Climate in Motion

SCIENCE, EMPIRE, AND THE PROBLEM OF SCALE

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this and saw all the gorgeous photos in this book: it seemed too luxurious for such a serious subject."[62] Here is an example of a self-conscious experiment in making human meaning out of scientific results, one that disrupted its readers' expectations by bending the rules of existing scientific and literary genres.

As this example suggests, the challenge of meaning-making identified by the IPCC is not simply a problem of translation. Nor is it new. The question of how to connect global models to "local stories" needs to be recognized as part of a long history of efforts to communicate discursively the human meaning of environmental information. This history includes some forms better known to literary scholars, like lyric poetry, travel narratives, nature writing, and futuristic fiction, and some more familiar to historians of science, such as cosmography, chorography, geography, natural history, medical geography, weather diaries, ship logs, and parish registers. Climatography is among the most recent of these genres, and it merits attention as a solution to the representational challenge first articulated by Karl Kreil: that of depicting climate, on the large scale and the small, maximally objectively and simultaneously subjectively, in its human significance.

CHAPTER 7

The Power of Local Differences

In 1884, Alexander Supan, professor of geography at the University of Czernowitz/Chernivtsi/Cernăuți summed up a lesson of the new dynamic climatology in his textbook *Principles of Physical Geography*: "It is, therefore, no exaggeration to say that the wind is the effective bearer of climate, and thus—since climatic conditions regulate organic life and with it human development—a cultural force of the greatest importance."[1] This chapter explains how the wind acquired this physical and cultural significance.

In designating the wind as the bearer of climate, Supan acknowledged and yet broke with a tradition of natural-philosophical explanation that dates back to ancient Greece. In the Aristotelian schema, climate is determined by the angle of incidence of sunlight at different latitudes, *klima* being the Greek word for slope or incline. Deviations from this "solar" climate were attributed to the winds that visited the location in question, each originating in a different location and carrying different qualities of air. Local winds and the variability they occasioned figured as disturbances overlaid on the simple geometry of climatic zones. Thus winds were incidental to *klima*, and yet they were significant within the ancient tradition of Hippocratic medicine. Knowledge of the typical winds at any given location was essential to maintaining good health. This tradition lived on in the nineteenth century. It was manifest, for instance, in the construction of wind roses, which visually summarized local statistics on the frequency of wind from each direction (figure 24).[2]

Supan alluded to the new significance that the nineteenth century had bestowed on winds. In the framework of dynamic climatology, winds were interpreted as products of encounters between contrasting air masses. Dynamic

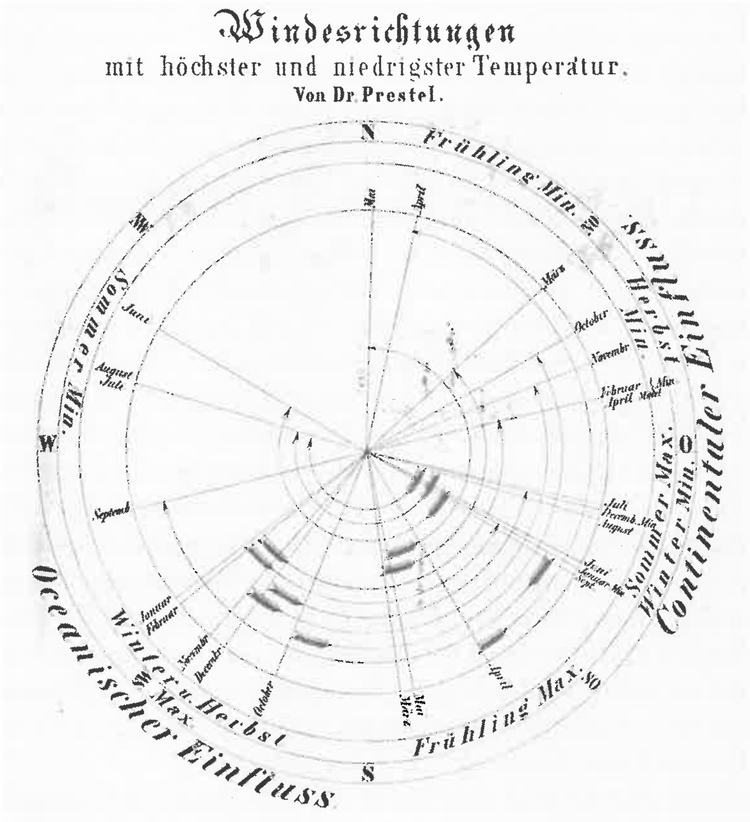

FIGURE 24. Thermal wind rose for northwestern Germany, 1861.

