THE EVOLUTION OF METEOROLOGY
A LOOK INTO THE PAST, PRESENT, AND FUTURE OF WEATHER FORECASTING

Kevin Anthony Teague and Nicole Gallicchio

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The Evolution of Meteorology
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A Look into the Past, Present, and Future of Weather Forecasting

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About the Authors

Two authors are responsible for the research and writing of this text: Mr. Kevin Anthony Teague, and Ms. Nicole Gallicchio. Both authors are BS Atmospheric Science degree holders, from the State University of New York, Stony Brook University.

Mr. Teague graduated from Stony Brook University in 2011. Along with his degree in Atmospheric Sciences, he also holds a BA in Psychology, attained from St. Joseph’s College, New York. Together with these two degrees, Mr. Teague has used his unique and well-rounded educational background to research, analyze, and interpret meteorological processes in a very different way. The ability of Mr. Teague to then convey his knowledge in a professional yet extremely understandable manner has been what sets him apart.

Ms. Nicole Gallicchio graduated from Stony Brook University in 2012. Ms. Gallicchio has a strong education in programming, higher mathematics, as well as a degree in Atmospheric Sciences. She takes great pride in thoroughly understanding the math and science behind weather phenomena. Ms. Gallicchio has the ability to present her knowledge and expertise in a concise and quantitative way.

Together, Ms. Gallicchio and Mr. Teague founded Forecasting Consultants LLC. Forecasting Consultants LLC is a private weather forecasting and forensic company, geared toward a multitude of industries and users. Through their business, it has allowed the authors to grow and expand their knowledge base in all aspects of atmospheric science.
Meteorology, the study of weather, is a science that has been around since antiquity. Meteorology is a science that encompasses weather forecasting, climatology, atmospheric chemistry and physics, and oceanic interactions. These sciences are still being explored in great depth even though they have been studied for thousands of years. Advancements in the sciences have rapidly expanded in more recent years and are projected to continue to grow exponentially. Considering all the variables and unknowns in the atmosphere, meteorologists have become extremely accurate, with forecasts extending further out in time than ever thought possible. These forecasts are conveyed across the world and are reliable sources for many outlets. Throughout the world many different industries use weather forecasting for numerous tools and economic advances. The capabilities and possibilities that meteorology assists with far surpass many expectations, with updates to weather models, satellites, radars, and more constantly being sought after and put into use. This expansion is a relatively recent boom. Prior to computers and satellite technologies, weather forecasting was more guesswork than anything. Right up until the mid-twentieth century, meteorology was imprecise, often displayed in comedic ways on television and radio. Today’s meteorology is nothing like 100 years ago, and that meteorology was nothing like 1000 years ago, and so on. Meteorology has gone from what was considered common knowledge that the moon and stars were signals of weather to come, and that weather was the forces of the gods, to what it is today, where weather is a quantifiable science, predicted and forecast days to months in advance with the help of computers that operate faster than the human brain. As knowledge grew and the field of meteorology was embraced, and as technological capabilities and worldwide cooperation increased, weather forecasting evolved to a daily “need” in the lives of all humankind.

This book was written to show the evolution of the field of meteorology, from its infancy in 3000 BC, through the birth of new ideas and the actual naming of the field as a science, and the technology boom, to today. This was not the original plan for this book. Originally, the authors were asked to write about extreme weather, and the scientific ideas and technology surrounding it. This subject matter cannot be fully understood without understanding of where the science was and where it is today. Upon researching the history of meteorology, it became very clear that there are very few concise single texts that show an outline of the history of the field of meteorology. The lack of resources out there led to the expanding of this text in order to include a full story of where meteorology was then to where it is now, and then not stopping there, but going into where the field is heading and what needs to be done to get the field to levels never before imagined. This book ends up being a comprehensive view of the history, but also a comprehensive view of forecasting technologies, organizations, governmental agencies, and world cooperative projects and legislation, along with a section
dedicated to climate change theories and understanding, as well as extreme weather statistics and histories.

