

DIGITAL GOVERNMENT: REVIVING THE NEWHALL SIMULATION MODEL TO UNDERSTAND THE PATTERNS AND TRENDS OF SOIL CLIMATE REGIMES AND DROUGHT EVENTS

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ABSTRACT

The agricultural landscapes of Nebraska reflect a complex pattern of soil climate regimes and inherent variability that influence the cropping systems, behavior of farmers, and the health and sustainability of rural communities. The USDA crops and soils databases were coupled with the Enhanced Newhall Simulation Model (ENSM) to explain spatial relationships of soil climate regimes, climatic shifts, crop yields and growing environments, as well as understand patterns, trends, and vulnerability to drought events. In addition, the soil water balance calculations of the ENSM were used to search for El Nino/Southern Oscillation (ENSO) signatures within the climate histories of long-term weather stations in Nebraska. As part of a drought decision support system, the ENSM illustrates the revival and new application of older nonspatial, deterministic models that can contribute to identifying regions of high climatic variability and shifts through time and space. The Enhanced Newhall Simulation Model was used to derive probabilities of soil climate regimes, the frequency and severity of drought events, and differentiate ecoclimatic boundaries. The ENSM can serve as a risk assessment tool to compare the vulnerabilities of rural communities to drought episodes. A longer-term goal of this project is to discover relationships of ENSO events and their teleconnections (signatures) to climatic variability in Great Plains communities.

1.1 INTRODUCTION

Drought is the dominant process of crop loss nationally and within Nebraska. Nearly two-thirds of the 18.6 million harvested acres are covered by crop insurance (USDA/RMA, 2004; USDA/NASS, 2004). For the most part, Nebraska's crop losses range from \$50 to 75 million in non-drought years, but the losses approach nearly \$200 million in drought years, such as 2000. In 2002, crop losses exceeded \$380 million in Nebraska and more than \$4 billion nationally (USDA/RMA, 2004). The analysis and understanding of drought processes in the Great Plains is an important component to developing drought mitigation strategies and reducing agricultural risks on the landscape. In building a drought decision support system for Nebraska, we have proposed a suite of drought indices linked to geospatial databases describing the agricultural statistics or infrastructure to identify drought regions and potential impacts. Most approaches to visualizing drought indices, such as the traditional Palmer Drought Severity Index (PDSI; Palmer, 1965), Standardized Precipitation Index (SPI; McKee et al., 1993; 1995), and the Drought Monitor (Svoboda et al., 2002) are small-scale maps that provide a regional (climate divisions) or national perspective, emphasizing current conditions. Most mapping approaches do not integrate thematic overlays of the agricultural infrastructure or provide the historical context relative to agroecosystems, or natural and managed ecosystems. In our research, we are describing the geography

of soil climate regimes and droughts, their characteristics, and the vulnerability of landscapes and communities to droughts at multiple temporal and spatial scales.

In this paper, we will introduce new applications of soil moisture regimes as a drought risk indicator of patterns and trends within an agricultural drought decision support system. The Enhanced Newhall Simulation Model represents a longer-term time window (growing season; 6 to 9 months) and historical context that can compliment SPI, PDSI, and the Drought Monitor, in describing different parameters of drought events. Our project illustrates how older deterministic soil water balance models can be revived to serve as new geospatial models for comparing drought events and their variability, as well as become indicators of climate change. In addition, these geospatial models can be designed to reach from regional scales to communities and farms. The Newhall Simulation Model was originally constructed in the early 1980s by USDA to derive soil climate regimes that describe the ecological boundaries of crops and classify growing season environments. In our context working with USDA Risk Management Agency, we have transformed the FORTRAN-based soil water balance model into a suite of indicators to assess drought risk, the intensity of drought events, climatic shifts, and inherent climate variability. Our application has been extended to compare drought histories of individual communities. The Enhanced Newhall Simulation Model (ENSM) is a modified version of Van Wambeke et al. (1992), originally intended for classification of soil climate regimes. Soil climate regimes (Van Wambeke et al., 1992; Soil Survey Staff, 1999) describe the pattern of days when soils are above 5°C or 8°C and moist, moist to dry, and provide a classification of growing season environments. Although the Newhall Simulation Model has been run on individual weather stations with 30 year normals for classifying soil moisture and temperature regimes, it has not been extended to classifying drought events.

