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Review

A Short Critical History on the Development of Meteorology and Climatology

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Abstract: The present study presents a brief discussion regarding the evolution of meteorology from the sixteenth to the twenty-first century, throughout antiquitiy, Aristotle's legacy, and contemporaneity. Part of the text is dedicated to illustrating the emergence of Brazilian climatology and a new paradigm, postulating physical geography and the French School of Climatology and Meteorology.

Keywords: atmospheric sciences; geography; Brazilian climatology; climatic rythm; weather

1. Introduction

The present paper shows a timeline of the last four centuries of studies on the history of meteorology and climatology as a science and its importance in regards to other advances in the atmospheric sciences, based on English literature.

The retrospective study of the concept of types of weather, which has undergone the evolution of meteorological instruments, and the resulting atomization of meteorological weather, regarding its constituent elements, structuring and consolidation of the networks of weather stations, and the construction of hypotheses and concepts, aim to understand and study the atmosphere.

One cannot fail to mention the role of traditional culture; especially the indigenous and peasant cultures, in the observation of weather over the centuries, taking into account the historical perspective of the scientific academies and universities in the methodological orientation of atmospheric sciences.

A chapter is also dedicated to the history and evolution of meteorology in Brazil, arising from the Portuguese Royal Family, and later, in the light and reflections of the French School of Geography which contemporarily gained academic space, climatology from the Geographic approach.

2. From Ancient History and the Legacy of Aristotle's *Meteorologica*

The work of Aristotle, *Meteorologica*, written around 340 BC, is the oldest treatise dedicated to meteorology. The subjects of the first three books include: the formation of rain, clouds and fog, hail, winds, climate change, thunder, lightning, and hurricanes.

A good number of weather forecasts in this work are derived from the Egyptian works and many other aspects are of Babylonian origin, mainly on the nomenclature and classification of the winds. Consequently, *Meteorologica* represents the sum of knowledge on the atmosphere at that time, compiling many current theoretical speculations [1].

The system established by Aristotle remained for two millennia as the standard of scientific texts, so that virtually all of the books on the European continent that dealt with the atmosphere until the early seventeenth century were essentially based on Aristotle's considerations, whereas in England his influence was much smaller [1].

The name "meteorology" also derives from Aristotle, although in his work *Meteorologica* the volume covers much broader subjects than what is currently understood by meteorology, including basically all the aspects of physical nature of the sky, air, earth, and sea.

The term used by Aristotle to define the atmospheric phenomena "meteors" presents an ancient (Greek) genealogy, and we highlight here two significant meanings. The first refers to the notion of "elevation", which can also be interpreted as "gaining altitude", "sublimation", or even "floating". In this sense, the term "meteor" can refer to "ascension", and so "*Meteorology*" is the discussion on elevated things. The second meaning refers to the characteristics of thought and discourse, for example, "dialogue about things elevated or unknown" or simply as "abstraction" [2].

The "*exhalation theory*" as part of the explanation of its hypotheses sought to gather elements to illustrate what kind of matter filled the region of meteor events. For this, Aristotle uses the exhalations, which would be produced by the action of the Sun on the earth's surface, and divides them into two categories: hot and dry, and cold and humid. The first would be produced when the sun's rays were upon dry land and would consist of earth particles, which would be "lit" by the igneous layer of the sub-lunar sphere. The second, cold and humid (also referred to as "vapor"), would occur when the solar rays were upon water, and then composed of aqueous particles. With this, all atmospheric phenomena were explained as the results of the different combinations between these two types of exhalations.

Aristotle's Theory of Exhalations seeks to explain both celestial heat (Sun and Moon) and that coming from within the Earth. Each type of terrestrial surface would emit a specific type of exhalation, emphasizing Vapor (water) and Smoke (dry things), and also offering a brief characterization of the different exhaled properties (aqueous, saline, sulfuric, terrestrial, and spirited).

In Babylon, cuneiform records on clay plaques indicate a very diverse and sophisticated intellectual society, with meteorological records being associated with astronomical events, which founded *astrometeorology*, a widespread practice in Europe.

Despite these experiences, the earliest known meteorological observations were those performed by the Greeks.

As farmers and hunters, ancestral men were heavily dependent on weather conditions, forcing them to observe atmospheric phenomena for signs that could predict future weather—usually up to forty-eight hours. A cumulative collection of *weather signs* was developed and passed down for generations, gradually taking the form of short and easily memorized proverbs. Records indicate that by 3500 B.C., Egypt already had a religion based on atmospheric phenomena, with various cults and rituals, especially for rain.

The Greeks were the first, as far as we know, to create records of meteorological observations, which were published in the form of almanacs—called "parapegnas" at the time. The main observations were on the winds, due to the importance of this type of information for navigation. These ancestral observations of weather were never completely disrupted and were fairly "crude" compared to modern observations. They consisted basically of sky condition (cloudy, rainy, clear, etc.), wind direction, the "heating" of the air (hot, cold, "normal"), and sometimes the amount of precipitation; the latter apparently being the first main element to be systematically recorded.

Considered one of the "*seven sages of antiquity*", Tales based much of his work on meteorology from Babylonian heritage, which led him also to seek a relationship between atmospheric phenomena and celestial bodies, as well as to make considerations about the equinox and the solstice, and conduct studies on the rain.

From the historical evidence, Anaximander would have been the first to consider the wind as "the flow of air", something quite close to the current scientific definition and which, surprisingly, was not readily accepted by many of the scholars in the succeeding centuries.

