

SUBTASK 2.4 – INTEGRATION AND SYNTHESIS IN CLIMATE CHANGE PREDICTIVE MODELING

Final Report

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SUBTASK 2.4 – INTEGRATION AND SYNTHESIS IN CLIMATE CHANGE PREDICTIVE MODELING

ABSTRACT

The Energy & Environmental Research Center (EERC) completed a brief evaluation of the existing status of predictive modeling to assess options for integration of our previous paleohydrologic reconstructions and their synthesis with current global climate scenarios.

Results of our research indicate that short-term data series available from modern instrumental records are not sufficient to reconstruct past hydrologic events or predict future ones. On the contrary, reconstruction of paleoclimate phenomena provided credible information on past climate cycles and confirmed their integration in the context of regional climate history is possible. Similarly to ice cores and other paleo proxies, acquired data represent an objective, credible tool for model calibration and validation of currently observed trends. It remains a subject of future research whether further refinement of our results and synthesis with regional and global climate observations could contribute to improvement and credibility of climate predictions on a regional and global scale.

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EXECUTIVE SUMMARY

The Energy & Environmental Research Center (EERC) completed a brief evaluation of the existing status of predictive modeling to assess options and feasibility for integration of our previous paleohydrologic reconstructions and their synthesis with current global climate scenarios.

Models applied in the field of climate modeling include coupled atmosphere–ocean general circulation models and earth system models of intermediate complexity. While both models are capable of providing quantitative estimates at continental and larger scales, their application on a regional scale is limited.

Results of our research indicate that short-term data series available from modern instrumental records are not sufficient to reconstruct past hydrologic events or predict future ones because the instrumental data represent only a fraction of climate cycles.

Reconstruction of paleoclimate phenomena provided credible information on past climate cycles and confirmed their integration in the context of regional climate history is possible. The paleoclimate proxies from the northern Great Plains may be more representative of the global climate cycles because of their unique position on a transboundary between three climatic provinces (Atlantic, Pacific, and Arctic). Similarly to ice cores and other paleo proxies, acquired data represent a credible tool for model calibration and validation of currently observed trends. It remains a subject of future research whether further refinement of our results and synthesis with regional and global climate observations could lead to credible climate predictions on a regional scale.

SUBTASK 2.4 – INTEGRATION AND SYNTHESIS IN CLIMATE CHANGE PREDICTIVE MODELING

1.0 INTRODUCTION

1.1 General Introduction

Global climate changes observed during recent decades and their socioeconomic implications are some of the most serious issues of our times. While there is little dispute over currently monitored warming trends, their causes, rate, and relative magnitude are a subject of heated scientific discussion centered around relative share of human-induced atmospheric contamination versus natural climate variability. Paradoxically, while both proponents and skeptics of anthropogenic global warming have access to similar or the same instrumental records and historical data, their model input information, conclusions, and predictive scenarios are different.

This Energy & Environmental Research Center (EERC) report does not evaluate or take a position on ongoing disputes between climate change experts. Instead, it focuses on screening level evaluation of the current status of predictive modeling that would allow for integration of our previous paleohydrologic reconstructions and their synthesis with existing global climate scenarios.

1.2 Background and Objectives

Recent EERC climate change-related activities focused on reconstruction of paleohydrologic history in the upper Midwest [1] and evaluation of regional socioeconomic impact of potential climate changes [2]. Our reconstructive effort focused on bottom lake sediments and geological proxies that would supplement limited climate data (100 years of modern records) and expand hydrology and climate-related information for the last 2000 years. The objective of the current project was to evaluate capabilities, limitations, and uncertainties of climate change models and their regional implications, including the feasibility of integration options for our previous research results. Detailed scientific validation of available information exceeds the intended scope of the project.

2.0 EXPERIMENTAL

Long-term global climate change predictions are based on interpretation of model scenarios and extrapolation from existing monitoring data. In most cases, available historical records and monitoring data are insufficient to provide a basis for credible predictions of future climate scenarios. The definition of whether the climatic changes represent a human-induced deviation or are just a part of natural climatic cycles is even more complex.

Contrary to short instrument records, reconstruction of paleoclimatic trends based on cyclicity of natural phenomena could be extrapolated for a specific region to predict reoccurrence of these events [2]. Our main hypothesis is that reconstruction of physical evidence from the real environment can ultimately provide more reliable, objective, and defensible input data than complex modeling efforts.

