1. INTRODUCTION

The surface of the Pacific Ocean covers some 60 million square miles (nearly 160 square kilometers), nearly one-third of the surface of the Earth. The ocean's area is greater than that of all of Earth's land masses combined. Since the northern Pacific Ocean lies west, or atmospherically upstream, of the continental United States, influence on U.S. climate is profound. Well-known Pacific phenomena—such as the Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO)—influence U.S. temperature and precipitation patterns to varying degrees. Sometimes, ENSO and PDO act together to amplify conditions (e.g. drying, moistening) in certain parts of the U.S. For example, the negative phase of the PDO (in place during the 1950’s) may have acted in tandem with the cold phase of ENSO (1954-56) to worsen U.S. drought.

This paper will explore the relationships between oceanic signals such as the SOI and the PDO and the major U.S. droughts of 1930-40, 1952-57, and 1999-2004. (Major U.S. wet spells of 1905-08, 1912-17, 1941-43, 1972-74, 1977-80, 1982-85, 1992-99, and 2004-05 will also be discussed.) Interestingly, the 1930’s Dust Bowl drought occurred during a period of positive-phase PDO and an insignificant (weak, or nearly neutral) ENSO signal. Conversely, the 1950’s drought— as mentioned in the previous paragraph—occurred during a period dominated by negative-phase PDO and cold-phase ENSO (La Niña). More recently, the U.S. drought that began in the late 1990’s had its roots in the La Niña of 1998-2001 and occurred during a PDO transition period.

Another focus of this paper will be to look at periods of transition from U.S. drought to wetness, or wetness to drought. As the nearly neutral ENSO signal of the 1930’s gave way to the warm-phase (El Niño) episode of 1939-41, there was a fairly rapid transition from the Dust Bowl era to a wet period in the early to middle 1940’s. In contrast, warm-phase periods of 1991-95 and 1997-98 were followed by the protracted cold-phase (La Niña) episode of 1998-2001; during the same period, the general U.S. wetness of 1992-99 was followed by pervasive drought from 1999-2004.

Finally, shorter scale U.S. weather changes will be examined in the context of ENSO to determine if there are implications for crop yields in the nation’s breadbasket.

Historically, there have been several instances of hot, dry growing seasons (and Midwestern yield reductions for grain corn) embedded within an overall pattern of U.S. wetness. Recent examples include 1983 and 1995, when (following wet springs) Midwestern crops withered under unrelenting mid- to late-summer heat and short-term dryness. The agricultural droughts of 1983 and 1995, along with other Midwestern droughts such as those that occurred in 1954 and 1988, were noted in the months immediately following the end of a warm-phase (El Niño) episode. But, some major Midwestern droughts (e.g. 1980) were not tied to receding warm-phase episodes, nor were all warm-phase cessations (e.g. 1998) linked to Midwestern drought.

2. PACIFIC DEcadAL OSCillation

Regardless of debate over the relevance of the Pacific Decadal Oscillation (PDO), one thing is clear. Over the last century, the PDO has been a powerful influence on annual temperature patterns across the continental United States (fig. 1).

![Fig. 1. U.S. annual average temperature since 1900 (source: National Climatic Data Center), and monthly PDO values (source: Climate Impacts Group).](image)

During the 20th century, the positive phase of the PDO correlated with rising U.S. annual average temperatures in the 1920’s and 1930’s, and again in the 1980’s and 1990’s. Similarly, the negative phase of the PDO was closely correlated with the relatively flat temperature trend from the 1940’s into the 1970’s.

3. THE SOUTHERN OSCILLATION (ENSO)

While the PDO helps to govern long-term U.S. temperature trends, the nation’s year-to-year precipitation
patterns are closely linked to the Southern Oscillation. A close look at the three longest-running warm-phase episodes shows the clear link between the warm-phase of the Southern Oscillation (El Niño) and U.S. wetness (fig. 2, 3, and 4).

Fig. 2. Indexed monthly SOI values (in black) and percent of the U.S. in a severe to extreme wet spell (in green), showing the correlated lag of several months between SOI values and U.S. wetness, 1911-15.

Notable U.S. Wet Spells

1. Spring 1905 – Winter 1907-08 Jan. 1907, 57.6%
2. Spring 1912 – Summer 1917 Jan. 1916, 60.1%
3. Spring 1941 – Summer 1943 Oct. 1941, 56.5%

* Also note the peak of 57.7% in Aug. 1993

Fig. 6. Notable U.S. wet spells, as defined by the Palmer Drought Index and NCDC’s climate divisional data. Amounts of peak areal U.S. coverage, and the month and year, are listed in the table. For the purpose of this paper, severe to extreme wetness was defined as having monthly PDI values greater than or equal to +3.0.
There have also been three long-running cold-phase events during the U.S. period of record, all of them during a time when MEI values are available. In the case of the 1950’s episode, drought in the U.S. was already rampant—in part due to the effects of the 1949-51 cold-phase (fig. 7). The 1950’s drought was arguably the nation’s second-worst overall drought on record, behind the Dust Bowl 1930’s.