1.2 OBJECTIVES

Our research is designed to build a suite of geospatial risk assessment tools within a drought decision support system that assists USDA programs and the National Drought Mitigation Center's ability to: 1) compute and map drought metrics, such as soil moisture regimes (Enhanced Newhall Simulation Model) across multiple time windows and spatial scales, 2) develop new drought interpretations and vulnerability maps through integration of national USDA databases with those from the automated weather network of the High Plains Regional Climate Center, the Unified Climate Access Network (UCAN), and the NWS cooperative station network, and 3) develop new thematic maps and interpretations to better visualize the drought events and shifts in soil climate regimes through time and space. The Enhanced Newhall Simulation Model can be applied to understanding climate regime changes in both natural and managed ecosystems, as well as at the community scale.

2. MATERIALS AND METHODS

2.1 SOIL CLIMATE REGIMES

Weather stations (see Fig. 1) were modeled on an annual time-step using the Enhanced Newhall Simulation Model (ENSM) and summarized to develop frequencies and probabilities of soil moisture regimes, as well as identify major drought and wet cycles. The root zone available water-holding capacity for each weather station was spatially derived through the State Soil Geographic Database (STATSGO; Soil Survey Staff, 1994) and Soil Ratings for Plant Growth (SRPG; Soil Survey Staff, 2000), and used as the primary soils input for the soil water balance calculations within ENSM. Key to our new efforts is the inclusion of "Centennial Stations", with weather records extending more than 100 years, which provides a unique archive to apply data mining and knowledge discovery algorithms for pattern associations between soil moisture regimes, crop yields, and oceanic parameters (Multivariate ENSO Index, MEI; <http://www.cdc.noaa.gov/~kew/MEI/mei.html>).

The Newhall Simulation Model (NSM) has long been used by the USDA Natural Resources Conservation Service to estimate soil moisture regimes as defined in *Soil Taxonomy* (Soil Survey Staff,

1975, 1999; Newhall and Berdanier, 1996). Van Wambeke et al. (1992) modified the original model and introduced new subdivisions of soil moisture regimes (Fig. 2) and variable soil moisture storage.

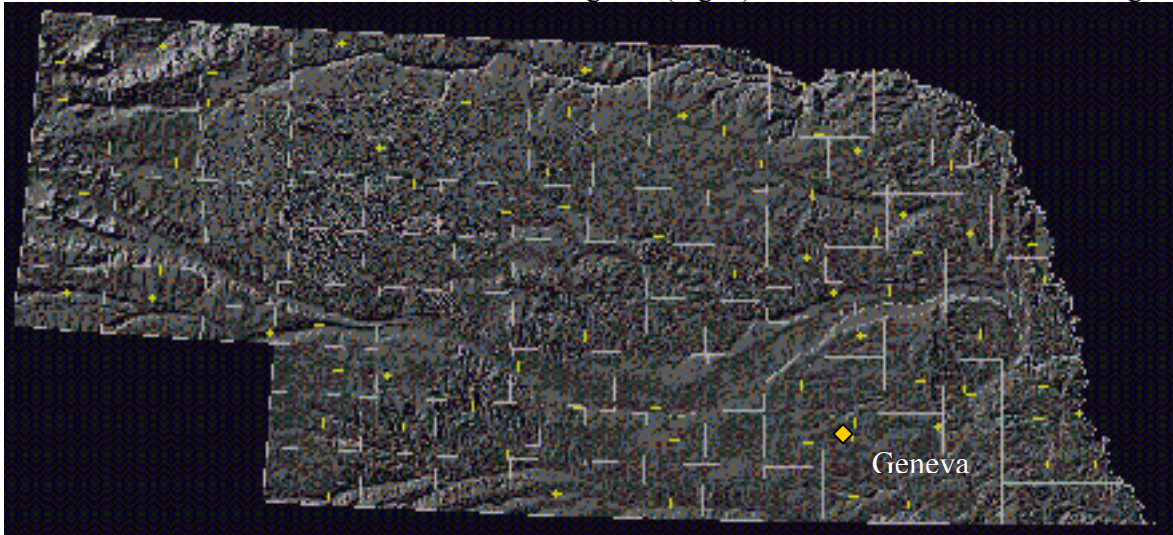


Figure 1. The distribution of NWS Cooperative Weather stations across Nebraska.

