THE PENNSYLVANIA STATE UNIVERSITY

SCHREYER HONORS COLLEGE

DEPARTMENT OF GEOGRAPHY

NEW OBSERVATION AND DEVELOPMENT ON A NEW LOCALIZED NORMALIZED HEAT PRECIPITATION INDEX

HAN YU

SPRING 2019

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Geography
with honors in Geography
Reviewed and approved* by the following:

Roger Downs
Professor of Geography
Thesis Supervisor/Honors Adviser

Andrew Carleton
Professor of Geography
Faculty Reader

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

This thesis develops a task-specific, Gamma-distributed Climate Social Impact Index (CSII) for analyzing the social significance of climatic variations. The CSII is designed to be covarying with human and/or physical environments in both spatial and temporal scales and is best at processing meso-scale climatic variations. Construction of the CSII is based on the Evapotraspiration Heat-Precipitation Index (EHPI) which the current author previously developed. The CSII is validated against climatic and social-demographic records of 15th century France. It was discovered that the CSII processes well the reconstructed temperature and precipitation conditions within 100 years period. But it was also proved that the CSII does demand a large set of imported data in order to function in full capability.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

This Honors Thesis is completed under the kind instruction and advices given by many faculties in the Pennsylvania State University, including Prof. Benjamin Hudson, with which I first constructed the idea of a climate index, and under whose supervision I finished the first research on this topic, which was presented at the Moravian Undergraduate Medieval Conference in 2017. After having decided to extend this 2017 research into my Honors Thesis, I have been helped greatly by my Faculty Reader of this thesis, Prof. Andrew Carleton, and my Honors Advisor, Prof. Roger Downs. I express my deepest gratitude to all the faculties mentioned above.

The dataset necessary to finish this thesis comes from the NOAA Paleoclimatology Program. The abundance of paleoclimate reconstructions and proxy temperature/precipitation data available on this dataset is what solidly supported the models, calculations and validation process involved in this thesis. All data used in this thesis were acquired via public domain and their original contributors cited. My appreciations go to those hard-working researchers who produced such useful datasets.

Also, all published research articles that I have studied in preparation of this thesis are cited and listed in the bibliography section at the end of this thesis. All these previous researches laid down the foundation for this thesis, and therefore my appreciations also go to all whom I have cited their work in this thesis.

Chapter 1

Introduction

This thesis aims at developing a spatially as well as temporally covarying climate social significance index that may be deployed not only to understand past climatic events and variations, but also capable of being projected upon current and/or predicted climatic events to help provide insight into the social-economic significance of such climatic events.

The several short-to-medium term rapid are they rapid if they're also medium-term climate events that were recorded during the Middle Ages have always been a major topic for both climatologists and historians in the academia. The famous Little Ice Age and the Medieval Climatic Anomaly have both attracted significant interest. Efforts have been made to recollect, reconstruct, model, and explain both the sequences of and the causation mechanisms behind such events.

Indeed, one important driving factor for historical climatic research is to extract knowledge of past climatic variations and project such acquired knowledge onto predictions of climate, to help alleviate the societal threats from such extreme climatic and meteorological events. As the science and methodology of climatology and statistics have advanced, constructing climatic indices to help better comprehend climatic patterns and to aid in decision making has become increasingly popular. For example, through utilization of demand-specified indices not only will academics be empowered to better understand the practical impacts of climatic events, but so too will decision makers of other government institutions acquire necessary knowledge of the impacts of such events on his/her field of expertise.

It is important to note that climatic patterns do not tend to be the same across even a short spatio-temporal range. The fact that there are few climatic indices that are spatially as well as temporally localized has obstructed their further expanded of usage in an historical context. Researchers and decision makers attempting to project understanding of the causes and impacts of past climate events to current conditions using such indices may find it indeed unwise to do so without being able to localize the index to the local situation. Therefore, my thesis attempts to solve this shortcoming of previous climatic indices.

The remaining chapters of this thesis will be divided into first a survey of past efforts in climatic indexing, especially paleo-climatic and historical climatic indexing. One section within this background chapter is dedicated to describing the past practical applications of time-and-space specific indices and a brief evaluation of their successes as well as limitations.

The background chapter will be followed by a literature review that briefly describes the relevant literature across many disciplines of climatic indexes, the social impacts of climate events, the construction of climatic indices, among other topics. The time range of the surveyed literature surveyed spans across the end of last century until the latest research findings. The literature review chapter is followed by a description of the methodology involved in constructing the localized climatic index, including the necessary mathematical models. In that chapter, the logic for relating the index to social impacts of climate events is also explained so that repeated validation work and experiments may be conducted in future studies.

The following chapters of this thesis will cover the validation results of the constructed index. This validation procedure utilizes the collected proxy data for the Medieval Climate Anomaly and the Little Ice Age Europe to test the index's ability to be localized in both spatial and temporal terms. A discussion chapter specifies the usage as well as limitations for this index the proposed methodology to use such an index for localized climatological decision making. A short conclusion chapter will briefly discuss the outlook for such climate index-based studies and invite more effort into localizing climatic indices to render them more functional for various scales of decision making.

Chapter 2

Background

Previous work on climatic indices spans a considerable range of disciplines. On the most micro scale, research has been done on constructing indices that accurately reflect subjective human bodily reactions to alterations in heat-humidity conditions in the immediate surroundings (i.e., “human comfort”). Bröde et al. (2012) derived an operation procedure for constructing such a human-thermal interaction index (Universal Thermal Climate Index, UTCI) tailored to a specific user-defined purpose. However, this attempt was confined within a minimal physical scale. At the same time, studies on larger scales have also been well underway. Many such efforts started as attempts to reconstruct historical climatic events and to render such reconstructions quantifiable in terms of socio-economic forces. One essential outcome of these studies is a series of paleo-climatology analysis methodologies based upon proxy climatic data such as δO18 and pollen sedimentation, as well as crucial methods for deriving heat-precipitation indices based on other proxy climate data records and mathematical models. In constructing the climate index previously introduced in this thesis, some of these index-building methods will serve as theoretical foundations. For example, Li et al. (2015) innovated upon the traditionally used Standardized Precipitation Index (SPI) and created a Nonstationary Standardized Precipitation Index (NSPI) that correlates with climatic teleconnection indices (such as NAO, ENSO) and provides better local relevance on both temporal and spatial terms both temporally and spatially.

