Selected Readings in Applied Climatology

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Edited by

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Cambridge Scholars Publishing

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This book first published 2015

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN (10): 1-4438-7562-7
ISBN (13): 978-1-4438-7562-2

TABLE OF CONTENTS

Section IV: Applied Climatology and Water/Energy Resources

Section V: Applied Climatology and Agriculture

Section VII: Communicating Climate to the Public

ACKNOWLEDGMENTS

The authors express sincere gratitude to Joseph B. Harris, Suzanne Rohli, and Eric Rohli for their generous assistance in reproducing the figures and tables as closely as possible to their original forms. We also appreciate the proofreading assistance of Kristen Rohli and Neely Martin-Whitaker, and the wisdom and support of Sam Baker and colleagues at Cambridge Scholars Publishing. Finally, we thank Jay Lee of Applied Geography Conferences, Inc. and Kent State University for the opportunity to participate in this project and for generous support during the process.

SECTION I:

APPLIED CLIMATOLOGY: AN OVERVIEW

CHAPTER ONE

WHAT IS APPLIED CLIMATOLOGY?

ROBERT V. ROHLI

1. Introduction

Climate consists of the long-term patterns of weather, across space and time. These patterns include not only the average weather conditions from place to place and from one period in history to another but also the extremes, variability in those long-term weather conditions, and the frequency with which those extremes occur at a place, or from place to place.

Climatology is the scientific study of climate. Climatology differs from meteorology in that meteorology involves the study of weather – the instantaneous condition of the atmosphere at a specific time and place. Climatology involves the generalized characterization of the weather conditions over long time periods, in and across space too. If someone says that you're acting grumpy today, then that's a different type of observation than someone saying that today you're in the grumpiest mood that you've displayed in the last six months, or that you're a grumpy person. In the same way, weather involves the observation at a given instant, while climatology involves the general characterization of weather, and an assessment of how unusual or extreme the weather is, in the bigger picture.

Most climatologists study the causes of climate. Why does San Francisco get little snow but yet feel so chilly for much of the year? What causes Kent, Ohio, to get snowfall totals that are as high as 250 centimeters in some years and as low as 60 centimeters in other years? What factors contribute to the fact that western Russia may experience several winters in a row of brutal sub-zero temperatures but then several winters in a row with much milder temperatures? Often the roots of these kinds of questions involve some type of influence by broad-scale circulation patterns in the atmosphere and/or ocean which undergo variation for reasons that are partially but not completely understood.

Applied climatology approaches the study of climate from the opposite perspective. Rather than emphasizing the *causes* of climate, applied climatology is concerned with the *effects* of climate on other economic, ecological, social, or recreational facets of society. These include, but are not limited to, agriculture, forestry, ecosystems and biomes, fisheries, architecture, energy supply and demand, human health, transportation, and economic and political activities and events. Even arts and literature are influenced by climate. For example, some art historians have noted that paintings from certain historical periods are more likely or less likely than paintings from other periods to show gloomy skies. To what extent are these differences attributable to differences in climate across the two periods versus differences in the preferred artistic motifs?

The frequency, variability, and extremes of weather events tend to exert more effects than the means, as society is designed to function under "normal" conditions. How does the frequency of severe weather events impact tourism in Florida? How often can we expect 6 centimeters of rain to fall within a 2-hour period in Baton Rouge, Louisiana, where a culvert cannot handle more than this rate of input of water? What is the probability that a citrus grove planted in Orange County, California, will experience no killing frosts for the next 15 consecutive years, so that the planter can recover his investment and yield a profit? Note that these are "how often" questions rather than "why" questions.

2. The Rise, Fall, and Rise of Applied Climatology

The formal, organized study of weather and climate has only existed for about 150 years – the work of several brilliant individuals such as Benjamin Franklin notwithstanding. The formation of the United States Weather Bureau in 1870 represented the first organized attempt at the federal level to measure, collect, store, and disseminate weather and climate information, to predict weather, and to sponsor weather and climate research, in any country in history. Although the U.S. Weather Bureau was moved to different cabinet departments a few times in its history, its mission remained the same: To protect life and property.

