Precursor Conditions to Onset and Breakdown of Agricultural Drought over the United States Corn Belt Region: Final Report

Instructions: Please remove any explanatory text and replace with your input to the report.

1. General Information

Project Title: Precursor Conditions to Onset and Breakdown of Agricultural Drought over the United States Corn Belt Region
PI/co-PI names and institutions: Paul E. Roundy
Report Year (Progress Report Fiscal Year or Final Report): Final Report
Grant # NA14OAR4310230

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

The proposal included a series of 8 stages that were sorted according to years 1-3. The primary were to identify corn belt region drought onset or decline events and find the favored weather patterns at the transition time by compositing the signals of the events in reanalysis and observed data. The proposal then provided to repeat the analysis in reforecast databases to diagnose the ability of numerical weather prediction models to predict the events. Finally, the work proposed developing statistical tools for prediction of drought or heavy rainfall periods based on the detected precursors. Some discussion of results is inserted beneath each numbered objective. Other results are included under the results section.

> (1) Use Corn Belt Region (CBR)---mean temperature, rainfall, and incoming solar radiation data to generate a time series of corn growth. The remaining steps will be carried out based on this corn---specific index as well as based on the NOAA CMI index.

A corn growth index, averaged over the CBR (Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska and South Dakota) was computed using data from the North American Regional Reanalysis dataset (NARR; Mesinger et. al, 2004). The NARR provides a long---term, consistent, high---resolution (~0.3 degrees, 32km) climate dataset for North America, which is run 8 times daily from 1 January 1979 to 31 December 2014. It was used to compute time series of daily mean 2---meter mean temperature, solar radiation, 10---meter zonal wind speed, 2---meter specific humidity,
2---meter relative humidity, and surface pressure. These variables were then used as inputs to the University of Nebraska Hybrid---Maize crop growth and yield model (Yang 2013) to compute a daily corn growth time series. This model has been extensively tested and calibrated across the CBR, making it an ideal candidate for this project. This model was tuned to produce a CBR corn growth time series for non---irrigated crops.

A simple CBR based moisture budget anomaly index was also created from the NCEP Unified Gauge---Based Precipitation Dataset (UPD, Higgins et al. 2000) and crop model derived evapotranspiration (calculated using the Penman---Monteith approach).

This dataset contains a 0.25° x 0.25° mesh of daily (1200–1200 UTC) precipitation observations over a 59---yr base period (1 January 1948–31 December 2006) for the region bounded by 20.125°N --- 49.875°N, 230.125°E --- 304.875°E. These precipitation data have been extended through the present, on a slightly shifted grid, and are updated daily. The UPD was averaged over the same states listed above, creating a CBR precipitation index, which was transformed to an approximately normal distribution using a Box---Cox power transform (Wilkes 2011). From there, the leading four seasonal harmonics and mean were subtracted to create a precipitation anomaly index. Both the precipitation anomaly time series and evapotranspiration time series are normalized by dividing by a day of year based seasonal standard deviation. This standard deviation is computed by regressing the square of the anomalies onto four seasonal harmonics, then taking the square root of the result.

(2) Identify from the growth index periods of drought onset and drought recovery over a long climatology as functions of stage of the growing season.

Agricultural drought transition periods were detected using both the precipitation budget anomaly and corn growth time series. For the budget anomaly time series, events were determined by creating a forward and backward looking *n*---day budget anomaly time series. Positive transition periods, or transitions away from drought, were defined as negative budget anomalies averaged over *n* days that were followed by at least *n* days with positive time---mean budget anomalies. The thresholds used for *n* were 10, 20 and 30 days. The mean from the n^{th} backward looking day to day zero must be less than –1 standard deviation and the mean from day zero to the n^{th} forward looking day must be greater than +1 standard deviation to qualify as a transition event. Negative transition events use the opposite metrics.