Theophrastus, who wrote *De Signis Tempestatum* (On weather Signs) and the "*De Ventis*" treatise on winds, falls into this category. One can relate the practice of forecasting time from empirical rules with these works, in which there are eighty signs for rain, forty-five for wind, fifty for storms, twenty-four for good weather, and seven signs for weather for periods of approximately one year. While the work of Aristotle was largely theoretical, the short treatise of Theophrastus stands out for its practicality, becoming the collection of proverbs and rules of prediction of the earliest known time, resulting in many later collections which present only variations in relation to this one.

By the end of second century B.C., the center of scientific activity was no longer Athens, but the city of Alexandria, which housed the largest library of antiquity. Claudius Ptolemy's *Almagest* treatise is one of the most sophisticated astronomical works of antiquity. He wrote about atmospheric events and ways of predicting them, even though this bore a strong resemblance to Theophrastus' work. For the next thousand years, Ptolemy's work was considered the basic authority for astrological predictions about weather.

Seneca wrote *Quaestiones Naturales*, which dealt mainly with astronomy and meteorology. The treaty combined the Romans' discoveries with that which had been recorded by the Greeks, Egyptians, and Babylonians, presenting a rather broad work ranging from speculations on the wind to the causes of thunder and lightning.

Pliny's main scientific work was *Naturalis Historia* (Natural History), of which the second book or chapter deals with meteorology, which distinguishes between regular and accidental meteors and "their quite irregular behavior".

3. The Middle Ages and the Inquisition

Between 400 A.D. and 1100 A.D., meteorological study was never completely eliminated, although all the activity of scientific speculation underwent a series of religious restrictions.

This long persistence of faulty hypotheses may be associated with the model of research and investigation in vogue in the Middle Ages, much more concerned with the argument of authority than with empirical evidence, which leads us to a long period in which we sought to find all the answers in books rather than in the world around us. In order for meteorology to really advance, this model had to be overcome, and the beginning of this process was partly due to the work of Roger Bacon. He advocated experimentation and mathematical approximation in all fields of scientific study. He was able to prove that the atmosphere had layers of air of different densities, and suggested that Ptolemy's Climatic Zones be subject to correction, due to topographical effects.

The Englishman William Merle, who lived in the fourteenth century, would have been the first westerner to keep a regular diary cointaining weather observations reported at Oxford, between 1337 and 1444 [3].

4. Modern Age: *Continuum* Time and Weather Forecast?

Throughout the sixteenth century, meteorology developed on two distinct bases: a purely theoretical group still relying on the work of *Meteorologica*, and another seeking to establish atmospheric predictions based on astronomical events. During this period, astrological predictions became very popular, as well as almanacs and calendars that brought new compilations regarding signs of weather. This popularization was associated with the protection of the Church and nobility, with respect to the astrologers, by the convergence of interests in maintaining the divine and mysterious aspects regarding such phenomena.

Krakow Academy professor Marcin Biem, from the city of Olkusz, systematically observed the weather conditions during the period of 1502 to 1540, and his notes form the most important database for these years.

The astrologer and theologian Marcin Biem is one of the most important figures for studies of this nature. His observations on weather were regularly and carefully noted on a daily basis for 682 months, containing 5915 entries. In his notes, three phases are identified: 1502–1507, 1524–1531, and other intermittent periods.

Considerations by René Descartes attached as "*Les Météores*" in the Discourses of Method, attempted to explain the nature and cause of all weather phenomena by showing that they would be based on certain general principles of nature, even if these were not sufficiently clear. Descartes went on to suggest explanations about *fono* and *electrometeors*, as well as optical phenomena. The validity of his conceptions about the formation of rain, snow, and hail should be evidenced, since they helped to prove the strength of the proposed new method. Descartes suffered from the question of scientific evidence and precision, since he could not count on any kind of instrumental support, being forced to resort to a deductive model, which, being based on misconceptions, brought few valid contributions.

This empirical study of meteors, also called "*meteoric tradition*", corresponds to a unique approximation between the emblematic phenomena of the atmosphere, the Aristotelian meteorological theory, and the belief in divine intervention.

The content of these stories was characterized as "weather abnormalities"; "unusual" was more valued than "normal" in relation to the weather standards. The meteoric tradition was therefore not concerned with discovering a global conception of atmospheric weather.

From this period onwards, "meteorologists" were increasingly invited to view their research as a quantitative and laboratory endeavor. Meteorology came to be conceived as a synoptic description of the weather conditions in different places, as well as the need to describe the weather chronologically.

The idea of continuous observation of the weather would have been formulated initially by Blaise Pascal, when writing about the barometer installed at the foot of Mount Puy-de-Dome. However, the study of the weather was still marked by the coexistence of two distinct empirical approaches—the qualitative reporting of the extraordinary and the quantitative measurement of the "*time-continuum*". The history of the beginning of modern meteorology reflects, in several aspects, the history of meteoric tradition [1,2].

Early modern conceptions of meteors focused on the description of violent storms, the occurrence of unusual auroras and strangely shaped hailstones, as well as intense events of cold, heat, snow, floods, and droughts. These "*meteors*" ruined properties and interrupted life, and were commonly interpreted as divine warnings and punishments.

During the seventeenth century, some writers began to challenge the authority of these omens, fighting the symbolic and public dimension acquired by such phenomena. Thus, there is great initiative in the face of moral and ideological instructions, in which the core of sixteenth and seventeenth-century literature rests on atmospheric phenomena, represented as signs of divine will. Since most of these events were local, it seemed natural to regard them as punishments or warnings directed at specific communities, cities, homes, or even individuals [1].

If the meteorological reporting had a meaning in the search for a regional identity, it is not surprising that its effort was essentially provincial. However, if it seems to us that provincial participation in empirical meteorology was by "*human mini-observatories*", this is due to the fact that the collection of data was seen as an acquisition of knowledge, associated with the notion of local belonging [2].