Curiously, the cold-phase event of 1973-76 did not specifically trigger nationwide drought. However, the U.S. was not immune to drought effects during this period (fig. 8). For example, U.S. corn yields were sharply reduced by drought in 1974, while the western U.S. experienced one of its driest wet seasons on record, after La Niña had ended, in the winter of 1976-77.

Starting in 1998, another long-lived La Niña helped to trigger the U.S. drought of 2000. There was some slow recovery in late 2000, but the return of weak cold-phase conditions in the winter of 2000-01 may have contributed to a second drought peak in 2002.

Other than the Dust Bowl Era (1930-1940), which largely occurred during an ENSO-neutral period, all the nation’s major droughts since the early 20th century have had their roots in La Niña (fig. 10). Drought-triggering cold-phase episodes have included 1909-10; 1924-25; 1961-63 and 1964-65; 1988-89; and 2007-08. Exceptions were the short-lived but hard-hitting droughts of 1980-81 and 1976-77. Conversely, a few cold-phase episodes (e.g. 1970-71) did not trigger continental-scale drought across the U.S.

**Notable U.S. Droughts**

- Spring 1900 – Autumn 1902
- Spring 1910 – Autumn 1911
- Summer 1924 – Autumn 1925
- Spring 1930 – Winter 1931-32
- Summer 1933 – Winter 1933-34
- Spring 1939 – Autumn 1940
- Summer 1952 – Spring 1953
- Winter 1976-77 – Autumn 1977
- Spring 1987 – Winter 1990-91
- Spring 2006 – Summer 2008

*Also note peaks of 64.4% in Aug. 1936; 57.6% in Dec. 1956; and 50.8% in Sep. 2000.

**4. U.S. AGRICULTURAL IMPACTS**

Corn, a tropical plant, is especially sensitive to weather extremes, especially during the reproductive and grain-fill stages of development. In the Midwest, those stages typically occur during July and August. High temperatures, limited moisture reserves, or a combination of both are highly detrimental to corn yield and production.
In the U.S., major corn production areas are focused in the Midwest. From 2000-04, about 85 percent of the U.S. corn production came from just ten states (fig. 11).

Winter wheat, a fall-sown grain, is sensitive to moisture shortages during both the establishment months, after planting, and the reproductive stage of development, during the spring. Heat is also a concern during the spring months, prior to maturation.

In the U.S. major wheat production areas are focused on the Plains. From 2000-04, more than half of U.S. winter wheat production came from seven Plains States (fig. 12).

U.S. corn yield has shown a steady increase since about 1940, largely due to technological advances. However, buried within the historic yields, dating to 1866, are some interesting patterns (fig. 13).

For example, corn yields were volatile from about 1869-1906, but rather stable from 1907-29. Following another volatile yield period during the Dust Bowl 1930’s, yields were remarkably stable from 1937-69. Volatile yields were again the rule from 1970-95, but relative stability has returned since 1996 (fig. 14, 15, and 16).
Efforts to tie U.S. corn yield volatility and stability to the Pacific Ocean’s influence have not been successful to date. However, it is perhaps worth noting that in recent years, corn yield volatility and stability have roughly corresponded to cycles of tropical inactivity and hyperactivity, respectively, in the Atlantic Basin (fig. 17). However, given the short period of the satellite monitoring era, further research is needed to investigate the previous periods of corn yield volatility (1869-1906) and stability (1907-29).

Montana’s winter wheat is especially vulnerable to drought damage due to minimal irrigation and low annual precipitation totals (fig. 18 and 19).

Drought-related problems with winter wheat are not captured well by yield calculations, because abandoned acreage is not counted as production area. As a result, wheat yields are inflated during drought years. Therefore, it is more useful to look at abandoned acreage as a drought measure. A caveat with this method is that some wheat is irrigated. In addition, government insurance programs have changed over time, making abandonment numbers an imperfect measure of drought stress.

With the exception of 1918-19 and multiple years during the Dust Bowl 1930’s, Montana’s worst years for winter wheat abandonment occurred during cold-phase episodes. In two cases (1936-37 and 2001-02), near-record levels of abandonment occurred in back-to-back years.

U.S. winter wheat abandonment is shown in figure 20. As previously mentioned, it is difficult to sort out changes in legislation that provide disaster relief to winter wheat producers. Nevertheless, U.S. winter wheat abandonment still shows a strong link to the Southern Oscillation, with La Niña tied to high rates of abandonment (fig. 21).

<table>
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<th>Year</th>
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<td>29%</td>
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<td>2001</td>
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<td>1998-2001 Cold Phase</td>
</tr>
</tbody>
</table>

Fig. 20. U.S. winter wheat abandonment, 1909-2009. Source: USDA/NASS.

Fig. 21. The nation’s ten worst years for winter wheat abandonment, 1909-2009.

5. REFERENCES