There are growing technologies in forecasting and public alerting when it comes to extreme weather. This is partially due to the increase in public knowledge of the devastation and possible threats that extreme weather poses. The cooperation between nations and companies in order to expand the reach and effectiveness of forecasts and planning when it comes to extreme weather is growing. There is a significant need to better prepare and combat weather’s potential fury and devastation. It cannot be more evident that extreme weather is a global issue, not sparing any corner of the world from its possible wrath, coming in endlessly different ways – dust, wind, heat, cold, rain, snow, ocean depth and temperature, fires, floods, etc. No one area is protected from weather and no location is protected from the threat of extreme weather. This has always been the case, and this will always be the case. What has changed is the knowledge of extreme weather events, and the technologies, theories, inventions, and education in the field to help keep life, property, and livelihoods safe and out of harm’s way as much as possible.

This book consists of five sections, starting with the ancient history of the first attempts to understand and predict weather. The book then flows into the very early birth of television, computers, and technologies useful to meteorology. The middle portion of the text consists of modern-day technologies, up through a few years ago. At this point, the text changes from a history book to a book of research, statistics, future paths, ideas, and suggestions, with a section on climate change and extreme weather events of today and beyond. There is also a section on the overall future direction of the field of meteorology. This text paints a broad picture of many ideas, each of which could have its very own 200-page text. It is created to help continue the debates, the expansion of ideas and knowledge, and to bring awareness to the overall path of the field of meteorology and where we may end up. The most fascinating aspect of this text is that it starts with the Ancient Babylonians and ends with the largest global agreement of any kind – the Paris Agreement.

Global research and scientific knowledge are at the forefront of expanding our understanding of meteorology and the atmospheric and oceanic sciences.
Acknowledgments

Writing this textbook was a complete honor, and we want to first off thank Justin Taberham for giving us the opportunity to be part of his series. After several weather and environmental conversations with Justin, we both seemed to have a professional connection that hopefully comes across in this text and throughout his series. We were delighted when we were first asked to be contributors to his series, and then when we were asked to author our own book we were overcome with excitement. We are both so very proud of the commitment and dedication to this project that we both showed and gave to each other.

Kevin: I greatly thank my wife Ashley for helping me cope with the stresses in all aspects of life, for helping me stay focused on all that is important, and for her never-ending love and commitment to me. Along with Ashley, I want to thank my parents, siblings, extended family, and friends, all of whom have shown an interest in this project. You have all helped me continue to work when I was hitting a wall, as well as helping me take a breather and decompress when I was getting too absorbed.

Nicole: I want to thank my immediate family for the support that they have provided me throughout this journey, along with the continued support in my future endeavors. My dad’s relentless liveliness and my mother’s kind words of encouragement have led me here today.

Throughout the research and writing of this book, we have been in touch with some of the greatest minds in the field of meteorology. With many conversations with staff from the National Weather Service, the Met Office, the World Meteorology Organization, and various agencies around the world, we thank you for your guidance, research, data, and all‐round help in accomplishing our goals and tasks. We thank all the reviewers who took the time to read our proposal, give feedback and recommendations, and helped shape this book into what it is today. Your comments and feedback were of tremendous value. We want to thank Professor Brian Colle and Stony Brook University for providing us with a strong foundation. We also want to thank the various individuals who went above and beyond, helping us with permissions of use for images and research, especially, but not limited to: Christy Locke of UCAR, Susan Buchanan of the NWS, Rhys Gerholdt of the World Resources Institute, Markus Steuer and Jan Eichner of Munich‐MR, Dean Lockett and Abdoulaye Harou of the WMO, Ken Mylne – Chair of OPAG(DPFS) for the WMO, Chantal Dunkowski of ECMWF, Clarke Rupert of the Delaware River Basin Commission, and Dmitry Nicolsky of the Geophysical Institute‐University of Alaska Fairbanks. We also want to thank the very hard work of and great communication with Teresa Netzler at Wiley, as well as our original contacts at Wiley who have since moved on: Delia Sandford, Rachael Ballard, and Audrie Tan.

