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THE PACIFIC OCEAN'S INFLUENCE ON DROUGHT AND WETNESS IN THE CONTINENTAL UNITED STATES AND THE NATION'S BREADBASKET

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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).

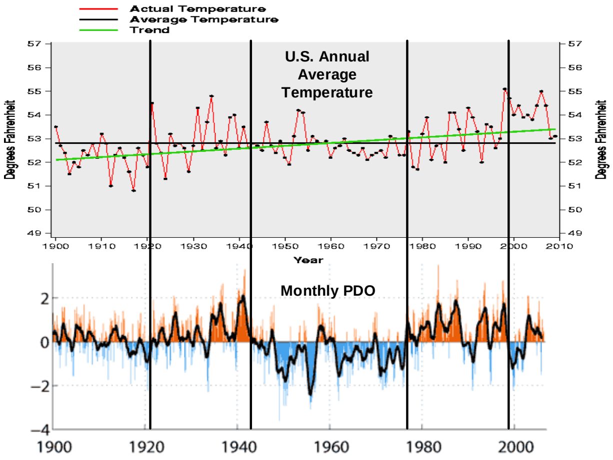

Fig. 1. U.S. annual average temperature since 1900 (source: National Climatic Data Center), and monthly PDO values (source: Climate Impacts Group).

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

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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).

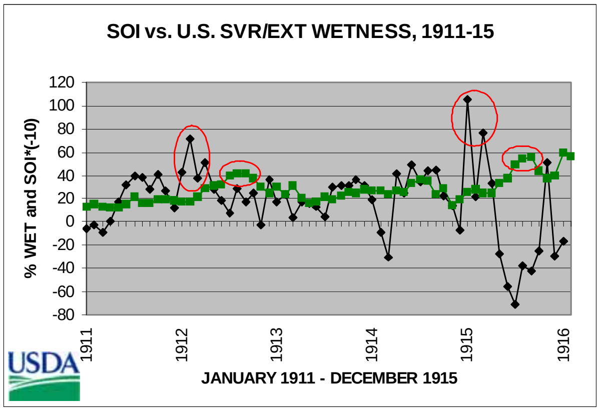

Fig. 2. Indexed monthly SOI values (in black) and percent of the U.S. in a severe to extreme wet spell (in green), showing the correlated lag of several months between SOI values and U.S. wetness, 1911-15.

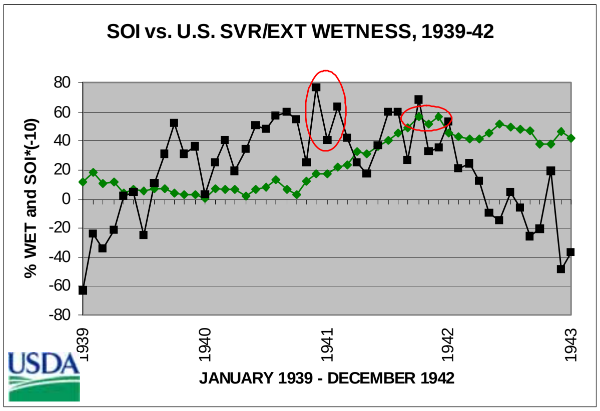

Fig. 3. Indexed monthly SOI values (in black) and percent of the U.S. in a severe to extreme wet spell (in green), showing the correlated lag of several months between SOI values and U.S. wetness, 1939-42.

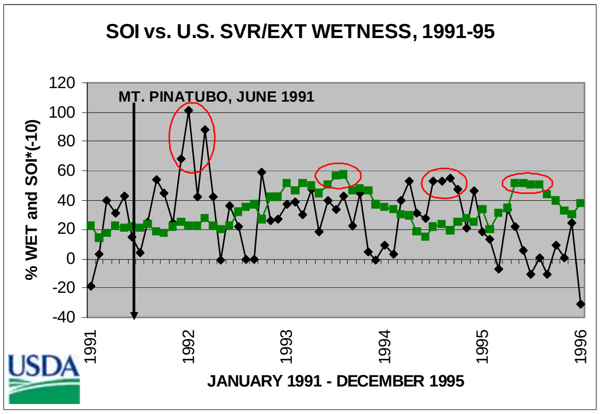

Fig. 4. Indexed monthly SOI values (in black) and percent of the U.S. in a severe to extreme wet spell (in green), showing the correlated lag of several months between SOI values and U.S. wetness, 1991-95. The eruption of the Philippines' volcano Mt. Pinatubo in June 1991 may have contributed to the long-lasting El Niño.