Van Wambeke (1982; 1985) applied the model to map soil moisture regimes across Africa, South America, and Asia. Our research follows these earlier definitions, concepts, and applications, but it attempts to improve the temporal and spatial resolution of the NSM and generate probabilities from long-term records that can be used to interpret climatic variability and trends, as well as community and farm-level drought vulnerabilities.

The NSM was developed to run on monthly normals for precipitation and temperature; generally 30 year normals were most reasonable and appropriate. However, the ENSM can also be run on monthly records of individual years to develop frequency distributions of soil moisture regimes. Both the original NSM and ENSM rely upon a modified Thornthwaite (1948) approach for the calculation of potential evapotranspiration (PET). Although the ENSM still shares inherited routines and concepts from the Palmer Drought Severity Index (Palmer, 1965), it provides reasonable estimations of soil moisture and temperature regimes, which can yield the historical perspective of shifts in soil climate regimes across the Northern Great Plains.

2.2 RASTER SURFACES AND MAPS

A raster interpolation (Thin-Plate Spline) procedure was used in conjunction with the ENSM results to map the frequencies of soil climate regimes at multiple scales--subcounty, county, watershed, and major land resource area (MLRA). Soil climate parameters were interpolated using "s.surf.tps" in GRASS 5.0 (Mitasova, 1992; Mitas and Mitasova, 1999; GRASS Development Team, 2004) to derive a 200 m resolution grid. Similarly, sub-calculations behind the soil climate regime classification can be mapped to produce ancillary themes of growing season precipitation, potential evapotranspiration, annual water balances, mean summer soil water balance (Precipitation-PET)_{June-July-August}, and soil biological windows (cumulative days that the soil is above 5°C and moist). The web-based, ENSM runs on the National Weather Service (NWS) Cooperative Weather Station sites throughout the conterminous 48 states, accessed through the Unified Climate Access Network (UCAN) daily data.

3. RESULTS AND DISCUSSION

3.1 WEB-BASED TOOLS

The Enhanced Newhall Simulation Model is part of a suite of drought indices to characterize the historical context of events and explore their relationships to crop yields and ENSO cycles. The drought

indices are part of a 4-tier architecture in the National Agricultural Decision Support System (NADSS; Figure 3) that integrates exposure analysis, risk assessment, knowledge discovery, and geospatial analysis tools operating across a coherent framework of climate (High Plains Regional Climate Center, HPRCC; and the Unified Climate Access Network, UCAN) and USDA databases, such as soils (Natural Resources Conservation Service), crop insurance (Risk Management Agency), and agricultural statistics (National Agricultural Statistics Service).

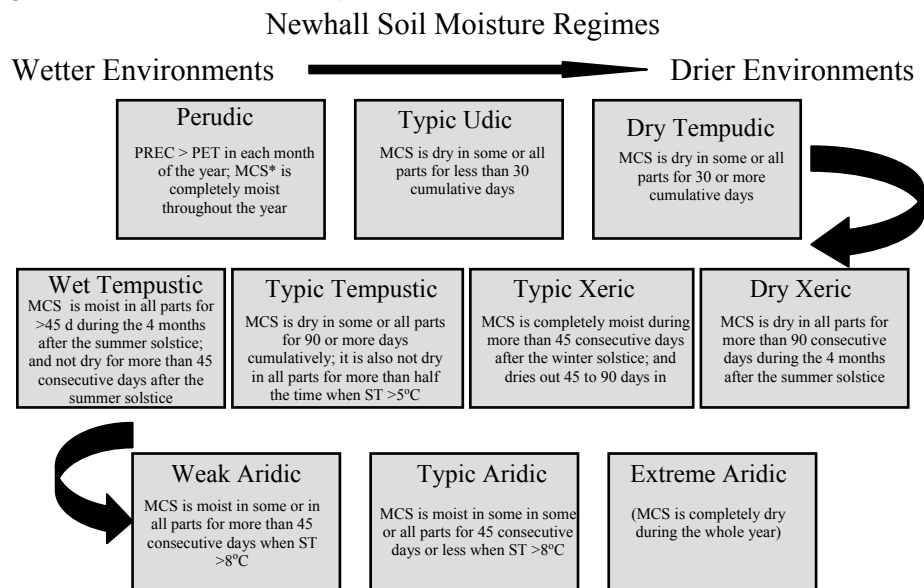


Figure 2. The classification of soil moisture regimes (Van Wambeke, 1985; Van Wambeke et al., 1992) is currently a hybrid of *Soil Taxonomy* (USDA, 1999) and the Newhall Simulation Model. *MCS is the Moisture Control Section of the soil profile which extends from 25 cm to 100cm below the soil surface.

