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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 by frequency band, ranging from synoptic to intraseasonal to interannual timescales. Next we will apply these same techniques to several other GCMs and target reanalyses 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 time-independent forcing that acts as 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 dry dynamical core model with a novel moist matrix physics scheme has been further developed and improved upon to yield realistic synoptic eddy variability in addition to a realistic mean state. 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. To allow the model to freely develop its own transient variability, the background forcing is carefully calibrated following a procedure similar to Hall (2000). An advected scalar representing specific humidity is also prognosed. A first manuscript detailing the background, methodology and framework as well as initial results discussing the rectified effect of a linear moist physics scheme on climate is forthcoming in Mapes and Kelly (2015).

- To selective highlight the role of atmosphere information pathways, a 30-year set of ensemble simulation of CAM has been performed as before, but using climatologically fixed instead of observed SST. Thus the control run is a free running atmosphere model and has no correlation with the observed state beyond initial condition memory. The nudged run relaxes temperature and winds to ERA-I reanalyses at a 6 hour time-step on a one degree finite volume grid. Nudging is applied uniformly in the vertical and is constrained horizontally using a window function centered over the South Asian monsoon region (box in Figure 1). For both the control and nudged runs, the model is initialized with the observed state on May 1st of each year and integrated for five months with May discarded, archiving daily data for JJAS. These seasonal simulations are performed for years 1983-2012 yielding a 30-member ensemble set to study seasonal to subseasonal predictability. At the post-processing stage, all daily data is linear detrended to remove the climate change signal and the climatology is subtracted. These daily anomalies are then further bandpass filtered at subseasonal (30-60 day and 10-20 day) and synoptic timescales (3-7 day) to partition variance into orthogonal frequency bands.

- Similar nudged experiments are also underway to more finely discriminate the role of the Indian monsoon and East Asian monsoon sub regions within the broader Asian monsoon system highlighted here, by implementing the nudging technique within smaller scale boxes. This probing will better inform previous studies to determine whether the two regions are truly different monsoon "systems" which vary independently (and on what scales), as well as illustrating their respective "outward" teleconnective influence.

RESULTS

Figure 1 highlights some subseasonal predictability results from a 30-year simulation in which we nudged the Asian summer monsoon in CAM5 to allow correlation tests of how a 'pacemaker' monsoon may be felt around the world. All figures show the anomaly correlation coefficient of 10-20 day variability for the pacemaker monsoon as an example, keeping in mind that all predictability information (i.e a significant correlation coefficient) gained outside the dashed box flows directly from accurate prediction of the monsoon itself, since observed SSTs are not included.

The top panel shows correlation for the zonal mean wind field at 200 hPa. The spatial scale of positive correlation is characteristic of a westward spreading Rossby wave structure with significant positive correlation spanning well over Africa and into the Atlantic. The large scale reach of the upper level monsoon anticyclone (Tibetan High) is clearly apparent, as an accurate monsoon predicts subtropical upper-level easterlies spanning half the globe. This is in line with previous findings which demonstrate the circulation over the monsoon region is critical to the globally averaged zonal mean circulation in the subtropics (Kelly and Mapes 2011, 2013).

The bottom panel is a result from the same experiment but showing the 10-20 day filtered SLP field. While surface pressure is not directly nudged, there is significant positive correlation over the South Asia region. Most interestingly, however, is the bullesye for maximum correlation on intraseasonal timescales is not within the nudged region itself (black box), but occurs to the northeast of it in the Phillippine Sea, near 120-140°E and 20-30°N, an important region for Navy interests. While further analysis is needed, its existence appears fundamentally related to subseaonal variation of the southwest corner of the North Pacific High, whose variability may be intrinsically linked to the monsoon through as yet unarticulated mechanisms.

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.

SOUTHERN HEMISPHERE MONSOON TELECONNECTIONS

Atmosphere teleconnections in austral summer in the Southern Hemisphere have also been investigated, as detailed in Kelly and Mapes (2015), which studies the role of Australian/maritime continent monsoon heating on summer climate near subtropical convergence zones. We find that subseasonal Australian monsoon heating is a key predictability source for summer Brazilian rainfall at the subseasonal timescale and is mediated by changes in the zonal mean circulation.