Applied climatology has played a major part in protecting life and property, because of its emphasis on links between climate and human health, livestock, and agriculture. However, in the early days of weather and climate research, in both the United States and abroad, much more emphasis was placed on understanding the causes of weather, rather than the effects of climate. Climate was relegated to secondary importance to such an extent that even by the dawn of the 20th century, few atmospheric scientists even considered long-range weather patterns or understood that climates change over time. The few that did recognize climate change at the turn of the century, such as Robert Ward, were marginalized in the discipline. Instead, climatologists were seen as little more than the record-keepers, with the most important work being done by meteorologists.

By contrast, developments in telecommunications, such as the telegraph in 1857 and the telephone in 1876, attracted the cutting-edge scientific minds of the day toward improved understanding of the simultaneous weather conditions over large distances, and the tracking of those systems as they moved across space. One example of the results of such developments in meteorology included Isaac Cline's prediction of the landfall of the great Galveston hurricane of 1900, despite his earlier disbelief that such a hurricane could ever happen in Galveston. Another example was the set of breakthroughs in the 1910s and 1920s, mostly by the Bergen School of Meteorology in Norway, in understanding how mid-latitude storms and their associated cold fronts and warm fronts form, grow, and die. These fronts, which separated large masses of air of different properties, reminded Wilhelm Bjerknes and his colleagues at the Bergen School of the trenches which separated large masses of troops, so they borrowed the term "front" from their recent horrific experience in World War I. Still though, the balance of knowledge remained far tilted in favor of understanding the causes of weather rather than the effects of weather and climate.

The need for understanding the causes of weather became even more urgent during World War II. For the first time, the world had seen combat that had occurred on land, sea, and sky, at the global scale, simultaneously. Never before had there been such a need to understand weather thousands of miles away from home. Whichever side could develop the better understanding of the principles governing atmospheric and oceanic circulation patterns, invent better instruments to detect and communicate those atmospheric and oceanic conditions, and apply those principles to forecasts of weather, would have a huge advantage. These demands further reinforced the importance of the causes of weather, rather than the effects of weather and (especially) climate. The polar front jet stream was discovered as airplanes flying toward the Pacific theater from the United States observed strong headwinds and ran short of fuel, but planes returning home from the Pacific experienced consistent tailwinds and fuel savings. Meteorology knowledge and a skillful weather forecast played a major and perhaps decisive role in the D-Day invasion. The lack of such knowledge perhaps saved the U.S.S.R., as Hitler opted to invade on the erroneous assumption that three consecutive harsh Russian winters would be very unlikely.

The immediate post-war period saw continued emphasis on the causes of weather. The war effort had created tools such as radar and sonar that, although designed for military uses, also had civilian applications in understanding the causes of atmospheric and oceanic circulations. As the Cold War and Space Race ensued, the emphasis on pure rather than applied science persisted. One positive impact of these efforts was continued advancement on the nature of the Earth-ocean-atmosphere system and principles that are still used today in geoscience. Advances in magnetometry, for example, revealed from clues in the iron-rich mineral magnetite on the ocean floor that the Earth's polarity shifted many times in the past. These shifts were then dated chronologically and used to estimate not only the age of the Earth but also the rate at which its tectonic plates were moving. It gave support for a previously-rejected hypothesis that the continents "drift" slowly over time. Post-war technology in meteorology provided new insights into the causes of weather. In 1948 the first regular, systematic, synchronous launching of weather balloons began. The Americans and the Soviets even collaborated to sponsor the "International Geophysical Year" of 1957, to not only showcase but also share their recently gained knowledge. Subsequently, the first meteorological satellite, TIROS, was launched in 1960. But through all of these innovations in understanding the causes of weather and celebrations of their newfound knowledge, scientists had mostly overlooked the impacts of weather, and especially climate.

By the 1960s, the paradigm had begun to shift. The publication of *Silent Spring* by Rachel Carson in 1962 had shifted the public mindset into realizing that impacts of our development and technology could not be ignored. The book increased public awareness of the effects of the pesticide DDT on birds, with an inferred influence on society. Although the book was immensely successful at generating awareness of the environmental impacts from DDT and spurred a ban on its agricultural use in many countries around the world, the impacts of the ban itself were not understood, even by Carson. For instance, millions died from malaria because of a reduction in the use of DDT. Other pesticides were substituted for DDT, which themselves had harmful or potentially harmful impacts. It was only decades later that the cascade of impacts of our activities began to be understood more fully (Mandavilli, 2006). Once again, a more acute awareness of, and foresight regarding, the potential impacts of pure science could have averted the consequences of science developed with the best of intentions.

