# Whither Climatology? Brückner's *Climate Oscillations*, Data Debates, and Dynamic Climatology

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In 1890 Eduard Brückner published his major climatological work with the wordy title *Climate Oscillations Since 1700, With Remarks About Climate Oscillations Since the Diluvial Epoch*.[1] The book brought a new impetus to the ongoing debate about climatic changes and variability, which had been a major point of contention in the climatological community throughout the second half of the nineteenth century. Brückner's postulation of periodic and global 35-year climatic cycles made a large and lasting impact. Among many others, Svante Arrhenius discussed the findings; and more than half a century later, Emmanuel Le Roy Ladurie used Brückner's data collection as important material for his own work in climate history.[2] The research and writing of the book, however, had not been an easy task for Brückner. In the foreword, he professed that the completion of the work "had been forced to be delayed again and again."[3]

Even a cursory reading of *Climate Oscillations* suffices to reveal the likely cause for the difficulties: in order to bolster his claims of persistent universal climatic cycles, Brückner had to cover large evidentiary ground. On the basis of information on glacial

[1] Eduard Brückner, *Klimaschwankungen seit 1700, nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit*, Geographische Abhandlungen 4 (Vienna: Ed. Hölzel, 1890); unless otherwise indicated, all translations into English are my own.

[2] See: Nico Stehr and Hans von Storch, "Der Klimaforscher Eduard Brückner," in *Eduard Brückner - Die Geschichte unseres Klimas: Klimaschwankungen und Klimafolgen*, ed. by Nico Stehr and Hans von Storch (Vienna: Zentralanstalt für Meteorologie und Geodynamik, 2008), 7; Arrhenius directly referred to Brückner's work in his 1903 textbook on "cosmic physics": Svante Arrhenius, *Lehrbuch der kosmischen Physik* (Leipzig: S. Hirzel, 1903), 570–571; for Ladurie's early and groundbreaking work on climate history, see: Emmanuel Le Roy Ladurie, *Histoire du climat depuis l'an mil* (Paris: Flammarion, 1967); the English version was published as: Emmanuel Le Roy Ladurie, *Times of Feast, Times of Famine: A History of Climate Since the Year 1000* (Garden City, NY: Doubleday, 1971).

[3] Brückner, *Klimaschwankungen seit 1700*, iii; English versions of some of Brückner's writings on climate change and climate variability can be found in: Hans von Storch and Nico Stehr, eds., *Eduard Brückner: The Sources and Consequences of Climate Change and Climate Variability in Historical Times* (Dordrecht: Kluwer Academic Publishers, 2000).

oscillations and the historical fluctuations of water levels in bodies of water, he had first presented a general outline of his ideas in 1887.[4] Two years later, Brückner had already added not only quantitative temperature and precipitation data from Scottish Arbroath to Australian Sydney, but also historical records of European vintage dates.[5] In his 1890 book, he then brought the full collection of his evidence to bear: he discussed reports and theories of climatic changes around the world, appended historical information on the frequency of cold winters and ice conditions on bodies of water, and correlated meteorological information with changes in agricultural production and the incidence of typhus.

What interests me in this paper is not a detailed analysis of Brückner's ambitious, if ultimately flawed, theory of climate cycles, but the fact that his book represented an exemplary embodiment of a particular approach in the then still young and inchoate field of climatology. The nineteenth-century version of the study of climates was not – or at least not only – the often-satirized prime example of narrow-minded, statistical drudgery, but a more complex and heterogeneous "science of the archive," marked by the use of diverse sources of quantitative and qualitative evidence to form a holistic representation of climatic conditions throughout history.[6] With this approach, climatological work revealed its close connections – both programmatic and institutional – to the "telluric," or earth-bound, sciences of geography and geology, which had similarly long historical dimensions, combined approaches from diverse fields, and shared a common interest in the phenomena of glaciations and their aftermaths.

The inductive, historical, and archive-based method of studying patterns in the climate confronted practitioners with problems arising from the heterogeneous and increasingly capacious data sets. Meteorological networks were expanding around the globe, supplying more and more numerical data on rainfall, temperature, and winds. At the same time climatologists – a designation I use as an umbrella term for scientists of all stripes working on climatic phenomena – also continued to uncover historical sources offering evidence of past climatic conditions. Faced with this wealth of diverse data, some practitioners in the meteorological and climatological communities started to both criticize the lack of common standards in data selection and evaluation and bemoan the dearth of convincing explanatory models for climatic phenomena. As I will show in this paper, the internal criticism led some practitioners to call for new deductive approaches and more narrowly defined data sets, increasingly drawn not from *around*, but from *above*, the earth and focusing on atmospheric dynamics rather than historical and geographic information. As Deborah Coen has described in her work, moves towards physical-dynamic approaches to the study of climates were already apparent before the First World War.[7] By the 1920s, some of the appeals for a reevaluation of the discipline

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[4] Eduard Brückner, "Die Schwankungen des Wasserstandes im Kaspischen Meer, dem Schwarzen Meer und der Ostsee in ihrer Beziehung zur Witterung," *Annalen der Hydrographie und Maritimen Meteorologie* 16, no. 2 (1888): 55–67.

[5] Eduard Brückner, *In wie weit ist das heutige Klima konstant? Vortrag gehalten auf dem 8. Deutschen Geographentage zu Berlin* (Berlin: W. Pormetter, 1889).

[6] The term "science of the archive" is borrowed from: Lorraine Daston, "The Sciences of the Archive," *Osiris* 27, no. 1 (January 1, 2012): 156–187.

[7] See, in particular, the case studies of Heinrich von Ficker and Aleksandr Ivanovitch Voeikov in: Deborah R. Coen, "Imperial Climatographies From Tyrol to Turkestan," *Osiris* 26 (2011): 45–65.

cited new developments in dynamic meteorology, and particularly Vilhelm Bjerknes' approaches to weather prediction, as a model for a future "dynamic climatology."

While climatology continued to be a field of many diverse approaches and methods and remained a long way from becoming the atmospheric and physical science it is today, it had entered a period of reevaluation and uncertainty with regard to the future trajectory of the discipline. Critiques of data practices and calls for a general re-envisioning of the content and methods of climatological research challenged the powerful historico-geographical tradition of the field. The ensuing debate formed one particular aspect of the complex dynamics of disciplinary specialization and of larger epistemological debates about the definition of the human versus the natural sciences at the turn of the twentieth century.[8] As "natural historians," climatologists were caught in between the two sides, having to negotiate the deepening distinctions that academics and their institutions began to draw between inductive and deductive, and idiographic and nomothetic, approaches.[9] Climatology, straddling the fields of meteorology, physics, geology, geography, and history, incorporated many different methods and data sets, which led not only to a rich inter-disciplinary dimension of the work, but also to difficulties with data heterogeneity and data overload and, ultimately, to arguments about the future trajectory of the field.[10]

In this paper, I will first discuss Eduard Brückner's use of evidence in his *Climate Oscillations* before examining the larger discussions in the field over what kind of data and what kind of disciplinary approaches would be considered feasible and valid in climatological work. Finally, I will briefly outline the early influence of dynamic meteorology on some of the attempts to imagine a new kind of physical and dynamic climate science. Through this history of data debates and methodological critique, I will draw out some of the origins and implications of the period of disciplinary reevaluation up to 1930.

## Eduard Brückner's *Climate Oscillations*

Eduard Brückner was born in Jena in 1863 to the German-Russian historian Alexander and his wife. He spent most of his childhood and early teenage years in Russia, before his parents sent him to Karlsruhe to finish his secondary school education. After receiving his diploma, Brückner went on to study geology, geography, paleontology, physics, and history at the universities of Dorpat (Tartu in modern-day Estonia), Dresden, and Munich. As a doctorate student in Munich, he became one of the first advisees of the young

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[8] For a discussion of the connected histories and the historiographical separation of the humanities and the sciences, see the articles in the recent Isis focus section organized and introduced by Rens Bod and Julia Kursell: Rens Bod and Julia Kursell, "Introduction: The Humanities and the Sciences," *Isis* 106, no. 2 (June 1, 2015): 337–340; for a case study of the differences between historical and atmospheric approaches in late nineteenth-century Norway, see Gunnar Ellingsen's contribution in this volume.

[9] Cf.: Lynn K. Nyhart, "Wissenschaft and Kunde: The General and the Special in Modern Science," *Osiris* 27, no. 1 (January 1, 2012): 253; for the locus classicus of the distinction between nomothetic and idiographic approaches, see: Wilhelm Windelband, *Geschichte und Naturwissenschaft* (Strassburg: Heitz, 1894).

[10] On the long history of information and data overload, see: Brian W. Ogilvie, "The Many Books of Nature: Renaissance Naturalists and Information Overload," *Journal of the History of Ideas* 64, no. 1 (2003): 29–40; Daniel Rosenberg, "Early Modern Information Overload," *Journal of the History of Ideas* 64, no. 1 (2003): 1–9.

Albrecht Penck (1858-1945), who in his mid-twenties had already become famous for his glaciological work. Continuing along some of his advisor's lines of research, Brückner wrote his 1885 dissertation on the glaciation of the Salzach area in Austria. United by their common interests, Brückner and Penck would become frequent and prolific collaborators. Their joint work culminated in the three-volume study *Die Alpen im Eiszeitalter* ("The Alps During the Glacial Epoch"), whose final tome appeared in 1909.[11] Almost twenty-five years before this publication, Brückner had started his academic career at the Deutsche Seewarte – a governmental institute for maritime meteorology led by the climatologist Wladimir Köppen. It was there in Hamburg that Brückner developed his first preliminary hypothesis of climate cycles, which grew out of his observations of ongoing glacial oscillations with short periodicities. In 1888, he took up a professorship at the university in Bern and continued his climatological and glaciological work. After a short stint at the university of Halle from 1904 to 1906, Brückner became Albrecht Penck's successor at the university of Vienna, where he would stay and work until the end of his life in 1927.

