North American Heat Wave Predictability: Assessing the Role of Land Surface Initialization on S2S and NMME Model Forecasts -- *Progress Report*

1. General Information

Project Title: North American Heat Wave Predictability: Assessing the Role of Land Surface Initialization on S2S and NMME Model Forecasts
PI/co-PI names and institutions: Paul A. Dirmeyer (George Mason University); Trent W. Ford (Southern Illinois University
Report Year: 1 July 2017 – 30 June 2018 (Year 2)
Grant #: NA16OAR4310095 (GMU) / NA16OAR4310066 (SIU)

2. Main goals of the project, as outlined in the funded proposal

(1) Evaluate the ability of numerical forecast models included in the Sub-seasonal to Seasonal (S2S) Prediction and North American Multi-Model Ensemble (NMME) Phase II (SubX) projects to predict heat waves following drought events in the United States
(2) Relate model forecast performance to parameterization of land surface variables, coupled land-atmosphere metrics and initialization of land surface conditions
(3) Assess how more realistic land surface initialization in forecast models influences their ability to predict and simulate heat wave events in the United States

3. Results and accomplishments

The research goal of this project is to enhance our understanding of the connection between heat waves and land-atmosphere coupling in the United States, as well as evaluating the ability of a suite of climate forecast models to predict heat wave occurrence. This goal is achieved by addressing the three objectives listed above:

Major Activities:

Research Activities in Year 2:

The second-year research foci have been on Objectives 1 and 2. To this end, we have continued to collect and analyze model hindcasts at various lead times from the S2S climate modeling community, and have adopted a variety of gridded observation-based temperature and atmospheric reanalysis datasets for model validation. We have developed a model verification framework to assess the fidelity of hindcasts of maximum, mean, and minimum temperature heat waves. The development of this verification methodology and verification results from the NCEP model are summarized in Ford *et al.* (2018). As a follow up, we are exploring the impact of distribution and parameter choice on weighting for fair evaluation of model heat wave forecast from short- to medium-range time scales. We will soon summarize these results in a methods-focused manuscript that will be submitted to *Journal of Geophysical Research-Atmospheres.*

In addition, we have begun evaluating the statistical relationship between land surface moisture and subsequent maximum temperatures in the MERRA-2 and ERA-I reanalysis datasets. In particular, we have evaluated the influence of antecedent moisture conditions on the likelihood of extreme heat, as well as the intensity and duration of extreme heat events. The thermodynamics connecting the land surface with air temperature anomalies in the MERRA-2 and ERA-I systems have been compared to the internal soil moisture – temperature coupling in the NCEP forecast model, with results suggesting underestimation of soil moisture coupling with the atmosphere in the Midwest and Southwest U.S. We are currently summarizing these results as well as running similar analyses for other forecast models. We will soon submit an article for publication based on these results in *J. Geophysical Research-Atmospheres*.

So far, the results of this project have been disseminated through a scientific article published in *NPJ Climate & Atmospheric Science* (Ford *et al.* 2018), an article published in *U.S. CLIVAR Variations*, and presentations in the S2S Prediction Task Force Kickoff Meeting in December, 2016 and the American Geophysical Union Fall Meetings in December, 2016 and 2017. Results will also be presented at the 8th GEWEX Open Science Conference in May 2018, and the 2nd International Conference on Subseasonal to Seasonal Prediction (S2S) in September 2018.

Significant Results:

To date, the major findings of this project are:

(1) The Poisson weighting framework, combined with a variety of model skill metrics provides a means for a fair comparison of heat wave forecast fidelity over S2S timescales

(2) Models examined in depth so far – CMA, NCEP, JMA – do not well forecast heat waves over the contiguous United States

(3) Model heat wave forecast fidelity is related to the strength of soil moisture-atmosphere coupling

Key Outcomes

To date, this project has resulted in a manuscript published and 2 additional manuscripts in process. In addition, the project has resulted in **4** conference presentations, and was the basis for an article in the U.S. CLIVAR *Variations* publication. This article summarizes the state-of-the science and recent research on land-atmosphere interactions and their role in subseasonal-to-seasonal forecasting. The project has benefitted from thesis research by a Masters student at George Mason University over the 2016-2017 academic year (M.S. degree conferred in Summer 2017); this student has continued on to pursue his Ph.D. at George Mason. The student's dissertation research is related to his work on this project. In addition, the project has benefited from the thesis research by a Masters student at Southern

Illinois University over the 2017-2018 academic year. One undergraduate student researcher at Southern Illinois University has also been working on the project, focusing on the role of land cover on heat wave characteristics and the models' abilities to capture these effects.