5. Contemporary Age: The Advance of Instrumentation and Atmospheric States

During the second half of the eighteenth century, cultural and theoretical changes caused considerable impact on society. By the end of the century these changes began to challenge both the foundations of meteoric tradition and theoretical meteorology. Thus, meteorology became the investigation of weather rather than individual meteors.

The origins of this modern approach lies in the conjunction of the view of weather as a system ordered by laws, associated with the tradition of weather forecasts. Contributors to the emerging theory of weather have recognized that the agenda of a meteoric science would have to be able to identify long-term changes, recurrent patterns, and if possible, predictive methods.

A new analytical approach continued to move meteorology into offices and laboratories, associating it with measurements, tables, graphs, and averages. Thus the autonomy of meteorology was only recognized by the size of the research processes, and no longer by the physical composition or behavior of the meteors.

Hook was one of the first to address the standardization of weather observations and weather recording, and with this we consider the first effort to create a concept regarding the weather patterns described here by the expression "*face of the Sky*". The measured elements were the force and direction of the winds, temperature, humidity, and atmospheric pressure, besides notes on lightning and thunder [4].

Garden and Middleton proposed an intelligible account of the ascent of "vapors", of the balance of the clouds, and of their fall in the form of rain, as well as of the origin and function of the winds.

Even more important was the fact that when Aristotle declined the discussion on weather forecasts, he effectively divorced "meteors" from "weather" [5].

Regarding wind systems, Bohun presented an interesting and important work for his time, in which he compiled the main explanatory proposals about winds and their causes [6]. The explanations are constantly associated with local and regional processes, not presenting a generalizing proposal, such as that presented by Halley [7].

Bohun also belongs to the group of authors who consider *weather* as something to be carried by the wind, leading him to consider that there could be some specific "*weather modes*", and that these would be carried by the wind—in this case defined as "a body of heterogeneous air". According to this author, the "*traveling winds*" that reach remote places carry, besides the *weather*, different types of air [6].

Other important series are those recorded by Johann Kepler and Friedrich Buethner. Also in the seventeenth century, Jan Antoni Chrapowicki, a Polish nobleman, kept a diary with almost daily notes regarding the period between 1656 and 1685, constituting an important reference for research that seeks to reconstruct past atmospheric conditions.

Efforts to form some sort of international network of weather-watchers did not achieve much success until the mid-eighteenth century. The first of these networks occurred in the middle of the seventeenth century in Italy, when Ferdinando II of Tuscany made meteorological observations a regular activity of the *Accademia del Cimento*. Thermometers, barometers, and hygrometers were used, and observers were sent to Florence, Pisa, Vallombrosa, Curtigliano, Bologna, Milan, and Parma. Subsequently, the network was expanded to include Paris, Osnabruck, Innsbruck, and Warsaw, thus taking on an international feature [3,4].

The influence of the *Accademia del Cimento* was present in later observation networks. Until the middle of the seventeenth century there was no standardized procedure for conducting meteorological observations, although the *Accademia del Cimento* had advanced in this direction, and its actions were only complemented by Robert Hook's work, "Method for Making a History of the Weather" [5].

HOOK does not advocate observations at any time of the day, but rather during times of significant changes in the weather, provided that at least one observation was made during the day. This article was presented to the *Royal Society* and copies were sent to various people involved in meteorological activities [5].

The referred article can be considered a watershed for meteorology, since for the first time an attempt was made to describe precisely what should be included in meteorological observation and how it would be done.

Edmond Halley's work proved fundamental to the advancement of atmospheric studies, in the eighteenth century. Air elasticity would be equivalent to the weight or pressure exerted by air compression. With this, it would be possible to identify the variability of this elasticity, based on places with known altitudes [8].

Halley establishes a very clear association between cloudiness and prevailing weather, thus seeking to understand weather from the processes of cloud formation, always linking great importance to the phenomena related to rainfall and the causes responsible for humidity variability. Halley presents, from information collected by merchant ships and by his own observations, an explanatory hypothesis for the occurrence of the trade winds and the monsoons, and his proposal is considered by many authors as the first model of the general circulation of the atmosphere.

In 1723 the initiative of James Jurin, then Secretary of the *Royal Society*, invited all observers who had training and equipment to annually submit their daily observations to the *Royal Society*. Along with the request sent to the observers, there was a set of instructions that included the daily reading of the thermometer, barometer, direction and force of the wind, amount of rain or snow collected, and the appearance of the sky. The result of this work was published annually in the *Philosophical Transactions* journal.

Although the most successful meteorological networks are a product of the nineteenth century, the first major boost was due to the *Societas Meteorologica Palatina*, created during the 18th century. Founded in the German city of Manheim in 1780, its first act was to request from the main universities, colleges and scientific academies their cooperation for data collection, offering in return all the necessary standardized instruments, at no cost. As a response, thirty companies and fifty-seven institutions accepted the task and received an initial kit containing properly calibrated instruments (barometer, thermometer, hygrometer, electrometer, windsock, rain gauge, and compass) and a notebook with instructions, which included, for example, the time of observations to be made at 07, 14, and 21 h.

The *Societas Palatina* collected data from North America, the Mediterranean, Russia, and all of Central Europe, which were published in their *Ephemerides*. With the death of its founder in 1790, the leadership of the organization suffered a strong shake, a situation that was further aggravated by the political crises arising from the French Revolution, leading to the end of the society. Its last bulletin for the year 1792 was published only in 1795.

Regarding pre-instrumental recordings and conceptions about the atmosphere and the weather, some elements of the work of Varenius [9] can be evidenced.

Concerning the atmosphere, the author relies on the then prevailing conception of the theory of Aristotle's exhalations. The first appearance of the word "*climate*" in the work by Varenius arises in the context of causal and circumstantial explanations (local effects) in correlation with the wind patterns. Varenius presents a division of the atmosphere between superior, intermediate, and inferior, apparently classified this way due to the phenomena observed at different altitudes.