Brückner's studies on climate oscillations – and indeed the development of nineteenth-century climatology as a whole – have to be placed in the context of disciplinary debates. When Brückner shifted his focus from glaciers to the less demarcated subject of "climate" in the 1880s, he joined an assorted assembly of practitioners with different disciplinary backgrounds and different approaches to the field. While the study of climatic phenomena already had a long history at that point, "climatology" was an emergent academic discipline in the late nineteenth century.[12] Its practitioners worked in the fields of geography, geology, and meteorology – disciplines that were themselves still in the process of finding a distinct identity in institutional academia.[13] One of the leading voices in the growing climatological community of the late nineteenth century was the Austrian Julius Hann, who authored the first large climatological textbook, in which he provided the often-cited definition of climate as the "mean condition of the atmosphere in a particular place at the surface of the earth."[14] While this 1883 description explicitly included the dimension of the atmosphere, both the local character of climate – its "particular place" – and the focus on the lowest strata of the atmosphere were central to the definition.

Hann's definition was by no means the only one at the time. "Climate" implied diverse parameters and disciplinary connections among the variety of geologists,

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[11] Albrecht Penck and Eduard Brückner, *Die Alpen im Eiszeitalter*, 3 vols. (Leipzig: Tauchnitz, 1909).

[12] For a recent overview article of the study of climates before the nineteenth century, see: Jean-Baptiste Fressoz and Fabien Locher, "L'Agir humain sur le climat et la naissance de la climatologie historique, XVIIe-XVIIIe siècles," *Revue d'histoire moderne et contemporaine* 62, no. 1 (2015): 48–78.

[13] On the history of disciplinary formation in the nineteenth century, see for instance: David Cahan, ed., *From Natural Philosophy to the Sciences: Writing the History of Nineteenth-Century Science* (Chicago: University of Chicago Press, 2003); on the development of the discipline of geography in Germany, see: Hans-Dietrich Schultz, *Die deutschsprachige Geographie von 1800 bis 1970: Ein Beitrag zur Geschichte ihrer Methodologie* (Berlin: Selbstverlag des Geographischen Instituts der Freien Universität Berlin, 1980).

[14] Julius von Hann, *Handbuch der Klimatologie* (Stuttgart: J. Engelhorn, 1883), 1; for the English version, see: Julius von Hann, *Handbook of Climatology*, trans. by Robert DeCourcy Ward (London: Macmillan, 1903); it is not without irony that Hann, who explicitly conceived of climatology as an auxiliary science to meteorology, was one of the most important figures in the disciplinary consolidation of the field.

botanists, medical doctors, colonial geographers, and others who worked with the term.[15] Alexander von Humboldt's 1845 description of climate as "changes [or "changeable parameters"] in the atmosphere that affect our organs in discernable ways" was still a frequently cited point of reference in the late nineteenth century, although by that time its practical significance was largely limited to the sub-field of medical meteorology.[16] Hann's definition, by contrast, was an attempt to distill the essence of the eclectic climatological work of the time. Still echoing Aristotelian conceptions, Hann described "climate" as a characteristic of a certain region and thus a feature of its geography. He also drew parallels to common geographic approaches by describing climatology as "more descriptive" compared to meteorology, which he deemed closer to the physical sciences.[17] Most nineteenth-century authors of climatological studies were indeed trained in the telluric fields of geology and geography. This common career trajectory was at least partly due to both questions of climatic changes arising from the geological debates about ice ages around the middle of the nineteenth century and the blossoming of geographical approaches in the context of a renewed imperial impulse in Europe around the same time.[18] Brückner himself combined his geological and geographical training in his ongoing work on glaciology, and he published his *Climate Oscillations* in a series of "Geographical Treatises" by the Vienna publishing house of Eduard Hölzel.

Although the book caused a stir in the climatological community, it was not a *deus ex machina* that suddenly introduced the issue of climatic instability and climatic variations to the field. Brückner was taking part in one of the defining debates of climatology in the late nineteenth century – especially among the active Germanophone community of practitioners.[19] Even in the early article version of the book – revealingly

[15] On the historical complexity of the term and the concept of "climate," see: James Rodger Fleming and Vladimir Jankovic, "Introduction: Revisiting Klima," *Osiris* 26, no. 1 (January 1, 2011): 1–15; on the same topic, see also James Rodger Fleming's contribution in this special issue.

[16] Alexander von Humboldt, *Kosmos: Entwurf einer physischen Weltbeschreibung*, vol. 1 (Stuttgart: Cotta, 1845), 340; see also: Karl-Heinz Bernhardt, "Alexander von Humboldts Auffassung vom Klima und sein Beitrag zur Einrichtung von meteorologischen Stationsnetzen," *Zeitschrift für Meteorologie* 34, no. 4 (1984): 213–217; Karl-Heinz Bernhardt, "Alexander von Humboldts Beitrag zu Entwicklung und Institutionalisierung von Meteorologie und Klimatologie im 19. Jahrhundert," *Algorismus* no. 41 (2003): 195–221.

[17] Hann, *Handbuch der Klimatologie*, 3.

[18] On the intellectual origins and the development of the ice age theory, see: Martin J. S. Rudwick, *Worlds Before Adam: The Reconstruction of Geohistory in the Age of Reform* (Chicago: University of Chicago Press, 2008), chap. 13, 34–36; Tobias Krüger, *Discovering the Ice Ages: International Reception and Consequences for a Historical Understanding of Climate* (Leiden: Brill, 2013); John Imbrie and Katherine Palmer Imbrie, *Ice Ages: Solving the Mystery* (Cambridge: Harvard University Press, 1986), 19–57; on the imperial context of the rise and formation of geography as an academic discipline in the nineteenth century, see: David N. Livingstone, *The Geographical Tradition: Episodes in the History of a Contested Enterprise* (Oxford, UK: Blackwell Publishers, 1993), 216–259; Felix Driver, *Geography Militant: Cultures of Exploration and Empire* (Oxford, UK: Blackwell Publishers, 2001); Sebastian Lentz and Ferjan Ormeling, eds., *Die Verräumlichung des Welt-Bildes: Petermanns geographische Mitteilungen zwischen "explorativer Geographie" und der "Vermessenheit" europäischer Raumphantasien.* (Stuttgart: F. Steiner, 2008).

[19] For some central documents from this debate, see: Theobald Fischer, *Studien über das Klima der Mittelmeerländer*, Ergänzungsheft zu Petermanns Geographischen Mitteilungen 58 (Gotha: J. Perthes, 1879); Franz von Czerny, *Die Veränderlichkeit des Klimas und ihre Ursachen* (Vienna: A. Hartleben, 1881); Theobald Fischer, "Zur Frage der Klima-Änderung im südlichen Mittelmeergebiet und in der nördlichen Sahara," *Petermanns Mitteilungen aus Justus Perthes' Geographischer Anstalt* 29 (1883): 1–4;

entitled "In How Far is Today's Climate Stable?" – Brückner emphasized that his contribution was to be seen against the background of the debate on climate change and variation in historic times – a debate that was directly questioning the definition of climates as stable, long-term averages of atmospheric conditions.[20] Indeed, Brückner believed that he had solved the issue by showing that the apparent unidirectional or progressive changes of climate that his colleagues identified were simply the up or, alternatively, the down of one climatological cycle.[21] His work was nevertheless neither the beginning nor the end of the debate, as variability continued to be one of the defining objects of climatological investigation. Despite Hann's insistence of climatology as a science of averages and means, even the *Handbook* author himself – just like Alexander von Humboldt before him – took changes and variations to be defining characteristics of climates.[22] This gave another impetus to researchers attempting to identify weather anomalies and their relation to larger processes of climatic change.[23]

The research into climatic variability posed serious challenges to climate scientists in the late nineteenth century. The network of meteorological stations was fast expanding around the globe, but the stations could only provide data series for certain parameters, like precipitation and temperature, and covered limited time periods.[24] For any information on the past conditions of climates – so vital for the debates on climatic changes – practitioners had to turn to alternative sources, which often included textual evidence from past centuries, eyewitness accounts, and any kind of material sources that promised information on past environmental conditions. With its collection from vintage date records to descriptions of harsh winters, Brückner's work was thus an outstanding example of the eclectic climatological approach of the time, still praised forty years later for its use of diverse datasets to shed light on climatic conditions before the existence of reliable meteorological records.[25]

The inclusion of all kinds of different data in climate studies, however, was not a response born solely of necessity. Rather, it was in accordance with the tradition of nineteenth-century geography to combine the available quantitative information with

Joseph Partsch, "Über den Nachweis einer Klimaänderung der Mittelmeerländer in geschichtlicher Zeit," in *Verhandlungen des VIII. deutschen Geographentages* (Berlin: W. Pormetter, 1889), 116–125; see also: Moritz Flügel, Nico Stehr, and Hans von Storch, "The 19th Century Discussion of Climate Variability and Climate Change: Analogies for the Present Debate?," *World Resource Review* 7, no. 4 (1995): 589–605.

[20] Brückner, *In wie weit ist das heutige Klima konstant?*, 101.

[21] Brückner, *Klimaschwankungen seit 1700*, 288–289.

