

A Perspective On the Climatological Causes Of the “Great American Dust Bowl” During the Period of 1932 - 1938

**Jonathan Ariel Forest Byrne
AMS, NSTA
Rising Sun Consulting
Boston, MA USA**

The Dust Bowl of the 1930s was a period of extreme drought and dust storms that significantly impacted the ecology and agriculture of Great Plains of the United States. The antecedent forcings, also anthropogenic in nature, occurred during the previous decade in which inappropriate farming methods were applied to a grassland type biome resulting in severe desiccation and erosion of the topsoil due to aeolian processes. The drought covered 4×10^5 km² with an epicenter maximum located on the Texas panhandle.

However this anomalous event was, in turn greatly exacerbated by climatic forcings including a persistently cooler than average SST in the Pacific basin (i.e. a negative PDO / ONI signal) resulting in a high return frequency La Nina. The downstream affect (typical of La Nina) resulted in anticyclonic ridging across the eastern Pacific basin and western North America forcing a poleward displacement of the mean polar and subtropical jet stream positions (typical of a La Nina pattern). Hence associated synoptic scale cyclones coupled with the polar jet stream shifted north of the drought epicenter resulting in extreme precipitation deficits. Additionally, warmer than average SST in the North Atlantic basin (i.e. a positive AMO -Atlantic Multi-decadal Oscillation MO) diminished the magnitude of the Azores-Bermuda anticyclone thus precluding the subtropical return meridional flow into the southern Great Plains.

This paper will be an investigation into both synoptic scale forcings responsible for the extreme drought conditions including various model studies for SST temperatures in the Pacific and Atlantic basins, crop and dust aerosol feedbacks that contributed to the Dust Bowl drought. Also included is a synoptic analysis of the dynamics responsible for the so-called “dust storms” that also impacted the Great Plains region during this period.

Overview

The “Dust Bowl” (1932-1938) represents one of the greatest natural disasters in U.S. history. This event was characterized by extreme drought conditions (coupled with at times extreme summertime temperature anomalies). The drought was concentrated especially across the western Great Plains with an epicenter of highest precipitation deficits occurring in the vicinity of the Texas panhandle. (Fig 1) The impacts of this event were as follows 1) Largest migration in U.S. history as a population of 3.5 million emigrated from the Great Plains 2) 500,000 residents were left homeless 3) 10^8 acres ($4 \times 10^5 \text{ sq}^2$) were affected by desiccated topsoil 4) 75% of the topsoil of the highest impacted area was eroded away by the end of the 1930s 5) Less than 25% of crops were recovered within the highest impact areas.(Worster, 2004)

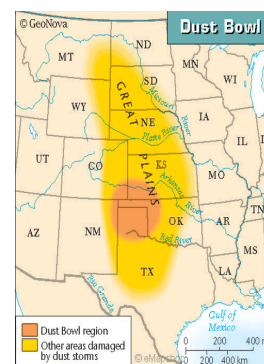
The precipitation deficits, most pronounced during the spring and summer months were exacerbated by agricultural practices that were inappropriate for the semi-arid / grassland biome common to this regions i.e. failure to employ dry land farming methods. This included the practice of replacing drought resistant prairie grass with drought sensitive wheat. The result was a desiccation of surface soil and an unprecedented dust aerosol loading of the

atmosphere consequently producing tertiary events referred to in historic literature as “dust storms”.

Antecedent Conditions

Based upon numerous studies the teleconnection between negative SST anomalies in the tropical Pacific basin (-PDO) which, in turn produced a higher frequency negative ENSO signal (La Nina), and a positive SST in the North Atlantic basin appear to be among the most significant forcings.(Fi 2) (Schubert et al 2004)

(However anomalous external forcings often associated with macroscale climate anomalies e.g. solar cycles were not observed as the sunspot number averaged less than fifty during this period.



Fig, 1: Region of highest drought impact during the Dust Bowl 1932 - 1938

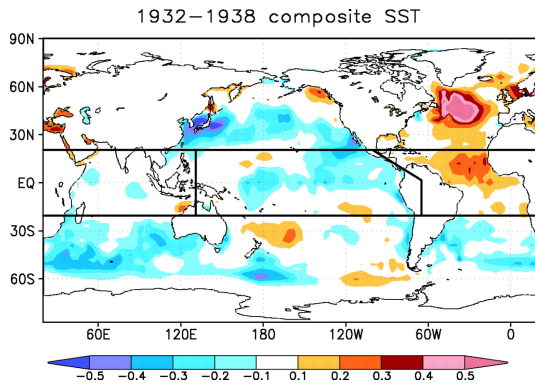


Fig. 2 Global SST anomalies averaged for the Dust Bowl 1932 – 1938. The boxes delineate various subregions (tropical oceans, Indian Ocean, Pacific Ocean, Atlantic Ocean) based upon 1902 – 1999 SST in units C. The data set represents a time average based extrapolations of limited ship observed SST using empirical orthogonal functions (Schubert et al 2004)

Recent Studies: Model Simulations

SST forced simulations indicate that the “cold phase” of the ONI i.e. the La Nina phase is typically related to drier the average conditions in the SW and SE portions of the U.S. Furthermore warmer than average SST in the Atlantic are also linked to drought conditions in the central U.S. especially on decadal time scales (including the U.S. drought of the 1950s and more recent droughts of the 21st century).