Through the work of our text and our business we look forward to continuing research and advancements in the realm of atmospheric science.
Section I

Building Blocks of Meteorology (3000 BC–AD 1950)
Understanding the history of meteorology and weather forecasting can only be accomplished just as any other subject: by learning the building blocks and uncovering the pioneers and the technological advancements of the field. Meteorology is the study of the atmosphere and its phenomena. What is known today about weather forecasting and meteorology is tremendously more comprehensive and complex than what was understood during ancient times, but at the same time is lacking and insufficient when looking at what is possible in the future. To first understand where we are today and where we may lead to in the coming years, we first have to look at where we came from. Although full sections or full texts could be dedicated to each of the following topics covered in this section – as well as many of the examples not even included – a solid foundation for the beginning of meteorology will be discussed, starting with one of earth’s first-known civilizations and advancing to the brink of the first meteorological inventions.

1.1 Ancient Babylonians

Some of earth’s earliest-known civilizations in ancient Mesopotamia first began record keeping and attempting to understand the skies dating back to 3000 BC. Calendars were created based on the lunar cycle, eventually leading to the development of a 360-day calendar, which was later adjusted to match the seasons based more on the solar cycle by King Hammurabi (1792–1750 BC) of Babylon. This was one of history’s first acknowledgments of seasons and weather. Advancements continued, all based on the sun, moon, and stars. By the eighth century BC the ancient Babylonians, under King Nabû-nāsir (747–734 BC), began to regularly keep records of the observations that were made of the sky. While mostly involving astronomy, these were some of the first recorded observations in history, and included time intervals of the rising and setting of the sun, eclipses, and position of the moon. To the Babylonians, much of what was observed was done by the supernatural; even so, they used these observations to begin to calculate when certain celestial events would occur in the future (Teresi, 2002, pp. 115–123).

A common technique used in their predictions was observing the halo around the moon (and sun). Certain halo conditions signified to the Babylonians that specific weather events, as well as other phenomena, would occur. One example was a report by King Nabû-šuma-škun, (mid-eighth century BC) that “a halo (in the area) of Virgo portends rain and flood in winter,” and
a second states, “if the moon is surrounded by a black halo: the month holds rain, variant: clouds will be gathered” (Verderame, 2014, p. 100). These relate astrology to meteorology, and are a common theme throughout the Ancient Babylonian civilization. It was this type of data collection and observation that led the Babylonians to create some of the earliest versions of calendars and time keeping, as well as being among the earliest to predict and anticipate weather and natural events that could impact their world.

### 1.2 Ancient Chinese

The Chinese were believed to have begun keeping minimal records based on actual weather, including temperature, dating back to 1400 BC. Around 1216 BC, rainfall was recorded, as well as type of precipitation, whether it was sleet, rain, or snow, along with wind and wind direction. While the Chinese also believed that the supernatural was responsible for the types of weather conditions that occurred, such as bad weather meaning the gods were angry, the Chinese were still able to begin to understand the hydrological cycle. During the Han dynasty, (206 BC–AD 220), the understanding of the hydrological cycle went from the idea of qi, or the energy of the earth and heavens, to the understanding that clouds were created from the rising waters due to evaporation. By the ninth century AD, the Chinese figured out a way to measure the amount of moisture in the air, by weighing charcoal as it absorbs moisture in the air. The Chinese also began to understand tides and past floods by locating water fossils on high land areas not commonly associated with water (Teresi, 2002, pp. 246–247, 257).

As the Chinese developed socially, their version of meteorology did as well. One example was the developing Chinese belief in the forces of yin and yang, which need to be in balance for the world, health, and morality to be in agreement. The yin and yang have tremendous influence, even today, especially in areas such as health and medicine. The Chinese also related the yin and yang to weather, needing perfect balance of the yin (clouds and rain – earthbound elements) with the yang (fire and heat of the sun – celestial elements). Certain weather events were believed to have occurred because one of the elements was more dominant than the others at those specific times (Hamblyn, 2001, p. 23).

The Chinese based their calendars on the moon, sun, and the weather dating back to the Qin (221–206 BC) and Han dynasties. The Chinese almanac still acknowledges this thinking, and divides the year up into 24 seasons, or festivals, each about 15 days long. These seasons mark weather events that typically took place during specific parts of the year. From “The Beginning of Spring” to “The Waking of the Insects,” “Corn Rain,” and “Great Cold,” each season marked their own effects on the Chinese agricultural lifestyle (LaFleur, 2010, pp. 425–426). These seasons, at the time, showed an accurate interpretation of the weather that occurred or was to occur, and each season can be viewed as an early style of climatology and weather forecasting.