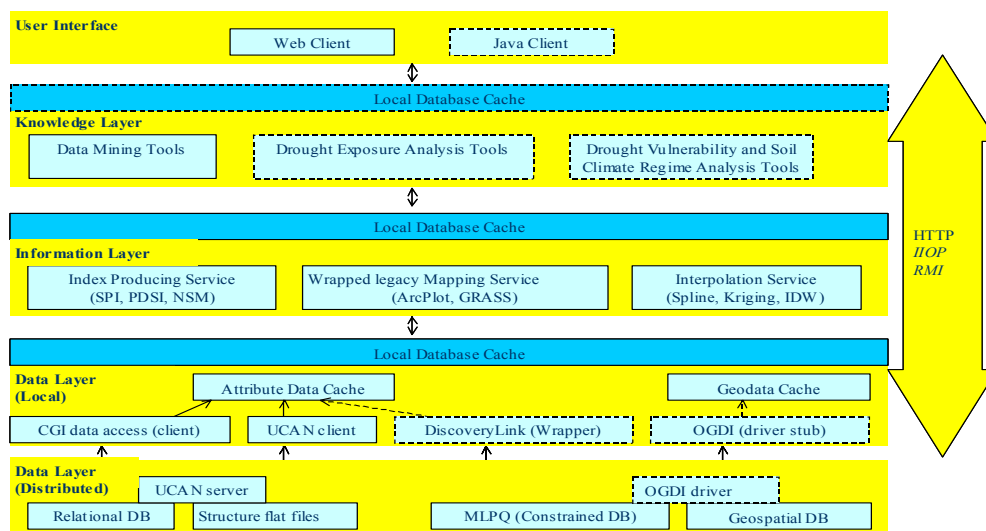


Figure 3. Four-tier architecture of NADSS, with the ENSM contained in the Information Layer. The Information Layer combines the ENSM with GRASS 5.0 to generate the raster interpolations of the weather station points and then resummaries the probability surfaces into a suite of geopolitical, ecological, and physiographic interpretations.

The enhanced version of the Newhall Simulation Model is part of the “Information Layer” in this architecture and draws upon the climate information from UCAN and the State Soil Survey Geographic

Database (STATSGO) for the root zone available water-holding capacity (RZAWHC; plant available water storage in the soil profile). Thus, the model runs are tailored to the dominant soil associations surrounding the weather station. However, a user-defined estimate of RZAWHC can replace these default values assigned to the weather stations.

Figure 4 presents the user interface for running the ENSM to derive model results for a single station, across its entire length of record or for a specified period of record. As a case study, the Geneva, Nebraska station was selected as an example for model runs from 1894 to the present and illustrates the changes in soil moisture regime through time associated with the western edge of the Corn Belt. For the 110 years of record, the dominant soil moisture is Typic Udic (54 of 110 years; 49%) and the major drought events are represented by Typic Tempustic, Typic Xeric, and Weak Aridic regimes. The Geneva station occurs near an important soil boundary known as the “Pedocal-Pedalfer” line, the zero point where the mean annual precipitation and evapotranspiration are equal (Marbut, 1935; Jenny, 1941). As Figure 5 illustrates, the percent occurrence or frequency of soil moisture regimes can be interpolated and summarized to county boundaries from the population of weather stations available. The “Pedocal-Pedalfer Boundary” represents the landscape position where mean annual precipitation equaled potential evapotranspiration over the period of 1961 to 1990, which is derived as a sub-calculation of the ENSM. Similarly, NADSS will produce soil moisture maps for Ustic and Aridic regimes to identify natural boundaries for the oscillation of these occurrences through time. From the Geneva station, Weak Aridic events have occurred only twice in the past 110 years, as a multi-year drought in 1936 and 1937 during the Dust Bowl period. Recent drought events are represented by less severe shifts to Typic Tempustic soil moisture regimes during 2000 and 2002.