Another major research direction focuses on de-ciphering the social-demographic impacts of climate events. Researchers such as Gogou et al (2016) have suggested that it may be the most efficient to correlate social-environmental changes in history with notable environmental events. Many such studies have strongly suggested that climatic events can indeed exert considerable impacts on social-economic and social-environment conditions through introducing greater variabilities in crop production, cattle prices, and even the spread of infectious diseases. Multiple studies utilizing sediment proxy heat and precipitation data from the Medieval period for example, have found that increased humidity and temperature in climatic conditions had favored the breeding of rodents prior to the major outbreaks of "Black Death", a fiercely contagious and deadly fever-like disease that once wiped out a significant portion of European population (1348-1350). The book by Rosen (2014) also detailed how a seven-year episode of unfavorable climate conditions (in late 13th century to early 14th century) triggered the Great Famine of the 14th century and subsequent social-economic turmoil in Europe (Rosen, 2014). Other studies include specific simulations and reconstructions of climatic impacts on societal details such as the price of building construction materials and techniques (Jame, 2010).

A previous effort by the author of this thesis, presented at the 12th Moravian Undergraduate Conference for Medieval Studies (2017), demonstrated the feasibility of a new heat-precipitation index that can be normalized to illustrate the societal significance of a drought or rainy event. The Heat-Precipitation Index (HPI) and its upgraded form, the Evapo-transpiration Heat-Precipitation Index (EHPI) proposed by the author, was validated against Medieval European climatic records obtained as proxy data from lakebed pollen sedimentation as well as tree ring records (Yu, 2017). Because this index was initially designed to illustrate climate variation and anomalies, it gives considerable quantified insight into the social-economic significance of climate events and variations. The first application of HPI and EHPI was to demonstrate that some major famines in Europe during the 14th to 16th centuries were not simply the result of extended droughts impacting agriculture -- commencement of the Little Ice Age and extended periods of heavy rainfall seem to be among the major contributors to repeated famines observed in records from those centuries. The short-term global cooling that followed the Kuwae eruption in 1453 was also evident in this index.

On larger scales, long-term anomalies in climatic trends such as the commencement and recession of the Little Ice Age and Medieval Climatic Anomaly have been observed to introduce long-term social stress across a large spatial scale. However, the fact that there is an apparent lack of recorded instances in climatic anomalies and trends, as well as the social stress conditions of such a scale, bring direct obstacles to quantifying social significance of long-term climatic trends. Same problem can be observed for climate patterns across large spatial scales. It is not the task or the capacity of the climate social impact index, therefore, to quantify and illustrate climatic impacts over large spatial-temporal scales.

Accordingly, this thesis attempts to integrate various perspectives of the climatic impact on social-economic conditions and calculate the potential significance of any given climatic event on the subsequent social and political events.

Chapter 3

Literature Review

The reviewed literature covers a wide range of topics concerning climatology and paleo-climatology, the processing of climate proxy data, construction of the thermal/climate index, recent anthropogenic climate change, and research on environment-related chronological diseases related to climate factors. Specifically:

The papers by Reinemann et al (2014), Amann et al (2015), Li et al (2015), Aberth (Aberth, 2012), Buckland et al (Buckland et al., 1996), Crowley & Lowery (2000) and many other scholars reported on climate patterns dating back between 2000 to 500 years (i.e., paleoclimatology). The reconstruction methods used to re-create the past climate patterns mostly involved interpretation of proxy temperature data based on δO18 content detected in polar ice cores as well as from deep oceanbed cores. Such proxy data work because of the direct relationship between temperature and δO18 content in the long term. The proxy data collected and used in my thesis here is mostly comprised of oceanbed and lakebed pollen as well as δO18 content data, therefore the previously-published research can serve as important methodological support.

The papers by McMichael et al (2017), Morellon et al (2011), Gogou et al (2016) and many other scholars reported progress in the field of climate-related anthropological behavior and related health problems.

On the most micro scale, human skin can feel subtle climate variations in the immediate surroundings of the human body. Work by Bröde et al. (2012) suggested an operational procedure for deriving a thermal climate index of direct human skin reaction to the immediate thermal climate. Even though the index so derived is called the Universal Thermal Climate Index (UTCI), it still considers the environmental humidity felt by the human body. However, the mathematical model behind the mechanism of UTCI takes the physiological conditions of human bodies into calculation, and therefore cannot be seen as a completely climatological index. Even so, the operational procedures for deriving the UTCI provided theoretical support for considering even the smallest scale of climate variations as having an impact on social-demographic patterns of correspondingly larger scales.

Interestingly enough, such correspondence between scales of climatic variation and social climatic impacts can be seen almost universally across the scale range, from individual human bodies to the large-scale upheavals and famines across Europe during the Middle Ages (Fraser, 2011). As described by Fraser, the "calamitous" 14th century was very likely accentuated by instabilities in climatic conditions to a considerable scale. Although the most bountiful historical climatic record is available for this spatio-temporal scale of climate-social interaction, this scale is also the most difficult to quantify. This difficulty arises because of the discrepancies in the types of records and proxy records available across both space and time, which render the derivation of a unified quantitative dimension that is suitable everywhere very difficult. On the other hand, despite the huge amount of historical records, there is a major lack in well-supported direct causation evidence between climatic anomalies and social instabilities. When Li et al. (2015) developed the NSPI, they also offered an inspiration and theoretical support for linking meso-scale climatic anomalies to social development patterns. By making climatic cyclical indices (cyclical oscillations such as ENSO and NAO define: El Niño Southern Oscillation, North Atlantic Oscillation) covariant with the precipitation index, the explanatory capabilities of the precipitation index can be greatly enhanced.

This body of research contributes to this thesis in terms of providing a theoretical basis for linking climate patterns to human health and behavior, such as risk of contracting contagious epidemics. Caution will be taken, however, to ensure that the stated relevance between the two factors are statistically significant and well supported.

Research conducted by Deniz et al (2011), Poole (1940), Xoplaki et al (2016), the United Nations (Vulnerability indices [electronic resource], 2001) and many other scholars as well as organizations reported work on the development of climate-human interaction indices serving various purposes and functionalities. These papers documented well-supported, verified algorithms for developing such indices and their usability.

Many other scholarly reviewed papers were surveyed for this thesis as well, supplementing the theoretical basis and methodological basis of this paper. The focus of many such papers is the Medieval Climate Anomaly (MCA), as it is one of the best periods that can be studied relatively easily to understand the climate-human interaction.

