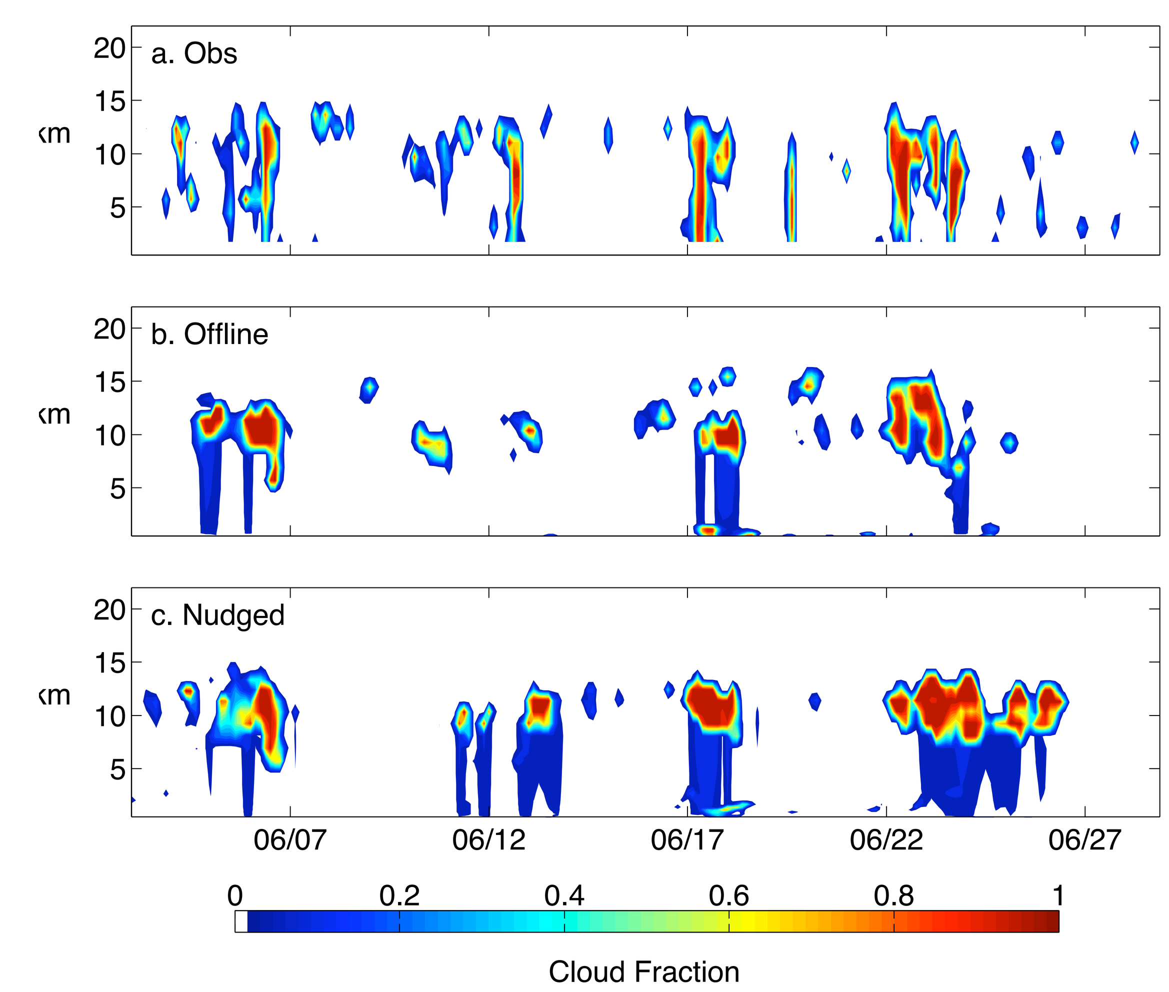


Fig. 4: Cloud fraction at ARM SGP site for June 2006. a. ARM observations, b. CAM5 with offline meteorology, c. CAM5 with U and V nudging.

Figure 4 shows how observationally constrained simulations compare to high quality cloud profile data from ARM at the SGP site. ARM data during locally forced convection has proven invaluable for evaluating and improving GCM parameterizations in single column models. When the non-local environment is nudged, the entirety of such datasets can be used.

4. Summary

Observationally constraining a climate model through nudging offers new vantage points for model validation against data, but presents challenges in practice. Topographic differences between reanalysis and climate model grids are significant enough that they must be corrected for in generating nudging fields. The choice of interpolation algorithm matters in this process. Imperfect remapping is inevitable, and can cause unexpected behavior in nudged models. For the United States summer, under-constraining the model by nudging only winds produces improved results.

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