PROcess Based Diagnostics – PROBE
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Introduction
Some of the most interesting properties of the climate system are emergent (e.g., sensitivity to external forcing, predictability at the regional scale). By emergent we mean a property that arises from complex interactions between, for instance, dynamics, radiation, cloud formation, and surface fluxes, rather than being a function of a single physical process. Most of the traditional global-scale diagnostics used for climate model evaluation are emergent in nature. Emergence therefore complicates our ability to attribute a systematic model-observation discrepancy to a specific piece of code or model assumption. Indeed, model developers are often left to their experience and trial-and-error when addressing these discrepancies. Unsurprisingly, some notable discrepancies have persisted across multiple generations of climate model development (e.g., the double ITCZ problem). Even with the availability of large archives of coupled GCM output (e.g., CMIP5) and complementary observations to go with them (e.g., Obs4MIP) our ability to address certain questions is limited.

Often those approaches can take the form of a Lagrangian conditional average, when which data is deficient, or 3) the comparison is inappropriate or misleading. Many things lead to the third situation. For example, Eulerian time averaging is often seen as a desirable form of data compression for such comparisons. However, the concept of emergence means that each field is strongly influenced by the cumulative actions of intermittent and transient phenomena that cannot be seen directly in the mean field of the (e.g., convective storms and cyclones). As a result, comparisons using time means are unlikely to reveal why a discrepancy exists (i.e., situation 3).

This suggests the need for a more effective approach to diagnostic-based model development.

Use Case - Extratropical Cyclones
Extra-tropical cyclones make excellent candidates for PBDs because: 1) Cyclones are specific, identifiable and well-understood phenomenon. 2) Cyclone activity shapes the distribution many quantities on both climatic and weather scales (e.g., cloud, temperature, wind). 3) Cyclones have interesting internal and external variability. 4) While today’s climate models can in principle resolve basic cyclone features, they are less able to represent smaller key features (e.g., fronts), and questions remain about their ability to capture more subtle changes in cyclone behavior and structure (e.g., variations between seasons, hemispheres). Instead, mid-latitude cyclone clouds are a key source of inter-model difference in climate sensitivity (Williams and Troulloud, 2007).

An ongoing project led by one of us, “The MAP Climatology of Mid-latitude Storminess” or MCMS, is designed to address just these sort of questions (see Fig. 2, http://gcss-dime.giss.nasa.gov/mcms/mcms.html).

Here we compare the SLP fields from the NCEP Reanalysis II (NRA2) and a climate model (GISS-E2-R) run with complementary historical boundary conditions for the years 1990-2010 (21 years). Fig. 2 depicts the traditional approach to diagnosing the mean SLPs, which in this case are generally similar except that the GISS result is systematically lower pressure especially over the ocean.

Next, we found the conditional mean SLP associated with cyclone activity using the cyclone area (red and cyan fill in Fig. 2) from each cyclone passing through the study area as a mask. As can be seen in Fig. 4a there is a close association between departures in cyclone related SLP and those found in the mean SLP of the NC42-2.

Here we used the PBDs provided by MCMs to highlight a reanalysis-climate model discrepancy in time-mean SLPs. We found clear that this discrepancy is a matter of enhanced coastal cyclonicities and differences in cyclone decay. From the model developer’s point of view these are much more targeted concerns than could have been obtained by traditional methods alone. Moreover, the emergent nature of cyclone activity suggest that simple model adjustments are unlikely to help, but if a remedy were to be found, the benefits are apt to extend to many cyclone influenced quantities such as cloud and precipitation.

References
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