Chapter 4

Method

As previously mentioned, my HPI and EHPI already have the capability to illustrate the social significance of climatic anomalies on both short and long timescales. Of the two forms of the index (HPI and EHPI), EHPI takes evaporation into consideration and essentially follows a Gamma distribution that is like the traditional Standardized Precipitation Index. Therefore, EHPI often demonstrates much better sensitivity to climatic anomalies, and exhibits better accuracy in terms of its social significance. For EHPI to be more task-specific, it has a drought form that is more sensitive towards drought anomalies and a humid form that is more sensitive to excessive precipitation. The basic forms of the two different indices are:

$$E_{drought}\ (t) \sim \text{Gamma}\ (\alpha,\ \beta\text{-}1), \tag{1.1}$$

$$\text{Where } \alpha \sim (dT,\ d18O,\ SPEI),\ \beta\ (t) \sim P \tag{1.2}$$

And

$$E_{humid}\ (t) \sim \text{Gamma}\ (\alpha',\ \beta'), \tag{2.1}$$

$$\text{Where } \alpha' \sim (dT,\ d18O,\ SPEI),\ \beta'\ (t) \sim \mu\ (P) \tag{2.2}$$

In both forms, two scale factors α and β are added to enable the index to adjust to any practical scales necessary such as the temporal scale, where α is the spatial localization factor and β is the temporal localization factor. As the two forms have demonstrated, EHPI utilizes the variation of the traditional SPI, the Standardized Precipitation-Evaporation Index (SPEI, which is a Gamma distribution index just as SPI) to establish the benchmark precipitation percentile at the local scale. This percentile is then adjusted by the raw thermal anomaly (dT) and an optional proxy thermal anomaly (d18O) that is specifically tailored for studying historic climatic records through proxy data. Next, this benchmark factor is scaled up through the cumulative precipitation (P) or the standard deviation of accumulated precipitation (μ[P]). Like other variants of SPI, EHPI also follows a general Gamma distribution. However, since EHPI also co-variates with local temperature conditions it better brings out the entire climatic picture. Therefore, EHPI sets a reasonable basis for identifying significant social impacts of climatic anomalies. For constructing the Climate Social Impact Index, it is more appropriate to utilize the humid form (H) of the EHPI to make calculations less complicated.

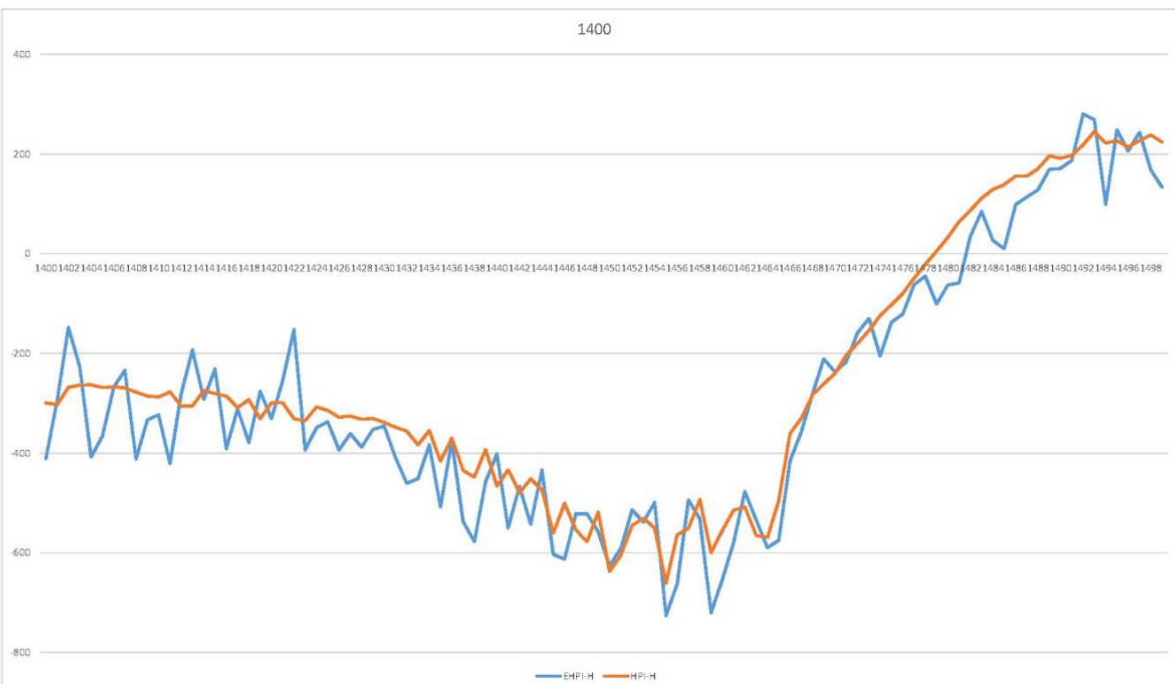

Figure 1. Demonstrated HPI (orange) and EHPI (blue) time series illustrating climatic variations and anomalies through the 100-year span of the 15th century (Yu, 2017). Note particularly the shift from a dominant humid phase (negative) to a drought phase (positive), and the major climatic fluctuations after the year 1453.

Just as spatial-temporal variations of climate patterns need to be localized to suit various research needs, the social impacts of climate variations also need to be localized to fulfill the purpose of the climatic social impact index. Therefore, it is necessary to examine the different spatial-temporal scales of such social impacts.

Based on the examination of climate-social inter-relationship given earlier, it is possible to construct the Climate Social Impact Index. Firstly, because this index will focus on providing the significance of climate anomalies seen through the societal lens, this index must covary with potential local conditions as specified by the user of the index. The local condition indicators may include: anomalies in cyclic climate patterns affecting the study area, local base demographic conditions such as density of residential population, types of residences present in study area, base disease epidemic conditions and climate region categorization of the study area, etc. The resulting index will generally follow a Gamma distribution just as the SPI yet will include more scaling components to ensure that the index can be as specific as initially designed. In the most general form, this index will exhibit a form not so different from the original humid-phase EHPI, as follows:

$$X^{mw} (s, t) \sim \text{Gamma} (\mu^t, \sigma^s, m, w, \gamma t), \quad (3.1)$$

$$\text{Where } \mu^t \sim [dT(t), dP(t), SPEI], \text{ while } \sigma^s (t) \sim \mu (P) \quad (3.2)$$

In the mathematical model above, μ^t and σ^s are the spatial and temporal localization factors in (2.1), respectively, while each covarying with user-specified time (t) and space (s) ranges. The three factors with which μ^t covaries are raw thermal anomaly (dT), raw precipitation anomaly (dP), and precipitation percentile given by SPEI (or the original form of SPI). Two additional factors, m and w are added, each representing base local climatological and demographic conditions. The final factor γt was first introduced by Li et al. (2015) when constructing the NSPI, the non-stationary version of the traditional Standardized Precipitation Index. This factor covaries with a chosen climatic cyclical pattern index, as specified by the user. The parameter γt is given by:

$$\gamma t = \sum^{n}_{i=0} b_i C_i (t) \tag{4}$$

Where b is constant, and C is the explanatory variable provided by the climatic cyclical pattern index selected (Li et al. 2015). This ensures that the index considers variations in local climatic system's climate conditions and helps explain local heat and precipitation variations.