The modern environmental movement continued throughout the 1960s, culminating in the passage of the Clean Air Act of 1970 in the United States. For the first time in human history, a federal government placed limits on acceptable thresholds of concentrations of pollutants in the air and water and enforced those limits. The thresholds were set to correspond to the concentrations of each pollutant that began seriously impacting life and property. So applied science was beginning to take hold. Rather than asking, "What is the cause of the pollutant?" scientists were asking, "What is the effect of the pollutant?"

And applied science was taking hold elsewhere as well. While the lunar landing in 1969 proved that we can land on the Moon, we don't continue to settle the Moon today because we don't reason that the benefit exceeds the cost. In other words, we don't believe that the effects of settling the Moon make it a worthwhile endeavor.

At about the same time that applied science was gaining traction among scientific thought, the study of climatology was beginning to gain increased respect as a viable and important field within the atmospheric sciences. Several factors explain this paradigm shift. First, the exponential increase in computational power and increasingly sophisticated numerical models had begun to allow for the simulations of not only weather systems for daily forecasts but also climatic patterns that might have occurred in the Earth's distant past or future. Second, the archived data from weather balloons, satellites, buoys, and other sources had become extensive enough to reveal long-term patterns of observed climate. The arrival of geostationary weather-observing satellites in the 1970s provides one example of the wealth of continuous environmental observations which were available over much of the Western world, and later, the planet. Third, the development of multivariate statistical techniques, mostly borrowed from other fields such as psychology and made possible by computer-based analyses, helped to identify underlying patterns in these datasets that may not have been otherwise apparent. And finally, concerns in the 1970s about the possibility of global cooling and, later, of global warming, attracted increasing scientific attention and raised the public consciousness of the importance of understanding climates and the causes and effects of climatic changes. Consequently, climatologists were elevated as equals within the field of atmospheric sciences and meteorologists were no longer considered the favored or superior scientists.

The labor pool was able to satisfy the demand for analyzing the impacts of climate on other facets of society, in addition to the causes of weather. World War II had created an overabundance of trained weather forecasters and analysts; many had failed to find use for those skills as civilian meteorologists after the war. Veterans and others were eager to apply their skills in private consulting companies which opened in response to the need for monitoring long-term weather patterns and their impacts, largely as a result of the regulations imposed by the Clean Air Act and its amendments and the opportunities afforded by additional weather observations and increased computing power.

According to Dixon (2013), this modern, enlightened perspective on the importance of applied science, the attention to impacts of phenomena, and the rise of climatology may have found its roots in Gove Hambridge's edited volume, *Climate and Man: The 1941 Yearbook of Agriculture*. But the modern movement in climatology only began to develop in earnest since the 1970s. One feature of applied scientific inquiry is consideration that systems are interconnected. "Systems science" emerged over this time as an interdisciplinary field of study that examines problems from a variety of disciplinary perspectives at a range of scales simultaneously. In the Earth and environmental sciences, including climatology, systems science has taken the form of "Earth systems science," which emphasizes the interconnections between processes occurring as parts of larger cycles, above Earth's surface (the atmosphere), in its water bodies (the hydrosphere), within the highest 100 or so kilometers of its land surface (the lithosphere), and within the living creatures above, on, and below the surface (the biosphere). Earth systems science and climatology also emphasizes the interactions between the four "spheres" and between the spheres and human systems. Those interconnections and interactions often include feedbacks – responses to a perturbation that may either amplify (positive feedback) or dampen (negative feedback) the initial perturbation. For example, long-term global warming could warm a small part of the polar ice-covered area, causing ice and snow to melt (initial perturbation). But the melted snow and ice may expose dark-colored surfaces, which would absorb further radiation, increasing the temperature further, and enhancing the probability of more ice and snow melting, which would further expose dark-colored surfaces, *etc.* This example is a positive feedback, as the initial perturbation is enhanced by the response to that perturbation. As another example, one impact of increasing surface temperatures (the initial perturbation) on a warm summer day is the rising of warm air from the surface to form a cloud which may precipitate. But the fallen precipitation will cool the surface, dampening the initial perturbation (negative feedback).

