Proposal Number: GC04-163

Lingering Memory and Extreme Weather: Climatology, Variability, and Prediction

Principal Investigator: **Ming Cai**
Associate Professor
Department of Meteorology & School of Computational Sciences and Information Technology,
Florida State University,
Tallahassee, FL 32306
Email: cai@met.fsu.edu
Phone: 850-645-1551
Fax: 850-644-9642

CO-Principal Investigator: **Huug M. van den Dool**
Adjunct Professor
Department of Meteorology, University of Maryland,
College Park, MD 20742
Principal Scientist, CPC/NCEP/NOAA
Email: huug.vandendool@noaa.gov
Phone: (301)763-8000 EXT 7570

Performance Period: June 1, 2004 – May 31, 2007

Extended Abstract

Due to nonlinear chaotic nature, the inherent predictability time scale of weather as an initial value problem is about 1-2 weeks. Beyond this average limit of predictability, intra-seasonal to interannual climate predictions tend to emphasize forecasting time mean (e.g., weekly, monthly, or seasonal) anomalies. The forecast skill of time mean anomalies hinges heavily upon the presence of large-amplitude anomalous “external” forcings (such as SST anomalies associated with ENSO events) rather than the atmosphere initial state (Shukla et al., 2000 and references therein). The challenge of intra-seasonal to interannual climate predictions is that atmospheric internal variability in the extratropics, which arises from continuous nonlinear interactions of synoptical variability and wave-mean interactions, often overwhelms the externally forced (teleconnection) variability, particularly over the regions where prominent atmospheric internal modes, such as the NAO, are present at all time scale. As a result, the signal coming from the anomalous external forcing is diluted significantly, leading to indecisive climate forecasts. Moreover, when there is a lack of presence of large-large amplitude anomalous “external forcing”, the skills of seasonal to interannual climate predictions are downgraded further.

The heart of the proposed study is to explore the possibility of predicting the intra-seasonal to interannual climate probability distribution of “extreme” weather events (or large amplitude synoptical scale anomalies) using a combination of dynamics based numerical model predictions and statistical relations between surface weather events and upper level circulation anomalies. The rationale for this strategy rests on two theoretical arguments. First, at the weekly, monthly, or seasonal scale, it is expected that there is a good correspondence between time mean anomalies and large amplitude anomalous weather events as we argued in the previous paragraph. In that regard, forecasting time mean anomalies is no easier than forecasting the statistics of large amplitude anomalous individual weather events (e.g., those anomalies that exceed 43% of local climate standard deviation, the case of $\alpha = 0.43$). Secondly, although there is little “memory” to speak of for individual weather events beyond the limit of predictability, the statistical behavior of all weather events as a whole in a certain domain at any given time may still well be dictated by a “lingering memory” stored in the “state of the atmosphere” or “the state of coupled system”. Here a “lingering memory” can be mathematically defined as the time scale of an integral of some types of weather activities over a specific domain. We will refer to the corresponding time series as a weather index. We argue it could be this type of lingering memory in the system that separates a mild winter with few storms from a cold and stormy winter or a hot and dry summer from wet and cool summer.

In order to advance this idea, one has to relax the traditional framework of verification in which the forecast anomaly, F(s,t), has to coincide precisely in both space (s) and time (t) with the observed counterpart, O(s,t). Instead, we need to relax the requirement of matching forecasts with observations in space temporal domain simultaneously. For example, we could simply attempt to verify the number of grid points that exceeds normal by “x percentage” of local standard deviation, where “x” ranges from 0 to 100. The preliminary results indicate that the time series of such a parameter has a longer time scale compared to the time series of a typical meteorological parameter at any given grid point. This suggests that the system as a whole would have a much longer memory than we traditionally think. We need to produce spatially integrated and location-insensitive parameters that measure large amplitude synoptical activities and the likelihood of extreme weather in a specific domain. Such a parameter effectively is indicative of a lingering memory because of its longer time scale. We envision that lingering memory is perhaps already

well captured by state of the art general circulation models beyond the 1-2 week predictability limit because it does not require accuracy in both spatial and temporal domain simultaneously.