The forms of factors m and w are not pre-determined. In theory, the local climatological factor m can simply be an accumulative record average of local precipitation amounts, temperature trend, or even a ten-year average of SPI records. On the other hand, the local demographic factor w is a standardization of the local demographic profile compared against a "benchmark" profile that is either arbitrary or realistic (derived from population surveys and/or historical records for the nearby localities). Even though neither m nor w take fixed forms, they can still be expressed as follows:

$$m = \sum^{n}_{j=0} X_j (N) \tag{5.1}$$

And

$$w = \sum^{n}_{j=0} Y_j (N) \tag{5.2}$$

Where X and Y are each localization indices and N denotes the user-specified reference time period.

Overall, the Climate Social Impact Index is by no means a stationary index with a fixed form. There is ample room for users of this index to suit the index to real-world conditions. It has to be noted, however, that this index has a native time and space scale limit. As explained previously, it is meaningless to quantify long-term, large-area climatic variation and its social impact using such indices. The fact that the entire mathematical model works around a medium-scale EHPI means that this index performs the best at meso-scale geographical regions (~300 km radius) paired with meso-scale climate and societal time spans of less than 100 years.

Chapter 5

Validation

The validation process of the CSII used the same historical data sources as the previous validation work of EHPI. However, because CSII is a meso-scale climate index, the time span of only 100 years was chosen, instead of conducting a multi-century reconstruction as I did for the EHPI.

For the purpose of this validation work, reconstructed paleo-climate data for 15th century France and Switzerland were acquired from the NOAA Paleoclimatology Program dataset. The types of acquired data include reconstructed precipitation anomalies centered on the historical site of Fountainbleau, France (Labuhn et al., 2016), thermal anomaly reconstruction based on lakebed sediment δ18O data from Lake Oeschinen in the Northern Alps (Amann et al. 2015) as well as French summer drought conditions (Labuhn et al., 2016), and reconstructed climate change (thermal) patterns based on lakebed sediments from Lake Silvaplana (Larocque et al. 2010), also in the Northern Alps. The reconstructed social-demographic benchmark data for 15th century France was reconstructed based on multiple sources of cattle (Poole, 1940) and crop prices (Durand & Leveau, 2004), as well as the general demographic conditions in Europe after the Great Famine in 14th century (Rosen, 2014). On the other hand, paleo-climatological studies regarding the benchmark climate conditions in 14th-15th century Europe were obtained from climate model simulations by Hunt (Hunt, 2006). Lastly, the Northern Atlantic Oscillation (NAO) record during the Medieval Climatic Anomaly was selected as the explanatory factor in γt (Trouet et al., 2009).

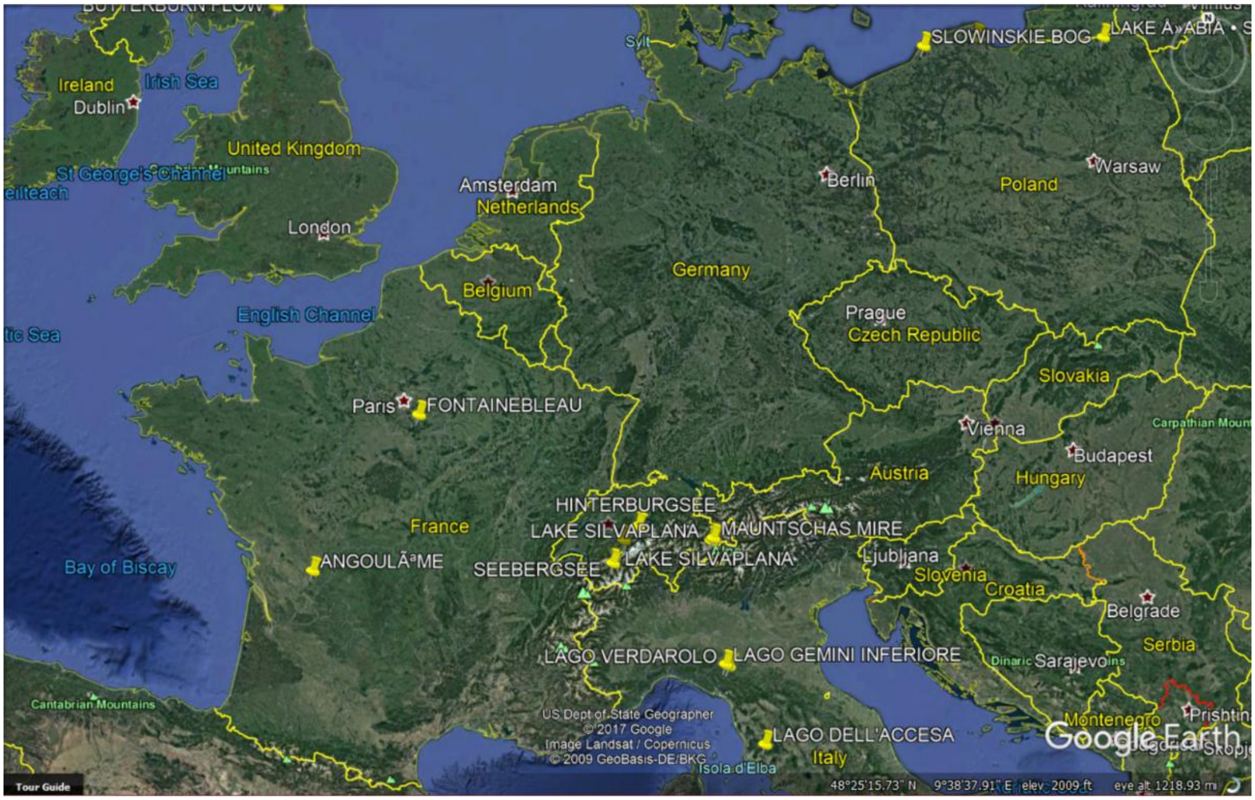

Figure 2. Geographical distribution of NOAA database for reconstructed paleo-climate data.