Another feature of applied Earth and environmental science, including climatology, is the increased recognition that many of the impacts are not predicted, and perhaps even not predictable. The nature of feedbacks, and even feedbacks on feedbacks, is inherently complicated. Furthermore, when natural systems interface with human systems, additional uncertainty is involved, because human behavior is inherently illogical, inconsistent across individuals, and even inconsistent in the same individual over time. Because of the realization that impacts may play out in unforeseen and sometimes seemingly unforeseeable ways, the perspectives of applied climatologists have become more important than ever.

The Technology and Information Revolution has provided unprecedented availability of environmental monitoring equipment and the collection of data from such equipment. For example, the (U.S.) National Weather Service's Automated Surface Observation System (ASOS) collects an array of atmospheric data on a near-real-time basis at hundreds of so-called "first-order" weather stations around the country. Radar-derived estimates of precipitation are now collected and used by hydrologic modelers to provide timely estimates of flood potential. The Oklahoma Mesonet, a collaborative endeavor by universities across the state, collects and archives a suite of atmospheric data from a dense network of 138 surface sites. Applied climatologists have played an important role in these and similar efforts. Paradoxically, such work has taken applied climatologists back to their roots as "record keepers," but this time the loop has been closed, with the applied climatologists themselves formulating research hypotheses and analyzing and interpreting the data that they have helped to collect, and therefore contributing directly to the advancement of science.

3. Role of the Applied Geography Conference in Modern Applied Climatology

The Applied Geography Conference was founded in 1977, in response to the need for geographers to participate in the "applied science revolution." Geography's traditional emphases on spatial and holistic features of the natural and human environment, the interconnectedness of the "spheres," and the intricate and complicated nature of human-nature relationships made the Applied Geography Conferences a welcoming home for applied climatologists. At every Applied Geography Conference since its founding, applied climatologists have participated and presented new ideas and perspectives. In many cases, applied climatologists have fertilized geography by sharing ideas borrowed from or expanded upon meteorological theory. They have also brought inherently geographical ideas, perhaps gained from Applied Geography Conferences, to the meteorology community. They have participated actively in what climatologist Stanley Changnon (2005) referred to as "the foundation upon which the world's weather-sensitive activities and infrastructure have been developed."

The purpose of this book is to trace the development of applied climatology seen through the lens of the Applied Geography Conferences. While it is recognized that applied climatology developed well beyond the radar of the Applied Geography Conferences, the use of the Applied Geography Conferences as the common denominator for characterizing applied climatology's development is appropriate, for two reasons: 1) the conference's history overlaps elegantly with the "golden age" (Changnon, 2005) of applied climatology; and 2) it is unlikely that major breakthroughs have escaped discussion at this conference.

The rest of this book is organized topically, with an essay introducing each of the book's sections that traces the role of applied climatology and connects the ideas within a specific topic area. Manuscripts from the Proceedings of the Applied Geography Conferences are included as examples of the work of applied geographers throughout this "golden age." Graphics have been updated to conform to contemporary standards, obvious typographical errors have been corrected, and other grammatical and organizational constructions were standardized across the manuscripts, but otherwise the works have been unedited from their original format; the editors preserved the denotations and connotations of original authors.

Facts and opinions presented by the original authors are not necessarily endorsed by the editors.

Section II features several papers that represent the prevailing thought at the time regarding how broad-scale circulation drives climate and climate variability. Though some of these papers are recent, it was the recognition of the importance of broad-scale circulation patterns that provided the early link from the causes of weather to the effects of climate. The impact of climate on the biosphere, water and energy resources, agriculture, and human systems is the topic of Sections III through VI, respectively. Finally, Section VII contains essays that present applied climatologists' viewpoints of how climatic variability and change are communicated to and perceived by the public which in turn drives the course of their research.

References

Changnon, S.A. 2005. Applied climatology – The golden age has begun. *Bulletin of the American Meteorological Society* 86, 915–919.

Dixon, R.W. 2013. Gove Hambidge (ed.), Climate and Man: The 1941 Yearbook of Agriculture. Washington, DC: United States Government Printing Office. *Progress in Physical Geography* 37, 562–566.

Mandavilli, A. 2006. Health agency backs use of DDT against malaria. *Nature* 443(7109), 250–251.

