Subseasonal Predictability of US Heat Waves/Droughts Associated with Planetary Wave Events Progress Report

1. General Information

Title: Subseasonal Predictability of US Heat Waves/Droughts
Associated with Planetary Wave Events

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2. Main Goals of the Project

Our study has been motivated by the idea that there is the potential for predicting US droughts, heat waves and flood conditions beyond the limits of traditional weather predictability because the likelihood of these events can be affected by the configuration of the planetary waves and some aspects of these waves may be predictable beyond the limit of instantaneous weather prediction. That the likelihood of these events can be affected by planetary wave anomalies has been demonstrated by our earlier US heat wave study as well as other studies. Based on these earlier studies our investigation has focused on characterizing and understanding the processes that produce one particular type of planetary wave pattern, namely modes that are influenced by the mean jets as they act like waveguides to Rossby waves. The resulting patterns promote covariability between very widely separated geographical locations on subseasonal and longer time scales. And though we have been primarily motivated by our earlier work on US heat waves, another application that has developed during the course of our study is their role in producing long lasting West Coast ridges, like those that appear to have caused, or initiated, drought conditions in California during the winters of 2013/14 and 2014/15. This development has caused us to investigate both internal and external processes for producing these key waveguide patterns.

3. Results and Accomplishments

Our project lasted two years and was extended by an additional year whose primary activity was finishing the writing and publication of two of the four papers that resulted from our project research. Each of the four papers was devoted to one of four subprojects. .

i. Connections between heat waves and circumglobal teleconnection patterns in the Northern Hemisphere summer

In an earlier study, we found that heat waves and dry spells in the US Great Plains that last for a week or so tend to be associated with a circumglobal teleconnection pattern (CGT). This pattern appears to be predictable for roughly two weeks and imparts similar predictability to these extreme events. In this subproject we generalized aspects of this study by determining whether heat waves in other parts of the globe are also associated with CGT patterns. This subproject helped meet our goal to identify planetary wave patterns that accompany subseasonal heat waves and droughts and that perhaps contribute to their predictability.

We analyzed a 12,000-year CAM3 simulation so that we would have an ample sample of extreme events. One effective approach that we utilized was to key on the leading two CGT patterns that occur during JJA in CAM3. These two patterns are trapped in the mean tropospheric jet and can be found as EOF1 and EOF2 of subseasonal variations in 300 hPa meridional wind. Fig. 1 shows the slow evolution of streamfunction anomalies that are associated with EOF1. That figure also demonstrates that during this evolution the likelihood of extreme events at the surface is enhanced or diminished at various locations throughout the Northern Hemisphere in reaction to the changing circulation. Given the predictability properties of related patterns that we found in our earlier studies, these results suggest that heat waves and dry spells in the regions affected by these patterns may have predictability at subseasonal ranges. It also implies that there may be a tendency for extreme events to occur simultaneously at various locations around the North Hemisphere.

