Final report

Title: Application of information theory to measure and increase the skill of long-term forecasting
PI: Krakauer
Project and Report period: August 2012-July 2015

Overall, the Scope of Work for this award as submitted on July 2012 was met. Numerous peer-reviewed publications, conference presentations, and originally unanticipated applications resulted.

Evaluation of the NOAA Climate Prediction Center (CPC) probabilistic forecasts of 3-month temperature and precipitation anomalies made at 0.5-month lead time was completed and published (Item 1) [1]. It was found that mean information gain was positive but low (about 2% and 0.5% of the maximum possible for temperature and precipitation forecasts, respectively) and has not increased over time. We developed a new decomposition of forecast information gain into Confidence, Forecast Miscalibration, and Climatology Miscalibration components was developed, allowing us to show that the CPC forecasts for temperature are on average underconfident while the precipitation forecasts are overconfident. We applied a probabilistic trend extrapolation based on exponential smoothing to provide an improved reference seasonal forecast. We showed that combining the CPC forecast with the probabilistic trend extrapolation more than doubles the mean information gain, providing one simple avenue for increasing forecast skill.

Additional related work included using spline smoothing and kriging to provide improved climatology forecasts. In particular, we estimated the nonlinear change in minimum average temperature in the USA, with application to regularly updating the hardiness zones used in horticulture and other fields [2]. This work was featured on the CPO website [3] and attracted a substantial amount of media coverage [e.g. 4, 5]. As well, we studied how heat and water exchanges between the surface and aquifers may influence the predictability of climate on seasonal timescales [6].

An application of our methodology to estimating precipitation trends over the coming decades by combining past observations with climate model output was published [7]. We also explored land surface components of seasonal predictability, including groundwater, soil moisture, and snowpack [8-11], which resulted in an invited post in Tom Gleeson's Water Underground blog to explain our work to lay readers [12]. Another aspect of predictability ventured into was societal ability to withstand climate change impacts [13]. As another form of outreach, the PI also successfully applied some of the developed methods as an invited participant in Spring 2015 in NOAA's online Climate Challenge series [14].

Our team evaluated the CFSv2 reforecasts (CFSRR) as well as seasonal predictions by the larger National Multi-Model Ensemble (NMME) using information-based metrics to quantify their skill and study alternative post-processing strategies (Items 2 and 3 in the Scope of Work). One important element in this work has been constructing reliable climatological forecasts of changing climate variables that can be used as a starting point for incorporating numerical model output. Results from this work have been presented at the NOAA 38th Climate Diagnostics and Prediction Workshop in October 2013; WMO/ICSU World Weather Open Science Conference in August 2014; in the NOAA Bias Corrections in Subseasonal to Interannual Predictions Virtual Workshop in October 2014; at the Society of Hispanic Professional Engineers Annual Conference in November 2014; and in the Fifth Symposium on Advances in Modeling and Analysis Using Python at the American Meteorological

Society (AMS) Annual Conference in January 2015. Manuscripts describing the work with CFSRR and NMME are in preparation for submission to peer-reviewed journals.

A journal article detailing aspects of work related to optimal temperature trend estimation has been published [15]. Another journal article considered using generalized linear modeling to allow linear regression tools to be applied to (non-normal) precipitation probability distributions [16]. The PI has also begun to explore applications of probabilistic evaluation and post-processing of numerical weather prediction model outputs to the emerging commercial interest area of solar resource forecasting; a second presentation on this methodology was presented at the 43rd Annual National Solar Conference in July 2014 and has led to the PI becoming involved in the leadership of the Solar Resource Assessment technical section of the American Solar Energy Society.

Our team has also published related work on model-data fusion to estimate trends in precipitation and their ecological impacts [17-20]. Work toward developing software tools has resulted in developed sets of Octave and Python routines posted as public Bitbucket repositories [21, 22], GNU Octave contributions such as a function for computations related to the generalized extreme value and multivariate t distributions [23], presentations of using Python for climate data analysis at AMS, which helped lead to a Software Carpentry workshop held at CCNY (September 2015) to teach students and young researchers in NOAA-related concepts of effective scientific computing workflows and reproducibility, and the PI's coordination of development of iterative sparse linear solvers and optimization routines under Octave's participation in Google's Summer of Code program. These all contributed to the software development goals of this project (Item 4).

The research undertaken as part of this proposal has also informed the PI's participation in the American Society of Civil Engineers (ASCE) Committee on Adaptation to a Changing Climate, which stressed the need for cooperation between climate scientists and engineers to develop time-evolving risk models for climate extremes that determine infrastructure design. A committee white paper was recently released as a book by ASCE summarizing our initial conclusions, with the PI a contributing author [24].

The work under this award has also led to a successful follow-up grant proposal to NOAA for "Forecasting risk of seasonal temperature extremes with the North American Multi-Model Ensemble (NMME)". Over the 2015-2016 timeframe, this award is expected to allow additional research and development for probabilistic seasonal forecasting utilizing multimodel ensembles such as NMME, in coordination with the seasonal forecast team at NOAA's Climate Prediction Center. The work also contributed to grant proposals to DOE for improving the representation of groundwater in global climate models and better simulating the climate impacts of anthropogenic groundwater extraction; to NSF for conducting urban flood risk assessment given changing climate and infrastructure; and to NASA for developing drought monitoring and seasonal prediction products that integrate projections of both water supply and demand.

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