Analysis of Present-Day and Future Precipitation in the Southwestern United States

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ABSTRACT
The southwestern U.S. is one of many regions susceptible to the effects of our changing climate system. Numerous climate phenomena, such as the North American Monsoon and Madden-Julian Oscillation, are known to correlate with precipitation and temperature variations in the Southwest. These processes can be linked to sea surface temperatures (SST) in the tropical Pacific Ocean which also influence global climate. This study explored the relationship between ocean temperatures in the Pacific and temperature and precipitation changes in the southwestern U.S. by comparing observational data in an Intensive Observation Period (IOP) of the Southern Great Plains to the Community Atmosphere Model (CAM 4.0) and the Community Climate System Model (CCSM 4.0). This comparison was used to verify that these model data accurately depicted the present climate and could be used to capture a reasonable prediction for our future climate. Our analysis showed a correlation between tropical Pacific SST and variations in temperature and precipitation in the southwestern U.S. that creates a persistent El Niño effect in part because of an increase in greenhouse gases. Our statistical analysis yielded large values for this correlation, confirming our hypothesis that our changing climate system is affecting weather patterns in the southwestern U.S. through increased tropical Pacific sea surface temperatures.
1. Introduction

a. Background Information

Numerous mechanisms affect weather patterns in the Southwestern United States. These mechanisms are being closely studied to create long term predictions on various scales for different aspects of everyday life. Different contributors affecting the amount of precipitation seen in the southwestern region of the United States, ranging from the North American Monsoon to the Madden-Julian Oscillation, are discussed in the following section. Phenomena, such as those mentioned above, can be correlated with tropical Pacific sea surface temperatures (SST). These Pacific Ocean SSTs hold a delicate relationship with our global climate, which continues to go through variations. These relationships are explored through our study and their connection to the southwestern region of the U.S.

(i) North American Monsoon

A monsoon is defined as a “seasonal reversal of wind direction that occurs because of temperature differences between the land and sea across all of the tropics (NOAA/NWS).” Throughout a common monsoonal period, large amounts of precipitation can affect the four corners (Arizona, New Mexico, Colorado, and Utah) of the southwestern U.S. Although variations occur in the monsoon’s intensity and onset, its frequent track begins in the southern region of Mexico in early June and moves towards the Sierra Madre Occidental, reaching the U.S. in early July. As the low level jet stream around North America changes its position and surface winds reverse (northwest to southeast) in the northern Gulf of California, large amounts of moisture push through into the United States. These relatively cool, moist maritime airs, stemming from eastern tropical Pacific, are known as gulf surges, which are characterized by the changes in surface weather (NOAA/NWS). Variations are seen in the North American...
Monsoon, in part, because of interactions between Pacific and Atlantic oceans and the atmosphere itself. The El Niño Southern Oscillation (ENSO), local ocean temperatures and land surface interactions, and Madden-Julian Oscillation (MJO) exert a relationship in terms of intensity and onset of a monsoonal period. In conjunction with the monsoon, the Great Plains will see a decrease in precipitation while the east coast will experience an increase as the onset of the monsoonal period approaches, which will be a key component in regards to observational analysis. This interaction between different regions plays out because of multiple sources of moisture the NAM intakes from numerous bodies of water (Gulf of California, Pacific Ocean, and Gulf of Mexico).

(ii) *Madden-Julian Oscillation*

The Madden-Julian Oscillation (MJO) can be classified as a “disturbance that modulates the tropical patterns of precipitation (NOAA/NWS).” Also known as the 30-60 day oscillation (cycles last 30-60), it consists of large-scale coupled patterns in atmospheric circulation and a strong (“active phase”)/weak (“inactive phase”) deep convection and precipitation (Zhang, 2005), frequently manifesting over the western Indian Ocean and moving towards the western and central tropical Pacific. Its dynamics involves planetary-scale circulations and its interactions with mesoscale convective activities (Zhang, 2005). Numerous regions are affected by this phenomenon (Zhang, 2005), both by suppressing and enhancing precipitation rainfall. Furthermore, the MJO is known to affect climate phenomena, such as the North American Monsoon and El Niño Southern Oscillations. The MJO is highly variable, with irregular intervals between two consecutive events and varying propagation speeds (Zhang, 2005). Thus, our lack of fully understanding its variability and gaps in our knowledge of the MJO make it
difficult to accurately forecast this phenomenon through weather predictions and climate models.