Links between warm-phase episodes and U.S. wetness can be seen even more clearly using a state-of-the-art Multivariate ENSO Index (MEI), developed by Klaus Wolter at NOAA/ERL/CDC (fig. 5).

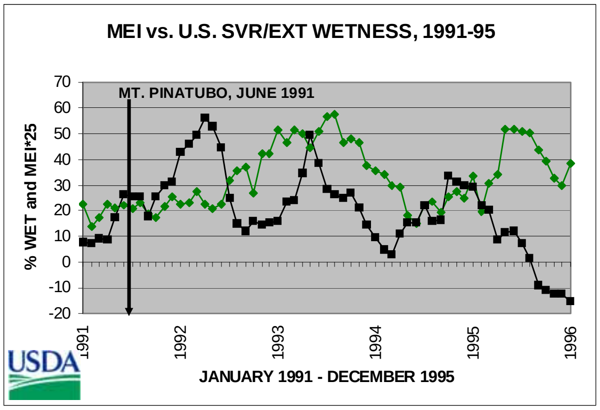

Fig. 5. Indexed monthly MEI values (in black) and percent of the U.S. in a severe to extreme wet spell (in green), showing the correlated lag between MEI values and U.S. wetness, 1991-95.

All three of the long-running warm-phase events cited above were associated with notable U.S. wet spells (fig. 6). In fact, the 1939-42 event vanquished the effects of the 1930's Dust Bowl. In addition, U.S. "years without summer" occurred—according to the National Climatic Data Center (NCDC)—in 1912 (fifth-coldest June-August period), 1915 (coldest on record), and 1992 (second-coldest summer).

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%
• 4. Autumn 1972 – Spring 1974	Apr. 1973, 67.4%
• 5. Winter 1976-77 – Spring 1980	Aug. 1979, 50.7%
• 6. Spring 1982 – Winter 1984-85	May 1983, 61.3%
• 7. Summer 1992 – Winter 1998-99	Mar. 1998, 58.6%*
• 8. Summer 2004 – Autumn 2005	Jan. 2005, 51.0%

* 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.

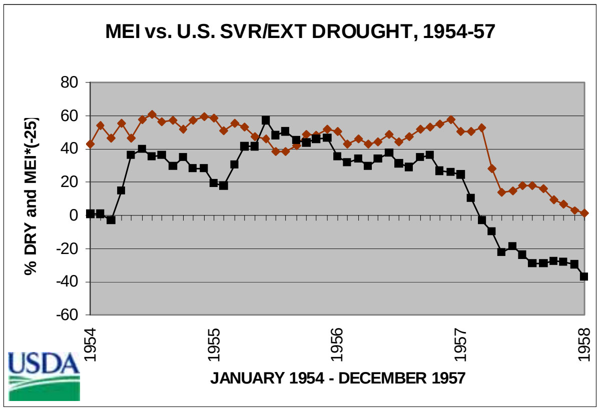

Fig. 7. Indexed monthly MEI values (in black) and percent of the U.S. in a severe to extreme drought (in brown), showing the correlated lag of several months between MEI values and U.S. drought, 1954-57.

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.

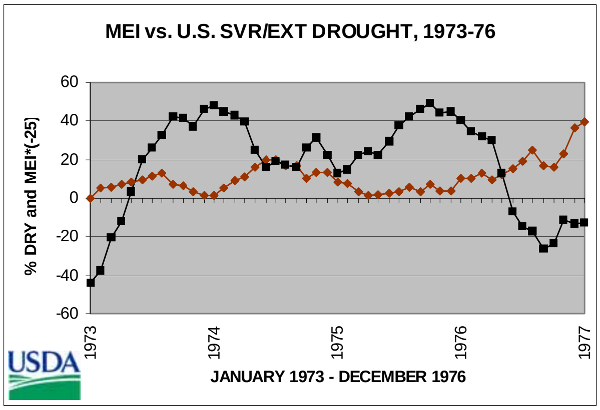

Fig. 8. Indexed monthly MEI values (in black) and percent of the U.S. in a severe to extreme drought (in brown), showing that the U.S. remained relatively free of significant drought—but weathered some regional drought issues—from 1973-76.