Another set of transition events were identified using the crop model derived corn growth index. The crop model outputs two valuable corn growth variables, leaf area index (LAI) as well as well as estimated stover (the leaves and stocks of crop plants). We found time local maxima and minima in the stover curves over the 35---year period to use as benchmarks for drought transition periods, where minima imply a transition from diminished harvest back to healthy harvest and maxima imply a transition from healthy harvest to diminished harvest. We also plan on creating LAI anomalies, which will be used to generate another set of events where transitions from negative (positive) to positive (negative) LAI anomalies signal a transition from anomalously slow (fast) growth to anomalously fast (slow) growth. We anticipate substantial agreement between these different indexes. In ongoing work in the remainder of year 1, all of the aforementioned cases obtained from each index will be cross---referenced to determine if each method is identifying similar periods.

In addition to the above, we plan to cross reference the drought development and decline cases obtained from the rainfall and crop growth indexes.

(3) Perform a census of the set of all events, including subjective observation of the synoptic evolution leading up to each transition event, and generate time lag composites of these events for the entire season as well as monthly and biweekly through the season (for applications in which sufficient data are available).

Weather maps targeting the synoptic evolution of each of the drought transition events identified by the precipitation anomaly index have been analyzed. There is substantial

variability in the evolution of the 500--hPa geopotential height anomalies leading up to the positive and negative transition events. The composite analysis provides a much clearer picture of the similarities in the evolution of these events. Fifteen days leading up to a 10--day positive transition, there is substantial anomalous troughing over East Asia, a weak composite mean ridge anomaly over the Pacific Ocean and anomalous ridging across Alaska and the Gulf of Alaska. Farther downstream, anomalous ridging is anchored over Alberta/Saskatchewan, implying large---scale subsidence over the CBR. There exists a generally weak, negative, composite mean outgoing long wave radiation (OLR) signal over the Maritime Continent implying enhanced convection in this region. By ten days leading up to the transition event, it is evident that Rossby wave dispersion is occurring across the Pacific Ocean into North America, with anomalous ridging over the central pacific, troughing off of the west coast of the continental United States (CONUS), and anomalous ridging over the western half of the CONUS. Further, a large region of enhanced convection is evident over the Indian Ocean, and the convective anomalies that were over the Maritime Continent have propagated east to the central equatorial Pacific Ocean. Over the next five days, the Rossby wave continues to propagate eastward, yielding strong anomalous ridging over the CBR and troughing off the west coast of the U.S.. This anomalous ridge eventually extends across the east coast of the U.S., inducing anomalous southerly flow off of the Gulf of Mexico, providing anomalous moisture transport across the CBR, while anomalous troughing west of the CBR provides large--scale dynamic ascent, allowing for precipitation. The evolution of ten---day negative transition events is markedly different from the evolution of the positive transition events. Corresponding figures are in the references.

The synoptic evolution of 10---day negative transition events is nearly opposite from the positive transition events in a composite mean sense, but with a small phase shift. Fifteen days prior to negative transition events, there are virtually no statistically significant 500---hPa geopontential height anomalies. Regions where convection was active in the positive transition composites now show suppressed convection. Over the next 5 days, a Rossby wave train emerges in the composite with anomalous troughing over the central Pacific, ridging off of the west coast of the U.S., and troughing across the western half of the U.S.. This pattern supports synoptic ascent across the CBR and enhanced rainfall across the CBR. Again, the convective anomalies in this composite are nearly 180 degrees out of phase with that of the positive transition composite. Over the next five days, composite mean troughing sets up across much of the central U.S. By lag 0, the synoptic pattern across the CONUS has changed significantly, now with anomalous troughing across the eastern half of the country. Overall, the negative transition composite analysis does not show any strong convection anomalies in the tropics; however, those weak anomalies that do exist are 180 degrees out of phase with those evident in the positive transition events.

Results provide a comparison of composite geopotential height anomalies in a longitude---time framework, but with latitude varying with time along an arc of trajectory of the strongest anomalies. The result based on positive transition events is shaded and the result for negative events is contoured. This result supports the view that the synoptic conditions leading to transitions toward or away from agricultural drought tend to be roughly opposite each other. This result also suggests that drought conditions prior to the transition event were maintained or amplified by a Rossby wave dispersion event beginning roughly 2 weeks prior to transition, probably over the western North Pacific Ocean. The wave train then shifts eastward toward the time of transition. The apparent origin of the wave train suggests that convective events, such as recurving typhoons in the western North Pacific region, might ultimately yield some transition events, potentially decreasing our ability to predict such transition events at long lead times. Further analysis in the coming months should illustrate the range of preferred pathways whereby such
transitions occur.