(iii) El Niño-Southern Oscillation

The El Niño Southern Oscillation is global phenomenon, having effects on multiple regions around the world during its active period. Characterized by warm ocean temperatures in the Equatorial Pacific, the occurrence of El Niño tends to have irregular intervals of about five to seven years. The Walker circulation, during non-el Niño events, pushes easterly trade winds, moving warm water towards the western tropical Pacific (NOAA). Furthermore, this creates an upwelling off the coasts of Ecuador and Peru, bringing in deep cold nutrient water to the surface. In contrast, the western Pacific equatorial experiences thunderstorms and typhoons through warm, wet low pressure. During an El Niño active phase, trade winds falter in the central and western Pacific, leading to a depression of the thermocline in the eastern Pacific, and an elevation of the thermocline in the west (NOAA). With the depression of the thermocline, cold deep nutrient water fails to appear on the eastern Pacific, thus bringing in dangerous amounts of rainfall. Also, the typical warm water and rainfall in the western Pacific is replaced by drought conditions in areas such as Indonesia and Australia (NOAA). Changes in climate surrounding numerous regions are attributed to El Niño phenomenon, thus making it important to identify key characteristics for future weather predictions.

With numerous mechanisms impacting the southwestern United States at a global and regional scale, it is imperative for scientists to have a clear understanding of the changes occurring in our present climate system. These processes, listed above, are associated with natural variability in tropical Pacific SST. Furthermore, these tropical Pacific SST changes are also part of the signal of global climate change due to the increase in greenhouse gases. Through
our study, we explore the relationship between the changes of temperature and precipitation in
the southwestern United States to sea surface temperatures in the Pacific Ocean and its variations
towards present weather patterns and future implications throughout this region. We compared
the Southern Great Plains (SGP) Intensive Observation Period (IOP) to the Community
Atmosphere Model (CAM v.4) and the Community Climate Atmosphere Model (CCSM v.4).
This analysis verifies that our model data depicts our current climate accurately and captures a
reasonable prediction for our future climate. Furthermore, a statistical analysis was implored
using a cross correlation of Pacific temperatures and global precipitation. Our investigation will
thus show that global climate warming is affecting ocean temperatures, correlating with changes
in precipitation anomalies in the Southwest.

2. Methods

a. Analysis of Present Climate

The Community Atmospheric Model (CAM) 4.0, an extension of the Community
Climate System Model (CCSM), is a stand-alone atmospheric component model, driven by
empirical ocean data (UCAR, 2011). Using the years 2007 to 2009, we averaged 6-hourly time
intervals from every three hours in a 24 hour period for both precipitation and temperature. A
precipitation average is computed through the synthesis of two rain rate variables, including
convective and large scale precipitation rates. Temperature values were analyzed through the
usage of a reference height temperature variable in the CAM. Both precipitation averages
(m/sec) and temperature units (K) were altered through mathematical order of operations to
duplicate observational data. In regards to temperature values, latitude and longitude numerical
components (36.609, -97.487) were included to provide a precise location in which the stored data could be extracted from.