Figure 6 shows the probability of Udic events across the conterminous U.S., based upon multiple temporal windows, and summarized to the NWS Climate Divisions and Major Land Resource Areas. The probabilities of Udic (Typic or Dry Tempudic) soil moisture regimes show extensive shifts in the Great Plains from the Dust Bowl era to the more “moist” period of 1971 to 2000.

3.2 SOIL MOISTURE REGIMES, CROP YIELDS, AND ENSO

From NASS crop yield data at the state and county levels, we see patterns associated with El Nino and La Nina events and soil moisture regimes that often elude traditional statistical approaches. Figure 7 presents the patterns between irrigated and non-irrigated corn yields and the Multivariate ENSO Index (Wolter and Timlin, 1993) in Fillmore County, Nebraska, which is associated with the Geneva weather station. The major La Nina (blue lines and areas) events show a connection to droughts and reduced corn yields in Fillmore County, whereas the El Nino phases (red areas) are largely associated with higher nonirrigated corn yields. As illustrated, both irrigated and non-irrigated (NIR) corn yields show the typical yield progression through time, that is a function of improved genetics and field-level management of conservation practices. The slopes of the yield trendlines can serve as an indicator of high versus low yielding environments.

When the sum of $MEI_{(July\ to\ December)}$ is compared with the following growing season characteristics, the La Nina phases (negative MEI indices) were associated with lower nonirrigated corn yields (Mean = 60 Bu/A) and higher variability (Standard Deviation = 35 Bu/A; CV = 58%) over 29 years. The El Nino phases (positive MEI indices) were followed by growing seasons with higher and more positive annual water balances (+25 mm versus -11 mm), 20 more days that the soil profile will be moist throughout and above 5°C, and higher NIR corn yields (Mean = 64 Bu/A), with less annual variability (Table 1).

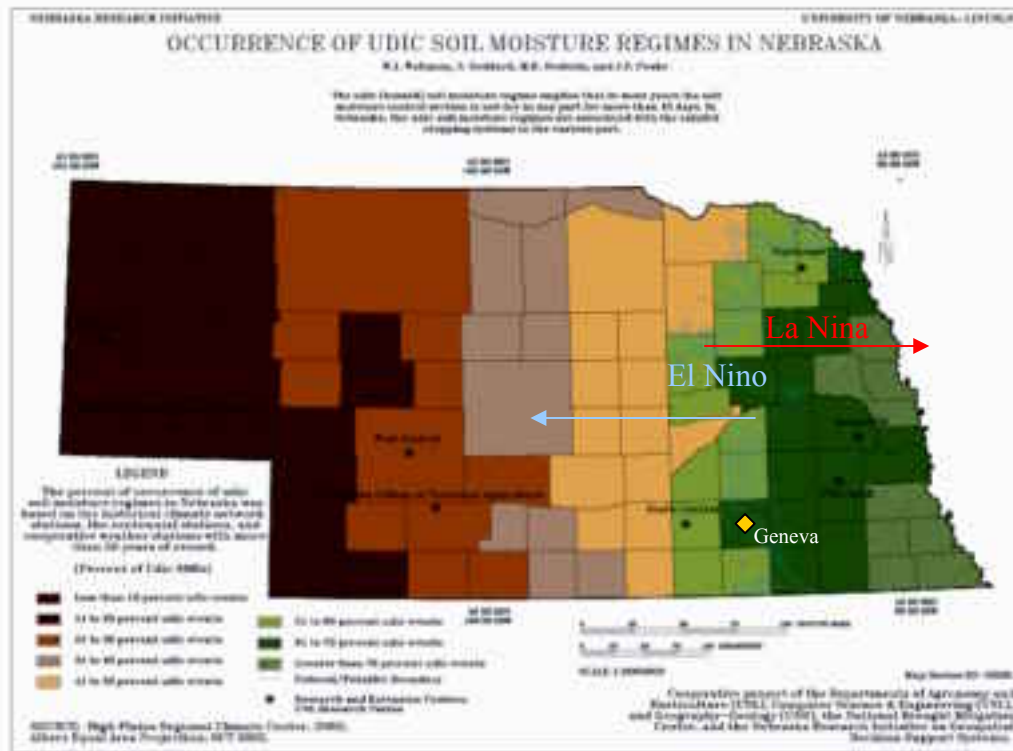


Figure 5. Mapping of Udic soil moisture regimes across Nebraska. The Pedocal/Pedalfer boundary shifts westward during El Niño episodes and moves eastward during La Niña events.