1) Complete the composite analysis and report results in peer reviewed article (completed 2016, see publications).
2) Repeat composite analysis on the CFS V2 and GEFS reforecast datasets. (we used CFS V2 and other models from the S2S datasets). Completed 2017.
3) Develop a probabilistic prediction system based on ensemble model forecasts and on identification of the precursor patterns for drought onset or termination to be applied in real time. (Third Year). A statistical algorithm was developed and its basics are reported here and were presented at the S2D meeting in Boulder CO September 2018. The regression algorithm is published by Roundy (2017).
4) Assess the skill of the model reforecast datasets against each other, against climatology, and against the statistical forecast algorithm. (Second and Third Years)
   Figure (1) provides a basic assessment of the skill. Skill against climatology was assessed, but comparison against models was done only via survey of the literature for model correlation scores, because there is no comparable index from models.
5) Develop an online public information product that shows the precursor patterns of drought transition events and indicates how well present and past analysis fields and model forecasts project onto these patterns and subsequent drought transition events. This product will be continuously extended in real time, based on both reforecast models and statistics of observations. (Second and Third Years). This portion of the project had to be discontinued as part of shrinking the project budget at the time it was funded (could not hire the programmers to complete the task).

3. Results and accomplishments

The proposed composite analysis of observations and reanalysis data has been completed and published in Monthly Weather Review (see publications, below). The proposed composite analysis of reforecast data is now under review by the editor (after minor revisions).

Here is the abstract summarizing the results of the composite analysis paper:

Agricultural drought in the U.S. Corn Belt region (CBR) has tremendous global socioeconomic implications. Unfortunately, the weather and climate factors that contribute to transition events toward or away from such droughts are poorly understood. This study applies composite, trajectory clusters, and a vertically integrated moisture budget to understand the phenomena that influence transition events that evolve over 20 and 60 days as modulated by interannual, intraseasonal, and synoptic-time-scale variability during May–August over the CBR. Results show that a shift in the low-frequency base state does not explain onset or decay of the 20- or 60-day drought transition cases. Instead, amplification of an intraseasonal Rossby wave train across the Pacific Ocean into North America, which occurs coincident with intraseasonal tropical convection on its equatorward side, triggers the transition. Trajectory analysis reveals similar source regions for air parcels associated with drought development and breakdown, but with a shift toward more parcels originating over the Gulf of Mexico during transitions away from drought. Finally, the vertically integrated moisture budget shows that advection and convergence of moisture on intraseasonal time scales dominates during these transitions. These results demonstrate that weather events (internal weather variability) are the primary drivers of agricultural drought transitions occurring over 20 and 60 days.

The abstract summarizing results for the model analysis paper follows:

The prediction of drought onset and decay in the United States Corn Belt Region (CBR) on seasonal to subseasonal time scales has not been well studied. This study utilizes the sub-seasonal to seasonal prediction archive to assess model errors in large-scale circulation patterns associated with agricultural drought transition periods, targeting models used by the European Center for Medium Range Forecasting, National Center for Environmental Prediction, and Australian Bureau of Meteorology. An analysis of the seasonal cycle of bias for geopotential anomalies at 200 hPa and net radiation at the top of the atmosphere in each model is presented and used to subtract the long-term bias from each model. Model fields are decomposed into three spectral bands, low frequency (periods > 100 days), intraseasonal (periods 20 to 100 days) and synoptic (periods < 20 days) to demonstrate each model's ability to predict patterns associated with agricultural drought transition periods in each band. Results demonstrate that ECMWF and NCEP struggle in predicting the large-scale circulation patterns associated with 20-day agricultural drought and onset transitions, but are more skillful in predicting the patterns associated with 60-day agricultural drought onset and decay events at lead F360 – F480. BoM was not skillful in predicting the circulation patterns associated with either type of drought transition. Results also demonstrate that the errors associated with these events are no worse than historical errors for the target study period.