[22] In the third edition of Hann's handbook, the part about climatic variability made up more than 40 pages and included discussions of the theories of Brückner, Arrhenius, and James Croll, among others; see: Julius von Hann, *Handbuch der Klimatologie*, 3rd ed. (Stuttgart: J. Engelhorn, 1908), 345–388.

[23] Cf.: Deborah R. Coen, "Climate and Circulation in Imperial Austria," *The Journal of Modern History* 82, no. 4 (December 1, 2010): 846.

[24] See: Katharine Anderson, *Predicting the Weather: Victorians and the Science of Meteorology* (Chicago: University of Chicago Press, 2005); on the development of nineteenth-century meteorological observation in Europe and, in particular, in France, see: Fabien Locher, *Le savant et la tempête: étudier l'atmosphère et prévoir le temps au XIXe siècle* (Rennes: Presses universitaires de Rennes, 2008); on the development of meteorological observations in Germany in the nineteenth and twentieth centuries, see: Klaus Wege, *Die Entwicklung der meteorologischen Dienste in Deutschland* (Offenbach am Main: Deutscher Wetterdienst, 2002); see also: James Rodger Fleming, *Historical Perspectives on Climate Change* (New York: Oxford University Press, 1998), 33–44.

[25] See, for example: Karl Knoch, *Klima und Klimaschwankungen* (Leipzig: Quelle & Meyer, 1930), 124–125.

qualitative sources – and natural scientific with humanistic evidence – to achieve a holistic representation of the *Ganzheit*, or the "whole," of the landscape or region in question.[26] This holistic approach was also evident in Brückner's work. In *Climate Oscillations*, he presented his diverse data in the form of text, tables, and graphs. While detailed descriptions of datasets were still the norm in climatological writing – a practice that the lengthy *Climate Oscillations* exemplified – Brückner also increasingly used visual representations to bring across his points. In his data tables, he showcased the impressive chronological and thematic range of his evidence – in one example, and on one single page, presenting his use of data of grave harvest dates, the frequencies of cold winters, and ice conditions in rivers, lakes, and glaciers in Europe over a period of nearly nine hundred years (Fig. 1). To visualize the climatic oscillations and to highlight their global extent beyond the European continent, Brückner used line-graphs that showed the fairly synchronous ups and downs of the climatic cycles on different continents and a curve for the "entire earth" produced by the averaging of local numerical data (Fig. 2). With his use of line graphs, Brückner also attempted to demonstrate the regularity and wave-like characteristics of the climatic fluctuations (*Schwankungen*), a term he used interchangeably with the loanword "oscillations" (*Oszillationen*) from the physical sciences.

[26] See: Geoffrey J. Martin and T. S. Martin, *All Possible Worlds: A History of Geographical Ideas*, 4th ed. (New York: Oxford University Press, 2005), 7–8; for an account of the subjects and methods of nineteenth-century geography, see: R. D. Dikshit, *Geographical Thought: A Contextual History of Ideas* (New Delhi: Prentice-Hall of India, 1997); as Dikshit argues on pp. 63-65, geography itself underwent a "crisis of identity" in the late nineteenth century, as its holistic methods came into conflict with a more general move towards disciplinary specialization; for a discussion of the notion of "unity" in German geographical thought, see: Richard Hartshorne, *The Nature of Geography: A Critical Survey of Current Thought in the Light of the Past* (Lancaster: Association of American Geographers, 1949), 264–267.

Säkulare Schwankungen des Klimas

| | dargestellt durch die Schwankungen: der Weinerte | der Häufigkeit kalter Winter | der Eisverhältnisse der Flüsse | der Seen | der Gletscher | Dauer d. Perioden: nach dem Term. der Weinernte | nach der Häufigk. kalter Winter |
|---|---|---|---|---|---|---|---|
| warm | — | 1020—40 | — | — | — | — | — |
| kalt | — | 40—55 | — | — | — | — | 35 |
| warm | — | 55—65 | — | — | — | — | 25 |
| kalt | — | 65—80 | — | — | — | — | 25 |
| warm | — | 80—05 | — | — | — | — | 40 |
| kalt | — | 1105—30 | — | — | — | — | 50 |
| warm | — | 30—45 | — | — | — | — | 40 |
| kalt | — | 45—65 | — | — | — | — | 35 |
| warm | — | 65—75 | — | — | — | — | 30 |
| kalt | — | 75—90 | — | — | — | — | 25 |
| warm | — | 90—00 | — | — | — | — | 25 |
| kalt | — | 1200—30 | — | — | — | — | 40 |
| warm | — | 30—45 | — | — | — | — | 45 |
| kalt | — | 45—55 | — | — | — | — | 25 |
| warm | — | 55—70 | — | — | — | — | 25 |
| kalt | — | 70—90 | — | — | — | — | 35 |
| warm | — | 90—10 | — | — | — | — | 40 |
| kalt | — | 1310—25 | — | — | — | — | 35 |
| warm | — | 25—50 | — | — | — | — | 40 |
| kalt | — | 50—70 | — | — | — | — | 45 |
| warm | — | 70—85 | — | — | — | — | 35 |
| kalt | 1391—15 | 85—05 | — | — | — | — | 35 |
| warm | 1416—35 | 1405—25 | — | — | — | 45 | 40 |
| kalt | 36—55 | 25—55 | — | — | — | 40 | 50 |
| warm | 56—80 | 55—75 | — | — | — | 45 | 50 |
| kalt | 81—95 | 75—95 | — | — | — | 40 | 40 |
| warm | 96—10 | 95—05 | — | — | — | 30 | 30 |
| kalt | 1511—15 | 1505—20 | — | — | — | 20 | 25 |
| warm | 16—40 | 20—35 | — | — | — | 30 | 30 |
| kalt | 41—50 | 35—45 | — | — | — | 35 | 25 |
| warm | 51—60 | 45—55 | — | — | — | 20 | 20 |
| kalt | 61—80 | 55—70 | 1556—65 | — | — | 30 | 25 |
| warm | 81—90 | 70—90 | 66—85 | — | — | 30 | 35 |
| kalt | 1591—00 | | 86—00 | 1600 [1] | 1595—10 | 20 | |
| warm | 1601—10 | | 1601—20 | — | — | 20 | |
| kalt | 11—35 | | 21—25 | 38 [2] | — | 35 | |
| warm | 36—45 | | — | 56 [3] | — | 35 | |
| kalt | 45—65 | | 1651—67 | 74 [4] | Zunahme | 30 | |
| warm | 65—90 bz. 85 | | — | 83 [5] | 1677—81 und | 40 | |
| kalt | 1691—05 | 1685—05 | 1702—20 | 1707—14 [6] | 1710—16 | 30 | 40 |
| warm | 1706—35 | 1705—30 | 21—35 | um 1720 | — | 45 | 45 |
| kalt | 36—59 | 30—50 | 36—50 | um 40 | — | 50 | 45 |
| warm | 56—65 | 50—65 | 51—70 | um 60 | 50—67 | 30 | 35 |
| kalt | 66—75 | 65—75 | 71—90 | um 80 | 60—86 | 20 | 25 |
| warm | 76—05 | — | 91—05 | um 1800 | um 1800 | 40 | — |
| kalt | 1806—20 | — | 1806—20 | um 20 | 1800—15 | 45 | — |
| warm | 21—35 | — | 21—30 | um 35 | 15—30 | 30 | — |
| kalt | 36—55 | — | 31—60 | um 50 | 30—45 | 35 | — |
| warm | 56—75 | — | warm | um 65 | 45—75 | 30 | — |
| kalt | 76—90 | — | 1861-80 | um 80 | 75—90 | 35 | — |

[1] Fuciner und Trasimener See.
[2] Kaspisches Meer, doch nur hoher Stand, verglichen mit dem Stand 1715/20.
[3] Fuciner See.
[4] Neusiedler See.
[5] Fuciner See.
[6] Zirknitzer See, Kaspisches Meer.

**Fig. 1:** "Secular oscillations of the climate represented by the oscillations of the grape harvest, the frequency of cold winters, and the ice conditions in rivers, lakes, and glaciers," representing data from 1020 to 1890 (Brückner, *Klimaschwankungen seit 1700*, 271).