Fundamental considerations regarding the first instrumental meteorological records highlight the role of the barometer. The success and expectations aroused by the barometer are comparable or perhaps greater than those produced by other instruments of the time, such as the microscope and the telescope. The barometer had two basic objectives: the determination of the weather and the calculation of mountain height. However, the barometer was also used, together with other instruments, to perform daily collections of quantitative records whose purpose was to provide, once average calculations and extreme values were selected, a description of the "temperament" and constitution of the atmosphere of a given locality, or for comparative purposes, of other geographical points.

With the instrumental advent, a common conception grew that the path to meteorological progress would be solely dependent on new instruments and experiments that provided increasingly accurate and larger data.

It is important to emphasize the role of scientific academies for the development of meteorology from the 18th century. The importance and influence of the *Societas Meteorologica Palatina* should be evidenced, being considered the first scientific entity with an exclusively meteorological orientation.

Eighteenth-century meteorology can be characterized by the transition of elements of the physical sciences, such as random observation and hypothesis elaboration, to "experimental and exact physics", which focused on the use of physical laws and applied mathematics on an experimental science.

One of the main advantages of the *Societas Palatina* was the simplicity of working with standardized instruments, avoiding many mistakes that were common in other projects, because the instrument artisans were already able to manufacture them on a large scale and with identical properties, in collaboration with physics "scientists".

This factor combines feasibility and economic interest in meteorological observations for agriculture and commerce, especially for governments, in view of the possibility of obtaining greater profits and greater productivity, thus avoiding periods of great famines. It was not uncommon to find men dealing with the meteorological record from a purely empiricist perspective, merely evaluating monthly averages, derived from voluntary observers who worked without any kind of standardized instrument or systematic routine. The packages with the instruments included a barometer, two *Réaumur* mercury thermometers, a hygrometer, and in some cases, a needle for magnetic declination.

Other instruments such as the windsock, rain gauge, and devices to detect the electricity of the air were carefully described in the manuals, so that they were constructed locally. Each station received twelve forms annually, one for each month. The observations of the instruments should have been held at 07:00 a.m., 02:00 p.m. and 09:00 p.m., using the symbology established by Johan Hemmer, one of the governing members of the society. Seeking practical utility for the records made, Johan Hemmer proclaimed agriculture and medicine as the fundamental motifs of the project.

As a consequence, classical meteorology persisted as a distinct undertaking in both the method and purpose of traditional rules, while the modern conception of meteorology was consolidated as a science of weather. This separation was maintained until the end of the eighteenth century, when "weather" was invariably defined as the "state or arrangement of the atmosphere, with respect to heat, cold, wind, rain, snow, etc.", in which "meteorology" was still referenced as "the doctrine of meteors". Neither "weather" nor "atmosphere" was necessarily associated with "meteorology". In classical meteorology, therefore, weather could never be considered a meteor cluster, since a list of all meteors in a given place and time could not be considered equivalent to the knowledge of weather at a given place and time.

While the theoretical reflections and concerns about the standardization of instruments and registers generally occupied only the virtuous minds of the *Royal Society* in the seventeenth century, in the eighteenth century this picture was substantially altered. The approach to the atmosphere became more complex; for most observers it was not enough to just read and copy the values indicated by the instruments, it was necessary to understand and relate them [1].

The term "*state of the weather*", throughout the eighteenth century, can be understood either as a descriptive synthesis (succession of weather or the configuration of the sky) or as an ideally defined and identifiable stage from predetermined elements, records that present a clear taxonomic option, being limited to expressing the variability of the atmospheric conditions from a specific number of categories.

In the nineteenth century, weather forecasts were discussed alongside religious and mystical issues, evidencing some suspicion in relation to the scientific methods used at that time. The meteorology began to look more closely at past events, searching for repeatable patterns, as future predictions did not achieve significant success [10].

It seems clear to us that the more sophisticated and complex societies become, the more urgent true knowledge of the weather is. The concern and appreciation of meteorology show great variation among societies, depending mainly on how protected they feel in the face of atmospheric storms. That is, the importance of meteorology is directly related to the usefulness of its applications, especially those associated to the anticipation of future atmospheric conditions.

However, this progress was accompanied by a growing need for organization, coordination, and centralization of scientific work, since the task required was far beyond individual efforts, raising the question of science funding, intrinsically associated with the strengthening of the first meteorological offices. The high investments and low accuracy of the "weather forecasts" had led to numerous controversies regarding this "new science": what merits distinguish scientific observation from popular knowledge about weather conditions?

The weather forecast was seen as a risky activity as it could shake the reputation of any dedicated and well-meaning scientist.

J. Herschel would have presented his best expression of an overview of meteorology in his book "*Meteorology*". In this work, meteorology was characterized as part of a dynamic science, in such a way that if the atmosphere were not mobile, someone could calculate its causes. With that, Herschel deliberately imposed his vision on meteorology, considering the atmosphere a physical chemical fluid to be studied on the basis of careful observation and grounded by mechanical theory [11].

To this end, Herschel established two steps for the construction of a theory for meteorology: (i) consider which agents or causes can help to produce a given phenomenon; (ii) consider which laws can regulate the action of these agents. Herschel intended to construct theoretical considerations about general circulation, storms, and trade winds, arriving at, it would seem, a first approximation of the notion of "air masses". In addition, he would also have established a rather coherent theory of waves in the atmosphere, although he could not prove it, writing again about "air masses", and the association of wind standards with barometric standards, and such variation would be responsible for the undulating movement of the air, in 1857 [11].