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.

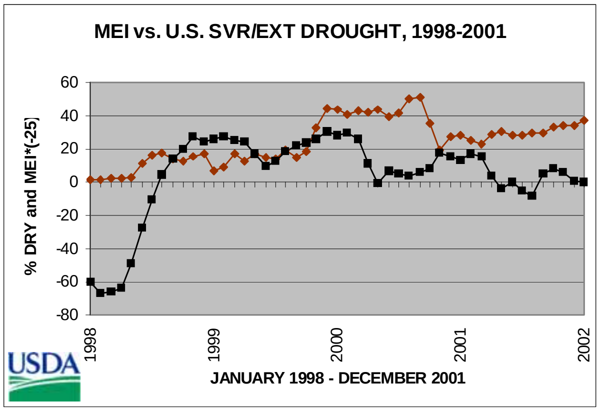

Fig. 9. Indexed monthly MEI values (in black) and percent of the U.S. in a severe to extreme drought (in brown), 1998-2001.

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

1. Spring 1900 – Autumn 1902	Apr. 1902, 48.8%
2. Spring 1910 – Autumn 1911	Aug. 1910, 47.7%
3. Summer 1924 – Autumn 1925	Jun. 1925, 46.8%
4. Spring 1930 – Winter 1931-32	Sep. 1931, 54.8%
5. Summer 1933 – Winter 1938-39	Jul. 1934, 79.9%
6. Spring 1939 – Autumn 1940	Dec. 1939, 62.1%
7. Summer 1952 – Spring 1957	Jul. 1954, 60.4%
8. Winter 1962-63 – Winter 1964-65	Dec. 1963, 48.1%
9. Winter 1976-77 – Autumn 1977	Jun. 1977, 52.5%
10. Winter 1980-81 – Autumn 1981	Apr. 1981, 50.6%
11. Spring 1987 – Winter 1990-91	Jun. 1988, 52.3%
12. Winter 1999-2000 – Summer 2004	Jun. 2002, 50.9%
13. Spring 2006 – Summer 2008	Jul. 2006, 51.3%

* Also note peaks of 54.4% in Aug. 1936; 57.6% in Dec. 1956; and 50.8% in Sep. 2000.

Fig. 10. Notable U.S. droughts, 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 drought was defined as having monthly PDI values less than or equal to -3.0.

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).

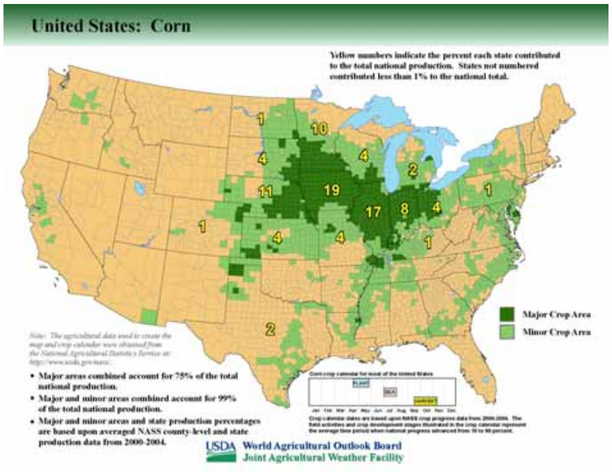

Fig. 11. U.S. grain corn production, 2000-04, with major and minor production counties defined with dark and light green shading, respectively.

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).

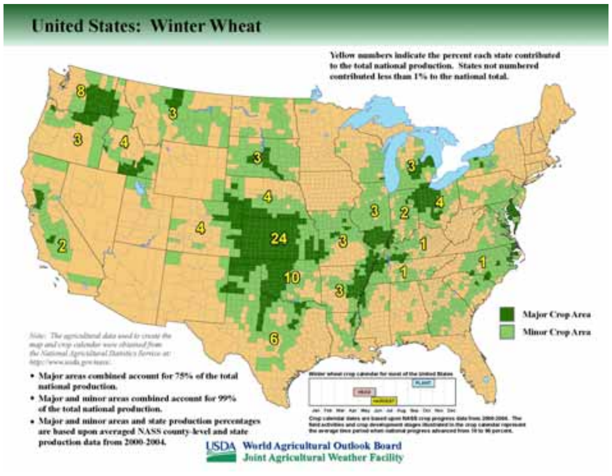

Fig. 12. U.S. winter wheat production, 2000-04, with major and minor production counties defined with dark and light green shading, respectively.