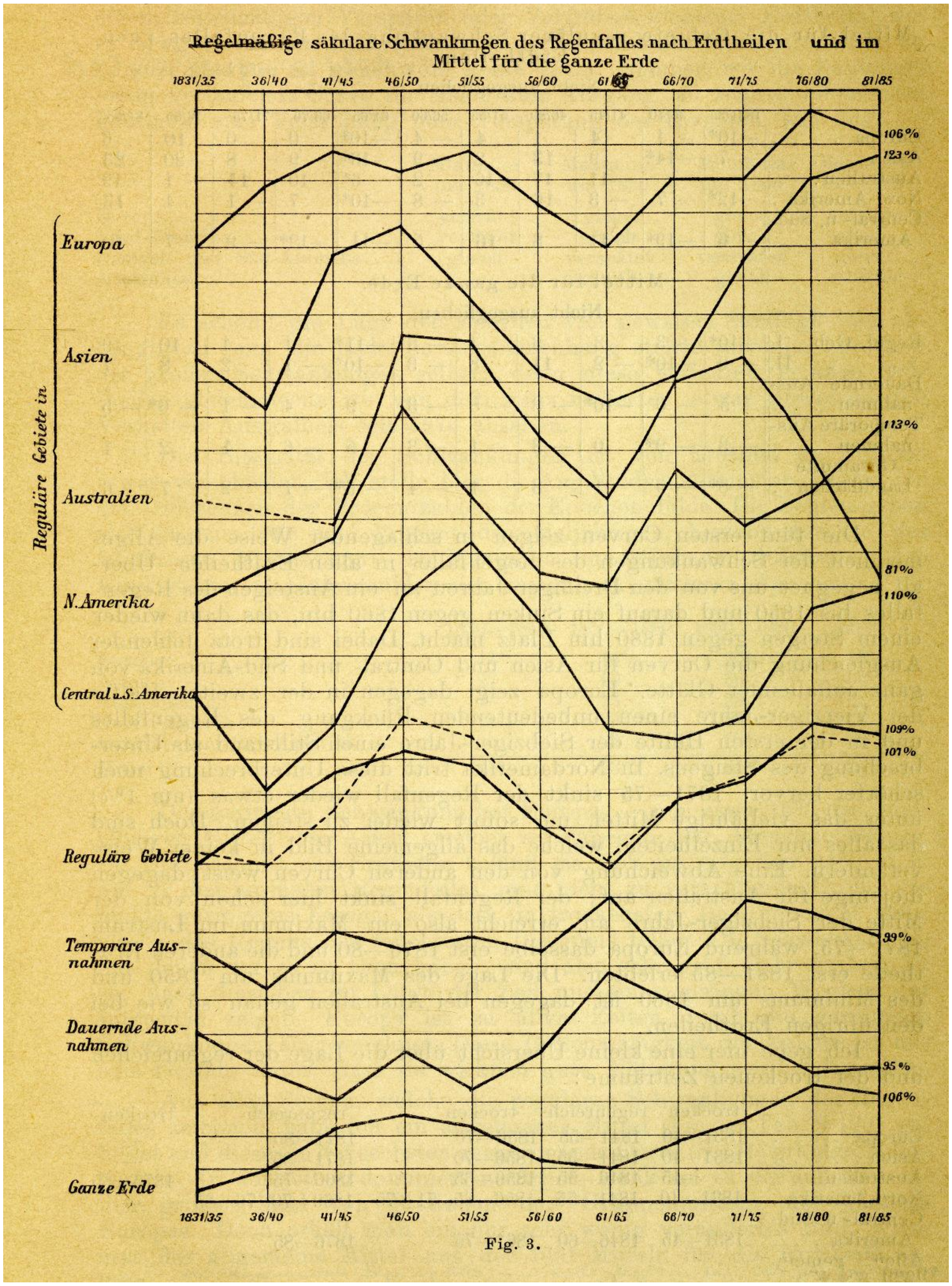


**Fig. 2:** "Regular secular oscillations of rainfall sorted by continent and as a mean for the entire earth" representing data from 1831-1885 (Brückner, *Klimaschwankungen seit 1700*, 171).

In other aspects of his work, however, Brückner looked to different disciplines for inspiration. His holistic approach to the study of climate explicitly included social, economic, and political dimensions. He introduced his 1889 presentation with a reference to the "deep impact" that climatic changes would have on "the entire existence and activities of mankind."[27] He then spent three of the remaining thirteen pages discussing the potential impact of climatic variations on agriculture and economy, correlating climatic cycles with cycles in production and trade.[28] In the book version and a following article, Brückner repeated the concerns, deepening the discussion of a correlation between climatic and economic cycles.[29] This correlation had been the subject of a number of articles in the late eighteenth century, among them notable contributions by the economist William Stanley Jevons.[30] And the topic would continue to be of interest in the early twentieth century, when the geographer and climatologist Ellsworth Huntington wrote on "climatic variations and economic cycles" after reading Brückner's work.[31]

Going beyond the question of economic cycles, Brückner also widened the extent of his analysis by including discussions of the particular vulnerability of arid regions to climatic fluctuations and the observed influence of climate variations on the frequency of disease.[32] The scope of Brückner's work was large, both in its use of diverse kinds of data from around the world and its explicit connections to human concerns. Climate, for him, was not just a physical phenomenon to be described by scientists, but a powerful force with deep socio-economic and cultural repercussions. Nineteenth-century climatology – just like the Victorian meteorology that Katharine Anderson has described in detail – displayed a marked "emphasis on the integration of culture."[33]

## Data Debates

The inclusive approach of Brückner's work was not out of the ordinary in nineteenth-century climatological studies. In fact, the eclectic methods to gather historical information from various sources were part of the familiar methodology of the *Altertumswissenschaften*, or classical studies, upon which European university education was built. As diverse as the views of different practitioners were, they shared the common vocabulary of the Greek and Latin canon and were accustomed to working with *Hilfswissenschaften*, or "auxiliary sciences," that could provide the evidence and data to allow glimpses of the distant past beyond the relatively short records of standardized, quantitative data from meteorological stations (see, for instance, the limited chronological scope of rainfall data in Fig. 2).

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[27] Brückner, *In wie weit ist das heutige Klima konstant?*, 101: "Solche [Klimaänderungen] aber könnten nicht ohne den tiefgehendsten Einfluss auf das ganze Leben und Treiben des Menschengeschlchts bleiben."
[28] Ibid., 110–112.
[29] Eduard Brückner, "Der Einfluß der Klimaschwankungen auf die Ernteerträge und Getreidepreise in Europa," *Geographische Zeitschrift* 1, no. 1 (January 1, 1895): 39–51.
[30] For Jevons' work on the sunspot-commerce correlation, see among other articles: William Stanley Jevons, "Commercial Crises and Sun-Spots," *Nature* 19, no. 472 (1878): 33–37; William Stanley Jevons, "The Solar Commercial Cycle," *Nature* 26 (1882): 226–228; Brückner referred to William Stanley Jevons' work on trade and business cycles, but refuted all correlation between the 35-year climate cycle and sunspot variation; see: Brückner, *Klimaschwankungen seit 1700*, 289, 292, 301–302, 324; on the role of the sunspot debate in the development of statistics, see: Theodore M. Porter, *The Rise of Statistical Thinking, 1820-1900* (Princeton: Princeton University Press, 1986), 274–278.
[31] Ellsworth Huntington, "Climatic Variations and Economic Cycles," *Geographical Review* 1, no. 3 (1916): 192–202.
[32] Brückner, *Klimaschwankungen seit 1700*, 272–283.
[33] Anderson, *Predicting the Weather*, 4; on climate-culture links in the nineteenth and twentieth centuries, see also: James Rodger Fleming and Vladimir Jankovic, eds., *Klima*, vol. 26, Osiris (Chicago: University of Chicago Press, 2011).

The ensuing diversity of evidence, however, still posed great challenges, which led to the "grave confusion" that Brückner perceived in climate change debates of the late nineteenth century.[34] In *Climate Oscillations*, Brückner took inventory of the many different opinions about climate variations, listing the sometimes-ambiguous source material from historical accounts about the disappearance of oases to viticultural geography, and calling into question the validity of some of the proposed evidence.[35] The critique pointed to more general questions: how could climatologists compare the commonly cited descriptions of North African environments by Herodotus to colonial data series of precipitation and barometric pressure from the nineteenth century? How could they square the often-contradictory accounts about climatic conditions written by imperial explorers? And how could they sort "good" from "bad" data, when the evaluation required intimate knowledge in areas as far apart as modern meteorological technology and the exegesis of classical Greek geographical treatises?

These questions could not be brushed aside easily. After all, the contentious debate over climatic changes and variations was in full swing in the late nineteenth century. Based on descriptions by past and present explorers of the Mediterranean region and North Africa, the German geographer Theobald Fischer and some of his colleagues argued for an ongoing expansion of desert conditions, which could not be explained solely through human action. The immediate reactions to these claims were divided into three distinct groups: there were the contributions that agreed and mused about various geological or cosmic causes for large climatic changes; those that agreed with the finding of large climatic changes, but found human actions, such as deforestation or the destruction of irrigation works, sufficient to explain the phenomena; and finally those that argued against any major climatic change having taken or taking place in either North Africa, the Mediterranean, or anywhere else around the globe.[36]

The contributors to the debate frequently attacked their opponents by claiming reliance on untrustworthy, incompatible, or unstandardized evidence, but often had to rely on the very same data for information on past climates. Franz von Czerny, for instance, lamented in 1887 that the "young science of meteorology" could not yet provide sufficient – and sufficiently reliable – data from past centuries for conclusive climatological answers; but he still used the existence of ruins in desert regions as evidence to bolster claims that the climate had, in fact, changed during historical times.[37] Authors on different sides of the debate would sometimes even use the same or similar evidence to back up widely divergent or even contradictory arguments, further demonstrating the problems of historical proxy data. The travelogues of the German Sahara explorer Heinrich Barth, for example, were used to argue both for and against an ongoing desiccation in the region.[38] And in an attempted overview of the climate change

[34] Brückner, *In wie weit ist das heutige Klima konstant?*, 115.
[35] Brückner, *Klimaschwankungen seit 1700*, 10–49.
[36] See footnote #19.
[37] Czerny, *Die Veränderlichkeit des Klimas und ihre Ursachen*, 1–4.
[38] See: Heinrich Barth, *Wanderungen durch das punische und kyrenäische Küstenland oder Mâg'reb, Afrikîa und Barka*, 2 vols. (Berlin: Wilhelm Hertz, 1849); Heinrich Barth, *Reisen und Entdeckungen in Nord- und Central-Afrika in den Jahren 1849 bis 1855*, 5 vols. (Gotha: Justus Perthes, 1857); for the use of Barth's writings in support of climatic changes in North Africa, see, for instance: Fischer, *Studien über das Klima der Mittelmeerländer*, 44; Fischer, "Klima-Änderung im südlichen Mittelmeergebiet und in der nördlichen Sahara," 3–4; for the use of Barth's writings against theories of progressive climatic changes in

debate, Brückner himself highlighted the fact that it "seems almost like a psychological puzzle, that for one and the same country serious scientists have at every step insisted on climate changes which are mutually exclusive."[39] Despite claims by Czerny and others that there was not *enough* material to arrive at a consensus over potential climatic instability, the diversity of the evidence used in the debate shows that practitioners were actually confronted with a large – and always growing – wealth of sometimes-ambiguous data.