### 1.3 Aristotle and Meteorologica

Perhaps the most influential early contributor to the beginning of meteorology is the Ancient Greek philosopher Aristotle, 384–322 BC. Aristotle is universally thought to be one of the world’s greatest thinkers. One of his most important pieces of work was his treatise *Meteorologica*. While this work includes chapters on astronomy, water, physics, and more, *Meteorologica* has very important sections on weather. He studied meteorology as part of his investigation of physics. Physics, to Aristotle, was the equivalent to what would now be called natural philosophy, or the study of nature (Hollar, 2013, p. 14).

In a sense, some of Aristotle’s views involved the supernatural, and didn’t always go into root causes of some phenomena. Instead, Aristotle
stated that there were four bodies — fire, air, earth, and water — that related to four principles — hot, cold, dry, and moist. Aristotle held fire as the highest body and earth as the lowest, and stated that they were the “material causes of the events in this world” (Webster, 1955, p. 339a). He took this supernatural viewpoint and then put his own spin on what he observed. Aristotle based a lot of his viewpoints on the sun, going as far as saying the reason the night is calmer than day is due to the absence of the sun.

Inside Meteorologica, Aristotle acknowledges the understanding of warm air rising and cooler air falling. This relates greatly to today’s understanding of warm air being less dense and rising and expanding, while cooler air is more dense, and is therefore falling and condensing. This idea of hot and cold is connected also with Aristotle’s early interpretation of a lower and upper level of the atmosphere, lower being the surface and upper where the clouds are located. He also describes precipitation as being broken down into three types: rain, snow, and hail. These precipitation types are then correlated to the upper or lower atmosphere. He explains that snow and frost are one and the same, the only difference being snow is in the upper region and is when clouds freeze, and frost is in the lower region and is when vapors freeze. He states that rain and dew are the same — the only difference being that rain occurs in the upper region and is in greater quantity than dew, which occurs in the lower region. The third, hail, Aristotle explains, is ice that forms mainly in the spring and autumn in warmer locations, and occurs only in the upper region, but very close to the surface and not high in the clouds. His reasoning for this was based on the fact that hail is often large, jagged, and non-circular. Aristotle felt that if hail were to have fallen from high up in the upper region the colliding stones would have broken themselves up into round and smaller stones and not the large angular ones that occur (Webster, 1955, pp. 346b–348b).

As for winds, Aristotle states that north winds are cold and south are warm. He states that east winds are warmer than west winds due to the origin of the sun in the east. Aristotle even goes as far as to combine the west winds with the north and east winds with the south. This shows that the basis of Aristotle’s understanding of wind heavily relies on theories revolving around hot and cold. Aristotle’s depth of wind includes theories on hurricanes as well, explaining that hurricanes are created by the converging of winds, which then begin to veer around and fall in on each other, which is his explanation for the eye of a hurricane (Webster, 1955, pp. 362b–365a).

Some of the more glaring errors in Aristotle’s work include that it snows and rains more at night than in the day, along with his usage of the words “always” and “never” to describe meteorology. Weather is not an “always” or “never” type of science, and many variables contribute to the final outcome, with each weather event different from the one before. In Meteorologica, Aristotle takes a more concrete viewpoint, seeing things as certainties and very cut and dry, albeit with often vague explanations.

Aristotle’s observations were new to the Greeks and his knowledge and breakthroughs were beyond anything of its time. Even though Aristotle’s interpretations of weather and the atmosphere were not extremely accurate compared to today’s standards, Meteorologica was the main go-to theory on weather for the next 2000 years. Aristotle’s influence sticks with us even today, as he wasn’t just the pioneer of the science of meteorology but also the word “meteorology” itself (Webster, 1955, pp. 338a–390b).