In 1853, Robert Fitzroy (one of the fathers of weather forecasting), while working in the Meteorological Department, who understood the imposition of the collective character on the task of recording and analyzing meteorological data, began to distribute instruments to ship officers and to gather their records books, as well as established a telegraphic observation network and published storm warnings and general forecasts about the weather. Fitzroy's management in the direction of the Department of Meteorology stimulated and widened the debate between a model science and that which is directed to practical and popular problems. His signal system in coastal areas coupled with his forecasts multiplied the attention directed to meteorology, making it a target of growing public interest and judgment [10].

The work of Heinrich Dove [12], who obtained immediate recognition with the publication of his book, *The Law of Storms*, in which he proposed an explanation for atmospheric circulation based on terrestrial rotation and the variations from incident solar radiation, concluded that the storms were the result of contact between "*airs with different properties*".

We can say that the tripod "detailed observations—sophisticated instruments—standard measures" was the heart of meteorological development in Victorian England, achieved by a collective effort led by the central authority.

The collective nature of scientific research is very present in meteorology, perhaps because the networks of stations are a necessity dictated by the scale of the phenomenon, since in this new orientation one looks for another scale, not the local one, but still one that is dependent on the field of view of the observers. The value of the collected information from these networks depends on both the size of operations and the control of individual elements. For the same reason, that is, because the elements of a network of meteorological stations are taken as part of a whole, the administration work becomes obvious, leading to the constant exchange of coordinated observations, instruments, and orientations. It is not surprising, therefore, that the networks of weather stations were not all the same.

Synoptic maps, which give a new meaning to the data collected, are one of the most striking innovations of nineteenth-century meteorology, constituting a great effort to attribute form and structure to the invisible forces of the atmosphere. The new visual appeal, as might be expected, brought new perspectives and reflections to meteorologists, and made noteworthy the expression "*meaning at a glance*", which referred to the ability to properly understand atmospheric conditions from a single visual analysis.

In particular, the construction of synoptic storm maps provided the scientists of the time with a powerful psychological experience regarding the discovery of a new natural order from detail grouping. Thus, the work with time charts and isobaric patterns were able to completely change a researcher's attitude towards the changes of weather.

In his work *Meteorographica*, Francis Galton presented a series of 93 maps of European weather, from December of 1861, with three daily entries for that month. With this, Galton became a pioneer in identifying and representing the so-called "*anti-cyclones*" (high pressure regions surrounded by winds moving counterclockwise).

For Galton, this type of map would also have the function of eliminating the "local deviations", thus favoring the upper scales of circulation. Galton's work, through his printing techniques and the transition from a local to a global scale, evidence his effort to consolidate a schematic representation. His maps, arranged in sequence, contained information on precipitation, cloudiness, atmospheric pressure, temperature, and wind speed and direction. With this work, Galton marked the transition from a fragmentary view of different local observations to a highly schematic view of the atmosphere, separate from the view of the observer and the point of observation.

From the study of these charts, Fitzroy also went on to argue that the atmosphere should be understood in terms of contention between heated and cooled air currents, which would produce local turbulence, which in turn would be displaced by larger bodies of air that involved them, thus leading to great storms [12].

Such technical means also provided the development of new theoretical conceptions regarding atmospheric circulation, since the researcher, using the synoptic charts, had his field of vision significantly expanded. This "tracking" of the phenomena was implied in the suggestion of its genesis and development, giving a new level of complexity to a series of occurrences and records, which in many cases were taken while random and disconnected events happened.

The nineteenth century can be thought of as the era of academies and large laboratory experiments with the institutionalization of Meteorology and Climatology in the academic environment.

5.1. The Development of Climatology during the Last 100 Years

The "*Handbook of Climatology*" is a great compilation of the main ideas and hypotheses about the structure and dynamics of the atmosphere. It regards climate as having a specific dynamic, rather than being static. Regarding precipitation, it highlighted only one characteristic, which refers to the great importance given to the maximum and minimum volumes of precipitation [13].

Wladimir Köppen, in his famous classification system, establishes a relationship between climate and vegetation and seeks to simplify the complex relationships between soil, vegetation, and climate, listing the interactions between these elements, which are essential for the support of animal and plant life [14]. Köppen puts "climate", and consequently Climatology, much closer to Geography than Hann's proposal, which considers them as almost exclusive tools of Meteorology [13,14].

Dove also differs from Hann and Köppen since he presents the focus of his work on aspects of atmospheric circulation, mainly in relation to the movement of cyclones associated with storms, and for being the precursor, in the literary review, to the expression "air masses", but does not explain the nomenclature [12–14]. One of the main works to have influenced Dove's proposal would be that published by Ferrel, in which there are forces acting in order for general atmospheric circulation, considering the specific gravity between different points in the atmosphere; the air flowing from the regions of high pressures to low ones, and the combination of the Earth's motion and the deflection in atmospheric movement on the equatorial axis and the latitudinal limits of trade winds [1,12,15].

The Norwegian School Theory, as we know, is based on the existence of atmospheric surfaces of discontinuity between hot and humid air (equatorial) and cold and dry air (polar). By this, the theory intended to demonstrate that the heated air appeared first in altitude and then in the surface, as opposed to cold air. Dove was also able to establish a similar concept to that of the air fronts, by determining that there were "inclined barriers" between cold and warmed air, certainly exceeding the speculative level [12].

The contribution of the British scientist Hubert Lamb should be noted, having gathered a variety of information and scattered historical records on geology and climate. Lamb worked at a time when paleoclimatology was in its infancy. The bases of dendrology, the study of the composition of the air imprisoned in glaciers and the analyses of coral layers, which would allow a better elucidation of the atmosphere of the past, were still not customary practices.