3.0 RESULTS AND DISCUSSIONS

3.1 Climate Change Models

Climate models are based on well-established physical and mathematical principles and, similarly to modeling efforts in other disciplines, experience ongoing development and refinement. Today's most robust models applied in the field of climate modeling are coupled atmosphere–ocean general circulation models (AOGCMs) and earth system models of intermediate complexity (EMICs). AOGCMs are capable of providing quantitative estimates at continental and larger scales. EMICs have been developed to simulate past and future climate change on generally large scales that cannot be addressed by comprehensive AOGCMs, primarily because of their high computational costs. At larger scales, EMIC results compare well with observational data and AOGCM results. The tradeoff is reduced resolution and simplified presentation. The EMIC's uncertainties in climate change projections can be addressed by repeated runs of large ensembles of model runs [3]. While both AOGCMs and EMICs are capable of reproducing observed climate changes and providing quantitative estimates at continental and larger scales, their application on a regional scale remains limited.

3.2 Modeling Status

Among the most recognized and widely published modeling centers contributing to IPCC (Intergovernmental Panel for Climate Change) and activities under the U.S. Global Change Research Program (USGCRP) are the National Center for Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL), National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS), Oak Ridge National Laboratory (ORNL), Canadian Climate Centre, Hadley Centre in the United Kingdom, and Max Planck Institute (MPI) for Meteorology in Germany.

Initial U.S. stages of climate change modeling and interpretive effort relied heavily on modeling centers in Australia, Canada, England, and Germany [4]. The study by the National Research Council stated "that while the U.S. community is a world leader in intermediate and smaller climate-modeling efforts, it has been less prominent in producing high-end climate-modeling results, which have been featured in recent international assessments of the impact of climate change." Regardless of large computational and parameter estimation errors resulting in large variability of projected global warming scenarios, modeling results from the last decade of the 20th century prompted enactment of a large number of national and international climate change activities. In the United States, the Global Change Research Program (USGCRP) began as a presidential initiative in 1989 to "support research on the interactions of natural and human-induced changes in the global environment and their implications for society" [5].

3.3 Data Source Analysis

High-quality databases and verified defensible assumptions entering parameter estimation are among the most important prerequisites of credible model outputs. Based on temporal and spatial variability of individual weather stations worldwide, the overall quality of climate records presents considerable challenge in weighting their relative value.

Among numerous model input parameters, instrumental temperature records represent the longest time series available and are, therefore, used as an example. The official record of temperature in United States comes from a network of approximately 1221 U.S. Historical

Climatology Network (USHCN) stations operated by NOAA's National Weather Service (NWS). The documented records extend to 1895, i.e., available time series are the same as the database used for the EERC research study. The qualitative differences between individual stations and their representativeness vary. To account for urban heat islands the regression-based approach of Karl et al. [6] was employed in the original HCN. No specific urban correction is applied in HCN Version 2 because the change point detection algorithm effectively accounts for any "local" trend at any individual station. Systemic surface station errors were recognized by the National Climate Data Center (NCDC) that in 2003 commissioned the new Climate Reference Network (CRN). New data presented in Figure 1 are accessible as USHCN Version 2 [7].

Based on research conducted by Watts [8, 9], 89% of individual weather stations fail to meet the NWS criteria such as 30 m (100 ft) distance from an artificial heating or radiating/reflecting heat source. The errors exceeding estimated global temperature rise of 0.7°C (1.2°F) bias toward high-temperature readings resulting from variability in station materials and development around their original siting (proximity to buildings, reflective surfaces, energy heat sources).

It follows that aside from the already noted short time series represented by modern instrumental records, each record has its own quantitative (numbers of stations, distribution) and qualitative variability (instrument errors, bias). In other words, these critical input data records are not perfect. Similarly to likely "contaminated" temperature data, snow–water ratio conversion during winter months presents a challenge in interpreting winter precipitation records, etc.