Ultimately, the lingering memory of the state of the extratropical atmosphere reflects the prominent atmospheric low frequency modes, the coupling between extratropical atmospheric variability and tropical atmospheric convection belt through teleconnectivity, or/and the coupling of troposphere and stratosphere. Specifically, the lingering memory comes from external forcing (such as ENSO) and internal/external regular/irregular low-frequency variability in the deep tropics (such as QBO, MJO, and TAV). It may well be part of the prominent extratropical atmospheric low-frequency modes (such AO/NAO, PNA, and PDO). Recently, ample evidence has been shown that the subseasonal to seasonal variability of AO is strongly related to the upper level Northern Annular mode (NAM, Baldwin and Dunkerton 2001, Black 2002, Shepherd 2002, Thompson et al. 2002). Because stratosphere NAM typically has a much longer time scale in comparison with AO, this brings the hope that AO and the extreme weather associated with AO can be predicted beyond the average 1-2 week predictability limit (Baldwin and Dunkerton 2001). Baldwin al. (2003) argues that the stratosphere-troposphere coupling is strongest in the seasonal scales and may play an equally important role as the tropical oceans to intra-seasonal to season climate predictions. However, the NAM or AO is well defined only for the wintertime circulation. It follows that prediction tools built upon the coupling between stratosphere and troposphere may not necessarily yield skillful predictions for summer drought/flooding and heat waves. Moreover, operational general circulation models may not necessarily have adequate resolution in the stratosphere. In other words, It follows although that the strong coupling between stratosphere and troposphere may improve seasonal climate prediction by a statistical method (e.g., long persistent stratospheric anomalies can be used as a predictor for tropospheric anomalies), yet it remains to be demonstrated that a dynamically based numerical climate prediction model would have a higher skill in predicting anomalies in stratosphere.

We conjecture that in seasonal time scales (in all four seasons), a lingering memory reflects the integrated effects of both the stratosphere-troposphere coupling and the coupling of extratropic anomalies and tropical oceans. Because of the longer time scale of tropical oceanic and stratospheric anomalies, such a lingering memory would be well captured in the initial states. We further conjecture that although a dynamically based climate prediction model is not able to predict the subsequent evolution of tropospheric and surface anomalies faithfully due to a lack of adequate representation of stratosphere dynamics and a poor skill in simulating teleconnection response as well as other model deficiencies, such a model would still be capable of predicting the subsequent evolution of the general level of weather activities because of existence of the lingering memory. This forms the scientific hypothesis for a new hybrid climate prediction strategy: *predicting the probability distribution of large-amplitude tropospheric and surface climate anomalies via statistical postprocessing using the "location insensitive" information (the lingering memory reflected in weather indices) predicted by a dynamically based climate model.* Because the evolution of lingering memory (or domain integrated weather indices) is predicted by a dynamically based numerical model, the powerful simultaneous diagnostic relation between long-lasting weather indices and probability distribution of large amplitude anomalies can be used directly without any extrapolation.

The proposed study is highly related to the core missions of the CLIVAR program. The diagnostics will enhance our understanding of global climate variability by linking weather to climate. We will explore a new strategy for intra-seasonal to interannual climate prediction. We will test the feasibility of utilizing the dynamics based long range forecasts in the range beyond the predictability limit. Particularly, this new strategy would lead to development of new forecast tools for intra-seasonal to interannual climate prediction in the presence or absence of strong external forcing (such as ENSO) and in both summer and winter. In that regard, this study would "extend the scope of SI prediction".

The proposed work is made of two tasks: (1) to derive global/regional weather related indices and to examine their climate variability and to relate them to probability of larger amplitude atmospheric anomalies, and (2) to assess the utility of making seasonal to interannual climate predictions using these weather related indices. In the subsequent sections that describe each of these two main tasks, we will begin with objective/hypothesis, and present some preliminary results showing supporting evidences, and then outline the proposed research. In addition, the description of preliminary results also serves to demonstrate the methodology and readiness of the proposed study. All the preliminary calculations are made with the NCEP/NCAR reanalysis II dataset, covering the period from 1979 to 2000.

The primary data source for the tasks (1) will be the NCEP/NCAR reanalysis dataset and AMIP dataset. We will also use CPC's global 50+ years of daily precipitation over land. For the task (2), in addition to the reanalysis and AMIP data, we will use archived multi-year MRF extended range forecast datasets and the operational GFS forecast outputs. NCEP will make a 5-year forecast data set for each new model release. A 1998-2002 daily forecast out to 30 days by the latest model is ready by July 2003. We will use these forecast outputs as well.

Below are sample questions that will be addressed in this study:

Can we estimate the time scale of the "lingering memory" of the system from these indices? If so, how does this lingering memory change from season to season? Do different weather related indices have a longer time scale in a particular season but shorter time scale in other seasons (e.g., subtropical PVI index could have a short time scale in winter seasons but a longer time scale in summers)? What is the interannual variability of the "lingering memory" time scale? Or is the interannual variability of the "lingering memory" time scale intimately related to the prominent externally/internally generated variability?

Do dynamics based numerical models (such as NCEP's GFS model) already have a reasonable good skill to forecast these weather-related and "location insensitive" indices beyond the 1-2 week predictability limit? What is the relation between the prediction skills of these indices and external forcing (such as ENSO)? Do the skills also depend on the phase of QBO or presence/absence of MJO? Are the skills related to the phase of NAM in winter seasons? Are the prediction skills of the weather indices are systematically better than the prediction skills of mean flow anomalies (such as NAO/AO indices which are based on geographically fixed patterns)?

Are the prediction skills of the indices related to the prediction skills of probability of extreme events? If so, is the correspondence between weather-related indices and extreme weather events consistently held even in the case that prediction skills of mean flow anomalies is below the usefulness level?