Lamb also studied singularity and pointed out seasonal cycles for the British Isles, based on calculations of the daily frequency of wind categories between 1898 and 1947, identifying five natural seasons based on periods that last 25 days, namely: spring to early summer , high summer, autumn, early winter, late winter, and early spring.

Several other types and systems of climate classification have been developed on the planet. Such systems are of great importance since they analyze and define the climates of the different regions, taking into account several climatic elements at the same time, facilitating the exchange of information and analyses for different uses and purposes.

Another highlight was the internationalization of meteorology and climatology in the twentieth century, especially by the advent of the radio, which played a predominant role for the communication of meteorological information between distant stations, covering hemispheric dimensions and, a posteriori, all existing ones.

For this, Vilhelm Bjerknes would be one of the pioneers to propose some sort of standardization for the cartographic representation of atmospheric phenomena. He suggested that synoptic charts, since they showed a great deal of information about large regions of the Earth's surface, would be an exceedingly difficult task to achieve. Thus, he would propose that the synoptic charts be produced according to an internationally standardized articulation in different scales and cartographic projections.

One of the most important proposals refers to Dynamic Meteorology, suggested by Tor Bergeron, when incorporating the concept of "air masses" in his analyses. The "air masses", in turn, corresponded to "features clearly identifiable from the synoptic charts", which would stand out by the horizontal uniformity in the distribution of their attributes, and in which each type of "air mass" would be able to produce a fixed amount of types of weather, which should be investigated on a regional scale.

Bjerknes states that the most significant changes in atmospheric weather in mid and high latitudes are associated with a line of discontinuity between "air masses" of distinct properties, and defends the possibility of a genetic approach to the study of masses of air [16].

Vilhelm and Jacob Bjerknes studied the atmospheric dynamics in a topic associated to hydrodynamics, explaining in the field of mathematics and theoretical physics the dynamics of vortices and the transition of turbulent and laminar flows. They realized that the density of heterogeneous fluids would depend on many variables capable of maintaining fluid circulation, where pressure and density intersected on a three-dimensional surface, forming a series of tubes called solenoids.

Regarding these issues, V. Bjerknes developed his method to "*construct images of the future state of the atmosphere from its present state*", introducing laws of mechanics and physics of the atmosphere.

Such advances led to the development of one of the main concepts established by the Norwegian School, the Polar Front, whose model would be a three-dimensional surface of discontinuity stretching across the Northern Hemisphere, separating the masses of polar and tropical air. This perception would cause an important and strong impact on Meteorology and Climatology with the study of aerology in commercial/military aviation in the First World War [1].

The experience obtained during the war period would have taught meteorologists that a truly effective forecast needs much greater and detailed geographic accuracy than traditional forecasts were capable of providing, in addition to emphasizing the focus on short-term changes, between three and six hours.

From this new perspective on the atmosphere, the Norwegian School would have founded the concept of the Polar Front, after which the concepts of hot front, opposition or "battle" between two different air masses, the notion of the life cycle of cyclones, and the capacity of mature cyclones to give rise to new cyclonic formations quickly emerged [17].

It was not long before they attributed the formation of cyclones and anticyclones to the movements of the polar front, which would be followed by "attacks" and "counterattacks" by polar and equatorial air, associated with large-scale ripples from west to east of temperate latitudes, considering other atmospheric phenomena as "details", internal to this circulation.

The period between 1920 and 1950 can be considered the transitional era between the revisions based on local empirical rules. This is due, to a large extent, to the works published by Bjerknes and Solberg, in which the idea that cyclones would act as wave disturbances and separate the masses of polar and tropical air was introduced.

It is important to emphasize the contribution of Carl-Gustav Rossby, who was the first scientist to determine the causes of the west winds in waves in 1939. The Rossby waves develop in response to the air flow over large scale orographic barriers and thermal patterns. There are approximately three to six long waves around the northern hemisphere on any given day (four to six in the summer, when the thermal patterns are weaker and the waves tend to assume a more sinuous pattern, and three in the winter, when circulation is more intense) and three to four in the southern hemisphere. The speed of sinuosity of the upper west winds is not uniform everywhere, for in some regions the flow becomes concentrated in narrow cores of stronger winds, known as jet streams. They play an important role in the rapid transfer of energy over long distances in the atmosphere; in mid-latitudes (40°–50°) the air can easily be transported around the Earth in a week.

In the 1950s and 1960s, with the advent of the first computers, numerical forecasting became a plausible reality. The impact of the introduction of meteorological satellites on weather forecasting should be mentioned. With these satellites, it was finally possible to observe atmospheric circulation as a whole, thus improving the connections between processes from different locations and scales, especially in the oceans and desert regions.

Mathematical models have become prominent in Meteorology and have adopted a deterministic view regarding atmospheric predictability, in which the future state of the atmosphere is determined by the conditions of the present state, associated with the conditions of physical and mathematical errors of atmospheric modeling.

Early teleconnection studies were related to the Southern Oscillation, in which Gilbert Walker and E. Bliss published "Word Weather". The authors analyzed pressure data at sea level and found negative correlations between regions of the South Pacific Ocean, Australia, and the Indian Ocean.

According to the same authors, in the 1930s, when the South Oscillation could be "interconnected" with the pressure, temperature, and precipitation patterns obtained by surface stations far from the region, the results indicated little acceptance by the scientific community, since the idea was new and controversial.