This issue of heterogeneous data made practitioners vulnerable to attacks questioning the commensurability and trustworthiness of the evidence used. To deal with the difficulties, Hann sometimes focused on delimited, particular localities to extrapolate universal climatic rules. One instance of this approach was his generalization of climatic conditions in mountainous regions constructed on the basis of information of one particular stretch of the Alps.[40] Similarly, Brückner extrapolated his universal climate cycles from his findings in Europe, for which he had the most complete datasets (Fig. 1). While the available historic data on grape harvests and the incidence of cold winters only gave evidence about European conditions, he argued, "we should not disguise the fact that indirectly [the proof] is of universal significance around the globe."[41] This is not to say that Brückner did not try hard enough to get information from other parts of the world. In fact, he collected as much evidence as he could, but then ended up having to bend some of the data to fit his inductive model of universal 35-year climatic cycles.[42]

The biggest problem, however, persisted despite the effort of climatologists to bring order into their varied datasets: while the existing evidence could be marshaled to point to the presence of one or another kind of climatic change or oscillation, the potential causes for these processes were not inherent in the data. And without a convincing explanatory mechanism, the debate over climate change was set to continue without a generally accepted resolution. Despite their interpretative differences, all sides of the debate were unified by an omnipresent uncertainty and evasiveness when it came to the discussion of the potential mechanism behind climatic changes. Practitioners marshaled competing hypotheses about solar influences, changes in land elevation, changes in oceanic circulation, shifts in the shape of the earth's orbit, changes in the earth's axis alignment, the impact of volcanic activity, and human action. None of these explanations could gather unified support, as the causal models remained not only based on different and sometimes contradictory data sets, but also unverifiable.[43] Brückner, for

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the region, see, for instance: Hermann Leiter, *Die Frage der Klimaänderung während geschichtlicher Zeit in Nordafrika*, Abhandlungen der k. k. Geographischen Gesellschaft in Wien 8 (Vienna: R. Lechner, 1909).

[39] Brückner, *Klimaschwankungen seit 1700*, 34–35; the English translation is taken from: Eduard Brückner, "Climate Change Since 1700," in *Eduard Brückner: The Sources and Consequences of Climate Change and Climate Variability in Historical Times*, ed. by Hans von Storch and Nico Stehr (Dordrecht: Kluwer Academic Publishers, 2000), 117–118.

[40] Julius von Hann, *Die Temperaturverhältnisse der österreichischen Alpenländer* (Vienna: Kaiserliche Akademie der Wissenschaften, 1884); this case is described in: Coen, "Climate and Circulation in Imperial Austria," 856–857.

[41] Brückner, *Klimaschwankungen seit 1700*, 272 [my translation].

[42] One case in point was Brückner's treatment of incongruities of European rainfall data from the eighteenth century; see: Ibid., 266–267; for the English translation of this part, see: Brückner, "Climate Change Since 1700," 160–161.

[43] For a short overview of the competing theories, see: Spencer Weart, *The Discovery of Global Warming* (Cambridge: Harvard University Press, 2003), 1–18; see also: Fleming, *Historical Perspectives on Climate*

all of his detailed work in gathering meteorological and climatological evidence and in performing data analyses, sounded vague in discussing the mechanisms behind his proposed thirty-five year cycles. In the short section on the subject in his book, he elusively expressed his "conjecture that processes on the sun may possibly be the cause of the climatic oscillations."[44]

In his attempts to define climatology, Julius Hann had considered the possibility of describing it as a descriptive sub-field of meteorology, but the short shrift given to causal mechanisms was not – or at least not only – because all climatologists freely chose to delimit their work in this way.[45] Rather, climatology was forced to be a descriptive discipline, because explanatory hypotheses could not be tested or substantiated. On the one hand, *cosmic* theories of climatic changes often lacked sufficient data. On the other, the investigation of potential *telluric* causes for climatic changes was often hampered by the mass of heterogeneous and controversial data from different environments, which made any attempt at constructing syntheses or viable models difficult.[46] This conundrum led some climatologists to review their own data practices. One year before the publication of Brückner's main study, Joseph Partsch had already criticized the "uncertainties of method" among climatologists in dealing with historical information. While Partsch – trained as a geographer, philologist, and historian – conceded that the historical methods were indispensable for climate scientists, he saw a lack of standardized guidelines for the interpretation of historical evidence and the undue focus on reports on weather extremes as some of the main issues.[47] A few years later, Wladimir Köppen mirrored Partsch's critique by casting doubt on the accuracy and comparability of historical accounts of climates: with an illustrative example of classical descriptions of Northern Europe, Köppen highlighted the fact that cultural evaluations often influenced the characterization of climatic conditions.[48]

Brückner himself joined the critics in likening his overview of the literature on climatic changes to "[walking] through a veritable labyrinth without the benefit of Ariadne's clew."[49] After the turn of the century, the criticism of climatological methods

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*Change*, 65 ff; Nico Stehr and Hans von Storch, *Klima, Wetter, Mensch* (Opladen: Barbara Budrich, 2010), 77–79; Robert P. Beckinsale, Richard J. Chorley, and J. Dunn, eds., *The History of the Study of Landforms, or, the Development of Geomorphology*, vol. 3 (London: Routledge, 1991), 48–56; André Berger, "A Brief History of the Astronomical Theories of Paleoclimates," in *Climate Change*, ed. by André Berger, Fedor Mesinger, and Djordje Sijacki (Vienna: Springer, 2012), 107–129.

[44] Brückner, *Klimaschwankungen seit 1700*, 240 [my translation].

[45] Hann, *Handbuch der Klimatologie*, 2–3.

[46] I am using "models" here in the sense of collections of observations and rules and not in the more narrowly defined sense of Paul Edwards as "mathematical simulations, based on physical principles, of […] long-term atmospheric conditions." Paul N. Edwards, "Representing the Global Atmosphere: Computer Models, Data, and Knowledge About Climate Change," in *Changing the Atmosphere: Expert Knowledge and Environmental Governance*, ed. by Clark A. Miller and Paul N. Edwards (Cambridge: MIT Press, 2001), 31–65; for an example of early modeling, see for instance: Vladimir Janković, "Climates as Commodities: Jean Pierre Purry and the Modelling of the Best Climate on Earth," *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 41, no. 3 (September 2010): 201–207.

[47] Partsch, "Über den Nachweis einer Klimaänderung der Mittelmeerländer."

[48] Wladimir Köppen, "Die gegenwärtige Lage und die neueren Fortschritte der Klimatologie," *Geographische Zeitschrift* 1 (1895): 625.

[49] Brückner, *Klimaschwankungen seit 1700*, 34; the English translation is taken from: Brückner, "Climate Change Since 1700," 115.

and results became even more outspoken. In 1901, the Swedish meteorologist Nils Ekholm reflected on the impossibility to draw any definite conclusions about climatic changes in the historical past:

> It remains to consider the variations of the climate during the historical period. Here we certainly find a richer material of observations than before, but at the same time such a want of order and regularity that it seems at present nearly impossible to obtain a survey of and establish a connection between the shifting phenomena. Here we cannot see the wood for trees. First, during the last hundred or hundred and fifty years, since there began to be regular meteorological observations, the survey becomes easier; but then, on the other hand, the time is too short, so that from this reason no reliable conclusions can be drawn. Moreover, the material is so rich that the energy of a single man is insufficient to work it out.[50]

A few pages later Ekholm referred to the meteorological data series from various European cities, concluding that "[w]hether the climatic variations during the last 100 or 150 years here considered are periodic, progressive, or accidental cannot yet be decided."[51] This was, among other things, an attack on Brückner's conclusions.

While Ekholm's summary may say more about his own cautious stance in the climate change debate than represent an unbiased overview, his insistence on data issues is telling. It was not so much a lack of data, but rather the overly "rich material" in climatology that Ekholm deplored. The diverse data drawn from different times, sources, and places represented an astounding archive of information; but for climatologists who aspired to establish their still young field in the academic landscape, this eclectic and heterogeneous archive of non-standardized data was also difficult to deal with. It offered a wealth of data, but little hope for clear-cut answers and causal explanations.

**Towards a Dynamic Climatology?**

The debates among practitioners about the collection, analysis, and interpretation of diverse data sets heralded a period of disciplinary uncertainty, which opened up a number of potential avenues for the study of climatic phenomena in the early twentieth century. One of these avenues led towards a convergence – or, rather, an *anticipated* convergence – with new approaches in physical meteorology and, thus, to a shift of focus away from Brückner's eclectic archive of historical weather information and towards a bias for physics, causal models, and the upper realms of the atmosphere.

This is neither to say that the field of climatology underwent a sudden transformation nor that approaches and practices in meteorology were uncontroversial and uniform. In any case, the borders between the two fields remained amorphous, or at least blurred, with many practitioners working on both issues of weather *and* climate. Nineteenth-century meteorology had struggled with some of the same data, issues, and approaches – and thus, some of the same difficulties – as climatological studies.

[50] Nils Ekholm, "On the Variations of the Climate of the Geological and Historical Past and Their Causes," *Quarterly Journal of the Royal Meteorological Society* 27, no. 117 (1901): 46; a digital version of this article can be accessed at: http://nsdl.library.cornell.edu/websites/wiki/index.php/PALE_ClassicArticles/GlobalWarming.html (item #5).