1.4 Theophrastus and the Book of Signs

Theophrastus (371–287 BC), whom Aristotle named as his successor at the Lyceum, is often credited for writing the treatise Book of Signs. Most of Theophrastus’ work is based on lore type ideas (discussed further in Section 1.7), while other work is based on no real factual backing, such as his theory that shooting stars are a sign of impending rain and wind and will
come into an area from the direction of the corner of the sky that the shooting stars were occurring (Thayer, 2012, p. 399). He touched on a type of climatology when he stated that an abundance of winter rains indicates a dry spring, and vice versa (Thayer, 2012, p. 407). Theophrastus’ interpretation regarding wind includes theories that a northerly wind will occur when the top part of a crescent moon is bent, and a southerly wind when the bottom of the crescent moon is bent (Thayer, 2012, p. 407). Also, winter will be calm in regards to wind if there is a long period of time when there are periodic winds as well as a windy autumn season leading up to the winter (Thayer, 2012, p. 415). Many other similar types of weather explanations are included in the Book of Signs and were never grasped as solidly as Aristotle’s Meteorologica, as they were based more on the lore of the time and were very hard to comprehend.

1.5 Ibn Wahshiyya and Nabataean Agriculture

These non-scientific approaches to the understanding of weather and weather forecasting continued into the tenth century AD. This was demonstrated by the work of an Iraqi named Ibn Wahshiyya. He is credited for translating the Nabataean Agriculture, which has many mysteries surrounding it, including when and where it was originally written (anywhere from about AD 100–900), who wrote it, and what its true meaning is. Even with these mysteries, the ideas of weather and weather forecasting occur throughout the text, due to their importance and influence on agricultural development. Wahshiyya translated a section that shows the significance placed on the moon. One translation includes an example that seeing the moon at night indicates clear weather ahead, and the longer you observe the moon, the longer the clear weather will persist. He explains that a halo around the moon also indicates clear weather to come. Similar examples are seen when the sun is observed as well. Wahshiyya writes about the connection between cloud coverage and weather, with examples such as low-lying clouds that dissolve away quickly being an indication of cold weather, and warm weather indicated by clouds that grow larger, fall apart into smaller clouds, and then dissolving altogether.

Also stated in the Nabataean Agriculture is the use of animals to help indicate weather, with one method being the hooting of an owl as an indicator for the ending of cold or bad weather. Other examples taken from Wahshiyya’s translation involve wind predictions, such as a west wind’s anticipation when a fourth night moon has a red-appearing crescent. North winds are also predicted by the occurrence of storms and lightning, such as when lightning is seen to the south while clear skies are observed overhead. This example also indicated that rain would come in from the south. One final example taken from this translation that shows the lack of understanding at the time is the indication of extreme cold, which Wahshiyya explains could be done when one sees sparks fly off clay pots when they are struck or scraped (Hameen-Anttila, 2006, p. 80–84). All these examples are more in line with the theories of Theophrastus, more superficial with less actual advancements to the understanding of weather, and based more strictly on observations from the past and lore-like theory.

1.6 William of Ockham and Nominalism

Nominalism regarded the universal idea or problem of universals as unreal. The problem of universals questions the existence of the properties or category of a particular phenomenon. Instead, nominalists regard only the concrete individual thing as real. This competed greatly for one of the first times against Aristotle. The work of William of Ockham (AD 1285–1347) used knowledge, understanding, and reasoning to start the beginning of a change in physics and
natural sciences, while in the past Aristotle and others based the natural sciences more on assertions (Hirschberger, 1977, 65, 92–94). Ockham focused a lot on Aristotle’s work, stating that the category of quantity is not needed and that mathematics is not real since it is a universal. His nominalist approach further states that mathematics needs to expand to substance and to qualities (“William Ockham”, 2015), which in theory would take away the vague assertions and instead make things more concrete, or real. In other words, nominalism was the beginning of taking away all of the ideas and theories of the past that were subjective, such as Aristotle’s theories in Meteorologica, and leaving only the objective, or seeing what is in front of you as exactly what it is. This frame of thinking lays the stage for the foundation behind modern science.