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).

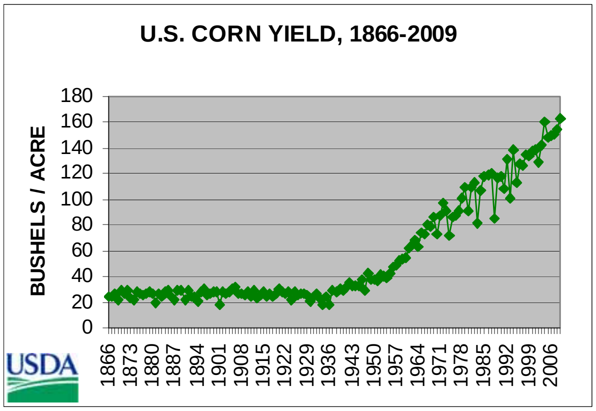

Fig. 13. U.S. corn yield, 1866-2009, based on data from USDA's National Agricultural Statistics Service.

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).

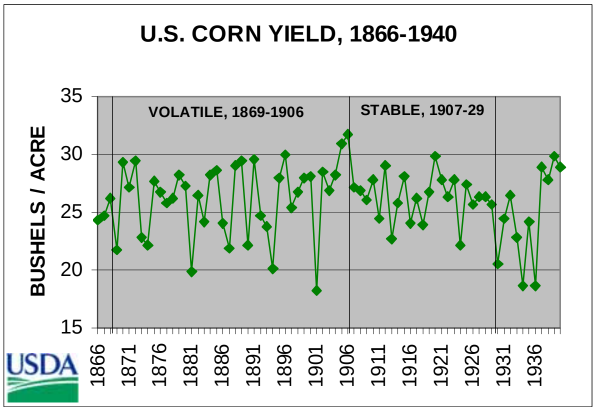

Fig. 14. U.S. corn yield, 1866-1940, showing yield volatility from 1869-1906 and stability from 1907-29.

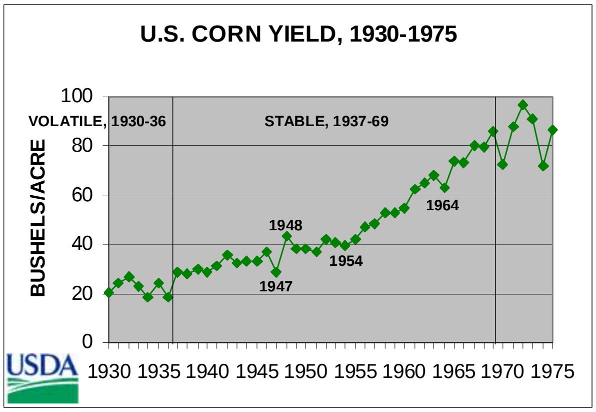

Fig. 15. U.S. corn yield, 1930-75, showing yield stability from 1937-69.

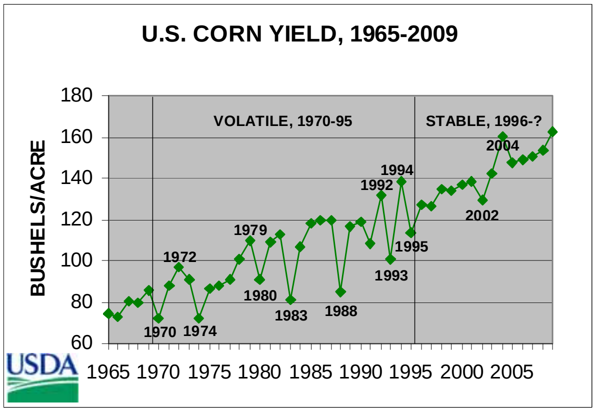

Fig. 16. U.S. corn yield, 1965-2009, showing yield volatility from 1970-95 and stability starting in 1996.

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).