[51] Ibid., 59.

Moreover, the status of climatology continued to be ambiguous, perceived alternatively as an independent field of inquiry necessary for the construction of meteorological theories, or as an auxiliary science to meteorology.[52] And nineteenth-century meteorology, just like climatology, grappled with the role and methodological function of the new science of statistics and with its own acceptance as an exact science within the academic community.[53] Cleveland Abbe summarized his view of the shortcomings of his discipline in a sweeping critique in 1895: "Hitherto, the professional meteorologist has too frequently been only an observer, a statistician, an empiricist - rather than a mechanician, mathematician and physicist."[54]

By that time, however, the criticism's sweeping claim was not applicable to the whole field of meteorology anymore: distancing themselves from purely empirical and inductive approaches, some nineteenth-century physical meteorologists had attempted to move towards Abbe's ideals and had established a "theoretical tradition" in meteorology.[55] As Katherine Anderson has shown, these practitioners already dealt with "accounts of the dynamics of the atmosphere," while the bulk of climatological work continued to be beholden to the telluric sciences and the Hippocratic focus on place and nature.[56] The ongoing disciplinary discussions around climate change debates around the turn of the century, however, challenged this distinction. Some climatologists started to envision their field turning away from the eclectic archives of terrestrial, historical evidence and towards the atmosphere in search for causal mechanisms behind climatic phenomena. They looked to developments in dynamic meteorology as an opportunity to gain more insight into global climatic dynamics and to refashion their own field of study along the lines of new developments in the study of weather.

The growing emphasis on atmospheric dynamics was becoming an increasingly viable avenue of research with the continuing international efforts for a coordinated collection and standardization of quantifiable data from meteorological stations and the development of atmospheric circulation models:[57] William Ferrel had worked on general circulation as early as the 1850s.[58] And Vilhelm Bjerknes – prodded by none other than Ekholm to start working in the field of geophysics – began to develop his influential model of a "general circulation theorem" in the 1890s, before publishing his seminal article on "The Problem of Weather Prediction, Regarded from the Vantage Point of

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[52] Hann himself referred to this ambiguity by describing a wider and a narrower way of conceptualizing meteorology; see: Hann, *Handbook of Climatology*, 2.

[53] See: Anderson, *Predicting the Weather*, 131–170; Frederik Nebeker, *Calculating the Weather: Meteorology in the 20th Century*, International Geophysics Series 60 (San Diego: Academic Press, 1995), 21–24.

[54] Cited in: Nebeker, *Calculating the Weather*, 28.

[55] The term is borrowed from: Ibid., 27–35.

[56] Anderson, *Predicting the Weather*, 8; on seventeenth- and eighteenth-century ideas of weather and climate, which continued to be important in the nineteenth century, see: Vladimir Janković, *Reading the Skies: A Cultural History of English Weather, 1650-1820* (Manchester: Manchester University Press, 2000); Jan Golinski, *British Weather and the Climate of Enlightenment* (Chicago: The University of Chicago Press, 2007).

[57] As Paul Edwards points out, the collection and standardization of meteorological data from around the world did not always go smoothly; see: Paul N. Edwards, "Meteorology as Infrastructural Globalism," *Osiris* 21, 2nd Series (January 1, 2006): 229–250; the International Meteorological Organization (later World Meteorological Organization or WMO), founded in 1873 nevertheless held the promise for a bright future of standardized and global data sets.

[58] See: William Ferrel, *An Essay on the Winds and the Currents of the Ocean* (Cameron & Fall, 1856).

Mechanics and Physics" in 1904.[59] In just seven pages, Bjerknes laid out an integrated approach in dynamic meteorology, combining theoretical and practical dimensions.[60] Remarkably, Bjerknes managed to do that without a single equation, which may have contributed to the widespread reception of the article. And while Bjerknes conceived of his work explicitly as a response to the "prognosis problem of meteorology" – or what James Fleming describes as the "Gordian Knot" of meteorology in this volume – the disciplinary developments caught the eye of scientists working on *climatic* issues as well.[61]

In an 1895 review article about the state of his field, Köppen had already described the "general circulation of the atmosphere" as one of the "central issues of climatology."[62] He cited a long and eclectic tradition of work on atmospheric circulation from William Ferrel, the Norwegians Henrik Mohn and Cato Maximilian Guldberg, to the German physicist and industrialist Werner Siemens.[63] For Köppen, this emphasis on atmospheric processes also meant that climatology was moving closer towards meteorology, with the "geographical element taking a backseat."[64] And it was from these meteorological investigations into atmospheric dynamics that Köppen expected "light," or new impulses and insights, for climatology.[65]

The disciplinary developments in climatology that would eventually bring the discipline over to the field of atmospheric physics were slow and would only come to full fruition in the second half of the twentieth century, where many accounts of modern climate science begin.[66] Bjerknes himself still lacked both computational capacity and sufficient data on atmospheric conditions to make full use of his mathematical models of

[59] Vilhelm Bjerknes, "Über einen hydrodynamischen Fundamentalsatz und seine Anwendung besonders auf die Mechanik der Atmosphäre und des Weltmeeres," *Kungl. Svenska Vetenskaps-Akedemiens Handlingar* 31 (1898): 1–35; Vilhelm Bjerknes, "Das dynamische Princip der Cirkulationsbewegungen in der Atmosphäre," *Meteorologische Zeitschrift* 17 (1900): 97–106; Vilhelm Bjerknes, "Das Problem der Wettervorhersage, betrachtet vom Standpunkte der Mechanik und der Physik," *Meteorologische Zeitschrift* 21 (1904): 1–7; Vilhelm Bjerknes et al., *Dynamic Meteorology and Hydrography*, 2 vols. (Washington, DC: Carnegie Institution of Washington, 1910); Vilhelm Bjerknes, "The Structure of the Atmosphere When Rain is Falling," *Quarterly Journal of the Royal Meteorological Society* 46, no. 194 (1920): 119–140; on Bjerknes' influence on twentieth-century meteorology, see: Robert Marc Friedman, *Appropriating the Weather: Vilhelm Bjerknes and the Construction of a Modern Meteorology* (Ithaca: Cornell University Press, 1989); Alan J. Thorpe, Hans Volkert, and Michal J. Ziemianski, "The Bjerknes' Circulation Theorem: A Historical Perspective," *Bulletin of the American Meteorological Society* 84, no. 4 (2003): 471–480; Sigbjørn Grønås, "Vilhelm Bjerknes' Vision for Scientific Weather Prediction," in *The Nordic Seas: An Integrated Perspective. Oceanography, Climatology, Biogeochemistry, and Modeling*, ed. by Helge Drange et al. (Washington, DC: American Geophysical Union, 2005), 357–366; Gabriele Gramelsberger, "Conceiving Meteorology as the Exact Science of the Atmosphere: Vilhelm Bjerknes's Paper of 1904 as a Milestone," *Meteorologische Zeitschrift* 18, no. 6 (2009): 669–673.

[60] Cf.: Gramelsberger, "Conceiving Meteorology," 672; see also: Nebeker, *Calculating the Weather*, 47–57.

[61] Bjerknes, "Das Problem der Wettervorhersage," 1; for Fleming's description of Bjerknes' contribution to unravelling the Gordian Knot of meteorology, see his contribution in this volume.

[62] Köppen, "Die gegenwärtige Lage und die neueren Fortschritte der Klimatologie," 626.

[63] On Mohn's approach to climatology, see Gunnar Ellingsen's article in this volume.

[64] Köppen, "Die gegenwärtige Lage und die neueren Fortschritte der Klimatologie," 627.

[65] Ibid.

[66] See, for instance: Weart, *The Discovery of Global Warming*; in his recollections, the climatologist Joseph Smagorinsky also dated the shift of climatology from "a branch of descriptive geography to one of quantitative physical science" to the late 1950s; see: J. Smagorinsky, "The Beginnings of Numerical Weather Prediction and General Circulation Modeling: Early Recollections," *Advances in Geophysics* 25 (1983): 36.

atmospheric dynamics.[67] He avowed in 1904 that "a strict analytical integration" of the equations was not possible and proposed the use of graphical methods to solve his own multivariable equations.[68] After his return from Germany to Norway in 1917, Bjerknes told his colleague Arrhenius that the dynamic approach in meteorology was still far from becoming an applied tool or – in his own words – "[t]here is still a long way to go to anything practical."[69] Arrhenius himself had voiced similar concerns about dynamic meteorology in 1903 and advised the tackling of simple problems instead of systematic issues.[70] Bjerknes' ideas ran up against issues of feasibility and they neither managed to transform the field of meteorology nor unify its practitioners and their approaches overnight.

Despite the evident obstacles, Bjerknes was generally optimistic about the future of his approach.[71] And in fact, the methods of graphical integration that he proposed and practiced would serve as the cornerstone of the Bergen School, which would become highly influential in weather forecasting in the interwar years.[72] Bjerknes' 1904 vision of a "dynamic" meteorology as an atmospheric physical science based on a combination of thermo- and fluid dynamics was a new avenue in research that slowly but steadily gained appeal, even beyond the field of applied meteorology.[73] Despite the practical limitations of the dynamical approach at the time, many of Bjerknes' contemporaries, including a number of climatologists, saw a potential for the future. A focus on atmospheric dynamics promised physical models of climatic phenomena that could – at least potentially – hold answers to some of the central questions of climatic variations and changes.