1.7 Religion, Folklore, and Animals

While the idea of an accurate concrete science behind weather knowledge was still lacking, theories began to emerge from the works of Aristotle, Wahshiyya, and Ockham, as stated previously. With that said, there has always been another important aspect to weather forecasting, dating all the way back to ancient history and that is with the use of religion and folklore. Babylonians had their beliefs of supernatural causes in connection with the celestial events that took place, and the Chinese believed that the angry gods produced dangerous weather. There were many other examples of greater beings controlling the weather, some into the eighth century AD and more recent, some of which are still practiced today.

Nearly 3000 years ago in the Wisconsin River area of North America, some of the earliest civilizations in that region prayed to the Green Water Spirit. One of those early civilizations was the Ho-Chunk tribe. Part of a long family line of warrior chiefs, Albert Yellow Thunder (1878–1951) explained that the Green Water Spirit was responsible for the melting of snow and ice, and the creation of lakes and streams from the melted waters. He also was responsible for creating game for hunting and the trees that surrounded the area (Kavasch, 2004, pp. 8–9).

The Vikings in the eighth century AD believed that two specific gods were responsible for the weather. One was Thor, the god of thunder. Since the Vikings were sailors, they spent many days at sea. Their Scandinavian location was prone to strong storms over the waters of the North and Baltic seas that were attributed to the wrath of Thor. Thunder was the sound of Thor in his chariot, and lightning was the flashes of the sparks of Thor’s ax killing his enemies. The second god was Freyr, the god of rain, sun, and fertile earth. Freyr was of huge importance because it was he who helped produce the Vikings plentiful crops (Reynolds et al., 2008, p. 26).

The thirteenth century AD involved the Aztecs, who believed strongly in many deities, some of which included weather aspects, especially Tlaloc, the god who controlled the weather. The Aztecs were an agricultural civilization, relying heavily on fertile soil, and proper weather conditions to keep crops rich. The location of the Aztec civilization in Mexico is in an area that experiences both drought and flooding. It was believed that Tlaloc was the one who decided which would occur. The Aztecs believed so strongly in Tlaloc that they even sacrificed children in order to keep Tlaloc happy and their lands healthy (Reynolds et al., 2008, p. 26).

More in line with the folklore aspect of beliefs, rain dancing and weather sayings were and still are used today. Rain dancing has been practiced by many cultures in order to bring on the rains during times of need. Cultures across the world still practice rain dancing (Reynolds et al., 2008, p. 27). Just as the rain dancing continues to this day, wise weather sayings are still often heard spoken in everyday society. Some of these include: “red skies at night, sailor’s delight” and “red skies in the morning, sailor’s warning.” These sayings have some basis in truth, even though they are not always right. They are based on the idea that when there is a red sky at night dry conditions are moving in, often as a high
pressure system, as the sun’s rays shine through dry particulate matter, thus causing the red coloring. Since weather typically moves from west to east, the idea of red skies at night in the sunsetting western sky means dry weather is moving in from the west. A red sky in the morning means the opposite: bad weather will be replacing the calm dry weather or that the high-pressure system creating the dry weather allowing the morning sun in the east to shine and become red in coloring will continue to move eastward and away. Some weather lore, based on patterns such as the example above, were first used as forecasting methods as far back as 300 BC, and while these do have some valid meanings behind them, they are of course not always accurate, but amazingly they are still leaned upon in today’s society.

Besides folklore and religion, animal behavior is known to be a signal of natural phenomena to come, including weather. Using animal behavior to forewarn about impending weather is an ancient practise dating back to the Ancient Chinese, and later the Greeks in the Book of Signs by Theophrastus, and in the Nabataean Agriculture by Ibn Wahshiyya, as well as still being relied upon today by many. Be it observing dragonfly behavior, the sounds of frogs, the singing and flying patterns of birds, even anthill development and livestock behavior, many cultures and civilizations tied weather events to these observations and used them as their tool for weather forecasting (Ehlert, 2012, pp. 105–106).

Chapter Summary

These beliefs, and lore, along with the first established theories and approaches to understanding weather by the Babylonians, Chinese, Aristotle, and Wahshiyya, to name a few, were the building blocks of weather knowledge and meteorology. All that was accomplished and learned up to the fifteenth century was done mainly without the use of technological assistance. This all changed quickly, as did the understanding and future capability to forecast weather.

References

Book References