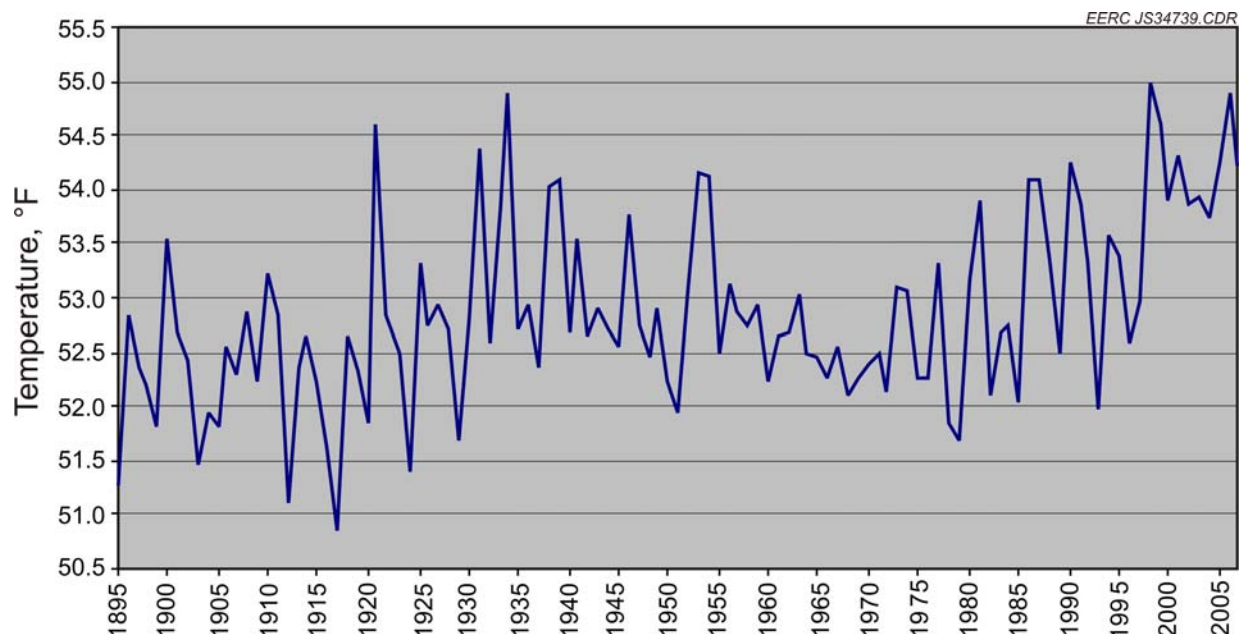


Figure 1. U.S. temperature record.

Data from satellites and balloon observations appear to be more accurate; however, depending on the initiation of individual monitoring programs, available data series still represent only a fraction of the information needed to evaluate long-term trends. Currently accessible Antarctic ice core data represent deuterium-based temperature reconstruction for over 420,000 years [10] (Figure 2). EPICA Dome C ice cores deuterium analysis [11] represent a period from of 750 thousand years and correlate well with Vostok data. For illustration, the USHCN V2 temperature record represents only 5.3% of the EERC paleoreconstruction and 0.03% of Vostok Antarctic ice core record. These facts are noted because time scale based on 100–150 years of instrumental records is widely used in most conclusions provided by IPCC studies and their opponents.

Data from a variety of sources are compiled to drive assumptions on parameter estimation. Radiative forcings are the most widely disputed input variables. Among primary forcings defined by IPCC [3] are long-lived greenhouse gases, namely CO₂, N₂O, CH₄, and halocarbons, ozone, stratospheric water vapor, surface albedo, aerosols, linear contrails, and solar irradiance. Relative share and magnitude of input variables translate into large output variability and a broad range for estimated predictive scenarios.

3.4 Regional Implications vs. Global Climatic Trends

The results of the EERC reconstructions of paleohydrologic history for the recent 2000 years in the upper Midwest (northern Great Plains) confirmed cyclicity of climate patterns across the region. Confirmation of cyclical trends or at least an analogy of modern and past hydrologic extremes would not be possible if it was based on short series of modern monitoring data, as presented in Figures 2 and 3.

