Evaluating Modes of Variability in Climate Models

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Climate models are an essential tool for studying and predicting climate change. Their usefulness, however, depends on how realistically they simulate the statistics of present-day climate, including its variability, among other factors.

A case in point is the current "hiatus" in the rate of global surface warming, thought to result partly from a natural decadal fluctuation of the tropical Pacific Ocean [e.g., *Kosaka and Xie*, 2013; *Trenberth et al.*, 2014]. The extent to which climate models are able to reproduce such hiatus periods relies on their ability to accurately simulate the Pacific Decadal/Interdecadal Oscillation, an internal mode of variability that affects climate worldwide [e.g., *Mantua et al.*, 1997; *Deser et al.*, 2010]. These and other internal modes of climate variability (notably El Niño–Southern Oscillation (ENSO) and the Atlantic Multidecadal Oscillation) can obscure anthropogenic climate change. They also complicate model validation and intermodel comparison because their phase is not locked to a specific year or decade.

Despite the importance of these modes, systematic evaluation of internal variability in coupled climate models remains a daunting task given the wide range of modes to consider, the length of the data record needed to adequately characterize them, and observational uncertainties.

The Climate Variability Diagnostics Package

As a step toward improving and facilitating the evaluation of internal climate variability in models, the Climate Analysis Section at the National Center for Atmospheric Research (NCAR) has developed a Climate Variability Diagnostics Package (CVDP; http://www2.cesm.ucar.edu/working-groups/cvcwg/cvdp).

The CVDP computes key metrics of internal climate variability in a set of user-specified model simulations and observational data sets. These metrics include characteristics of coupled ocean-atmosphere phenomena such as ENSO, Pacific decadal variability, and Atlantic multidecadal variability, as well as prominent modes of regional and hemispheric atmospheric circulation variability along with their associated signatures in underlying sea surface temperatures. Spatial patterns and time series are computed for each mode of variability, and the results are stratified by season. Time series and running decadal trends of global mean temperature and precipitation are also provided to assess evolving rates of global warming and hydrologic cycle strength over time. Interannual standard deviation maps give a more general view of the spatial characteristics and amplitudes of variability. Methods used to define the various phenomena are referenced, with links to the peer-reviewed literature on which they are based.

A unique feature of the CVDP is the ability to specify any number of model integrations at a time, including the full set of models participating in the Coupled Model Intercomparison Project phase 5 (CMIP5) or different ensemble members or time periods of the same model, as well as the ability to specify particular observational data sets for analysis (including multiple data sets for a given variable, allowing assessment of observational uncertainty). Because of the resource-intensive nature of the computations, the CVDP includes an option to output results to network common data form (netCDF) files for access at a later date.

The CVDP also provides graphical displays that allow immediate viewing of the diagnostic plots; these displays can be output to postscript or portable network graphics (png) files for later use. A key feature of these presentations is the single-page display format to facilitate model intercomparisons and evaluation (see Figure 1 for an example). CVDP output is presented via a website and includes a table summarizing model performance for 11 key metrics of internal variability on the basis of pattern correlations and root-mean-square errors with respect to the chosen observational target. As such, the table enables intercomparisons of model fidelity, as well as a means of tracking model improvement.

An example of CVDP output applied to the full set of CMIP5 models over the historical period 1900–2005 is viewable at http://webext.cgd.ucar.edu/Multi-Case/CVDP_ex/CMIP5-Historical/.

CVDP as an Open-Source Community Activity and Repository

The CVDP is designed with the potential for future community contributions in mind: for example, inclusion of additional parameters, modes of variability, and temporal resolution (e.g., daily data). As such, users are encouraged to build on the existing source code (written in the freely available NCAR Command Language (NCL) software package) by incorporating additional standard and well-documented metrics relevant for Earth system model evaluation and intercomparison.

To further promote community involvement, we have applied the CVDP to various multimodel archives and are making the data openly available, stored in a community-accessible online CVDP Data Repository (http://www2.cesm.ucar.edu/working-groups/cvcwg/cvdp/data-repository). These data comprise the CVDP analysis output for a broad suite of scenarios of the CMIP3 and CMIP5 multimodel and multiensemble member archives, as well as major community projects, including the Community Earth System Model/Community Atmosphere Model (CESM1-CAM5) Large Ensemble Project [*Kay et al.*, 2014] and the CESM1-CAM5 Last Millennium Community Project. The CVDP Data

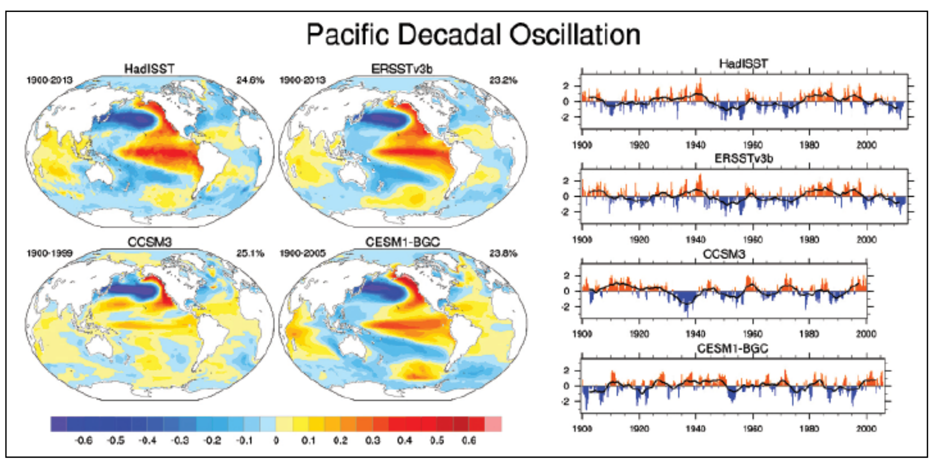

Fig. 1. A sample graphical display from the National Center for Atmospheric Research (NCAR) Climate Variability Diagnostics Package (CVDP) showing the Pacific Decadal Oscillation (PDO), defined according to the study of Mantua et al. [1997], in two observational data sets (HadISST1 and ERSSTv3b) and two Coupled Model Intercomparison Project (CMIP) models (CCSM3 and CESM1-BGC). (left) The spatial patterns show the global sea surface temperature (SST) anomalies, measured in kelvins, associated with (right) a one standard deviation departure of the PDO time series. The name of each data set, period of analysis, and percent variance explained by the PDO are given above each pattern. The normalized monthly PDO time series is shown as orange and blue bars, with the 10-year low-pass-filtered version shown as the black curve. Note that the CVDP accommodates different lengths of records for each data set. Note how the spatial pattern of the PDO improves in the tropics and Southern Hemisphere when we compare a previous generation of the NCAR model (CCSM3) to the latest version (CESM1-BGC). Also note that it is difficult to assess improvement in the temporal character of the PDO because of the limited lengths of the record in both the observations and model simulations.

Repository thus provides the community with immediate access to canonical metrics of climate variability and associated data from the CMIP archives and additional model ensembles without the need to download and process large quantities of data.

For more information, see http://www2.cesm.ucar.edu/working-groups/cvcwg/cvdp.

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