SECTION II:

APPLIED CLIMATOLOGY AND ATMOSPHERIC CIRCULATION VARIABILITY

CHAPTER TWO

OVERVIEW OF APPLIED CLIMATOLOGY AND ATMOSPHERIC CIRCULATION VARIABILITY

T. ANDREW JOYNER

1. General Circulation of the Atmosphere

The globally-interconnected atmospheric circulation system is one of the most important features of weather and climate. Not only does it move air around the planet, but it also moves whatever matter is in the air, such as water vapor, ice crystals, liquid water droplets, soot particles, pollutants, and salt crystals that become suspended every time a wave breaks on a shoreline. When this so-called "general circulation" causes air to move over surfaces that have more moisture than the surfaces over which they sat, the air can evaporate water from the new surface. This water can later be condensed into clouds and form precipitation. The general circulation can also push air over surfaces where water is less abundant. In such cases, water already condensed elsewhere can fall on the drier surface. Similarly, the general circulation can bring warmer, colder, more polluted, or less polluted air into an area. It also steers the weather systems that bring the day-to-day changes in weather, which collectively comprise climate. Although locally-generated circulations can also be important, the general circulation can reduce or eliminate local-scale effects in the same way that a river's current can overwhelm smaller circulations within a local part of the river.

The amazingly powerful, omnipresent, and complicated natural wonder known as the general circulation of the atmosphere ultimately results from two simple, fundamental laws of nature. The first law of thermodynamics says that energy can never magically appear or disappear. Instead it can only be transformed from one form to another. Virtually all of the energy that drives the general circulation of the atmosphere comes from the Sun and is transformed into energy of motion, or kinetic energy, which moves the atmosphere. Thus, the first law of thermodynamics implies that the more energy Earth gets from the Sun, the more energetic the system of circulation will be. On bodies that do not have matter in the form of an atmosphere, such as the Moon, the energy received from the Sun must be transformed in other ways.

One form of the second law of thermodynamics says that the energy in a system must be redistributed from places where it is more abundant to places where it is less abundant in the system. In the Earth-ocean-atmosphere system, the tropical parts of the system receive the most direct impact of energy from the Sun because of their position relative to the Sun's incoming rays. So the general circulation moves this surplus of energy toward the polar parts of the system, where less energy is received, in fulfillment of the second law of thermodynamics.

It is upon these two premises that the general circulation of the atmosphere is based, but because of the Earth's size, rotation, and distribution of land and water features, the redistribution of energy from the equatorial areas to the polar areas is more complicated. Warmed air near the surface of the equatorial areas rises, because warmer air is less dense than the surrounding air. As it rises, it cools, and its water vapor can condense. So the equatorial areas are characterized by a more-or-less continuous belt of low surface atmospheric pressure (called the equatorial trough, or intertropical convergence zone) caused by the release of pressure at the surface by the rising air, extensive and persistent cloud cover, and abundant rainfall. The air aloft then proceeds laterally poleward, both in the Northern and Southern Hemispheres. But by the time the air is about one-third of the way toward the poles in each hemisphere, it sinks back down toward the surface. This sinking air creates a semi-permanent belt of enclosed high-pressure systems (anticyclones), cloud suppression, and generally dry conditions about one-third of the way toward the poles (around 30°N and 30°S latitude) in many places around the Earth.

At the same time, the frigid air over the polar areas sinks, because cold air is so dense. This sinking creates a permanent surface anticyclone near the polar surface. The second law of thermodynamics implies that air must move from areas of higher pressure to areas of lower pressure. So the air with high pressure around 30° of latitude moves toward lower pressure on its equatorward side and its polar side, while polar high-pressure air must also move toward lower pressure (*i.e.*, away from the pole). So, air moving poleward from 30° of latitude meets air moving equatorward from the pole (in each hemisphere) near 60°N and 60°S latitude. This converging air is forced to rise, in each hemisphere, which creates a series of enclosed areas of low pressure (cyclones) near 60°N and 60°S latitude and the attendant cooling, condensation of water vapor, cloud cover, and abundant precipitation. So, many, but not all, areas near 60°N and 60°S latitude around the world are characterized by cloudy, damp conditions.