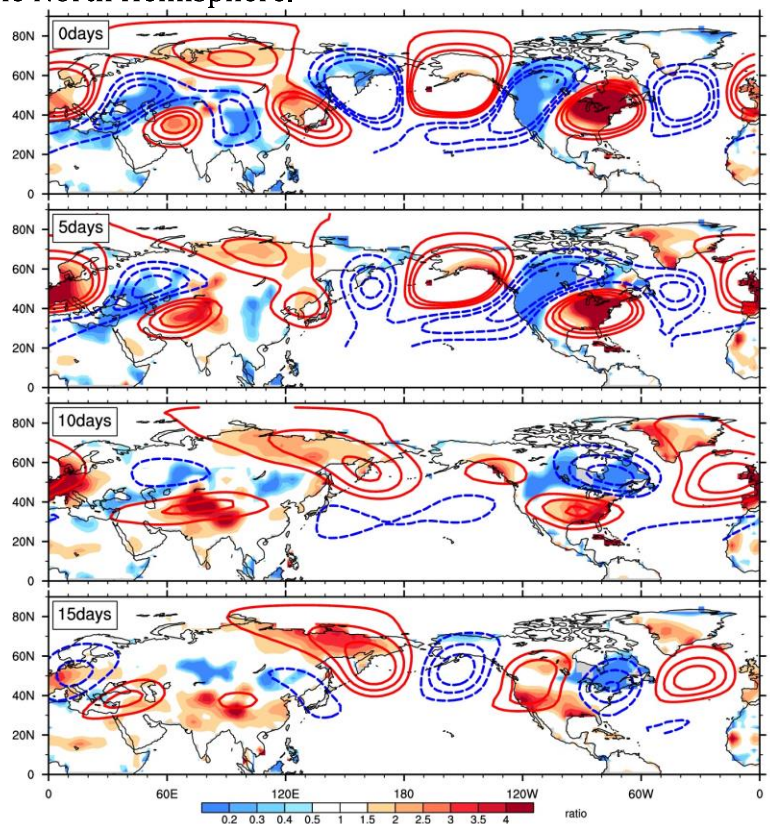

Fig.1. Shading represents ratio of probability of a heat wave occurring 0 days (top), 5 days (second row), 10 days (third row) and 15 days (bottom) after an extreme CGT1 event relative to the probability of a heat wave without any precondition. Contours represent a composite of 300 hPa streamfunction anomalies on the corresponding days at ±1, 2,3 $x10^6 m^2 s^{-1}$ intervals (Teng and Branstator 2015).

ii. Dynamic origin of the circulation pattern during the 2013/2015 California drought

We investigated the origin of the circulation anomalies that occurred during the winters of 2013/2014 and 2014/2015 and that appear to have been instrumental in causing the well-known West Coast drought conditions that were prominent during those years. Of particular interest has been the ridge off the coast that persisted during those years and which some studies have speculated was driven by tropical SSTs, especially La Nina events. We were struck by how dissimilar Pacific SST anomalies were during those two winters leading us to hypothesize that in fact internal midlatitude dynamical processes may be the primary source of the ridge pattern. Our analysis of reanalysis fields and general circulation model control integrations appeared to support the hypothesis that the ridge is an intrinsic pattern of variability. For example we found the west coast ridge pattern that occurs in nature and a coupled GCM is part of a hemispheric-wide pattern that also occurs in a stand alone atmospheric GCM (see Fig. 2). Narrowing the processes that are necessary for formation of the ridge pattern even more was our finding that it occurs in a planetary wave model even if it is driven by randomly generated forcing. On the other hand these results do not preclude the possibility that tropical heating anomalies can on occasion force the intrinsic ridge pattern. And indeed we located tropical Pacific regions where heating increases the likelihood of a ridge event occurring, but these regions are not in the vicinity of La Nina events. (see Fig. 3) This study has several implications for subseasonal to seasonal prediction of drought in California. Perhaps most important from a prediction stand point is that it suggests that diabatic heating anomalies other than those associated with ENSO may potentially enhance the probability of a ridge that causes drought in California.

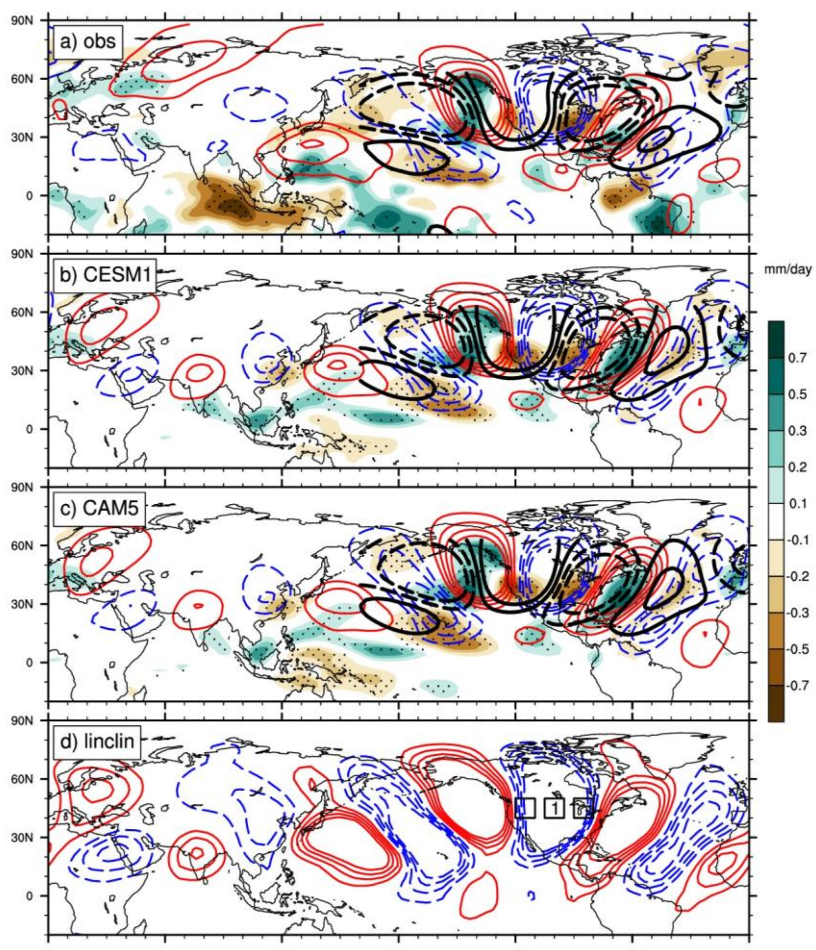

Figure 2. Subseasonal anomalies of v200 (red and blue contours), z200 (black contours) and precipitation (shading) during DJF months when there is a ridge in a box centered at 100W, 45N. a) nature, b) coupled CESM, c) stand alone CAM5, d) linear planetary wave model.