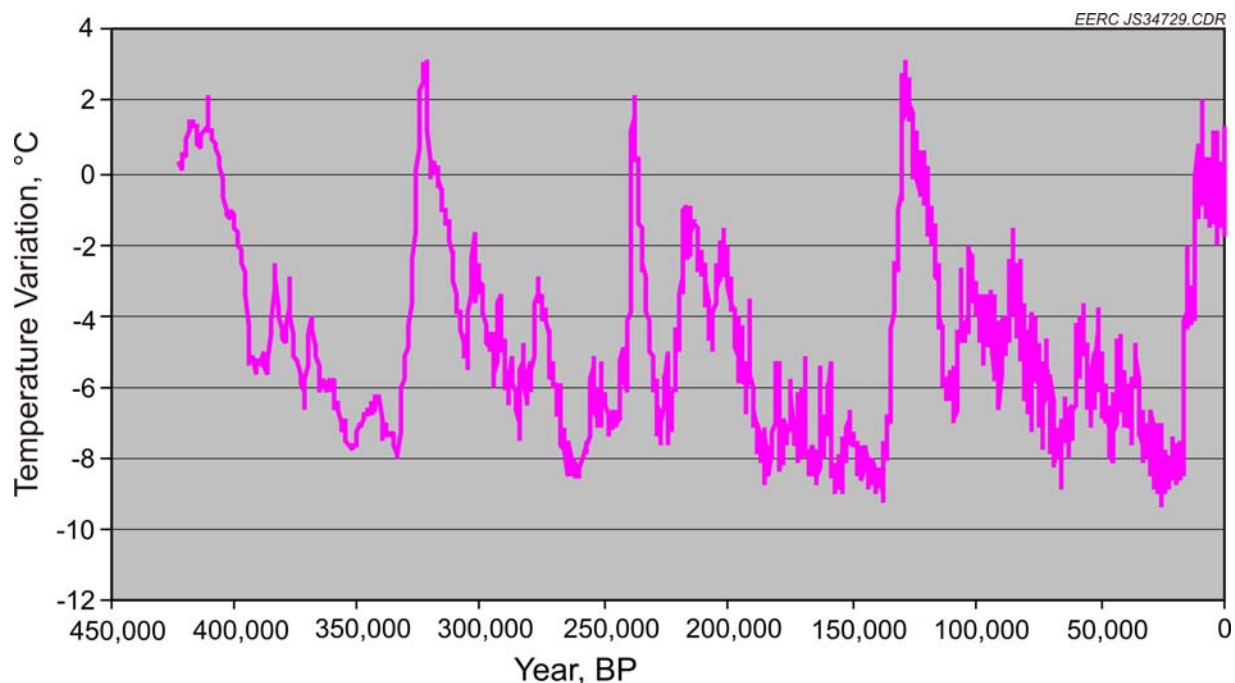


Figure 2. Vostok ice core temperature reconstruction.



Figure 3. Devils Lake level fluctuation (1867 – November 2005).

Information on lake level, precipitation, and temperature used in our study was insufficient for evaluation of long-term cyclicity; except for a historical low documented for Devils Lake from 1930 to 1940, data for the complete period of high lake levels were unavailable prior to 1886. In addition, the accuracy of data recorded before 1920 may be questionable. Contrary to modern climate records, analyses of paleo proxies, mainly diatom-transfer function, allowed for reconstruction of historical lake-level records for the recent 2000 years that correlate well with recently observed regional climate phenomena and other paleorecords. A map of the study area and compilation of regional studies is provided in Figures 4 and 5.

As demonstrated in Figure 5, the upper Midwest region/Souris–Red–Rainy Watershed experienced cyclic reoccurrence of wet and dry climate. While drier conditions prevailed in the recent 1000 years, the second half of the 20th century experienced relatively fast onset of wet conditions with a magnitude comparable to cyclic events between 2000 and 1000 years before present. While this trend does not confirm or exclude periods of extreme wetness or drought in between, it definitely indicates that analogous conditions have occurred on the regional scale in the past.

The climate predictions for Souris–Red–Rainy Watershed were presented in U.S. National Assessment of Climate Change (NACC) report from 2000 [12]. The prediction for 1990–2090 was based on results of Hadley and Canadian models. In directly opposite scenarios for the Souris–Red–Rainy Watershed, the Dakotas could turn into either swamp or desert, depending on the model used [13]. The NACC document failed to meet criteria of the Information Quality Act [14] and was withdrawn from official government reports.

Our reconstruction confirmed that frequent climate fluctuations resulting in alternating periods of drought and wet conditions are typical for the northern Great Plains and suggest that