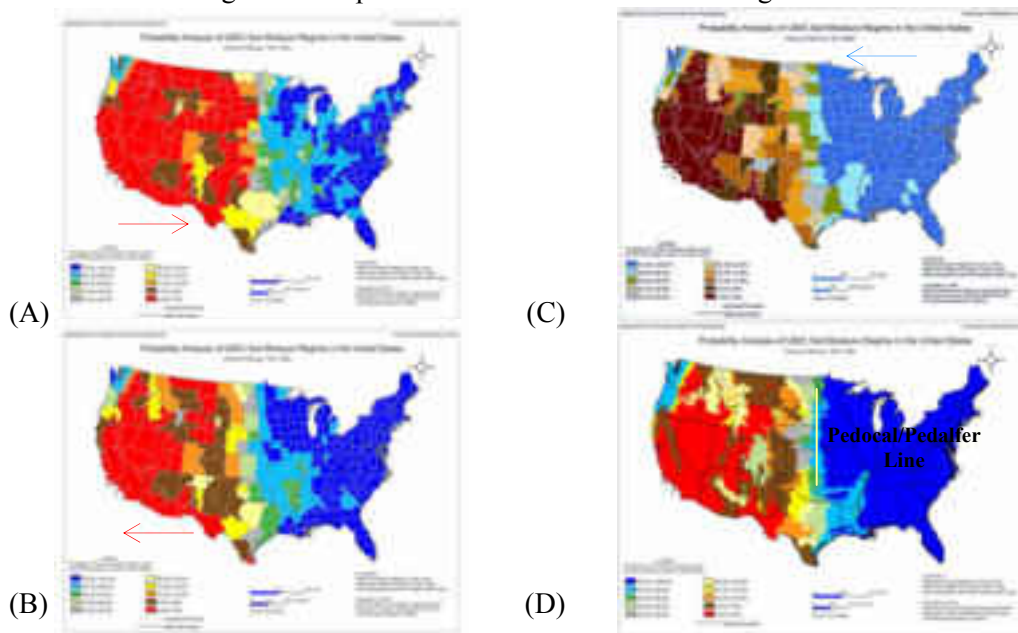


Figure 6. Frequency of Udic soil moisture regimes across the (A) Dust Bowl (1931-1940), (B) 1931 to 1960 normal, (C) 1971 to 2000 normal, and (D) 1961 to 1990 normal summarized to Major Land Resource Areas. The ENSM has been expanded to cover all NWS cooperative weather stations across the conterminous U.S. Thus, the ENSM can be used to compare the drought histories and oscillations across climate divisions and major land resource areas, with varying temporal windows.

In contrast to the Geneva weather station and Fillmore County, Table 2 illustrates the differences in MEI relationships across a different temporal window for Otoe County, Nebraska. Soybean yields over the 30 yr period 1971 to 2000, show virtually no differences associated with ENSO events, despite the stronger (more positive) series of El Nino episodes. Soybeans are more drought tolerant and become semi-dormant during extended drought episodes, but quickly recover with later rains. Crop yields may or may not reflect the ENSO signature in different geographic settings. However, the mean annual precipitation, annual water balance, and mean summer deficits are significantly different ($\alpha=0.05$) in Otoe County, with more rainfall and more positive soil water balances during the growing season following stronger El Nino episodes from April to December.

Within the layered NADSS framework, a knowledge-based solution has been developed that provides real time assessment of drought associations with ENSO teleconnections, searching for ENSO indice-ENSM associations and rules that can be mapped and serve as forecast tools to describe drought risk at county scales. Two separate data mining algorithms represent the knowledge discovery in the project-Representative Episodal Association Rules (REAR; Harms et al., 2001) and Minimal Occurrences with Constraints and Time Lags (MOWCATL; Harms and Deogun, 2004). Harms et al. (2003) and Tadesse et al. (2004a; 2004b) found the REAR and MOWCATL algorithms to be effective tools for identifying associations between oceanic indices (MEI; Wolter and Timlin, 1993) and local drought conditions. These algorithms discovered that most drought occurrences for selected weather stations in Nebraska had strong associations with negative MEI, positive SOI (Southern Oscillation Index), and negative values for PDO (Pacific Decadal Oscillation) and NAO (North Atlantic Oscillation Index).