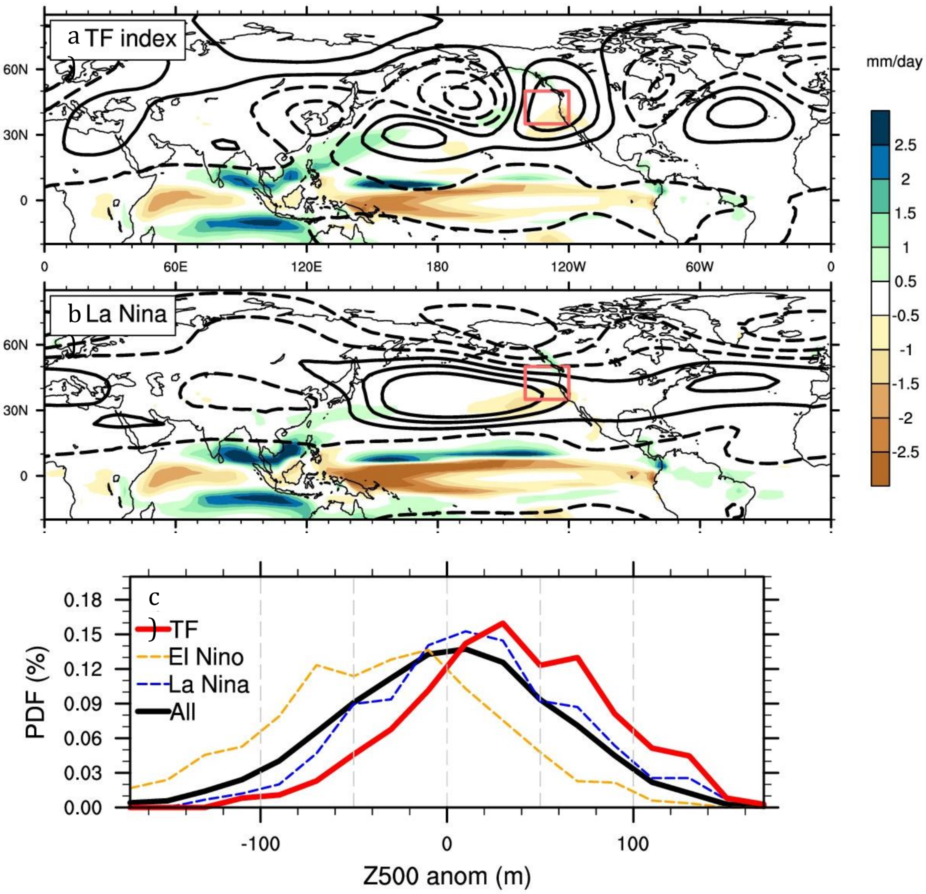

Figure 3. CESM1 composite maps of Z500 (contours, at ±5,15,25m) and precipitation (shading) anomalies for months with a) a tropical forcing index below 1 std dev and b) a Nino34 SST index below 1 std dev during DJF. c) PDF of domain-averaged Z500 anomalies off the West Coast (outlined, 140°-120°W, 35°-50°N) for all DJF months (black), and for months used to construct the composites in a), and b) as well as for positive Nino34 events.

iii. Seasonal contrasts in Northern Hemisphere tropospheric waveguide-enabled teleconnections

The above two subprojects indicate the importance of planetary wave fluctuations that are trapped in the mean tropospheric jets. In this third subproject we investigated such variations further through systematic examination of the impact of waveguides on subseasonal planetary wave variability. An important consequence of the resulting circulation anomalies is that events in one part of the globe can affect events a very long distance away. A unique attribute of our study was that we considered all seasons since we expected that analyzing the seasonality of the impact of the waveguides would serve as an effective way of highlighting these features and testing our understanding of the waveguide mechanism.