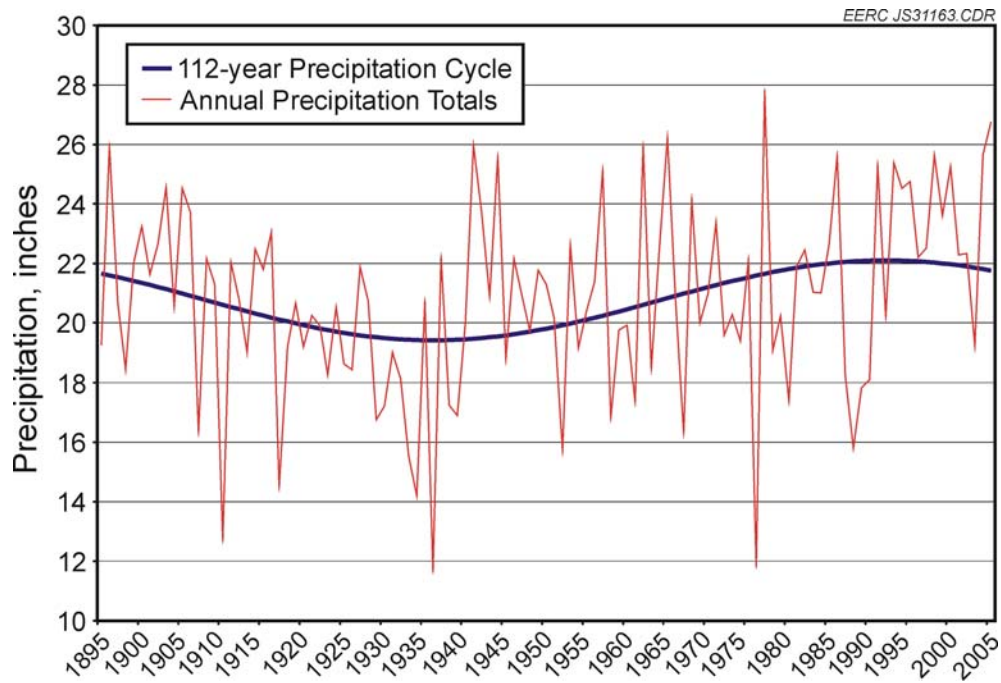


Figure 4. Annual precipitation totals from 1895 to 2006 for the Red River Basin. The precipitation cycle of 112 years is shown as the smooth, thick line [2].



Figure 5. Research area.

the severity and length of extremes exceeded those on modern record. What are the primary drivers of regional climate shifts, and is there a relationship with globally observed climate patterns? Modern instrumental records allowed us to evaluate only a fraction of the historical climate cycle (Figures 2 and 3). On the contrary, reconstruction of inferred lake salinity (Figure 6) used as a proxy for lake levels provides information on multiple overlapping cyclic patterns that are controlled by different global and regional climate drivers and their mutual interactions.

Because of the unique position on a transboundary between three climatic provinces: the wetter Atlantic province; the drier western Pacific province; and the cold Arctic province, the contribution of globally observed climate drivers is likely more pronounced than in regions controlled by one dominant climate driver.

Data reveal differences between the first and second millennium and suggest that in addition to numerous short-term cycles with small amplitude, several longer cycles with larger amplitude are apparent in the first millennium. Finally, an even longer cycle with an apparent onset in our times could complement the cycle centered in the first millennium that may draw an analogy with a 1500-year Dansgaard, Oeschger, and Lorius cycle [15] documented in ice cores from Greenland. Expanding our research by several millennia (i.e., length of the core recovered from bottom sediments) would likely yield more complete information on climate cyclicity since the end of last glaciation and formation of the Devils Lake about 10,000 years BP. It would also allow a complete analysis of longer cycles that are apparent, but only their fractions are documented.

Orbital effects on climate are well-documented and widely accepted. Milankovitch variables such as eccentricity (~100,000-year cycle), earth axis tilt (~41,000-year), and precession (2000–3000-year) were confirmed from ice cores (Figure 1). The relative

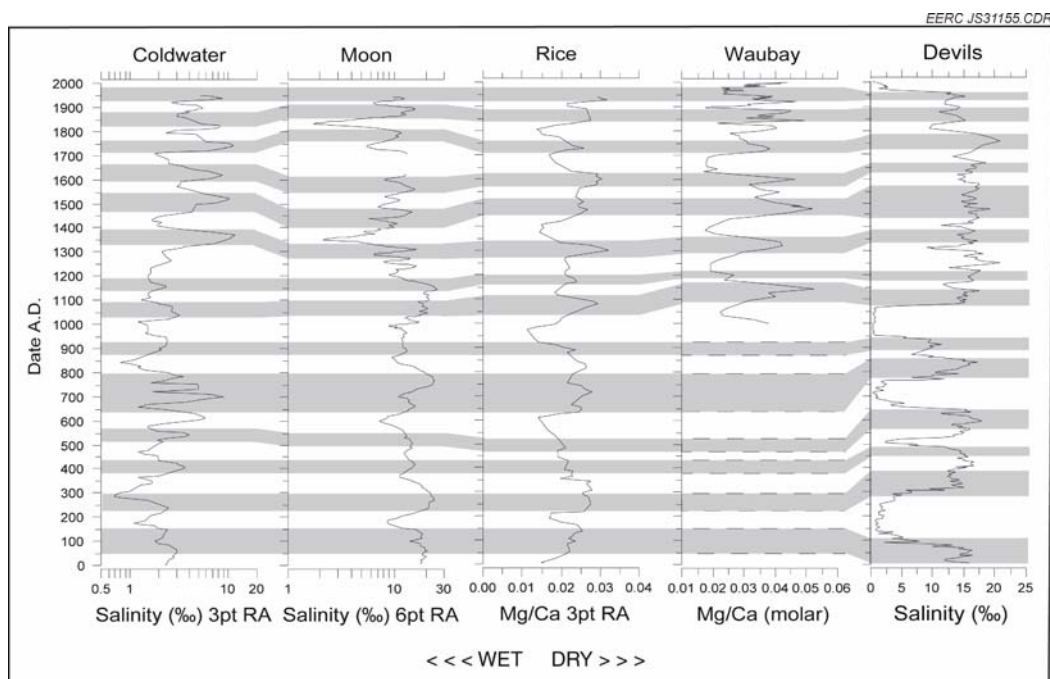


Figure 6. Regional records of climate change (EERC and SCWRS data integrated with data from Fritz et al. and Shapley et al. [16, 17]).

