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Understanding Predictability and Model Errors Through Light, Portable Pseudo-Assimilation and Experimental Prediction Techniques

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LONG-TERM GOALS

1. Confirm the efficacy of pseudo-assimilation (nudging) for model development guidance, calibration, experimental prediction, and predictability studies.
2. Illuminate global predictability pathways using the above toolkit.

OBJECTIVES

1. Assemble multiple analyses in common format and multiple GCMs of a range of complexities.
2. Nudge the GCMs to the reanalyses, globally or in masked regions, while carefully recording the 4D dataset of nudging tendencies.
3. Interpret and exploit that dataset for the project's goals.

APPROACH

Our methods are best shown in their use toward final purposes: predictability (or *information flow*) research. Our initial focus is on the Asian summer monsoon, a key source of tropical variability with likely global impact. Improving model fidelity in simulating the monsoon may translate to predictive skill in other parts of the world. We are using the CAM5 atmosphere model as our primary tool to probe information-flow pathways. CAM5 is nudged towards reanalysis in the monsoon region only, to examine how a perfect or "pacemaker" monsoon may influence remote regions. Long AMIP-style ensemble simulations with daily output allow us to see remote effects ranging from intraseasonal to interannual timescales and beyond. Next we will apply these same techniques to several other GCMs and target reanalysis to bracket methodological uncertainties. Similar nudging experiments will also be applied to other key source regions of potential predictability, such as the whole tropics, east Pacific, etc.

To put a floor under multi-GCM research, we developed a "simplest dynamics" GCM suitable for global flow experiments, using nudging to devise a bias correction (or calibration) for a primitive equation solver. The success of this exercise shows that even an absurdly incomplete or inaccurate

atmosphere model (hydrodynamics only) can be bias-corrected to have a pretty realistic mean flow. On top of this calibrated baseline model, a graduate student is examining the sensitivity of global variability to "simplest physics": a linearized matrix which produces tendencies as a linear function of temperature and moisture anomalies. We are especially interested in unforced intraseasonal variability, an important predictability frontier, and how its simulation depends on the sensitivity of convection to mid-level moisture. Such variability has been postulated to result from "moisture modes" whose strength can be dialed up and down cleanly in this model.

WORK COMPLETED

- A comprehensive multi-year (1980-present) target dataset has been preprocessed for CAM5, which includes multiple reanalyses (MERRA, JRA25, ERAI) and various model resolutions and configurations (spectral element and finite-volume dynamical cores).
- Model code for running and evaluating predictability experiments using regional nudging has been developed. Diagnostic codes for the results have been developed, including frequency-resolved anomaly correlations to map predictability or information-flow pathways across the globe at various timescales.
- Model code has also been developed to allow for selective nudging of the zonal mean scale (wave number 0) in the finite-volume core of CAM5, akin to spectral nudging. This will further enable us to investigate regional-global linkages leading to possible remote predictability. For example, could prediction of tropical-subtropical zonal mean wind fluctuations improve the predictability of climate in western ocean basins (as suggested by Kelly and Mapes, 2011; Kelly and Mapes, 2013)?
- A long AMIP-style ensemble simulation of CAM5 employing localized nudging of the Asian summer monsoon has been completed. Relaxation of winds, temperature, and specific humidity fields was applied at 6h damping timescale at all levels, over the region indicated by the green box in Figure 1. Ensembles of 30 boreal summer (1980-2009) integrations were initialized on May 15th from each of the individual years. Daily outputs have been archived from June 1st to August 31st (JJA season), after a 15-day spin-up. These data allow correlation tests of how a 'pacemaker' monsoon may be felt around the world, on subseasonal as well as interannual timescales.
- A simplest-dynamocs dry dynamical core model has been developed to have a realistic climatology. The model is driven by a constant 3D forcing field, devised as the climatology of nudging in a nudged-to-reanalysis run for a given season of the year. This forcing, which represents all the missing physics in the model, makes the model's mean state realistic, and it vacillates with unforced dynamic variability due only to advective instabilities. An advected scalar representing specific humidity is also prognosed. In some experiments, the model is further fitted with a novel simplest-physics anomaly convection scheme, based on a matrix derived from cloud resolving models. This work forms the framework for a new tool to study the impact of convection's sensitivities on large-scale dynamical variability, in realistic flow settings.