Through systematic analysis of reanalysis datasets and an atmospheric general circulation model control integration we found substantial geographical and seasonal dependence in the strength and structure of the resulting waveguide patterns, as is evident in the accompanying Figures 4a and 4b. One of the most striking characteristics is that during summer the waveguide teleconnections are much weaker and limited in zonal extent than during winter, so, for example, North America is more isolated during summer while during winter waveguide-trapped teleconnections are circumglobal. We also used a linear planetary wave model to confirm that linear dynamics are sufficient to explain the characteristics seen in our data analysis. (Compare the top and bottom rows of Fig. 4.) As seen in the figure, one of the interesting characteristics is that the strength of waveguide teleconnections depends on their exact longitudinal position – shifting the pattern by 15 degrees can noticeably affect its amplitude. The linear model indicates this characteristic depends on rather fine scale features in the climatological mean planetary waves, so representing waveguide teleconnections in climate and prediction models may be challenging.

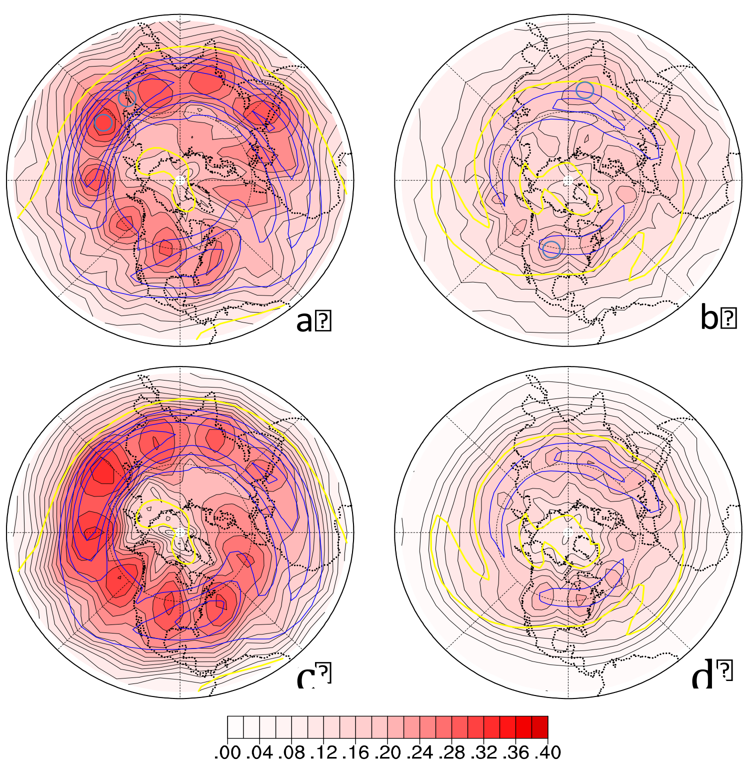

Figure 4. Northern Hemisphere RMS of various one-point correlation maps for subseasonal v200 plotted at the base point of each map. The top row is for reanalysis data – a) DJF, b) JJA. The bottom row is for solutions of a stochastically driven linear planetary wave model.

iv. Heat waves in the US Great Plains and planetary wave and soil moisture variability in a CESM1 large ensemble experiment

In this last subproject we analyzed how changes in the characteristics of planetary wave fluctuations caused by climate change as well as changes in mean soil moisture could affect the statistics of extreme midlatitude events. We utilized a 30-member CESM1 ensemble simulation. Each member simulates 1920 to 2100 using historical forcing (1920-2005) and RCP8.5 (2006-2100). We compared the statistics of heat waves and accompanying dry spells in the Great Plains of the US during these two epochs and found a substantial increase in heat wave temperature during the future period both because of a 5-6C warming in the climate mean surface temperature and because of a heavier positive tail in its distribution.

The amplification of temperature variability and heat waves in the Great Plains appear to be primarily caused by enhanced local land-atmosphere coupling resulting from a warmer/drier future climate at the surface. This finding is in contrast to the hypothesis put forward by numerous earlier studies that anthropogenic climate change might intensify future midlatitude extremes by enhancing planetary wave variability. In the earlier studies the evidence supporting this hypothesis has either been based on a simple model or on the relatively short observational records. In our study that rests on a huge population of events from a comprehensive model, changes in planetary wave variability do not appear to make significant contributions to the strengthening of summertime subseasonal temperature variability and heat waves in the Great Plains. Figure 5 demonstrates there is no enhancement of midlatitude planetary wave anomalies during simulated future heat waves; on the other hand it shows a consequence of changes in soil moisture, namely an increase in the deficit of the precipitation anomalies that accompany Great Plains heat waves. Thus our results provide a good example of how extreme events can be affected by climate change through processes that do not involve amplified planetary wave variability as our analysis diagnosed that the change in heat waves and associated drought intensity resulted from changes involving land-atmosphere feedbacks.