4. Highlights of Accomplishments

- Developed a framework for validating S2S model heat wave forecasts at a variety of lead times
- Comprehensively verified heat wave forecasts from 3 models so far
- Decomposed the statistical coupling between soil moisture and air temperature relevant to heat wave occurrence
- Established a climatology of heat waves and assessed heat wave characteristics within multiple atmospheric reanalysis datasets
- Determined the spatial variability of soil moisture – temperature interactions
- Presented findings at multiple workshops/conferences, developed 3 manuscripts, augmented the thesis work of 2 MS-level graduate students, 1 PhD-level graduate student, and provided a research opportunity for 1 undergraduate student

5. Transitions to Applications

N/A at this time.

6. Publications from the Project

Conference Papers & Presentations:

Ford, T.W., Dirmeyer, P.A., and D. Benson (2017) "Evaluation of Heat Wave Forecasts Seamlessly Across S2S Time Scales: Skill Attribution and the Role of Land-Atmosphere Interactions.

Dirmeyer, P.A., Ford, T.W., and D. Benson (2016) "Predictability of Heat Waves Following Drought Events in the United States in S2S Models". NOAA Sub-seasonal to Seasonal Extremes Workshop. December 7, 2016. Palisades, New York.

Ford, T.W., Dirmeyer, P.A., and D. Benson (2016) "Land-Atmosphere Interactions and Subseasonal-to-Seasonal Forecasting of Extreme Heat in the United States". CLIVAR *Variations* Webinar Series. December 8, 2016.

Ford, T.W., Dirmeyer, P.A., and D. Benson (2016) "Evaluation of the Ability of S2S and NMME Models to Predict Heat Waves Following Drought Events in the United States". American Geophysical Union Fall Meeting. December 15, 2016. San Francisco, California.

Published Articles:

Dirmeyer, P. A., T. W. Ford and D. O. Benson, 2018: Evaluation of Heat Wave Forecasts Seamlessly Across Subseasonal Time Scales. *npj Climate & Atmos. Sci.*, (in press).

Ford, T. W. and P. A. Dirmeyer, 2016: Land-atmosphere interactions and subseasonal-to-seasonal forecasting of extreme heat in the United States. *US CLIVAR Variations*, **14**(4), 30-35.

Ford, T.W., P.A. Dirmeyer, D.O. Benson, and C. Wong, Land-Atmosphere interactions and subsesaonal heat wave forecasts from a suite of climate forecast models. *J. Geophys. Res.*, (in prep.).

Dirmeyer, P.A., T.W. Ford, and D.O. Benson, Seamless evaluation of forecasts from days to months: Rationale for a variable-length validation window. *J. Geophys. Res.*, (in prep.).

7. PI Contact Information

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8. Budget for Coming Year

Incremental amount: $118,132 for Y3 period (through 30 June 2019)

9. Future Work

The focus of our research activities during the next year will include the following:

(1) Continued verification of S2S model heat wave forecasts

Over the last year, we have made significant progress in designing and implementing a methodology for verifying S2S model heat wave forecasts. We have applied this framework to extensively evaluate heat wave forecasts from 3 models in the S2S group. We will continue to evaluate the remainder of the suite of S2S and SubX models in order to more comprehensively understand our current heat wave forecasting capabilities and how these relate to land-atmosphere interactions.

(2) Continued analysis of soil moisture – atmosphere coupling relevant for heat wave processes

The initial results from the land-atmosphere coupling analysis suggest the dynamic and thermodynamic processes connecting soil moisture to boundary layer conditions relevant for heat wave onset are important components for heat wave prediction. Additionally, our initial results from model soil moisture validation has shown that the NCEP and CMA models do not well capture observed soil moisture variability. These results necessitate further analysis to determine the specific processes that couple the land surface and atmosphere, and how these processes act to initiate extreme heat conditions. Additionally, we will assess how model soil moisture fidelity relates to the model's ability to capture soil moisture-atmosphere coupling and resultant heat wave occurrence, frequency, and intensity.