contribution of solar drivers such as an ~11.2-year sunspot cycle, ~22-year combined sunspot and magnetic cycle, or ~80–90-year Gleissberg cycle remain the subject of dispute. The climate impact of numerous other drivers such as the Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO), El Nino and El Nina patterns, and El Nino Southern Oscillation (ENSO) is documented, but their causes and modeling remain the subject of scientific debate and speculation. Correlation between temperature record and selected climate forcings is in Table 1.

For illustration of selected variables, the Devils Lake level is plotted against the U.S. temperature record and a combination of PDO and AMO. Figure 7 indicates good correlation between temperature, PDO, and AMO and an expected inverse relationship with lake levels until 1960. This relationship loses significance from about 1960 and follows the same trend since about 1985. In this case, we may hypothesize that the land management changes in the upper watershed that resulted in reduced retention and the size of Devils Lake became dominant factors that altered patterns observed in the past. The lake simply became so large that the overall impact of increasing temperature on its fluctuation is reduced. Without a detailed assessment, however, this suggested scenario cannot be confirmed.

Table 1. Correlation of Temperature and Selected Factors [18]

Factor	Period	Correlation with USHCN 2	
		Pearson Coef.	R ²
CO ₂	1895–2007	0.66	0.44
Total Solar Irradiance	1900–2004	0.76	0.57
PDO and AMO	1900–2007	0.92	0.85
CO ₂ (last decade)	1998–2007	–0.14	0.02

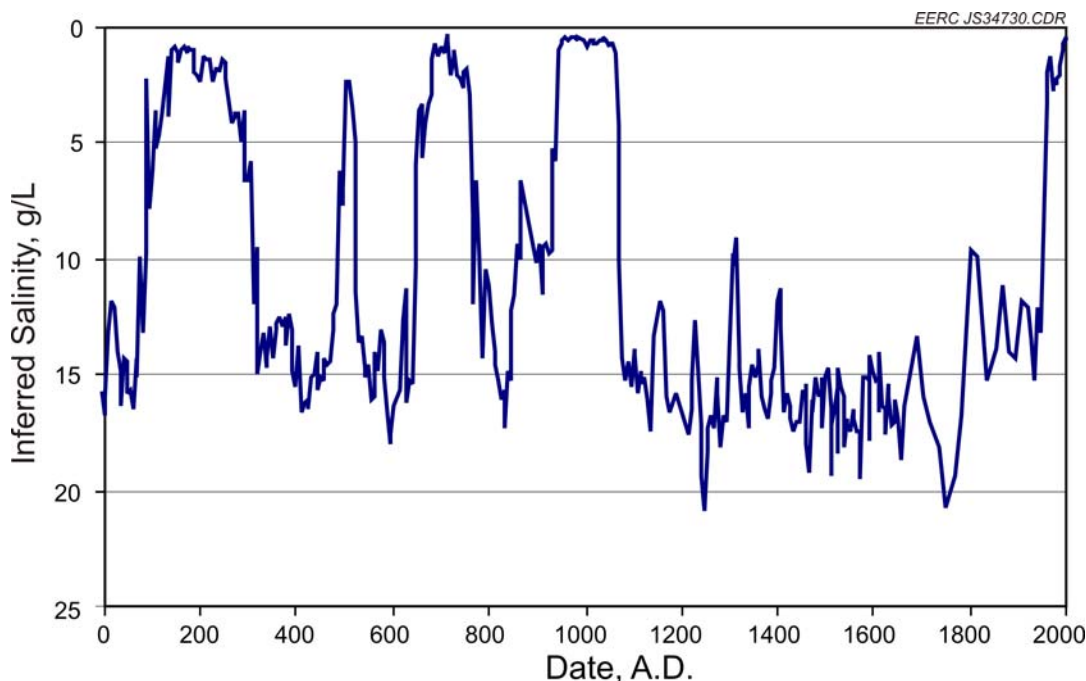


Figure 7. Inferred salinity 0–2000 A.D.

3.5 Discussion

Results of our research indicate that short-term data series available from modern instrumental records are not sufficient to reconstruct past hydrologic events or predict future ones. Reconstruction of paleoclimate phenomena provided credible information on past climate cycles and confirmed their integration in the context of regional climate history is possible. Similarly to ice cores and other paleo proxies, acquired data represent an objective, credible tool for model calibration and validation of currently observed trends. It remains a subject of future research whether further refinement of our results and synthesis with regional and global climate observations could lead to credible climate predictions.