However some uncertainty surrounds the significance of SST forcing on drought conditions as compared to other feedbacks e.g. crops and dust. GISS Model5 study (Cook, Miller and Seagar, 2008) revealed that the drought pattern most accurately resembled the 1930s drought when all three feedbacks i.e. SST, dust aerosols, and crops (fig 6)

However a recent model simulation indicates relatively weak negative SST anomalies in the tropical Pacific with a meridional overdriven circulation that resembles a –PDO. Nonetheless the simulation reveals a direct correlation between negative SST anomalies in the tropical Pacific (-PDO, positive SST anomalies in the North Atlantic basin (+AMO), and negative precipitation anomalies in the Great Plains region of the U.S, especially near and along the lee of the cordillera (Fig 2)

Dusters and “Black Blizzards”

One environmental feedback and perhaps the signature event of the Dust Bowl were the “dust storms” These tertiary events resulted from, in part, the deep desiccation of the upper 20cm – 30 cm of surface soil coupled with mesoscale (thermal winds) and synoptic scale forcings i.e. strong frontal convergence.

Dust storm occurred as two subtypes 1) The so-called “duster” that consisted of shallow layer turbulent mixing within boundary layer i.e. within the lowest few hundred meters. Dusters were generally associated with both thermal and synoptic scale winds and weaker frontal convergence. Visibilities were typically reduced to 1 – 2 km during such events with a more localized fallout and dispersion of dust. 2) The alleged (or legendary!) “Black Blizzards” were of much lower return frequency but were nonetheless of more extreme impact. Turbulent mixing associated with these events occurred within a much deeper layer of the troposphere. In

fact strong turbulent mixing coupled with high- density aerosol loading resulted in an ionized column / potential charge gradient producing frequent lightning discharges and near zero visibilities,

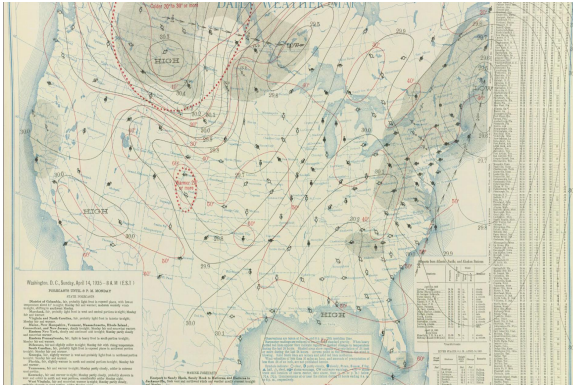


Fig 3. Surface map for “Black Sunday” 4/14/35; Note the strong frontal passage and attendant pressure gradient in the northern Plains associated with the so-called “Black Blizzard (Map courtesy of the NOAA Dailey Weather Maps project)

North Atlantic Multi- Decadal Oscillation (AMO)

During cooler SST regimes the Atlantic basin is dominated by a semi-permanent anticyclone centered near 30 latitude north (i.e. the Azores – Bermuda high). Its associated poleward meridional circulation is a significant contributor to distribution of moisture in central North America through both mesoscale fluxes e.g. showers / thunderstorms, to synoptic scale precipitation associated with extratropical cyclones (Fig 4) .

However warmer SST produced a weaker semi-permanent North Atlantic anticyclone. Hence the meridional circulation associated with the ridge was diminished allowing for a prevailing easterly low level jet circulation in the vicinity of the

Caribbean and the sub-tropical Atlantic to become more dominant (Fig 5) .(Schubert – NASA et al, 2004)

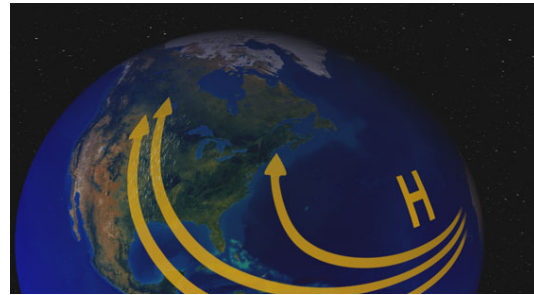


Fig 4. A typical summertime circulation pattern featuring a well developed anticyclone over the Atlantic basin..