Our earlier results showed that drought transition events occur twice as frequently during low frequency states that project well onto a particular pattern (highlighted in our first paper). However, preliminary results suggest that forecast probabilities for upcoming transition events based on the presence or absence of this background state remain relatively small for any given forecast day (i.e., lower than a few percent). Thus skillful prediction would also need to include intraseasonal patterns (which implies lower predictability on seasonal timescales). Results imply that notice for upcoming events is limited to a small probability given by the base state and a larger contributing factor based on the evolving intraseasonal state.

As suggested in our revised budget when we were required to take a budget cut, the reduction of funding imposed by NOAA made it impossible to pay for assistance to complete creation of the proposed online forecast system. The lead graduate student's progress during the first year of the project was also slowed because the reduction of funds required that he serve one more year as a teaching assistant before he could transition to full research assistant support on the grant for the second year. However, we did complete statistical model development during the no-cost extension as reported below.

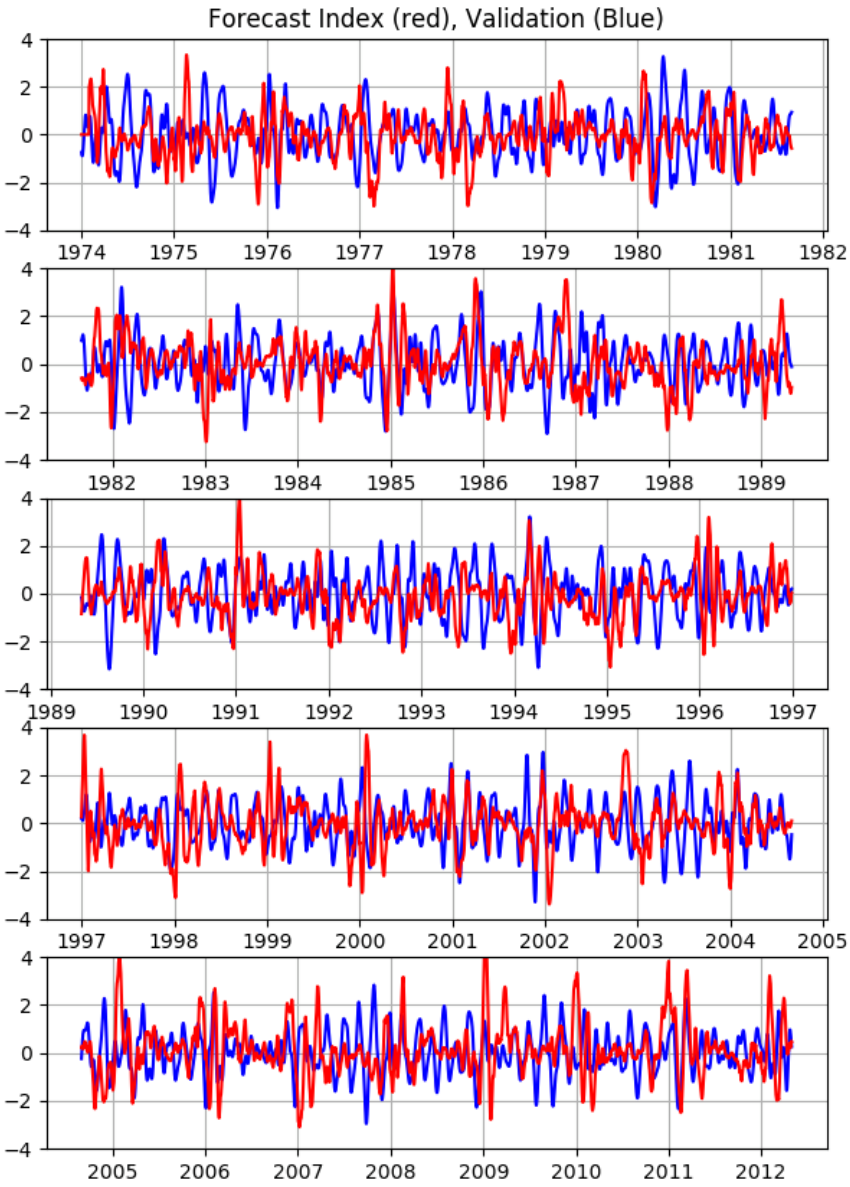
4. Highlights of Accomplishments

a. Generated precipitation and corn growth indexes for the corn belt region.
b. Identified a list of past transition events from wet to dry or from dry to wet, and identified a similar set of events based on reduced or enhanced crop growth.
c. Analyzed the synoptic environments of the sets of identified drought transition cases.
d. Generated composites of global atmospheric circulation patterns and patterns in anomalous tropical convection to assess the mean conditions associated with transition toward or away from agricultural drought events.
e. Analyzed the low frequency, intraseasonal, and synoptic environments of the sets of identified drought transition cases.
f. Identified a low frequency atmospheric pattern over North America that supports increased observation rates of 20 and 60-day transition events toward or away from drought.
g. Demonstrated the critical role that intraseasonal and synoptic variability plays during drought transitions, and showed that a particular low frequency background pattern favors both transitions toward and away from drought.
h. Found several signals in the tropical atmosphere that precede 20 and 60-day drought transitions, and provided a mechanism for how they interact with the intraseasonal 200 hPa geopotential patterns associated with drought transitions.
i. Identified preferred source regions of parcels associated with drought onset and decay, as well as their moisture impact on these events.
j. Showed that the largest contributors to a vertically integrated moisture budget during these transitions are due to intraseasonal changes in moisture advection and convergence over the CBR.