Bjerknes' methods were thus far removed from Brückner's historical study of climate cycles, which paid little attention to atmospheric phenomena or causal mechanisms. The Bergen group's approaches would, in fact, contribute to a widening of the gap between telluric and atmospheric approaches in the study of climate: in their 1910/11 textbook, Bjerknes and his co-authors set their own "dynamic method" apart from the "climatological method," which they regarded as unable to deal with the "irregular phenomena" of the atmosphere because of their focus on means and averages.[74] Some meteorologists now turned explicitly against climatology – meaning climatology of the Brücknerian kind – as an outdated method. The term "climatology" itself appeared more and more as a term of abuse among physically and atmospherically-minded meteorologists. In their eyes, climatology became the old-fashioned, stubborn,

[67] Only in the 1960s did computers become powerful enough to process models based on Bjerknes' equations; see: Paul N. Edwards, "A Brief History of Atmospheric General Circulation Modeling," in *General Circulation Model Development*, ed. by David A. Randall (San Diego: Academic Press, 2000), 70.
[68] See: Joseph J. Tribbia and Richard A. Anthes, "Scientific Basis of Modern Weather Prediction," *Science* 237 (1987): 493–499.
[69] Bjerknes, "Das Problem der Wettervorhersage," 3; the quote from Bjerknes' letter to Arrhenius is taken from: Ralph Jewell, "Tor Bergeron's First Year in the Bergen School: Towards an Historical Appreciation," *Pure and Applied Geophysics* 119, no. 3 (May 1, 1980): 478.
[70] Arrhenius, *Lehrbuch der kosmischen Physik*, 736.
[71] See: Grønås, "Vilhelm Bjerknes' Vision for Scientific Weather Prediction," 360.
[72] See: Friedman, *Appropriating the Weather*.
[73] On the importance of thermodynamics in the development of meteorological theories in the second half of the nineteenth century, see: Gisela Kutzbach, *The Thermal Theory of Cyclones: A History of Meteorological Thought in the Nineteenth Century* (Boston: American Meteorological Society, 1979).
[74] Bjerknes et al., *Dynamic Meteorology and Hydrography*, v. 2, 3–4.

and mildly embarrassing old relative of a young and dynamic meteorology.[75] Alfred Wegener, of continental-drift fame, advised meteorologists-in-training who did not want to "limit themselves to [either] practical weather forecasting or *climatology* […] to scrupulously study theoretical physics. The article, tellingly published in a volume on the "results of the exact natural sciences," celebrated Bjerknes as the most important innovator in meteorology. Mathematical analysis," Wegener wrote, "has replaced statistics as the main tool of the meteorologist."[76]

Wegener himself also played a part in making the shift towards the atmosphere possible, by collecting atmospheric readings from kite-mounted instruments he used during his Greenland expeditions. With his efforts, he took part in the consolidation and expansion of atmospheric data gathering around the globe led by Teisserenc de Bort and Richard Assmann.[77] The two pioneers of aerological research both responded to a call for more atmospheric information and stimulated continued atmospheric research. With more and more data provided by balloons, airships, kites, and airplanes over the first half of the twentieth century, the upper strata of the atmosphere became an increasingly viable place for both meteorological and climatological investigation.[78]

In the 1920s, promoters of a physical turn in climatology now criticized what they saw as the overly descriptive methods and the focus on averages and means by Hann, and they explicitly cited Bjerknes and the "Norwegian school" as examples to follow.[79] And even practitioners who explicitly distanced themselves from parts of Bjerknes' work and approach, now began to think about new dynamic models of climatology. In 1921 Albert Defant, a student of the Austrian dynamic meteorologist Felix Exner, provided the equation-heavy "outline of a theory of climatic variations" based on disturbances in

[75] Cf.: Jacob Darwin Hamblin, "Seeing the Oceans in the Shadow of Bergen Values," *Isis* 105, no. 2 (June 1, 2014): 354–355; as Magnus Vollset shows in his contribution to this volume, the low prestige of climatology among meteorologists persisted unabated into the 1940s and 1950s.

[76] Alfred Wegener, "Ergebnisse der dynamischen Meteorologie," in *Ergebnisse der exakten Naturwissenschaften* (Springer, 1926), 96 [my emphasis]; see also: Patrick Hughes, "The Meteorologist Who Started a Revolution," *Weatherwise* 47, no. 2 (1994): 29–35.

[77] See: Friedman, *Appropriating the Weather*, 48–51, 67–69; Stefan Brönnimann and Alexander Stickler, "Aerological observations in the Tropics in the Early Twentieth Century," *Meteorologische Zeitschrift* 22, no. 3 (July 1, 2013): 349–358.

[78] See: Friedman, *Appropriating the Weather*, 37–38, 48–51; Kutzbach, *The Thermal Theory of Cyclones*, 134–139; C. Lüdecke, "From the Bottom to the Stratosphere Arctic Climate Features as Seen from the First International Polar Year (1882–1883) Until the End of World War II," in *Climate Variability and Extremes during the Past 100 Years*, ed. by Stefan Brönnimann et al., Advances in Global Change Research 33 (Springer Netherlands, 2008), 29–45.

[79] A. Stevens, "The New Outlook in Meteorology and Its Geographical Bearings," *The Scottish Geographical Magazine* 43, no. 4 (1927): 218–236; for a similar criticism of Hann's conception of climate and a call for new emphasis on atmospheric circulation in climate science, see: Hans Schrepfer, "Die Polarfronttheorie in ihrer Bedeutung für die Klimate der Festländer," *Geographische Zeitschrift* 30, no. 3 (January 1, 1924): 161–177; the portrayal of Hann as part of the "old school" of climatology overlooked the fact that Hann had actively supported Bjerknes' work and helped to make it known outside of Scandinavia; see: Friedman, *Appropriating the Weather*, 38–39; Gramelsberger, "Conceiving Meteorology," 671; Hann had also worked on thermodynamic models to explain meteorological phenomena himself, especially in his work on Föhn winds; see: Julius Hann, "Zur Frage über den Ursprung des Föhn," *Zeitschrift der österreichischen Gesellschaft für Meteorologie* 1 (1866): 257–263; Julius Hann, "Der Föhn in den österreichischen Alpen," *Zeitschrift der österreichischen Gesellschaft für Meteorologie* 2 (1867): 433–445; Julius Hann, "Einige Bemerkungen zur Entwickelungs-Geschichte der Ansichten über den Ursprung des Föhn," *Meteorologische Zeitschrift* 20 (1885): 393–399.

atmospheric circulation systems.[80] And meteorologists of the Bergen School – among them Vilhelm Bjerknes' son Jacob – continued to supply new theoretical detail and features to the dynamic model of the atmosphere.[81] In 1930, these still disparate developments culminated in the mission statement of a new kind of "dynamic climatology" by Tor Bergeron, who had been a collaborator of Bjerknes in Bergen. In the article, Bergeron called for a focus on analyses of air mass and front phenomena to bring climatology closer in line with meteorological approaches and to describe the "entirety of phenomena" (*Gesamterscheinungen*). Clearly distinct from Brückner's ambitions to create a vast searchable archive of past climatic conditions around the globe, Bergeron was referring to a holistic image of the "frequencies and intensities" of dynamic atmospheric systems.[82]

This, however, was not the decisive blow that Bergeron may have hoped for. Climatology retained its colorful range of methodologies. Rather than in disciplinary revolution, the debates over data and approaches of the late nineteenth century and the proposals of an alignment with atmospheric dynamics in meteorology ensued in tentative reform and reevaluation among climatologists. "Dynamic climatology" existed, above all, in calls for a new approach to the science, as in Defant's and Bergeron's respective articles. In the same year as Bergeron's publication and in a short popular volume describing the state of the field of climatology, Karl Knoch referred to the "harsh criticism" that traditional climatological methods had come under, but added resignedly that improvement attempts had not yet managed to "replace the old with something better that could deliver similarly significant results."[83] Knoch's mention of the "significant results" that new climatological methods had failed to produce referred, most likely, to the still purely notional nature of new dynamic approaches in the field.

It is, moreover, important to remember that the early decades of the twentieth century were also the time of the desiccationist theory of the geographer Prince Kropotkin and of Ellsworth Huntington's climatic-cultural analyses of world history.[84]

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[80] A. Defant, "Die Zirkulation der Atmosphäre in den gemässigten Breiten der Erde: Grundzüge einer Theorie der Klimaschwankungen," *Geografiska Annaler* 3 (January 1, 1921): 209–266 ; for Exner's main meteorological work, see: Felix M. Exner, *Dynamische Meteorologie* (Leipzig: Teubner, 1917); for more information on Exner's conceptual and methodological criticism of Bjerknes' work, see: Deborah R. Coen, *Vienna in the Age of Uncertainty: Science, Liberalism, and Private Life* (Chicago: University of Chicago Press, 2008), 288–292.

[81] See: John E. Kutzbach, "Steps in the Evolution of Climatology: From Descriptive to Analytic," in *Historical Essays on Meteorology, 1919-1995*, ed. by James Rodger Fleming (Boston: American Meteorological Society, 1996), 353–377.

[82] Tor Bergeron, "Richtlinien einer dynamischen Klimatologie," *Meteorologische Zeitschrift* 47, no. 7 (1930): 246–262; on Bergeron's training in the Bergen School, see: Jewell, "Tor Bergeron's First Year in the Bergen School"; on Bergeron's contribution to developing the Bergen cyclone model, see: Friedman, *Appropriating the Weather*, 169 ff.; Bergeron's claim to novelty with his model of a "dynamic climatology" did not go undisputed; see, for instance: S. Chromow, "'Dynamische Klimatologie' und Dove," *Zeitschrift für angewandte Meteorologie* 48, no. 10 (1930): 312–314.