To verify the information yielded by the CAM, we compared its data to Atmospheric Radiation Measurements (ARM) through a Climate Research Facility located in Perkins, Oklahoma. The observational data is associated with the Southern Great Plains (SGP) region during an Intensive Observation Period (IOP) in part because of its flat surface area, mean elevation of 1,300 feet above sea level, and robust observed datasets (Netstate, 2011). Two observational data sets, from 2007 to 2009, were collected that included different time intervals in a 24 hour period, temperature numerical values, and precipitation rates. Mathematical processes adjusted the time intervals to be an average of 6 hours in a 24 hour period while precipitation itself was derived from the variable “rain-rate”, thus calculating the rate in which precipitation descends from the atmosphere towards a land surface per day. Temperature values were derived from observations within the observed data sets.

We also analyze the precipitation and temperature data from the CCSM for the years 2007 to 2009. As with the CAM model, time intervals were altered to 6 hourly in a 24 hour period, while a total precipitation is computed using the two variables convective and large scale precipitation and adjusted to mm/day. Temperature values, derived from the model using reference height temperature, were modified to Kelvin. In order for our comparison to be accurately evaluated, latitude and longitude coordinates were included (36.609, -97.487).

**B. Future Climate**

Once this comparison was placed, a future data set was extracted, using the CCSM, through the years 2097 to 2099. This period coincides with our present climate date (2007-2009)
chosen for our observations and CAM. Although a future climate date, the coupled model holds the same climate variables seen in our present run. Thus, we extracted a reference height temperature (K) and implored a total calculation on both convective and large scale precipitation with mm/day as units.

C. Statistical Analysis

Figure 1: A statistical analysis was implored using Niño SST indices and global precipitation.

Through our calculated results in our future run, we were able to create a cross correlation of tropical Pacific temperatures and global precipitation of a lag of one season. This lag, which corresponds to three months, was implored because of the time needed for changes to propagate (e.g. Trenberth et. al., 2002). This information will provide a correlation between our temperatures in the Pacific Ocean and the southwestern United States.
3. Results

By means of global and regional model representation and statistical analysis, numerous maps were produced to demonstrate the correlation seen in Tropical Pacific temperatures and variations in the Southwestern United States. As mentioned in section 1, to accurately analyze both the Community Atmospheric Model (CAM) and Community Climate System Model (CCSM) using observational information, we extracted both temperature and precipitation data from all of our data sets listed in section 2.

a. Affirmation of Data Interpretation

The data sets below, which are all in six hourly increments in a 24 hour period, are presented in present climate. Observational data was derived from the Atmospheric Radiation Measurement Research facility in Perkins, Oklahoma. The first two histogram plots, listed in Fig.1, show the observed data for precipitation and temperature for the Southern Great Plains region. Its spread accurately depicts observed precipitation rates captured throughout the time period of 2007 through 2009. Temperature observations are represented in Celsius for computational purposes for further cross examinations. Negative values are observed in the region for winter months captures colder air temperatures in the three year run. In comparison to the observed plots, model outputs in the CAM and CCSM yield a different spread than what is seen in the first two histograms. This can be attributed to a model bias. Examining our precipitation plots, we see the model having a lesser spread than that of the observed.
Figure 2: Precipitation and Temperature histograms on a six hourly period in a 24 hour period for observed data, the CAM, and the CCSM beginning in 2007 and ending in 2009.
This is because the known model biases, common to most climate models, manifests as light rain most of the time, and an under-estimation of large rain events. Now, with the observed data, measurements are able to capture sudden downpours, runoff, strong thunderstorms, and other immediate local weather occurrences. This verification thus allowed us to have confidence in the model to portray a fairly accurate forecast of a future date, with precipitation being the main climate variable.

b. Global Model Outputs

Figure 2: (left) A global temperature plot was created using the coupled model (CCSM) to investigate a future climate in the year 2097-2099 and present climate in the year 2007-2009. Furthermore, a difference in future and present climate
was calculated to explore the possible changes occurring. (Right) The southwestern United States portrays a present and future climate. A difference was also calculated to investigate the changes occurring within the region.