Following acquisition of the above historical records and proxy data reconstructions, I was able to construct a time series illustrating the social significance of climate variations through 15th century France:

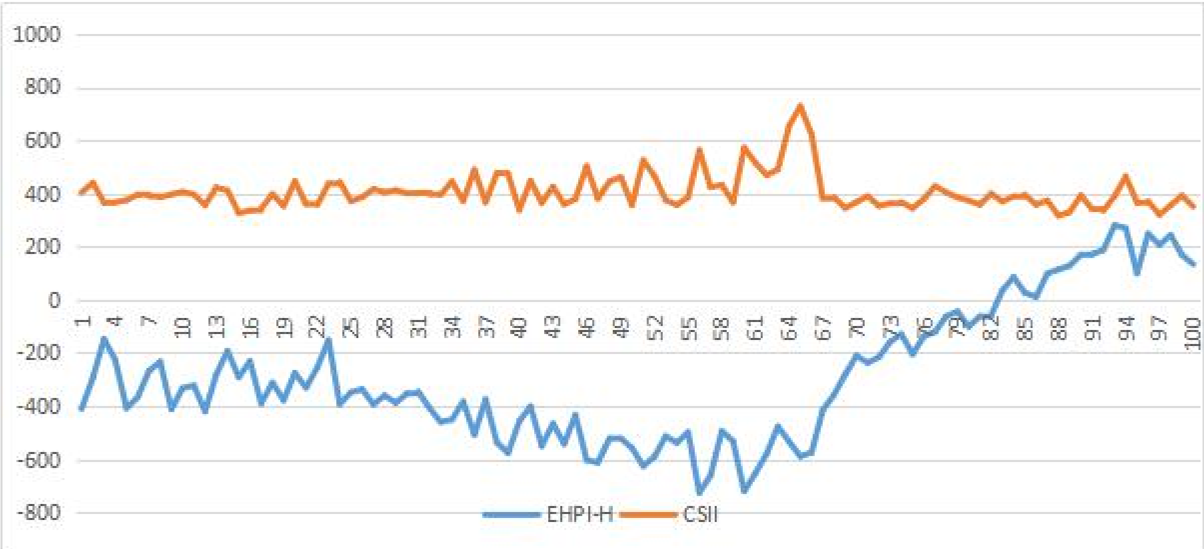

Figure 3. Reconstructed climate social significance in CSII, compared to the original EHPI for the same period. Note that variations of CSII are now contained in one domain.

When compared with the EHPI, it is apparent that by keeping the data within one domain instead of crossing between positive and negative domains, CSII is easier to read and interpret than EHPI. Also, as CSII filters out the "noise" of non-significant climate variations, it has become easier to identify climate events having the most social significance. The clear increase in climate fluctuations after 1453, for example, is much easier to see in CSII than in EHPI.

Also, another major advantage of CSII is that this index is strictly case-by-case, giving the index great flexibility while requesting that the user fine-tunes the index for every new application of the index before deployment.

As can be concluded from Figure 3, following the onset of a new wave of climate instability (and in short term, the global cooling effects following the eruption of volcano Kuwae in early 1453), variations in climate patterns had become increasingly significant in terms of their social impact, and by 1465 reached their highest significance. The index then departs from the same general trend as EHPI and drops back to pre-1453 values. Interestingly, the NAO records revisited by Trouet et al. (2009) seem to agree with the point that the decade between 1453 and 1465 saw a particularly unique phase in terms of a sudden and short negative phase of NAO (Trouet et al., 2009).

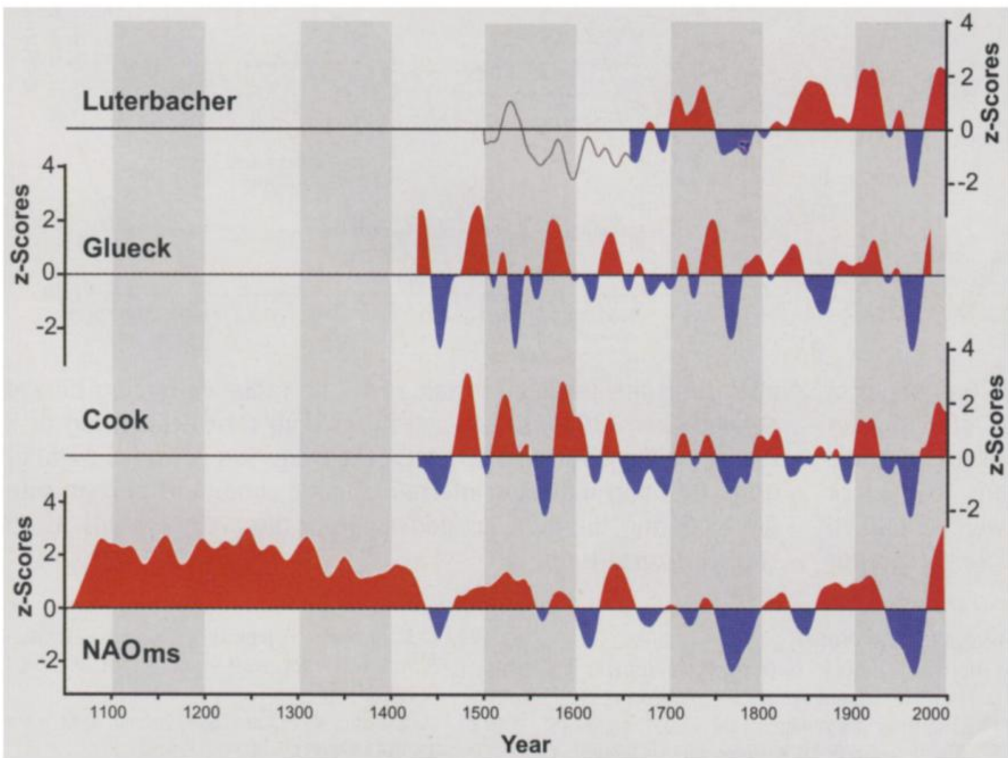

Fig. 2. Proxy-based NAO reconstructions. NAO_{ms} compared with reconstructions by Cook *et al.* (*3*), Glueck and Stockton (*13*), and Luterbacher *et al.* (*14*). All series were smoothed with the use of a 30-year spline and normalized over the 1500-to-1983 common period. The blank period in the Luterbacher reconstruction represents the period before 1659, for which only seasonal values were available.

Figure 4. This figure (from Trouet et al.' s 2009 paper) illustrates the reconstructed history of the NAO. Note the relatively short negative NAO phase in the middle of the 15th century (Trouet et al., 2009).

Although the NAO has been regarded as the major driver behind the famous Medieval Climatic Anomaly, also known as the Medieval Warm Period (Diaz & Trouet, 2014), there is evidence that relatively short periods of negative phase between longer positive phases are likely to bring more significant social effects than usual conditions that can be identified as the long-term trend. Such effects can also be observed in records from the height of the Little Ice Age, especially the winters of 1784 and 1816. Both events resulted in ample historical records about how residents in both Europe and North America dealt with "the Long Freeze-Up" and "the Year Without a Summer". Historically, the decade of 1450-1460 had indeed seen some of the more violent episodes in the history of France, even including other areas of Western Europe (note that the War of Roses commenced in 1455).

Such correspondence between climatic and societal shifts, however, is by no means conclusive in demonstrating the "accuracy" of the social impact of climate variations during the 15th century, as illustrated by the CSII. However, the purpose of CSII is not to demonstrate climate-social causation of any kind, but as an illustration of how the significance of various climatic events has co-varied throughout space and time. Indeed, the general distribution of CSII does exhibit better fit for actual climatic shifts than the previous EHPI and is in accordance with other major climatic indices.