We also collaborate with Dr. William Boos, an ONR investigation who also has Asian monsoon interests and has been recently published in Boos et al (2015). That work also dovetails with Indian government-funded work in the Mapes group using the GFS operational forecast model.

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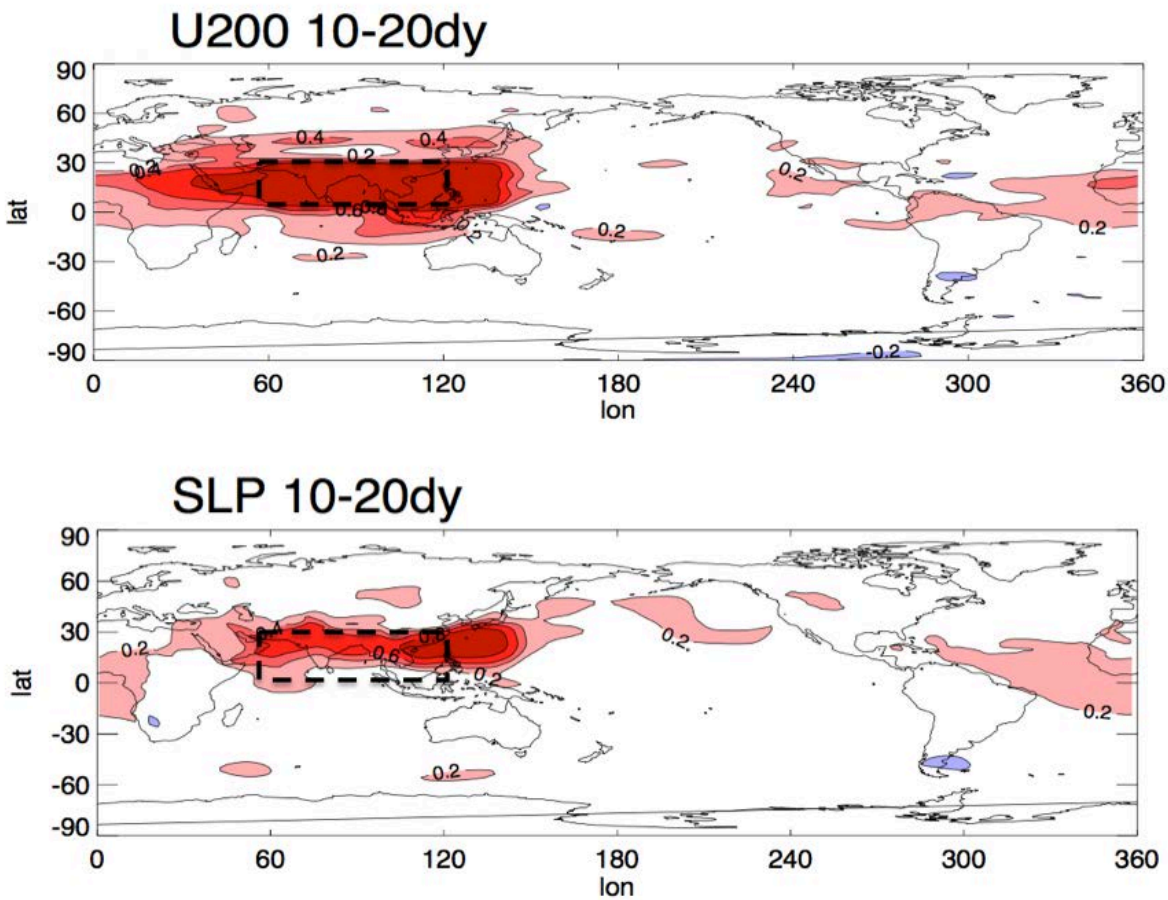

Figure 1: 10-20 day filtered anomaly correlation from 1983-2012 for zonal wind at 200 hPa (top) and sea level pressure (bottom). Correlation is for a CAM5 simulation employing nudging over the Asian monsoon domain (black dashed box) and ERA-I reanalysis for the same ffiltering technique and time period.