The rotation of the Earth causes the wind patterns created by the high-to-low-pressure circulations to be apparently deflected from their true directions. In the belt between the equator and 30°N, the near-surface wind is bent so that it usually comes from the northeast. Between the equator and 30°S, the near-surface wind is bent so that it usually comes from the southeast. In the belt between 30°N and 60°N and between 30°S and 60°S, the surface winds near the surface usually come from the west. Most of us who live in these mid-latitudes have noticed that storm systems and cold fronts are steered by these west-to-east currents of air. And in the belt between 60°N and the north pole, and between 60°S and the south pole, the surface winds near the surface usually come from the east. Aloft, the deflection due to the rotation of the Earth generally causes west-to-east flow across most of the Earth, in both hemispheres.

As with other features of weather and climate, the general circulation of the atmosphere undergoes variability on various time scales. For example, during some winters the upper-level general west-to-east flow aloft takes many small dips equatorward (troughs) and poleward (ridges) on its general west-to-east flow. During other winters, there are few but intense troughs and/or ridges. During still other winters there are few troughs and ridges and those that exist are weak. The variability in this feature and other features of the general circulation may occur on a wide range of time scales as well.

Atmospheric scientists usually consider the hemispheric-scale flow pattern of the middle-to-upper troposphere as a single, continuous, organized system that circumnavigates the pole, largely from west-to-east in each hemisphere, bounded on the equatorward side by the polar front jet stream, which exists near the leading edge of the polar air masses. The sharp contrast of air mass properties at this leading edge leads to sharp differences in pressure, which triggers the particularly rapid wind flow characteristic of the polar front jet stream. The entire continuous system, known as the circumpolar vortex, typically expands in winter, as the cold pool poleward of the polar front jet stream expands, and contracts in summer, as the warmer air masses advance poleward.

2. Links between Atmospheric Circulation and Oceanic Circulation

The general circulation of the atmosphere is also interconnected to a general circulation of the ocean. Changes in the strength and/or position of the atmospheric circulation or some sub-components of it are inherently tied to variations in the strength and/or position of the surface ocean circulation adjacent to the atmosphere. These changes in surface ocean circulation then cascade downward to affect deeper circulation patterns in the ocean. Therefore, it is no surprise that a firm foundation in understanding atmospheric circulation is necessary for understanding the impacts to the ocean associated with applied climatology. Often, the link between the circulation and the applied impact is through synoptic meteorological or synoptic climatological research.

An important and well-known link between atmospheric and oceanic properties involves the periodic oscillation of sea surface temperatures in the tropical equatorial Pacific Ocean. At the end of each year, waters tend to warm in the tropical Pacific, and even extend to the normally-cool-ocean-current-influenced eastern tropical Pacific near Peru. This natural, seasonal warming is anomalously intense for a period of several months approximately every three to seven years, in what is known as an El Niño event. El Niño events have tremendous environmental and ecological repercussions, largely because the oceanic upwelling of cold water near the Peruvian coast weakens and fails to move nutrients back upward where they can contribute to rich food webs. In other years, the normal, seasonal oceanic warming in the tropical equatorial Pacific leaves the eastern Pacific unaffected, producing anomalously cold sea surface temperatures and even more intense upwelling than normal near the Peruvian coast for a period of several months in a La Niña event.

El Niño and La Niña events are also linked to anomalies in the atmospheric general circulation, particularly in the tropics, where the alteration between circulation patterns associated with El Niño and La Niña is known as the Southern Oscillation. However, the atmospheric circulation anomalies linked to the Southern Oscillation ripple beyond the tropics.

The combined, interdependent oscillation of oceanic and atmospheric circulation anomalies associated with these features is known as El Niño – Southern Oscillation (ENSO). Because ENSO-related variability impacts weather patterns and weather-dependent endeavors, it has traditionally been an area of focus by geographers and particularly by applied climatologists. These impacts are on the atmosphere's so-called synoptic circulation.

3. Synoptic Meteorology and Synoptic Climatology

The analysis of weather features such as cyclones, anticyclones, fronts, and jet streams, necessarily takes on broad scales, because these features are relatively large. The word "synoptic" comes from "syn" which means "same," as in a synonym, and "optic," which means "to see." So "synoptic" refers to "seeing at the same time," or a snapshot of the broad-scale – the "synoptic scale" – condition of the atmosphere – its fronts, pressure patterns, jet streams, and similar features – at an instant in time. A typical weather map as shown on your favorite news program would be an example of a synoptic weather map.