Currently, in another technical-scientific context, and with the advance of climatic studies that couple and show more clearly the role of the ocean in the atmosphere, climatic teleconnections have been increasingly more accepted. In the literature of the last decade, there are approximately eleven teleconnection patterns in the Northern Hemisphere: the North Atlantic Oscillation (NAO) and the East Atlantic Pattern (EA), in the Atlantic Ocean; the East Atlantic/Western Russia pattern (EATL/WRUS), the Scandinavia pattern (SCAND) and the Polar/Eurasian pattern, in Europe and Asia; and the West Pacific pattern (WP), the East Pacific/North Pacific pattern (EP/NP), the Pacific/North American pattern (PNA), the Tropical/Northern Hemisphere pattern (TNH), the Pacific Transition pattern (PT), and the Arctic Oscillation (AO), in the North Pacific and in North America. Except for the last two teleconnections, that show variability periods of three and two months, and last from December to February and August to September, respectively, all of the others are observed every month.

The main modes observed in the Southern Hemisphere that compose the variability of precipitation are the Pacific and South Atlantic Configuration (previously mentioned), the Madden-Jullian Oscillation (MJO), the El Niño Southern Oscillation (ENSO), the Atlantic Decadal Oscillation (ADO), and the Pacific Decadal Oscillation (PDO).

ENSO is the main source of global interannual climate variability. In the case of South America, it provides a significant contribution to the precipitation variation in several regions and represents an important variability modulate of the highest frequency.

It is a connected ocean-atmosphere oscillation which produces changes in pressure, wind, tropical convection, and in the surface temperatures of the seas, mainly in the Pacific Ocean, but with reflections in many places on the planet. It indicates two phases called El Niño and La, in a system understood as a barometric seesaw (balance) between the central-east and west Pacific. In addition, it occurs in repetitive rhythms of two to seven years, with a variability period of 14 to 22 months.

The origins and assumptions of Dynamic Meteorology became necessary from the moment this subject influenced the development of Dynamic Climatology. This would be an early attempt to explain the planet's climates as integrations between circulation and disturbances of the atmosphere, through which patterns of regional circulation could be derived, in this case also referred to as types of weather.

Dynamic Climatology would seek, through the understanding of the dynamic and thermodynamic mechanisms of the types of weather, associated with the local scale, to establish an explanation for regional climate. That is, regional climate would be explained by the existing processes at higher scales.

In any case, we seek to present some important characteristics to the study and understanding, throughout history, of the types of weather, rescuing some references in the field of knowledge of climatology and meteorology, especially since the next section intends to illustrate some climatic classifications after the second half of the twentieth century, in light and design of the scale of regional analysis.

5.2. Brazilian Proto-Climatology and "Monteiro's" School

Brazilian climatology had its origin in the natural sciences, based on Humboldtian conceptions and the systematic presumptions of regional nature. This approach was present in the detailed descriptions made by European travelers and naturalists who toured Brazilian lands in the first half of the 19th century [18].

The historical landmark for the birth of climatology in Brazil was the reorganization of the Astronomical Observatory of Rio de Janeiro in 1871, and the creation of the Central Meteorological Office of the Ministry of the Navy in 1888. From this moment on, the scientific phase of atmospheric sciences in the country began.

In the late nineteenth and early twentieth century, there were no higher Geography courses in Brazil, which were implanted only in 1934 in the Universities of São Paulo and the then Federal District (RJ). Geographical studies were based on European models. Three works are considered pioneers in Brazilian climatology: "*Outline of the Climatology of Brazil*" by Henrique Morize, "*The Climate of Brazil*" by Frederico Draenert, and "*Metéorologie du Brésil*" by Delgado de Carvalho [19–21]. These works have a pioneering character since they deal with the Brazilian climate in all its territorial extension, in the search of synthesis and concerns with the proposal of classification, in line with the assumptions drawn by Hann [22,23].

In the first decades of the twentieth century, several attempts to identify the weather-producing systems were carried out, but the studies of Adalberto Serra and Leandro Ratisbona, from the 1930s onwards, expanded knowledge about the atmospheric circulation of the South American continent, incorporating the new paradigms of synoptic meteorology [22–24].

Since the 1960s, Brazilian climatology has developed into three major sectors of science: Geography, Agronomic Sciences, and Meteorology. This section regards the need to deepen the study of their constituent elements and the thematic diversity required by the degree of scientific and technological development. In Geography, more precisely, Climatology adopts a dynamic approach, based on the rhythm paradigm.

With the end of World War II, a renewal movement of Geography began, mainly in France, where new paradigms for Climatology, that breach the concepts of weather and climate elaborated by Julius Hann, were proposed. Max Sorre bases his criticism on the static, separative, and descriptive character of climatology practiced until that moment. In the work, *Traité de Climatologie Biologique et édicale*, Sorre points out the insufficiency of the climate concept elaborated by Hann:

> "the set of meteorological phenomena that characterize the average condition of the atmosphere at any one place on the earth's surface". This definition is simple and convenient. It corresponds to an average, that is, to an entirely unreal abstraction, and leads to an abuse of arithmetic means to characterize the elements of climate. It presents a static, artificial character, because it does not mention the development of phenomena in time. However, rhythm is one of the essential elements of climate [25].

The definition proposed by Sorre takes into account the time factor (duration). For him, climate constitutes the series of atmospheric states on a certain place in its usual succession.

> Just as weather—in the meteorological sense—is a singular state of the atmosphere, the local climate is a singular, irreducible combination. There are not perhaps two points on the globe whose climates are identical. However, the action of climate factors reveals sufficient generality that we practically have the right to consider, regarding local climates, the regional ones. The notion of regional climate is a part of the path to abstraction. One can legitimately talk about regional climates, or, if you will, about climatic regions, and thus we are led to introduce the idea of a climatic limit, of great importance to biogeography. This idea has often been conceived and used without the notion of measurement. There is no linear climatic limit—if it is found—except in very rare cases, such as a normal mountain obstacle in the sense of propagation of climatic influences. In general, there are limiting zones, spots, where combinations of characteristic elements of climatic regions in contact are made and dissolved. In these very diverse zones, random combinations of factors may make one or another climate type reappear locally in all their purity [25].