[83] Knoch, *Klima und Klimaschwankungen*, 11.

[84] For Kropotkin's article and the ensuing discussion, see: Prince Kropotkin, "The Desiccation of Eur-Asia," *The Geographical Journal* 23, no. 6 (June 1904): 722–734; Prince Kropotkin, John Walter Gregory, and Edmond Cotter, "Correspondence: On the Desiccation of Eurasia and Some General Aspects of Desiccation," *The Geographical Journal* 43, no. 4 (1914): 451–459; for a selection of Huntington's work on climatic variations and changes, see: Ellsworth Huntington, *The Pulse of Asia: A Journey in Central Asia Illustrating the Geographical Basis of History* (Boston: Houghton Mifflin, 1907); Ellsworth Huntington, *Palestine and its Transformation* (Boston and New York: Houghton Mifflin, 1911); Ellsworth

Huntington, now maybe most infamous for his eugenicist convictions, cited Brückner as inspiration for his work on climatic cycles and continued the geographical, or telluric, tradition of the field.[85] Thus, while some climatologists attempted to align their methods with theoretical meteorology, others moved even more definitively to a telluric and descriptive interpretation of their field of study, leading the geographer Stephen Jones to refer to two kinds of climatology in 1937, with "the climatology of geographers […] a long way from the climatology of meteorologists."[86] In Germany, in particular, the former branch of climatology became more closely linked to racial and völkish ideas. To name just two examples: Willy Hellpach – despite his deep liberal political convictions – gradually developed his theory of the psychological influences of climate to arrive at a description of climatic zones as "constitutive of *Völkertum* [race/nation]"[87]; and Albrecht Penck – Brückner's teacher and collaborator – developed ideas of a climatically-defined "Kulturboden" or "cultural soil," which would later become a central part of imperial Nazi ideology.[88]

## Conclusion

Huntington, "Changes of Climate and History," *The American Historical Review* 18, no. 2 (January 1, 1913): 213–232; Ellsworth Huntington and Stephen Sargent Visher, *Climatic Changes: Their Nature and Causes* (New Haven: Yale University Press, 1922); Ellsworth Huntington, *Civilization and Climate*, 3rd ed. (New Haven: Yale University Press, 1924); Huntington was a controversial figure even in his lifetime. Especially among German-speaking geographers and climatologists, he did not enjoy a particularly high reputation for his often sensationalist work; for a scathing critique of Huntington's work, see for instance: Joseph Partsch, *Palmyra, eine historisch-klimatische Studie* (Leipzig: B. G. Teubner, 1922); Eduard Brückner was another critic. He wrote a letter casting doubt on Huntington's academic merits, when the latter applied (ultimately with success) for a position at Yale University; see: Fleming, *Historical Perspectives on Climate Change*, 98.

[85] Huntington, *Civilization and Climate*, 25.

[86] Cited in: William A. Koelsch, "From Geo- to Physical Science: Meteorology and the American University, 1919–1945," in *Historical Essays on Meteorology, 1919-1995*, ed. by James Rodger Fleming (Boston: American Meteorological Society, 1996), 519; for an overview of developments and disciplinary conflicts in geography in the early twentieth century, see: Livingstone, *The Geographical Tradition*, 260–303.

[87] Willy Hellpach, *Geopsyche: Die Menschenseele unterm Einfluß von Wetter und Klima, Boden und Landschaft*, 5th ed. (Leipzig: Wilhelm Engelmann, 1939), 160; for the first edition of the book, still without the emphasis on race, see: Willy Hellpach, *Die geopsychischen Erscheinungen: Wetter und Klima und Landschaft in ihrem Einfluss auf das Seelenleben* (Leipzig: W. Engelmann, 1911).

[88] For Penck's influential article on "cultural soil," see: Albrecht Penck, "Deutscher Volks- und Kulturboden," in *Volk unter Völkern: Bücher des Deutschtums*, ed. by K. C. Loesch (Breslau: Hirt, 1925), 62–72; on the political involvement and influence of Penck's ideas, see: Hans-Dietrich Schultz, "'Ein wachsendes Volk braucht Raum': Albrecht Penck als politischer Geograph," in *1810-2010: 200 Jahre Geographie in Berlin: an der Universität zu Berlin (ab 1810), Friedrich-Wilhelms-Universität zu Berlin (ab 1828), Universität Berlin (ab 1946), Humboldt-Universität zu Berlin (ab 1949)*, ed. by Bernhard Nitz, Hans-Dietrich Schultz, and Marlies Schulz (Berlin: Geographisches Institut der Humboldt Universität zu Berlin, 2010), 91–135; Jürgen Zimmerer, "Im Dienste des Imperiums: Die Geographen der Berliner Universität zwischen Kolonialwissenschaften und Ostforschung," in *Universitäten und Kolonialismus*, ed. by Andreas Eckert, Jahrbuch für Universitätsgeschichte 7 (Stuttgart: Steiner, 2004), 95; Mechtild Rössler, *"Wissenschaft und Lebensraum": Geographische Ostforschung im Nationalsozialismus - ein Beitrag zur Disziplingeschichte der Geographie*, vol. 8, Hamburger Beiträge zur Wissenschaftsgeschichte (Berlin: D. Reimer, 1990), 225.

In the first third of the twentieth century, climatology remained a field unsure of its own identity. Its practitioners were unable to overcome the data problems of research into climatic variability from the late nineteenth century, and just as unable to come up with new viable methods accepted by a majority of their peers. But this moment of disciplinary reevaluation and uncertainty also made dynamic atmospheric approaches attractive to those who had become critical of climatological data practices and who were looking for a more demarcated and deductive approach for the future of their field. Brückner's profoundly historical approach, bridging the deepening fault lines between the natural sciences and the humanities, still served as a model for the work of some climatologists, but had begun to be challenged by calls for what would become known as "dynamic climatology" – the study of climatic phenomena based on models of atmospheric dynamics.

In her study on the history of population ecology, Sharon Kingsland has argued that "the very act of imposing mathematics (or any model) on nature often involved a rejection of history in favor of a harmonious, unifying concept."[89] Climate science – or rather, one part of climate science – exhibited a similar development in the early twentieth century. The social dimension, which had been inherent both in Brückner's historical data and in his discussions of climatic variation, began to play a lesser role in the work of those climate scientists who started to move away from the messy concerns of the earth and geography and into the atmosphere and approaches modeled on dynamic meteorology. The new numerical and mathematical approaches attempted to turn climatology into a distinctly natural science, reducing the archival and historical aspect of the discipline.

The full practical application of a dynamic, numerical, and atmospheric climate science was still only a distant possibility at the time. The first calls for disciplinary reform, however, began to take shape well before the advent of both the electronic computer and fully developed atmospheric circulation models – two technologies at the center of modern dynamic climate science today.[90] In fact, the new ideas about climatological approaches in the first decades of the twentieth century were not premised on the availability of new technologies of data analysis.[91] Instead, they were closely connected to both the availability – and, more often than not, the *promise* of the imminent availability – of numerical and standardized data from the upper realms of the atmosphere, and on the privileging of these over other kinds of data as a result of the attempts to

[89] Sharon E. Kingsland, *Modeling Nature: Episodes in the History of Population Ecology*, 2nd ed. (Chicago: University of Chicago Press, 1995), 8.

[90] I am borrowing the chronological sequence of "climatology" and "climate science" from: Matthias Heymann, "The Evolution of Climate Ideas and Knowledge," *Wiley Interdisciplinary Reviews: Climate Change* 1, no. 4 (2010): 581–597.

[91] I am largely following Jon Agar's claim here that computers did not cause a "rupture" or "phase change" in science, but rather provided new capacities for already existing approaches to solving particular problems; see: Jon Agar, "What Difference Did Computers Make?," *Social Studies of Science* 36, no. 6 (December 1, 2006): 869–907; see also: Geoffrey C. Bowker, *Memory Practices in the Sciences* (Cambridge: MIT Press, 2005), 109 ff; for a case in point, see: David Sepkoski, "Towards 'A Natural History of Data': Evolving Practices and Epistemologies of Data in Paleontology, 1800–2000," *Journal of the History of Biology* 46, no. 3 (August 1, 2013): 401–444; on the larger historical dimension of "data-driven" science, see: Bruno J. Strasser, "Data-Driven Sciences: From Wonder Cabinets to Electronic Databases," *Studies in History and Philosophy of Biological and Biomedical Science* 43, no. 1 (2012): 85–87.

overcome the interconnected difficulties of heterogeneous data sets and the lack of convincing causal models. This ultimately meant that the very broad approach towards what counted as climatological evidence from the second half of the nineteenth century – exemplified by Brückner's study on climatic cycles – was challenged by a more delimited approach in the first half of the twentieth century, frequently modeled on the work of Vilhelm Bjerknes and his colleagues on atmospheric dynamics.

Meanwhile, other climatologists went further in different, and sometimes opposite, directions, focusing on the earth-bound and historical dimension of their discipline. Some, like Ellsworth Huntington, Willy Hellpach, and Brückner's teacher and collaborator Albrecht Penck, embraced and further developed long-standing notions of climate-culture links, combining climatological, geographical, and evolutionary ideas into environmentally deterministic models of human – and occasionally of racial – development. The geographic approaches to climatic issues did not wane in the first half of the twentieth century. But they were beginning to be scrutinized and challenged by the growing calls for new dynamic-physical approaches throughout the first half of the twentieth century and beyond.

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