The analogy of some regional results with global climate patterns (PDO and AMO continental temperature average) reflect on the unique position of the northern Great Plains on a transboundary between three climatic provinces (Atlantic, Pacific, and Arctic). As a result, the contribution of globally observed climate drivers and their overlap could be more pronounced than in regions controlled by drivers specific for one climate province. It follows that climate reconstructions from transboundary regions may be more representative of the global trends and, as such, serve as a valuable calibration tool for predictive scenarios.

Increased temperature and sea level rise are the most widely feared consequences of global warming. Numerous scenarios developed in IPCC 2007 [19] report project temperature change ranging from 0.6° to 6.4°C from the end of 20th century (1980–1999) to the end of the 21st century (2090–2099) [19]. Based on the modeling scenario applied, projections for sea level rise range from 0.18 to 0.59 m.

In order to provide a perspective on the modeled scenarios, Figure 8 presents recently published forecasts for sea level rise compiled from IPCC reports and independent sources [3, 16, 20–23].

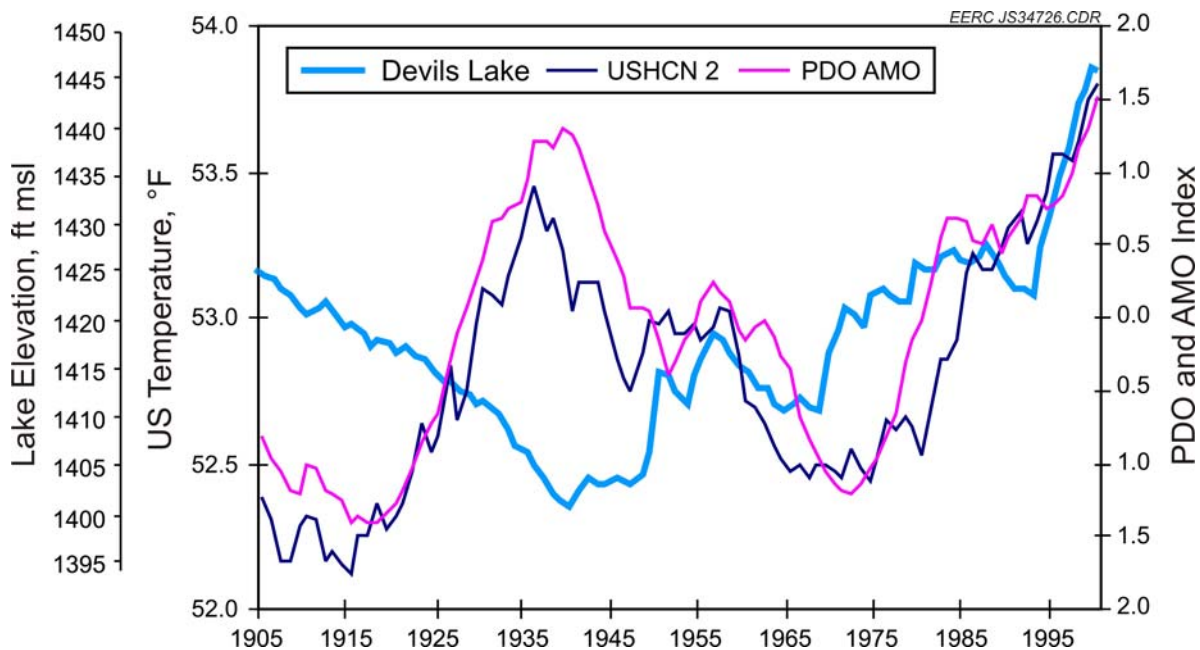


Figure 8. Lake level vs. temperature, PDO and AMO.

Results of intensive land management practices and increasing energy demand necessarily became factors in climate change. There is little scientific dispute about warming trends observed in recent decades. On the contrary, the cause, rate, and magnitude of predicted changes and relative contribution of individual forcings to AGW became a cornerstone of heated scientific debates among climate experts and policymakers worldwide. Because of short-term instrumental data series and their considerable challenges (Section 3.2) models are widely used to extrapolate possible climate scenarios. Are these scenarios credible enough to be presented in executive summaries that become publicly accepted for national and international environmental and energy policies?