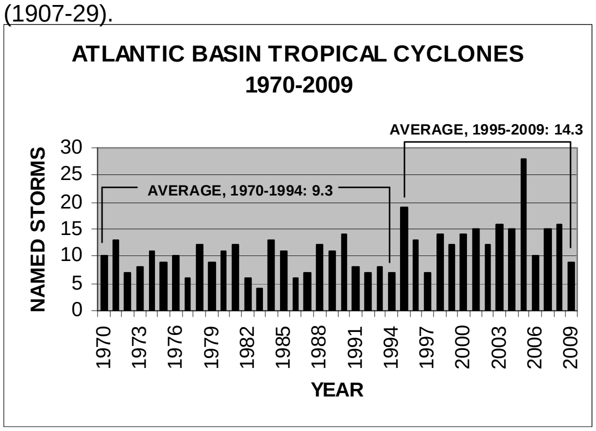

Fig. 17. Atlantic Basin tropical cyclones, 1970-2009. There were an average of nine named storms per year from 1970-94, but 14 storms per year from 1995-2009.

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.

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

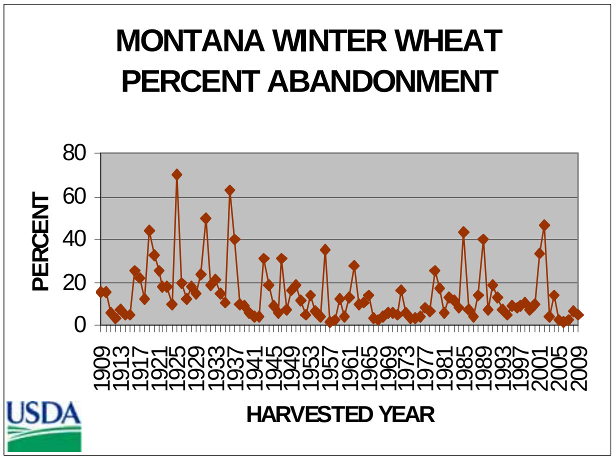

Fig. 18. Montana winter wheat abandonment, 1909-2009. Source: USDA/NASS.

Montana Winter Wheat Abandonment:
The Ten Worst Years, 1909-2009

1.	1925	70%	1924-25 Cold Phase
2.	1936	63%	Neutral
3.	1931	50%	Neutral
4.	2002	46%	1998-2001 Cold Phase
5.	1919	44%	1918-19 Warm Phase
6.	1985	43%	1984-85 Cold Phase
7.	1989	40%	1988-89 Cold Phase
8.	1937	40%	Neutral
9.	1956	35%	1954-57 Cold Phase
10.	2001	33%	1998-2001 Cold Phase

Fig. 19. Montana's ten worst years for winter wheat abandonment, 1909-2009.

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).

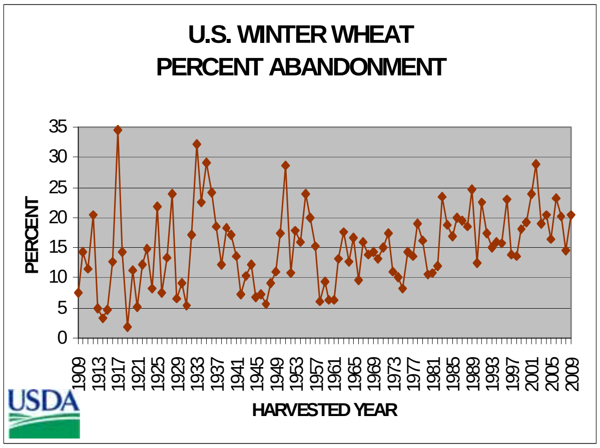

Fig. 20. U.S. winter wheat abandonment, 1909-2009. Source: USDA/NASS.

U.S. Winter Wheat Abandonment:
The Ten Worst Years, 1909-2009

1.	1917	34%	1916-17 Cold Phase
2.	1933	32%	Neutral
3.	1935	29%	Neutral
4.	2002	29%	1998-2001 Cold Phase
5.	1951	29%	1949-50 Cold Phase
6.	1989	25%	1988-89 Cold Phase
7.	1936	24%	Neutral
8.	1955	24%	1954-57 Cold Phase
9.	1928	24%	1928-29 Cold Phase
10.	2001	24%	1998-2001 Cold Phase

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

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