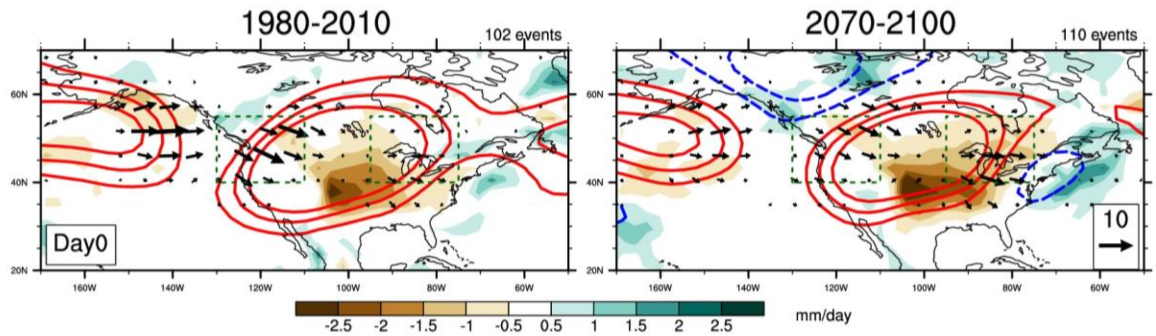

Figure 5. Composites of anomalous 200hPa streamfunction, precipitation and Plumb flux anomalies during Great Plains heat wave events for two epochs of a 30 member climate change experiment with CESM1.

Another, ongoing subproject that was initiated through support from this contract, also concerns the impact of soil moisture on intraseasonal events. It concerns reconfiguring CESM1 for seasonal predictions within NMME by including observed land surface properties including soil moisture in the initial state. As the current NMME submission does not initialize the land surface the hindcast comparison between the NCAR operational NMME submission and the initialized land hindcast affords the opportunity to understand the impact of soil aridity on the *in situ* water budget and the remote wave5 teleconnection amplitude all within seasonal predictions of the recent California drought.

4. Highlights of Accomplishments

- Found three locations in the Northern Hemisphere where heat waves frequently occur and are connected with planetary wave patterns that may be predictable on subseasonal time scales
- Highlighted the contribution of internal dynamical processes to the origin of the circulation pattern over North America during the 2013-2015 California drought and contrasted it with the potential impact of tropical heating anomalies including heating at locations not associated with La Nina.
- Quantified dramatic contrasts in the position, strength, span and scale of waveguide enabled teleconnection patterns in northern winter and summer; these subseasonal planetary wave fluctuations may impact the likelihood of heat waves and dry spells
- Determined that in a large ensemble of climate change realizations with CESM, an increase in the surface temperature of extreme heat waves in the central US results primarily from a shift in the mean and from changes in

surface moisture and heat fluxes rather than from a change in planetary wave fluctuations.

5. Transition to Applications

We have found it most fruitful to concentrate on investigating the structure and generating mechanisms for planetary wave patterns that we believe are instrumental in producing long lasting and extreme North American subseasonal and seasonal climate anomalies. We have not initiated the transition of our findings to applications, but we are confident that in the future operational centers will add the waveguide teleconnection patterns that we have documented to the collection of patterns they consider when forecasting the prospects for subseasonal and seasonal US droughts and heat waves. And we suspect that studies like ours of mechanisms for producing West Coast ridges will encourage forecasters to think beyond ENSO when looking for predictors of droughts and precipitation extremes in the western US.

6. Publications from the Project

Teng, H., G. Branstator, G. A. Meehl, and W. M. Washington, 2016: Projected intensification of subseasonal temperature variability and heat waves in the Great Plains. *Geophy. Res. Lett.*, doi: 1002/2015GL067574.

Teng, H., and G. Branstator, 2017: Causes of extreme ridges that induce California droughts. *J. Climate,* **30**, 1477-1491, doi:10.1175/JCLI-D-16-0524.1

Branstator, G., and H. Teng, 2017: Tropospheric waveguide teleconnections and their seasonality. *J. Atmos. Sci.,* **30**, 1513-1532. doi:10.1175/JAS-D-16-0305.1

Teng, H. and G. Branstator, 2017: Connections between heat waves and circumglobal teleconnection patterns in the Northern Hemisphere summer. AGU Monograph "Patterns of Climate Extremes: Trends and Mechanisms", Wang, Gillies, Yoon and Funk, Editors, AGU Monograph.

7. PI Contact Information

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8. Budget

The project has ended.

9. Future Work

The project has ended.