Chapter 6

Discussion

The development of the Climate Social Impact Index involved both a qualitative understanding of climate-society relationships on multiple scales, and quantitative model-building that ultimately led to the basic form of the CSII. However, the CSII is not by itself an entirely new index: it borrows heavily from the EHPI which the author of this thesis previously developed. Generally speaking, the CSII is a direct improvement over EHPI, being contained within one index and is highly case specific. Although CSII lacks the ability to process large-scale climate events through the time span of multiple centuries, it is uniquely suited to exposing major climate instabilities and highlighting the social significance of such instabilities. As seen in Figure 3, the Climate Social Impact Index filters out the "background noise" that can sometimes distract the researcher from an essential insight into historical events, and which often occurs when the researcher is analyzing "raw" climatic indices such as the original SPI.

In short, the Climate Social Impact Index is very task-oriented and is probably not fit for analyzing long-term general climate trends and changes. CSII requires the input of multiple user-specified factors, even more than the NSPI that demands a user-supplied cyclical climatic index as a factorial explanatory parameter (Li et al. 2015). The nature of CSII essentially requires that its user have a clear picture of the task at hand and available data to deploy the CSII. These characteristics of the CSII make it both a potential strength in terms of the focus on user-defined task, and a shortcoming that limits the usability and availability of CSII. In reality, the amount of climatic and social-demographic datasets required to properly deploy the CSII may be sufficient for deeper analysis even without introducing the CSII.

Notwithstanding, the Climatic Social Impact Index has a distinct advantage in its visual representation and acquisition of insights. The previous example in the validation chapter above demonstrates that the user may identify the most socially significant climate events with relative ease. The user may then be guided towards deeper research into the time/space span highlighted by CSII in terms of the climate-social inter-relationship.

At the same time, the validation example given in the previous chapter only demonstrated the possibility to chart CSII against time. When mapped geographically for a given time slice, CSII easily becomes a spatial variable that can be visualized and analyzed in geographical terms, linked with geophysical features as well as spatial differentiations in social-demographic conditions within the study area. Introduction of a spatial covariant in CSII distinguishes the index from other variants of SPI, which are normally strictly one-dimensional indices (such as the SPEI and NSPI). The user may indeed feel more freedom exploring geographical differentiations of climatic conditions with the aid of CSII, and indeed hopefully researches involving spatial visualization and analysis of CSII may be reported in the future.

Chapter 7

Conclusion

This thesis demonstrates the utility of the CSII for showing the covariation of historical climate and societal events at meso- time and space scales. It is also a proposal and invitation for more research into task-specified, spatial-temporal social significance indices regarding climate variations and anomalies. The fact that climate variations exact constant effects on social-demographic processes, to this day, are still understudied by many climatologists and geographers in general. Indeed, there is no definitive evidence on direct causation mechanisms between climate conditions and societal conditions (except for environmental determinism, which had been proved to be just as inconclusive and lacking direct evidence). However, one must understand that it is not the long-term climatic conditions that have the most impact on social conditions, but sudden and strong shifts in climatic norms, such as the Medieval Climatic Anomaly, the Little Ice Age, and the sudden global cooling triggered by eruption of Kuwae volcano. Moreover, such studies are not limited to paleo-climatology. A recent study by Hipp and Chalise (2015) looked into the relationship between environmental attributes and county-level diabetes in the United States. Similar researches include geographic distribution research for chronic obstructive pulmonary diseases in countries such as Norway by Halvorsen & Martinussen (2014). Although not strictly climatological researches, studies like this are starting to shed light on the field of climate-social interactions, which still demands more attention from across the disciplines. The fact that environmental determinism was largely abandoned did not prove that climate and social conditions are indeed separate, only that it reminded the Academy that the complex mechanism linking climate and social conditions had yet to be fully comprehended.

BIBLIOGRAPHY

Aberth, J. (2012). *An environmental history of the Middle Ages: the crucible of nature*. London ; New York: Routledge.

Amann, B., Szidat, S., & Grosjean, M. (2015). A millennial-long record of warm season precipitation and flood frequency for the North-western Alps inferred from varved lake sediments: implications for the future. *Quaternary Science Reviews*, *115*, 89–100. https://doi.org/10.1016/j.quascirev.2015.03.002

Bagheri, N., Gilmour, B., McRae, I., & Konings, P. (2015). Community cardiovascular disease risk from cross-sectional general practice clinical data: a spatial analysis. *Preventing Chronic Disease*, *12*, E26.

Beatrice, S., Floarea, D., Ileana, I., & Cecilia, A. (2014). The Prevalence of Chronic Diseases by Exposure to Nitrates from Environmental Factors. *ARS Medica Tomitana*, *20*(2). https://doi.org/10.2478/arsm-2014-0015

Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., … Havenith, G. (2012). Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). *International Journal of Biometeorology*, *56*(3), 481–494. https://doi.org/10.1007/s00484-011-0454-1

Buckland, P. C., Amorosi, T., Barlow, L. K., Dugmore, A. J., Mayewski, P. A., McGovern, T. H., … Skidmore, P. (1996). Bioarchaeological and climatological evidence for the fate of Norse farmers in medieval Greenland. *Antiquity*, *70 (1996)*, 88–96.

CAMPBELL, B. M. S. (2010). Nature as historical protagonist: environment and society in pre-industrial England. *The Economic History Review*, *63*(2), 281–314.

Chandrajith, R., Nanayakkara, S., Itai, K., Aturaliya, T. N. C., Dissanayake, C. B., Abeysekera, T., … Koizumi, A. (2011). Chronic kidney diseases of uncertain etiology (CKDue) in Sri Lanka: geographic distribution and environmental implications. *Environmental Geochemistry and Health*, *33*(3), 267–278. https://doi.org/10.1007/s10653-010-9339-1

Ciftci, S., Duzgun, S., & Erkan, B. B. B. (2014). Risk analysis based on spatial analysis of chronic obstructive pulmonary disease with respect to provinces in Turkey. *Journal of Computational and Applied Mathematics*, *259*, 413. https://doi.org/10.1016/j.cam.2013.08.023

Crowley, T. J., & Lowery, T. S. (2000). How Warm Was the Medieval Warm Period? *Ambio*, *29*(1), 51–54.

Deniz A., Toros H., & Incecik S. (2011). Spatial variations of climate indices in Turkey. *International Journal of Climatology*, *31*(3), 394–403. https://doi.org/10.1002/joc.2081

DeWitte, S. N. (2015). Setting the stage for medieval plague: Pre-black death trends in survival and mortality. *American Journal of Physical Anthropology*, *158*(3), 441–451. https://doi.org/10.1002/ajpa.22806

Diaz, H., & Trouet, V. (2014). Some Perspectives on Societal Impacts of Past Climatic Changes: Climate Changes and Their Effects in Medieval Times. *History Compass*, *12*(2), 160–177. https://doi.org/10.1111/hic3.12140

Durand, A., & Leveau, P. (2004). Farming in Mediterranean France and Rural Settlement in the Late Roman and Early Medieval Periods: the Contribution from Archaeology and Environmental Sciences in the Last Twenty Years (1980-2000). In *Making of Feudal Agricultures?* (pp. 177–253). Brill Academic Publishers.