RESULTS

Figure 1 highlights results from a 30-year simulation 'nudge' (top row), in which we nudged the Asian summer monsoon in CAM5. The control run (bottom row) is an AMIP-configured CAM5 control run over the same time period (1980-2009) with monthly observed SSTs. SST variability is thus included in both simulations, so there is some correlation with observed flow, due to the model's skill when forced with prescribed observed SST. Nudging the atmosphere in the monsoon region makes the model fields even closer to the observed (increased correlation), but where, and by how much? For example, a 'pacemaker' monsoon (nudged region indicated by green box in center column) yields a striking improvement in Middle East summer temperature (pink box in center column), with better veracity of T850 on mean bias, interannual, and intraseasonal timescales. The center column of Figure 1 shows the bias result: maps of the time mean JJA bias of T850 in the nudged run (top) and the control run (bottom) with respect to ERA-40. Control CAM5 has a warm bias over virtually all landmasses in the Northern Hemisphere. While the reduction in bias is most pronounced over the Middle East, the nudged monsoon also reduces the warm biases over North America and Eurasia. Biases in CAM5's representation of Northern Hemisphere subtropical highs over the ocean also show a marked reduction (not shown). Evidently, the small core region of the Asian monsoon has a fundamental teleconnected impact on Northern Hemisphere summer climate in general.

The right and left columns of Figure 1 show that core-monsoon nudging also injects realism into Middle East T850 on interannual (right) and intraseasonal (left) timescales. To separate the timescales, band-pass filtering was applied to the concatenated time series of daily JJA data from 1980-2009 (92 days * 30 years = 2760 days), allowing independent correlation coefficients to be devised at interannual and intraseasonal frequencies. More refined filtering will allow us to make maps of the global teleconnections emanating from monsoon variability on several timescales from synoptic through interannual.

Previous work has demonstrated the Asian monsoon to be a critical eddy momentum pump for the subtropical zonal mean zonal wind in both observations (Kelly and Mapes, 2011) and the Community Atmosphere Model (Kelly and Mapes, 2013). Figure 2 displays changes in the mean zonal wind from the same model simulations as described above. Nudging the monsoon region leads to a change of CAM5's easterly bias found at subtropical latitudes (10-30N). This change appears to be tied to an improvement in precipitation (heating) in the model, as CAM5 rains too far west in the Arabian Sea in the control run (not shown). This westward bias in precipitation in the control contributes to a western bias of the upper-level Tibetan Anticyclone, a critical stationary eddy in the mean zonal wind budget. Improved precipitation in the nudged simulation leads to an improvement in this entire chain of mechanisms, with a reduced bias of the mean subtropical flow in the end (precipitation heating -> Tibetan High -> eddy momentum fluxes -> mean zonal wind). The mean zonal wind in the subtropics (10-30N) at 200mb is interrogated further in the right and left columns of Figure 2 which shows the anomaly correlations for the high-pass and low-pass components, respectively (as in Figure 1). Again, the 'pacemaker' monsoon's influence is felt on the mean zonal flow from short to long timescales (subseasonal, seasonal, and time-mean bias).

IMPACT/APPLICATIONS

Incisive tools to guide model development remain a major goal. We also hope that multimodel-robust indicators of information flow can help us narrow down the sources of especially-interesting errors that limit predictability. Our work is in proof-of-concept mode, not ready for applications.

RELATED PROJECTS

We collaborate with Dr. William Boos, an ONR investigation who also has Asian monsoon interests. The work also dovetails with Indian government-funded work in the Mapes group using the GFS operational forecast model.

REFERENCES

Kelly, P., and B. E. Mapes, 2011: Zonal mean wind, the Indian monsoon, and July drying in the western Atlantic subtropics. *J Geophys Res.*, 116, D00Q07. doi:10.1029/2010JD015405