Synoptic meteorologists study these types of weather features, how they form and interact with other features, and how they produce impacts to life and property. At first glance, "synoptic climatology" would seem to refer to the long-term pattern and variability associated with features like the jet streams, the semi-permanent cyclones and anticyclones, migrating warm fronts and cold fronts, and their impacts to life and property. In the beginning, that was the domain of synoptic climatology.

But over time, the synoptic meteorologists have increasingly left the "impacts" sides of the research to the synoptic climatologists and have concentrated instead more on the interplay between atmospheric dynamics and the synoptic conditions of the atmosphere. At the same time, synoptic climatologists seized the opportunity to increasingly emphasize the impacts and in the process tightened their links to geography with its traditional emphasis on human-environment interactions. As a result, in recent decades, synoptic climatology has come to refer to the relationship between the broad-scale atmospheric circulation features and the surface environment. Here, "surface environment" is defined broadly to include not only environmental quality *per se* but also other features of the surface environment, such as the biosphere, water and energy availability, agriculture – the subjects of other sections of this book, and more.

Early announcements of this "new synoptic climatology" had been made since the 1970s. Werner Terjung's (1976) call for geographical-climatological research of the highest form – physical-human-process-response systems, that recognizes the cascade of linkages between and within systems, is an early example. Later, climatologist Brent Yarnal called for climate research as an integrated, interactive system (Yarnal *et al.*, 1987), and Andrew Carleton (1999) saw the onset of synoptic applications to weather prediction. The latter suggested that all geographical climatology has at least an implicitly applied component. The fact that all three of these papers were published by flagship journals in American geography testifies to the importance of these viewpoints within the community of geographers.

Two subsequent papers published in *Progress in Physical Geography* tend to stand out in terms of their emphasis on the synoptic approach. Sturman (2000) saw the importance of air pollution studies as an obvious topic emanating from the synoptic approach *per se* and through its linkage to mesoscale circulations. Sheridan and Lee (2012) emphasized the importance of a synoptic climatological approach in understanding spatial and temporal variability in the semi-permanent pressure patterns that drive circulation – the study of atmospheric teleconnections.

However, the seminal work on the "new synoptic climatology" was Yarnal's (1993) *Synoptic Climatology in Environmental Analysis: A Primer*. This volume clarified the role of synoptic climatology as an applied subdiscipline and identified three major types of synoptic climatological analysis (synoptic typing, map pattern classification, and regionalization). Perhaps more importantly, Yarnal (1993) also provided worked examples of quantitative methods that should be part of any synoptic climatologist's toolkit. These include a comprehensive review of the capabilities and limitations of manual classification methods, correlation-based analyses, eigenvector-based techniques, compositing, indexing, and specification.

Yarnal (1993) emphasized the contrast in method between what he called "circulation-to-environment" vs. "environment-to-circulation." In the former, the categorization of climate is done first, with all temporal entities in the analysis (*i.e.*, days, months, *etc.*) included in the classification, and subsequently, an analysis of the percentage of those days that meet the environmental criterion of the research study is determined. By contrast, the "environment-to-circulation" approach

(Yarnal, 1993) involves the pre-selection of only those temporal entities (*i.e.*, days, months, *etc.*) that meet the environmental threshold of the study in the categorization of atmospheric circulation. For example, Rohli *et al.* (2004) use elements of both approaches in categorizing atmospheric circulation associated with excessive tropospheric ozone in Louisiana.

Carrying out the blueprint for this "new synoptic climatology" has played to the advantage of its practitioners in the last decade. "Integrated environmental assessments," particularly those that forecast impacts of changes in climate involving large research groups, have increasingly been funded and published. New research centers such as the Department of the Interior's Climate Science Centers and the National Oceanic and Atmospheric Administration's Regional Integrated Science Assessments (RISA) increasingly favor the broad, holistic perspective of the new synoptic climatology.