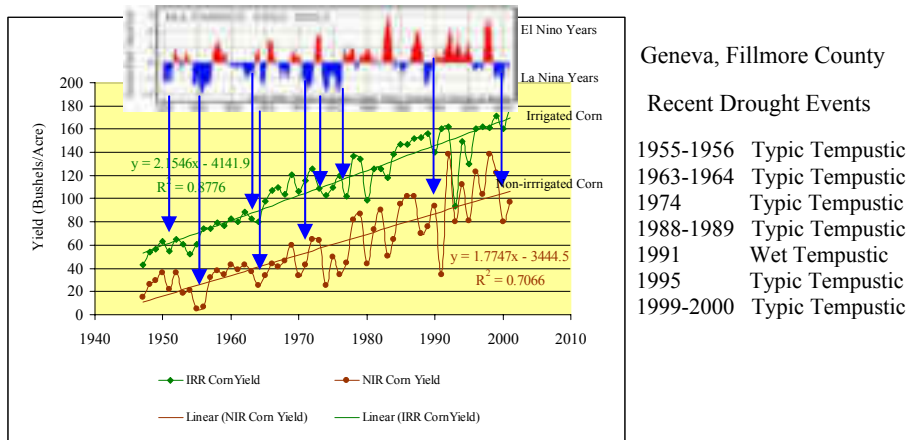


Figure 7. Drought events and impacts upon corn yields of Fillmore County, Nebraska.

Table 1. Summary of ENSO characteristics in Fillmore County, Nebraska, 1951-2000 normals.

ENSO Phase	Mean MEI	NIR Corn Yield (Bu/A)	Yield CV (%)	AWB* (mm)	BIO5** (d)
La Nina Events					
MEI _(July-Dec) Negative	-4.11	60	58%	-11	195
El Nino Events					
MEI _(July-Dec) Positive	5.47	64	51%	+25	215

*Annual Water Balance = Mean Annual Precipitation – Potential Evapotranspiration;

** BIO5 = Cumulative Days when Soil is Moist and Above 5 °C

The REAR algorithm finds episodes of events that occur together in a relatively short time interval, while MOWCATL finds patterns in one or more sequences that precede the occurrence of patterns in

other sequences. The knowledge discovery application in NADSS is functional over any weather station in the U.S., with the ability to compute associations and rules, relating site-specific drought indices with more global ENSO processes.

Table 2. Summary of ENSO characteristics in Otoe County, Nebraska, based upon 1971-2000 normals.

ENSO Phase	Mean MEI	NIR Soybean Yield (Bu/A)	Yield CV (%)	PREC (mm)	AWB* (mm)	MSD** (mm)
La Nina Events						
MEI _(Apr-Dec) Negative	-4.86	32	20%	728	+10	-160
El Nino Events						
MEI _(Apr-Dec) Positive	8.36	32	17%	836	+107	-129

*Annual Water Balance = Mean Annual Precipitation – Potential Evapotranspiration

** MSD = Mean Summer Deficit (PREC-PET)_{June-July-August}

4. SUMMARY AND CONCLUSIONS

The Enhanced Newhall Simulation Model can provide the historical context of drought events during growing seasons through the classification of soil moisture regimes. Soil moisture regimes can be mapped at multiple scales to identify counties and ecological regions with higher probabilities of drought events, or polyclimatic environments. The Enhanced Newhall Simulation Model results can be coupled with MEI indices, along with USDA NASS and RMA databases to derive new drought interpretations and forecasts prior to the next growing season. In Fillmore County, Nebraska, La Nina events during the July to December window are followed by greater yield variability and an average yield reduction of 4 Bu/A in the next growing season. In Otoe County, mean annual precipitation, mean annual water balance, and the June-July-August water balance are significantly different under ENSO phases. From the 1971 to 2000 records, the stronger the El Nino phase from April to December, the more likely we see greater shifts westward of the Udic soil moisture regime and more positive water balances at key stages of crop phenology. Future research will focus on development of new data mining algorithms to extract rule structures that can describe relationships between oceanic parameters (MEI, SOI, PDO, and NAO), soil moisture regimes, soil biological windows, and crop yields in the Northern Great Plains.

5. ACKNOWLEDGEMENTS

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