Farmer, D. L. (1957). Some Grain Price Movements in Thirteenth-Century England. *The Economic History Review*, *10*(2), 207–220. https://doi.org/10.2307/2590858

Fraser, E. D. G. (2011). Can economic, land use and climatic stresses lead to famine, disease, warfare and death? Using Europe's calamitous 14th century as a parable for the modern age. *Ecological Economics*, *70*(7), 1269–1279. https://doi.org/10.1016/j.ecolecon.2010.02.010

Gogou, A., Triantaphyllou, M., Xoplaki, E., Izdebski, A., Parinos, C., Dimiza, M., … Lykousis, V. (2016). Climate variability and socio-environmental changes in the northern Aegean (NE Mediterranean) during the last 1500 years. *Quaternary Science Reviews*, *136*, 209–228. https://doi.org/10.1016/j.quascirev.2016.01.009

Graham, N. E., Ammann, C. M., Fleitmann, D., Cobb, K. M., & Luterbacher, J. (2011). Support for global climate reorganization during the "Medieval Climate Anomaly." *Climate Dynamics; Heidelberg*, *37*(5–6), 1217–1245. http://dx.doi.org.ezaccess.libraries.psu.edu/10.1007/s00382-010-0914-z

Graham, Nicholas E., Hughes, M. K., Ammann, C. M., Cobb, K. M., Hoerling, M. P., Kennett, D. J., … Xu, T. (2007). Tropical Pacific - mid-latitude teleconnections in medieval times. *Climatic Change; Dordrecht*, *83*(1–2), 241–285. http://dx.doi.org.ezaccess.libraries.psu.edu/10.1007/s10584-007-9239-2

Halvorsen, T., & Martinussen, P. E. (2014). The geography of chronic obstructive pulmonary disease: A population-based study of Norway. *Social Science & Medicine*, *111*, 25–34. https://doi.org/10.1016/j.socscimed.2014.03.018

Hindmarch, E., Oram, R., Ceron-Carrasco, R., & Gutierrez, A. (2012). Elsbotle; the archaeology and environmental history of a medieval rural settlement in East Lothian. *Proceedings of the Society of Antiquaries of Scotland*, *142*, 245–299.

Hipp, J. A., & Chalise, N. (2015). Spatial analysis and correlates of county-level diabetes prevalence, 2009-2010. *Preventing Chronic Disease*, *12*, E08.

Hunt, B. G. (2006). The Medieval Warm Period, the Little Ice Age and simulated climatic variability. *Climate Dynamics*, *27*(7–8), 677–694. https://doi.org/10.1007/s00382-006-0153-5

Izdebski, A., Pickett, J., Roberts, N., & Waliszewski, T. (2016). The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity. *Quaternary Science Reviews*, *136*(Supplement C), 189–208. https://doi.org/10.1016/j.quascirev.2015.07.022

Jame, J. (2010). Impact of climate change on building construction: AD 1050 to 1250. *AVISTA Forum*, *20*(1–2), 43–49.

Journal of Geophysical Research. (2018). In *Wikipedia*. Retrieved from https://en.wikipedia.org/w/index.php?title=Journal_of_Geophysical_Research&oldid=830979347

Koenigsberger, H. G. (1987). *Medieval Europe, 400-1500*. London ; New York: Longman.

Labuhn, I., Daux, V., Girardclos, O., Stievenard, M., Pierre, M., & Masson-Delmotte, V. (2016). French summer droughts since 1326 CE: A reconstruction based on tree ring cellulose d18O. *Climate of the Past*, *12*, 1101–1117. https://doi.org/10.5194/cp-12-1101-2016

Larocque, I., Grosjean, M., Heiri, O., Trachsel, M., & Kamenik, C. (2010). Thousand years of climate change reconstructed from chironomid subfossils preserved in varved lake Silvaplana, Engadine, Switzerland. *Quaternary Science Reviews*, *29*(15–16), 1940–1949. https://doi.org/doi:10.1016/j.quascirev.2010.04.018

Li J. Z., Wang Y. X., Li S. F., & Hu R. (2015). A Nonstationary Standardized Precipitation Index incorporating climate indices as covariates. *Journal of Geophysical Research: Atmospheres*, *120*(23), 12,082-12,095. https://doi.org/10.1002/2015JD023920

Mann, M. E. (2002). Medieval Climatic Optimum. In *Encyclopedia of Global Environmental Change* (Vol. 1, pp. 514–516). John Wiley & Sons, Ltd, Chichester.

McMichael, A. J., Woodward, A., & Muir, C. (2017). *Climate change and the health of nations: famines, fevers, and the fate of populations*. New York, NY, United States of America: Oxford University Press.

Morellón, M., Valero-Garcés, B., González-Sampériz, P., Vegas-Vilarrúbia, T., Rubio, E., Rieradevall, M., … Soto, J. (2011). Climate changes and human activities recorded in the sediments of Lake Estanya (NE Spain) during the Medieval Warm Period and Little Ice Age. *Journal of Paleolimnology*, *46*(3), 423–452. https://doi.org/10.1007/s10933-009-9346-3

Oviasu, O. I. (2015). Using a dual kernel density estimate as a preliminary evaluation of the spatial distribution of diagnosed chronic kidney disease (CKD) in Edo State, Nigeria. *GeoJournal*, *80*(5), 711–720. https://doi.org/10.1007/s10708-014-9590-6

Poole, A. L. (1940). Live Stock Prices in the Twelfth Century. *The English Historical Review*, *55*(218), 284–295.

Pozo, J. S. del, Gandarillas, A., Berjón, F. D., & Soto, M. ª J. (2010). Chronic liver disease and cirrhosis mortality and social deprivation: a spatial analysis in small areas of Madrid region

Mortalidad por cirrosis y otras hepatopatías crónicas y privación social: un análisis espacial por áreas pequeñas de la Comunidad de Madrid. *Nutrición Hospitalaria*, *25*(4), 597–605.

Reinemann, S. A., Porinchu, D. F., MacDonald, G. M., Mark, B. G., & DeGrand, J. Q. (2014). A 2000-yr reconstruction of air temperature in the Great Basin of the United States with specific reference to the Medieval Climatic Anomaly. *Quaternary Research*, *82*(2), 309–317. https://doi.org/10.1016/j.yqres.2014.06.002

Rosen, W. (2014). *The third horseman: climate change and the Great Famine of the 14th century*. New York: Viking.