k. Completed the composite study of reanalysis and observational data to diagnose

prevailing synoptic, intraseasonal, and low frequency patterns during the drought onset and decline events. Published results in Monthly Weather Review (see publications). Results showed that onset or decline events are both favored in the same low frequency background condition, but with opposite intraseasonal states. Intraseasonal variations dominate the transition periods.

l. Completed and submitted for peer review the follow up composite study analyzing the same events in reforecast databases. This work was accepted for publication June 12, 2017.

m. In 2018, the PI completed creation of a statistical model that uses precursor geopotential height anomalies to predict transitions toward or away from drought. Results were presented in a poster at the S2D meeting in Boulder CO September 2018. Figure (1) shows a cross-validated reconstruction of a time series of next months rainfall minus this months rainfall (designed to predict changes in the present rainfall state), based on 30-days of geopotential height anomalies projected onto the seasonally-evolving structures of geopotential height associated with CBR rainfall data. The algorithm uses the method of seasonally varying regression slope coefficients the PI published in Roundy (2017).



5. Transitions to Applications

The statistical prediction algorithm uses the recent 30 days of 200 hPa geopotential height anomalies to predict next month minus recent month total precipitation in the corn belt region. The above figure provides a basic skill assessment. The correlation skill is around 0.2, which is

an improvement over comparable results based on numerical weather prediction for 1-month precipitation forecasts.

6. Publications from the Project

Authors, Year: Title. Journal name and specifications/status.

Roundy, P. E. (2017), Diagnosis of seasonally varying regression slope coefficients and application to the MJO. Q.J.R. Meteorol. Soc., 143: 1946-1952. doi:10.1002/qj.3054

Schiraldi, N.J. and P.E. Roundy, 2017: The Evolution of Agricultural Drought Transition Periods in the U.S. Corn Belt. *Mon. Wea. Rev.,* **145**, 451–472,https://doi.org/10.1175/MWR-D-16-0225.1

Schiraldi, N.J. and P.E. Roundy, 2017: Seasonal-to-Subseasonal Model Forecast Performance during Agricultural Drought Transition Periods in the U.S. Corn Belt. *Mon. Wea. Rev.,* **145**, 3687–3708, https://doi.org/10.1175/MWR-D-17-0026.1

7. PI Contact Information

Paul E. Roundy
Department of Atmospheric and Environmental Sciences
University at Albany
Albany, NY 12222
proundy@albany.edu
518-442-4476

8. Budget for Coming Year

Project is completed.

9. Future Work

Further work is planned to publish the forecasting algorithm. I am willing to discuss the statistical tool with NOAA developers if they are interested in using the algorithm.