A global temperature plot (fig.2 right) was thus created from the verification of the Community Atmospheric Model with empirical ocean data. In contrast from present climate, the future climate plot portrays an increase in temperature in numerous regions around the globe. Furthering this viewpoint, the difference in present and future global temperature shows an increase in temperature in the Inter Tropical Convergence Zone (ITCZ). This “tongue” that appears in the difference model is similar to that of an El Niño shape and is located within its region of occurrence. In the southwestern United States (Fig. 2 left), temperature for a future and present climate date are shown above. A difference is then created to investigate the increase of temperatures occurring within the region. An overall increase is seen across the region, as temperatures increase in the Pacific.

Through our precipitation plots, 2 sub variables were used to create global precipitation diagrams seen in Figure 3, including large scale and convective precipitation. These were the totaled up to create a “total precipitation” variable to plot globally. Again, in our global plots, we see the same trend as that of our global temperature plots. The difference globally can be seen, especially in the ITCZ region. This “tongue”, or persistent precipitation, appears in the same region of the El Niño occurrence, implying a correlation. Focusing on the southwestern United States, we see an increase in temperature from the future and present precipitation run. An increase in precipitation, especially in the Arizona and New Mexico region, can thus be correlated with variations occurring in Tropical Pacific using a statistical analysis approach, to test the hypothesis that the change in precipitation over the southwest U.S. is a teleconnection response to the tropical Pacific temperature.
Figure 3: A global precipitation plot was created using the coupled model (CCSM) to investigate a future climate in the year 2097-2099 and present climate in the year 2007-2009. Furthermore, a difference in future and present climate was calculated to explore the possible changes occurring in regards to precipitation. (Right) The southwestern United States portrays a present and future climate. A difference was also calculated to investigate the changes occurring within the region.
c. Statistical Analysis Output

Figure 4: A cross correlation with a lag of one season, due to the time needed for changes to propagate (Trenberth et. al., 2002), was implored on El Niño 3 to global precipitation. A positive correlation can be seen surrounding our study area, the southwestern United States.

With a persistent El Niño-like pattern occurring in the Tropical Pacific, a statistical analysis was implored to investigate the correlation of global precipitation and how it relates to the southwestern region of the U.S. Through a lag of one season (3 months) of changes in the tropical Pacific, we are able to see a positive correlation occurring in the southwestern region.

4. Discussion and Conclusion

Through our approached statistical analysis, we were able to correlate tropical Pacific temperatures to global precipitation and visualize a connection occurring in the southwest region. Through a positive correlation in the southwestern United States, an increase in tropical ocean temperatures will thus increase precipitation within this region. A persistent El Niño-like pattern
is observed in both global climate plots through their calculated difference. This can be attributed to the warming seen in sea surface temperatures from present day to future climate. Past studies (D.B. Einfeld et. al., 1997) have shown a warming trend over the last century. Although ocean temperatures have leveled off over the past several years (Tribbia, personal communication) because of La Niña effects, the overall trend shows an increase in our future global climate. In addition, changes that occur in our global climate system control the variations occurring in our oceans. Through our model runs and statistical analysis, we expect an increase in ocean temperatures in the tropical Pacific due to our changing climate. This increase is likely a contributor to the increase in precipitation in the southwestern region.

For further accuracy of our results, we plan on imploring further statistical analysis. This analysis will provide us with the necessary verification to correlate our ocean temperatures to global precipitation. Furthermore, local feedbacks have been known to play a role in weather patterns in the southwestern region of the U.S. Comparisons of local and regional feedbacks of the studied area can be contrasted with those from the tropical Pacific to see how they compare with each other. Finally, to verify this El Niño-like trend occurring in the tropical Pacific, a robust data will be analyzed to further our investigations and confirm our results. This can be taken a step further and analyze phenomena affecting the southwestern U.S. Overall, the importance to further our understanding of the connections between variations in tropical ocean temperatures to the southwest is essential to have precise forecasts of our altering climate.
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