By its own words, the IPCC-TAR 2001 stated: “In climate research and modeling, we should recognize that we are dealing with a coupled nonlinear chaotic system and, therefore, that the long-term prediction of future climate states is not possible” [22]. The ongoing development and refinement of computer models undoubtedly provides better and more credible forecast scenarios. It is important to note, however, that arbitrarily assigned certainty or perception of “likelihood” are constantly changing with better understanding of input parameters, improved data processing, and increasingly more educated interpretive and synthetic capabilities.

4.0 CONCLUSIONS

The EERC completed a brief evaluation of the existing status of predictive modeling to assess options and feasibility for integration of our previous paleohydrologic reconstructions and their synthesis with current global climate scenarios.

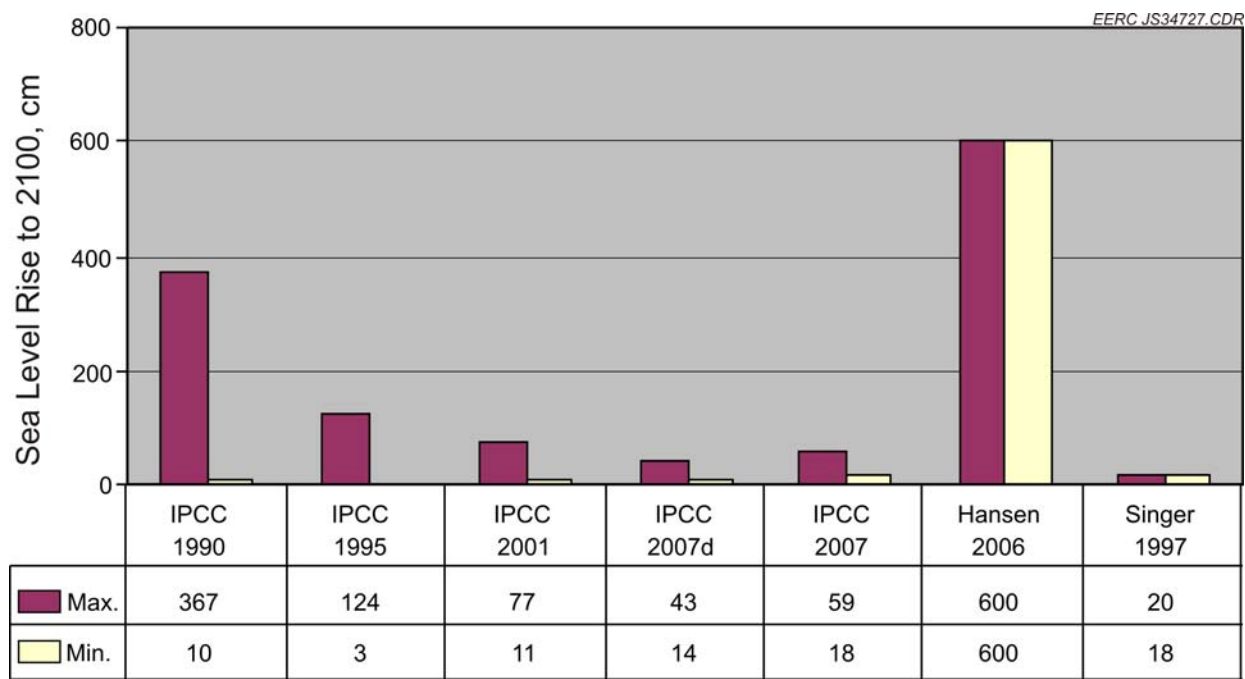


Figure 9. Sea level rise scenarios to 2100.

Models applied in the field of climate modeling are AOGCM and EMIC. While both models are capable of providing quantitative estimates at continental and larger scales, their application on a regional scale is limited.

Results of our research indicate that short-term data series available from modern instrumental records are not sufficient to reconstruct past hydrologic events or predict future ones because the instrumental data represent only fractions of climate cycles.

Reconstruction of paleoclimate phenomena provided credible information on past climate cycles and confirmed their integration in the context of regional climate history is possible. The paleoclimate proxies from the northern Great Plains may be more representative of the global climate cycles because of their unique position on a transboundary between three climatic provinces (Atlantic, Pacific, and Arctic). Similarly to ice cores and other paleo proxies, acquired data represent a credible tool for model calibration and validation of currently observed trends. It remains a subject of future research, if further refinement of our results and synthesis with regional and global climate observations could lead to credible climate predictions on a regional scale.

The future research effort should focus on 1) detailed analysis of multiple overlapping cyclic patterns that are controlled by different global and regional climate drivers and their mutual interactions; 2) acquisition of high-resolution regional paleorecords representative of climate cyclicity since Devils Lake formation, i.e., the entire postglacial regional record; and 3) synthesis of information from this extended paleorecord with globally observed climate phenomena.

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