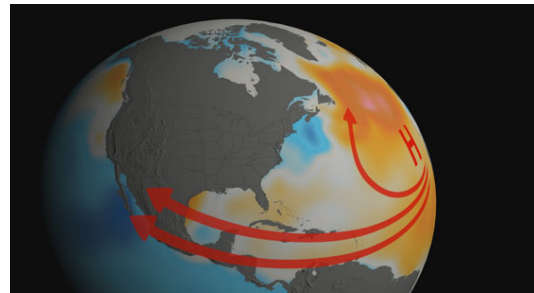


Fig 5. An anomalous pattern that features warmer than average SST in the Atlantic basin resulting in a diminished strength of the North Atlantic anticyclone. Note the redirection of the return flow from meridional (fig 4) to a more zonal low level jet circulation precluding moisture transport into central North America (Courtesy of NASA)

The Role of Other Teleconnection Signals: AO, NAO, PNA.

The Arctic Oscillation, (hence AO) an annular mode defined by opposite signals in atmospheric pressure between the Arctic and mid latitudes (37 N – 45 N) was predominantly negative during the Dust Bowl period i.e the prevailing mean index range was between 0 and -0.5 (Fig 8) based upon the 1950 – 1999 mean AO index.

Although the AO mode is typically higher impact during the winter months through decreased polar jet stream indices and associated meridional mixing of air masses, it may be speculated that the negative signal contributed to the development of dust storms through the synoptic scale forcing of extratropical cyclones and associated frontal passages (Fig 8) In fact at the time of the infamous “Black Blizzard” of April 14th, 1935 (Fig 3) The AO was approaching a minimum value of -0.7 for that year.

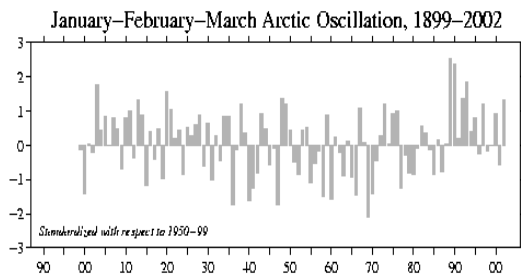


Fig 8 JFM Arctic Oscillation indices for the period 1899-2002 based upon the 1950 – 1999 mean. (Graph provided by D. Thompson’s WWWSite.seasonal – means / Monthly-means)

GCM – NSIPP Studies

GCM -NSIPP model simulations of the Dust Bowl era consisted of a 3 latitude x 3.75 longitude grid. Included in the parameterization were SST observed by ships during this period. The study indicated a correlation between significant precipitation deficits centered especially leeward of the Cordillera of North America i.e. across the western Great Plains (This also raises the question around the diabatic impact of zonal- leeward airflow across the cordillera).

However, it is also interesting to note the relatively weak negative SST anomalies within the Pacific basin which indicates a less significant correlation between this parameter and the drought conditions of the Dust Bowl (Fig 2)

Recent GCM Studies

Recent NCEP – GCM studies (M. Hoerlling et al 2014) revealed a “moderate La Nina “ (negative) phase of the ONI in the subtropical Pacific during the preceding winter 1933/ 1934 (also antecedent to Great Plains drought conditions during 1975/1976) condition while an El Nino prevailed during the preceding winter of 1930/1931 (also antecedent to drought conditions in 1987 / 1988). This outcome is consistent with weak evidence for correlations between Great Plains spring – summer precipitation indices and global surface temperature.

However in another study conducted by Schubert et al found that a combination of positive temperature anomalies in the Atlantic basin and negative anomalies in the tropical Pacific produced significant precipitation deficits and surface warming over the continental United States. This model sensitivity is supported by empirical evidence for a relationship between natural multi-decadal states of the Pacific and Atlantic basins and multi-decadal drought frequency over the United States. (McCabe et al 2004) In addition recent studies indicate a summertime climate sensitivity to Atlantic forcing (e.g. Schubert et al. 2009; Findell and Delworth 2010; Kushnir et al 2010).

Moreover, a 30 member multimodal GCM ensemble was used by the CPC (Climate Prediction Center) to predict standardized precipitation – soil moisture – temperature anomalies for the continental U.S for the period May – June 20102. (Fig 6) The model was based upon observed SSTs, sea ice, and greenhouse gas conditions. Although the ensemble indicated a weak relationship between observed and simulated values (as the anomalies in all three categories diminished especially in the eastern half of the U.S.), anomalies were maintained throughout the region that coincides with precipitation and soil anomalies during the Dust Bowl.