Sorre points out that "rhythm no more expresses the quantitative distance of successive values, but the more or less regular return of the same states" [26].

Pédelaborde, a French author who is very important in Climatology studies, shares the Sorrean paradigm only in the dynamic conception, in which climatic elements must be analyzed by their interaction. He stresses that what matters is the way in which this complex manifests itself, the framework that it creates, and the physiological action that it exerts. What matters, also, are the atmospheric conditions that determine this complex [27].

Pédelaborde states that "the greatest interest to the geographer is at the regional level, since it would perform the 'maximum of generality compatible with the maximum of concrete truth', while the local climate would be 'an accidental fact that masks the root causes'" [26].

It was in this context in the French School of Geography that Maximilien Sorre, considered the one who most advanced in terms of the formulations from the region as a category of analysis, proposed that Geography should study the ways in which men organize the environment, using space as their abode [23].

Sorre, when proposing a conceptual review that replaced the definitions of weather and climate using average statistical parameters, clarified:

> The climate, in a given place, is the series of states of the atmosphere, in their usual succession. And the weather is nothing more than each of these considered states, in isolation. This definition reserves the synthetic character of the notion of climate,

> emphasizes its local aspect and, at the same time, shows the dynamic character of climate, introducing the ideas of variation and differences included in that of succession [28].

This "Sorrean" concept of climate would commence from Ward's conception (1914) of all kinds of weather in a particular place, but adding this genetic concept to the notion of rhythm and succession. Sorre did not disregard the mean values, which he said would be fundamental in climatic variability analyses, since "*the action of a factor depends not only on its current intensity, but on the more or less sudden character of its appearance (differential limit), its frequency and its duration, characteristics which are included in the idea of variability*" [25].

The most interesting of Sorrean conceptions is that, without having carried out any empirical study on climatology, his work concentrated only on theoretical discussion, however Sorre captured the essence of climate's dynamic and genetic character. Many scholars consider Max Sorre the intellectual mentor of the eminently geographical climatology [23].

In the 1950s, when he interned in France (Sorbone), Monteiro became aware of Sorre's theoretical presumptions and the reflections aroused by this contact appeared in his first works [29–31]. Shortly before, Pierre Pédélaborde proposed the synthetic method of air masses, interested in the elaboration of a set of techniques that allowed the definition of the types of weather faced in its totality, showing less interest in the issue of rhythm [32,33]. While Pédélaborde was preoccupied with all types of weather, Monteiro was more interested in their sequential chain mechanism, in other words, in their rhythm.

Thus, the author elaborated a set of procedures with the certainty that the functioning of rhythm, analyzed from the chaining of the types of weather on a daily scale, would be the only possible strategy in understanding the atmospheric mechanisms and the role of climate as a geographical phenomenon, and its interference in human activities and spatial arrangements [23].

The theoretical foundation established by the author assumes a concept of rhythm as:

> Expression of the usual succession of the types of weather that leads, implicitly, to the common concept, since there are variations and deviations that generate different degrees of distortions until reaching extreme standards. Knowing what is meant by dry year and rainy year leads to a slow task of revision, until one can opt for a more convenient standard for our purposes [34].

It is assumed that "the first valid approach for this concept of rhythm comes from the annual variations perceived through monthly variations" [34]. However, the notion of rhythm would not be reached, since chronological decomposition is required in smaller units, at a daily level (until time), to be able to understand the continuous succession of atmospheric states.

For Monteiro:

> Only through the concomitant representation of the fundamental elements of climate in at least daily chronological time units, compatible with the representation of regional atmospheric circulation, which generates the succeeding atmospheric states, constitute the basis of rhythm [34].

The theoretical basis of rhythmic analysis was Monteiro's great contribution to Brazilian Geography since previously it took centuries of development and evolution of scientific and technological thought, parallel to the conception of types of weather, as shown in the sections above [23].

Its great validity, therefore, does not require the use of series of weather (the case of the totality of Pédélaborde's types of weather) or series from the historical series of the World Meteorological Organization, since the norms that are no more than arithmetic averages of different meteorological elements are not able to portray weather, nor climate.

Finally, it is possible to state that the Brazilian School of Climatology emerged thanks to the emancipatory posture adopted by Monteiro in the 1950s, 1960s, and 1970s, serving as the basis and stimulus for many studies in Brazil and abroad. This entire historical approach aimed to demonstrate the background that made the emergence of Brazilian geographic climatology possible [23].

6. Conclusions

The perception and recording of types of weather are restricted to an essentially local scale, closely associated with the field of vision of the observer and his sensory experience, since the delimitation of a type of weather was carried out by individual work and not from the collection of data by a network of stations regarding the temporal dimension, a notion which would be associated to daily and weekly scales.

The consolidation of the networks of meteorological stations and the advent of synoptic charts were responsible for a significant change in the way the atmosphere was visualized and interpreted, with the striking presence of new phenomena, visible only using the synoptic scale, and that began to win greater attention especially in the context of atmospheric circulation theories, to the detriment of local occurrences. This feature was maintained throughout the twentieth century, although there are exceptions, and was strengthened with the emergence of numerical prediction and computational models.

It is obvious that the more sophisticated and complex societies become, the more urgent need there is of the true knowledge of the weather. However, the transmission of this knowledge to a language aimed at the needs of the public sphere has proven to be a difficult point for researchers.

Regarding this problem, it is important to emphasize that the concern and appreciation of meteorology show great variation among societies, depending in large part on how protected they feel in the face of atmospheric weather. That is, the importance of meteorology is directly related to the usefulness of its applications, especially those associated with the anticipation of future atmospheric conditions.

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