Sadori, L., Giraudi, C., Masi, A., Magny, M., Ortu, E., Zanchetta, G., & Izdebski, A. (2016). Climate, environment and society in southern Italy during the last 2000 years. A review of the environmental, historical and archaeological evidence. *Quaternary Science Reviews*, *136*(Supplement C), 173–188. https://doi.org/10.1016/j.quascirev.2015.09.020

Sauerzapf, V., Jones, A. P., & Cross, J. (2009). Environmental factors and hospitalisation for chronic obstructive pulmonary disease in a rural county of England. *Journal of Epidemiology and Community Health (1979-)*, *63*(4), 324–328.

Seager, R., Burgman, R., Kushnir, Y., Clement, A., Cook, E., Naik, N., & Miller, J. (2008). Tropical Pacific Forcing of North American Medieval Megadroughts: Testing the Concept with an Atmosphere Model Forced by Coral-Reconstructed SSTs*. *Journal of Climate; Boston*, *21*(23), 6175–6190.

Stine, S. (2000). On the Medieval Climatic Anomaly. *Current Anthropology*, *41*(4), 627–628. https://doi.org/10.1086/317388

Stivrins, N., Brown, A., Veski, S., Ratniece, V., Heinsalu, A., Austin, J., … Ceriņa, A. (2016). Palaeoenvironmental evidence for the impact of the crusades on the local and regional environment of medieval (13th–16th century) northern Latvia, eastern Baltic. *The Holocene*, *26*(1), 61–69. https://doi.org/10.1177/0959683615596821

Surge, D., & Barrett, J. H. (2012). Marine climatic seasonality during medieval times (10th to 12th centuries) based on isotopic records in Viking Age shells from Orkney, Scotland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *350–352*, 236–246. https://doi.org/10.1016/j.palaeo.2012.07.003

Trouet, V., Esper, J., Graham, N. E., Baker, A., Scourse, J. D., & Frank, D. C. (2009). Persistent Positive North Atlantic Oscillation Mode Dominated the Medieval Climate Anomaly. *Science*, *324*(5923), 78–80.

Vulnerability indices [electronic resource]: climate change impacts and adaptation. (2001). Nairobi, Kenya: United Nations Environment Programme.

Xoplaki, E., Fleitmann, D., Luterbacher, J., Wagner, S., Haldon, J. F., Zorita, E., … Izdebski, A. (2016). The Medieval Climate Anomaly and Byzantium: A review of the evidence on climatic fluctuations, economic performance and societal change. *Quaternary Science Reviews*, *136*, 229–252. https://doi.org/10.1016/j.quascirev.2015.10.004

Yu, H. (2017). Introduction of Heat-Precipitation Index: A New Look at High-to-Late Medieval via Climate Records and Major Historical Events. Presented at the 12th Moravian Undergraduate Conference in Medieval and early Modern Studies, Bethlehem, PA.

ACADEMIC VITA

Name: Han Yu

Address: 80 Simmons Hall, University Park, PA , USA 16802

Telephone: +1 (814) 409-8101

Email: yfh5047@psu.edu

Date of Birth: 5th December 1996

Website cy20090440.wix.com/hanyu

Personal Statement

I am an undergraduate student in the Department of Geography in the Pennsylvania State University. My academic interest and focus are climatology and climate-human interaction. During my undergraduate career I was able to gain a well-rounded knowledge base in various aspects of geography. My career plan is to pursue graduate and doctoral studies and eventually establish a tenure track in a well-recognized institution and conduct research on climate geography.

Education

08/2015 – 05/2019 **B.S. Geography**

Schreyer Honors College

Pennsylvania State University

State College, Pennsylvania, U.S.A.

Geography Major with General Focus

GIS Minor and Environmental Enquiry Minor

Courses e.g.: Cartography (Static and Dynamic), GIS & Image Analysis (Advanced), Global Climates, Honors Rhetorical Courses, Medieval European History

09/2012 – 06/2015 **Graduation Certification of Ordinary High School**

Hangzhou No.2 High School of Zhejiang Province

Hangzhou, Zhejiang, China P.R.

Natural Sciences Focus

Final exams in 9 subjects e.g.: Rhetoric, Mathematics, English, Physics, Chemistry, Biology, Politics, Geography, History

Study Projects

08/2017 – 12/2017 Conference Paper *"Introduction of Heat-Precipitation Index: A New Look at High-to-Late Medieval via Climate Records and Major Historical Events*" At 12th Moravian

Undergraduate Conference in Medieval and early Modern Studies, held in Moravian College, Bethlehem, Pa., U.S.A.

Established a new index used to evaluate the suitability of medieval climate as a new approach to analyzing and understanding the complex historical events in Medieval Europe.

06 – 09/2016 Field Research "Learning Motivation Survey of Aged People"

Organized by Zhejiang University in Hangzhou, Zhejiang, China.

Participated as field surveyor and data researcher.

Work Experience

07 – 08/2017 <u>China Household Panel Survey (CHPS) in Zhejiang & Income Monitoring Survey for Disabled Households of Zhejiang Province</u>

County-Level Director

The China Household Panel Survey is a national sampling survey project hosted by Zhejiang University (ZJU). The contents of the survey covered almost every possible aspect of households, including financial conditions, demography, health & medical condition, etc.

The Income Monitoring Survey for Disabled Households of Zhejiang Province intends to comprehensively evaluate the development status of the disabled population and their households. The responsibilities of the county-level director include team logistics, coordination with local administration, on-site supervision/quality control, intra-/inter-team coordination, and routine management, etc.

Extracurricular Activities

05/2016 – present Campus Advocates at Penn State

President

Founded the club serving Penn State students which is based on the Rhetoric and Civic Life course offered to Schreyer Honors College and Paterno Fellows students. The mission of the club is to facilitate and promote the various voices of Penn State students on topics of concern and is striving to help students find their own voice and advocate for their concerns.

Voluntary Work

07/2014 Volunteer at Green Leaders Adventure

Worked on the improving and rebuilding of one primary school in rural Siem Reap, Cambodia for 60 hours. Led the team of classroom improvements and was later praised as the leader of the most effective team. Completed the repainting of both the outer and inner side of the wall of the classroom; painted specially designed teaching-assisting patterns on the classroom floor; constructed the new sitting area around the classroom.

Additional information

Scholarships/Awards

Annually 2015-2019 Schreyer Honors College Scholarship for Academic Excellence

Annually 2016-2019 College of Earth and Mineral Sciences Scholarship

IT Microsoft Office, ArcGIS (Pro, Map, and Online), CARTO, MapBox, R, JavaScript, HTML

Languages

Mandarin (native), English (fluent), Russian (basic)

Interests

Travel, reading, poetry composition, fly fishing