4. Synoptic Climatology and the Applied Geography Conferences

Applied climatologists at the Applied Geography Conferences have contributed in important ways to our understanding of the general circulation of the atmosphere through synoptic climatological approaches. The seven papers comprising the remaining chapters in Section II, organized chronologically, provide early to recent representative examples of the new synoptic climatology. Gregory Bierly and Randall Repic (1994) used an environment-to-circulation approach to trace the evolution of the cold pools that are part of the digging troughs in the circumpolar vortex and their role in generating extreme low temperatures that impact corn in Michigan. Kent McGregor's (1996) paper on ENSO and its impacts follows, and it is followed by McGregor's update since 1996. Its rich literature review makes it an excellent example of the early modern knowledge of ENSO and its impacts on water availability, and it also nicely contrasts what was known in 1996 with what is known today. A paper by Anthony Vega, C.H. Sui, and K.M. Lau (1997) then is included to tie together the circulation variability associated with ENSO using a synoptic climatological approach. Two environment-to-circulation-based papers by Mark Hildebrandt (2000, 2001) focusing on mesoscale circulation and their impacts on temperature and tropospheric ozone follow, in the spirit of Terjung's (1976) emphasis on the "cascade of linkages" and the recognition that pollutant transport is obviously dependent on atmospheric circulation and its variability. The foci of this research are two metropolitan areas that are well-studied for their localized warm signal known as the urban heat island: Phoenix (*e.g.*, Brazel *et al.*, 2007) and St. Louis (Arnfield, 2003). The section concludes with a contemporary example of the use of the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis (NNR) dataset, by Jennifer Collins, David Roache, and Edgar Kopp (2012). The use of the model-based NNR dataset provides an excellent example of an important source of contemporary data used in studying atmospheric circulation variability.

References

Arnfield, A.J. 2003. Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *International Journal of Climatology* 23, 1–26.

Brazel, A., Gober, P., Lee, S-.J., Grossman-Clarke, S., Zehnder, J., Hedquist, B., and Comparri, E. 2007. Determinants of changes in the regional urban heat island in metropolitan Phoenix (Arizona, USA) between 1990 and 2004. *Climate Research* 33, 171–182.

Carleton, A.M. 1999. Methodology in climatology. *Annals of the Association of American Geographers* 89, 713–735.

Rohli, R.V., Russo, M.M., Vega, A.J., and Cole, J.B. 2004. Tropospheric ozone in Louisiana and synoptic circulation. *Journal of Applied Meteorology* 43, 1438–1451.

Sheridan, S. and Lee, C.C. 2012. Synoptic climatology and the analysis of atmospheric teleconnections. *Progress in Physical Geography* 36, 548–557.

Sturman, A.P. 2000. Applied climatology. *Progress in Physical Geography* 24, 129–139.

Terjung, W.H. 1976. Climatology for geographers. *Annals of the Association of American Geographers* 66, 199–220.

Yarnal, B. 1993. *Synoptic Climatology in Environmental Analysis.* London, UK: Belhaven Press.

Yarnal, B., Crane, R.G., Carleton, A.M., and Kalkstein, L.S. 1987. A new challenge for climate studies in geography. *Professional Geographer* 39, 465–473.

CHAPTER THREE

LOW TEMPERATURE EVENTS IN CENTRAL MICHIGAN: THE SEASONAL ROLE OF MIGRATORY HUDSON BAY COLD POOLS

GREGORY BIERLY AND RANDALL REPIC

(1994)

1. Introduction

The susceptibility of crops to injuries from low temperature exposure poses risks in midlatitude agriculture during the early growing season (Levitt, 1941). The various agricultural species respond quite differently to reduced temperatures, and there are numerous factors including soil moisture, suddenness and duration of freeze, extremity of temperature drop, and rapidity of subsequent thawing which control the level of injury sustained. Prior exposure to cold temperature, as well as the level of maturity, also govern the plants' ability to resist injury (Levitt, 1980; Steward and Bidwell, 1991).

South-central Michigan is an area vulnerable to early spring freeze events which may prove harmful to newly planted crops. For many plant species, however, freezing temperatures are not required to induce chilling injury or retard growth. Corn (*Zea mays L.*), the major crop in Michigan in terms of acreage sown and economic value, is tolerant of only a small range of temperatures. Temperatures below 47°F can prevent growth and cause chilling stress, and may temporarily inhibit the potential yield of the plant (Keeling and Greaves, 1990). Wallace and Bressman (1923) found that growth stopped entirely below 40°F and that germination and rate of growth were both affected by temperatures below 50°F. Although plant injury during seedling emergence has been a primary concern of previous