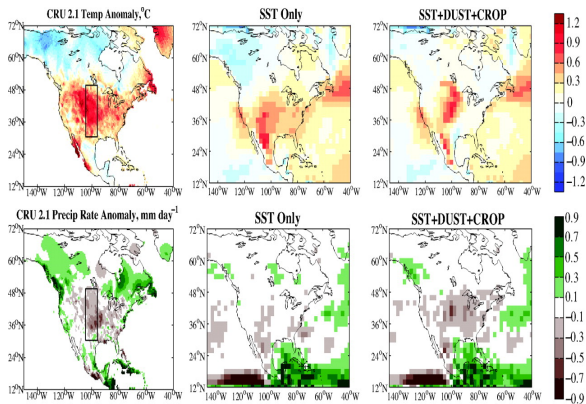


Fig 6 The top row represents temperature; the bottom row precipitation. The 1st row This GCM simulation represents SST feedback;(Bowen ratio = 0.52) 2nd SST + (Explanation begins at the top of the next column)

Crop; (Bowen ratio = 0.59) 3rd SST+Crop + Dust; The 3rd column represents the best fit for Dust Bowl conditions in real time. Also note that SST+Crop + Dust augments SST feedbacks. The simulation is based upon CRU (Climate Unit Research Unit) data composed mainly of monthly climate grids or the world with a spacial resolution of 2 – 2.5. Anomalies are for the period 1932 – 1939 based upon 1920 – 1929 averages.

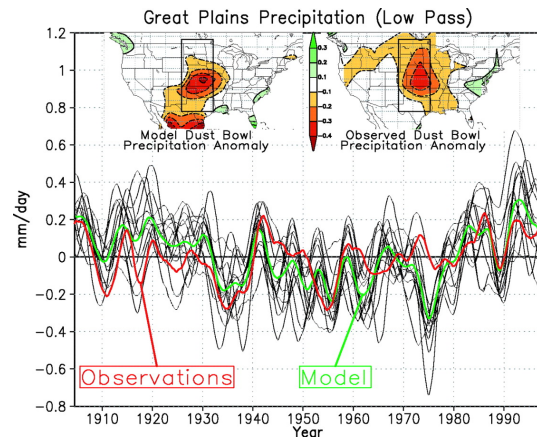


Fig 7. Time series of precipitation anomalies over the U.S. Great Plains (30 N to 50 N, 95 W to 105 W. A filter is used to remove time scales shorter than about 6 years The thin black curves are the results from the 14 ensemble members from the C20C Runs. The green solid curve represents the ensemble mean. The red curve indicates observations. The maps show the simulated (left) and the observed (right) precipitation anomalies averaged over the Dust Bow period (1932 – 1938) Units mm /day (Shubert et al 20

Summary

Hydro-climatic anomalies are the result of stochastic forcings including multiple variables both terrestrial and hydrospheric in nature. In particular, teleconnections between SST anomalies within the Atlantic basin (positive) and Pacific basin (negative) can produce synoptic scale changes in middle and lower latitude circulation patterns . One outcome is a redistribution of precipitation resulting in spatial and temporal deficits. Such deficits are especially high impact when sustained on the time scale of years resulting in additional positive feedbacks e.g. soil desiccation coupled with significantly reduced evapotranspiration, and dust aerosol loading of the atmosphere.

In the case of the Dust Bowl, numerous model studies, especially where multiple feedbacks are included e.g. SST, dust and crops most accurately simulate the zone of highest drought impact i.e. the lower western Great Plains along an east of the cordillera, with an epicenter of maximum drought over the Texas panhandle. However it should also be noted that GCM simulations of the SST in the Pacific basin indicated only a weak anomaly. Although this may be attributed to a limited data set (e.g. ship observations), it also alludes to the significance of the aforementioned additional feedbacks / forcings responsible for the Dust Bowl drought as well as other droughts that especially impact central North America

Schubert SD, Suarez MJ, Pegion PJ, Koster RD, Bacmeister JT (2004) On the causes of the 1930s Dust Bowl. *Science* 303:1855 – 1859.

Schubert SD, Suarez MJ, Pegion PJ, Koster RD, Bacmeister JT (2004) Causes of Long Term Droughts in the Great Plains, *J Clim* 17: 485 - 503

Cook IC, Miller RL, Seager R (2009) Amplification of the North American Dust Bowl through human-induced land degradation *Proceedings of the National Academy of Sciences of the United States of America* vol 106 no. 13

Worsster, D. Dust Bowl: The Southern Plains in the 1930s; *Southern University Press* 2004

Seager R, et al, (2008) would advance knowledge of 1930s SST have allowed predictions of the Dust Bowl drought? *J.Clim* 21:3261 - 3281

Cronon T. M. Paleoclimates: Understanding Climate Change Past and Present. *Columbia University Press* 2010

References