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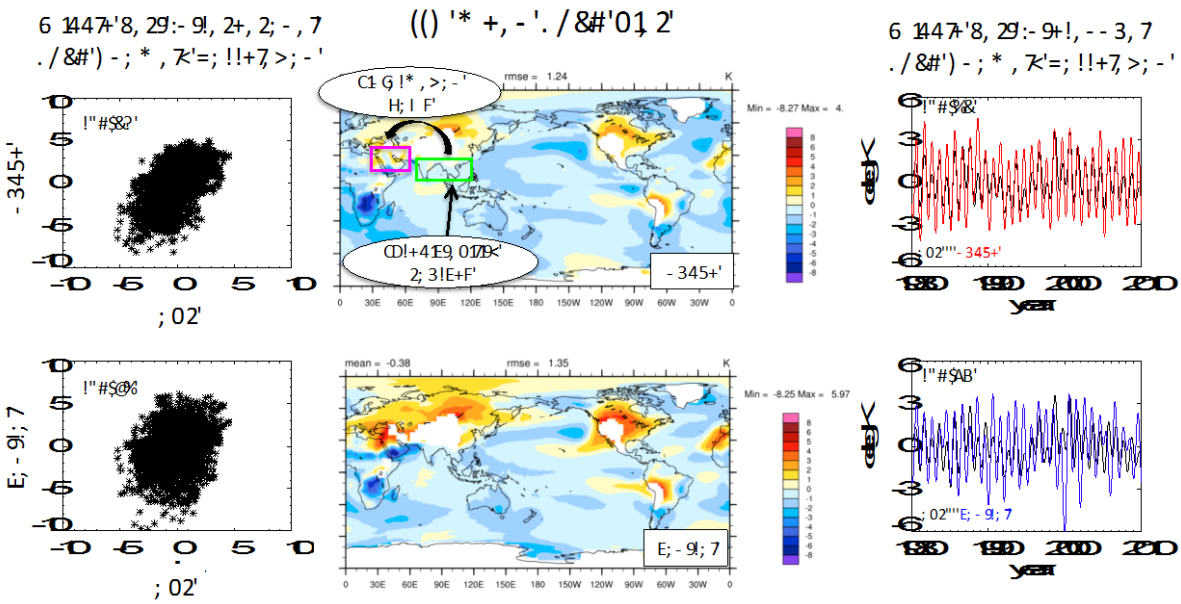

Figure 1: The remote impact of nudging the Asian monsoon region on Middle East temperatures. Center column shows time mean JJA bias of 850mb temperature in CAM5 simulations referenced against ERA-40 climatology. Green box represents the area where nudging is applied and pink box is the "Middle East" used to construct right and left panels. Right panel shows anomaly correlation times series of low-pass filtered JJA daily data over the Middle East. Left panel shows scatter plot of high passed filtered daily JJA data (92 days x 30 years) over the Middle East.

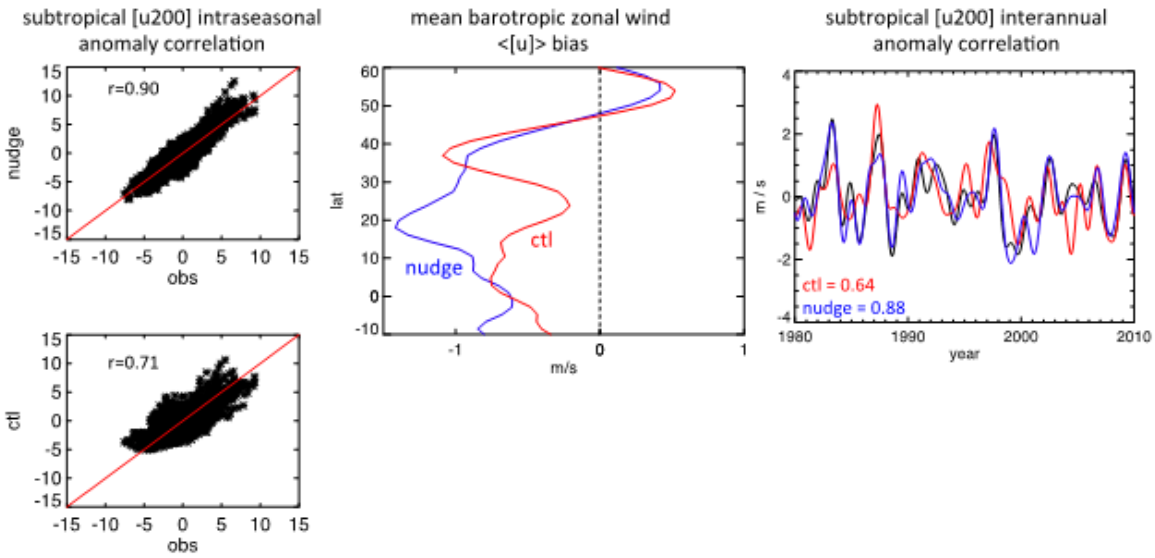

Figure 2: The remote impact of nudging the Asian monsoon region on the zonal mean wind. Center column shows time mean JJA bias of vertically averaged zonal mean zonal wind CAM5 simulations referenced against ERAI climatology. Right panel shows anomaly correlation times series of low-pass filtered daily JJA 200mb zonal mean wind data over latitude belt 10-30N. Left panel shows scatter plot of high passed filtered daily JJA 200mb zonal mean wind data (92 days x 30 years) over latitude belt 10-30N.