climatology posed questions such as, given a dry atmosphere initially at rest, what spatial contrasts of temperature and pressure would produce winds like those observed in nature? Once set in motion, how would such air currents be affected by the earth's rotation? Down the road, the theorist might try to incorporate the effects of moisture and friction into the explanatory framework. In this way, nineteenth-century dynamic climatology no longer treated winds as displaced air from a foreign clime, as in an Aristotelian framework. Nor did it approach winds in the manner of climate dynamics today. Indeed, this nineteenth-century way of posing questions might strike some readers as odd. Today, what seems to require explanation is not the onset of atmospheric motion, but departures from geostrophic flow—that is, deviations from an equilibrium state of motion in which the force arising from a pressure gradient is balanced against the Coriolis force of the earth's rotation, such that air flows along lines of equal pressure. This "quasi-geostrophic" way of thinking about atmospheric motions was not developed until the 1930s. It was driven, however, by questions that had been nagging nineteenth-century dynamicists for some time. Namely, what maintains the contrasts of temperature and pressure that give rise to energetic atmospheric motions? How is it that the atmosphere can support unstable conditions long enough for them to sustain strong winds? These were questions that Austrian researchers like Julius Hann and Alexander Supan helped to place on an international research agenda.

By the 1870s, governments and learned societies across Europe and North America had invested deeply in meteorological observations. In Britain, France, the Netherlands, Scandinavia, and the United States, the aim was, above all, to construct an advance-warning system for storms. These efforts, which rested on the synchronization of measurements via telegraphy and on the production of synoptic charts, resulted in a growing base of empirical knowledge about the strength and direction of winds in relation to the distribution of surface air pressure. Empirical rules for storm forecasting began to accumulate. One held that wind strength in a cyclone is proportional to the pressure gradient, or the difference between barometric readings at neighboring stations.[3] Another described the direction of winds in a cyclone, that is, a storm characterized by rotational motion around a center of low pressure.[4] For many naturalists at the time, these were simply handy rules of thumb for predicting strong winds.[5] For others, they held clues to the basic physics of storms. Only a few saw another potential: to apply this new empirical knowledge of pressure and winds to elucidate the global geography of climate. Those who rose to this last challenge tended to be scientists in the employ of Europe's great land empires—above all, Wladimir Köppen and Alexander Voeikov in Russia, and Julius Hann and Alexander Supan in Austria.

Hann developed his dynamical approach to climate as he painstakingly worked his way through the data of the growing station network of the ZAMG, which he joined as an assistant in 1867, becoming director from 1877 to 1897. He insisted that a detailed map of atmospheric pressure was "one of the most important foundations of the scientific understanding of the climatic conditions" of the region under study.[6] Here was a physical-mathematical solution to the Austrian Problem of precisely representing local variation while simultaneously revealing a higher unity. The form it took reflected the broader emphasis on phenomena of mixing and exchange in post-1848 accounts of the historical development of the Habsburg Monarchy and its economic and political future.

Thus the study of pressure gradients and the winds to which they gave rise seemed to hold the key to understanding the distribution of the earth's climates. This chapter also takes up the second part of Supan's claim: dynamic climatology was linked to new ways of thinking about human health and cultural development. The newly dynamic science of climate quickly became a topic of popular interest, in an age fascinated by stories of the progress of modern science. By the 1880s, schoolchildren as well as readers of German-language popular science journals and even provincial newspapers had ample opportunity to acquire a basic understanding of the new theories of atmospheric motion. Climatology provided tools of scaling with which people throughout the Habsburg lands could envision their place within imperial networks of circulation and exchange. Not until the turn of the century did scientists begin to question the physics behind this popular view.

THE WAYS OF THE WINDS

The Austrian research program in dynamic climatology can be said to have been launched in 1866, when Julius Hann, then an assistant at the ZAMG, overturned the reigning theory of the warm, dry mountain wind known as foehn. Hann had used thermodynamics, the new science of the relationship between heat and motion, to explain what happens as air is forced upward along a mountainside. As a parcel of air rises into regions of lower pressure on its way up the mountain, it does work by expanding. This process lowers the parcel's temperature as well as its specific pressure, causing condensation—and often precipitation. By the reverse process, as the air then makes its way down the other side of the mountain, it contracts and its temperature and specific pressure rise. This temperature rise will be greater than the temperature decrease on the upwind side, since the decrease was offset by the latent heat of condensation. This was a principle that was quickly understood to be applicable most generally to rising motions in the atmosphere. Hann had demonstrated the power of a new way of thinking about climatic phenomena, in terms of the interconversion of heat and motive power.

It was Hann's judgment that a global science of climate could only progress on the basis of more precise and detailed regional studies of the distribution of air pressure, a basic thermodynamic variable. The German-Russian climatologist Wladimir Köppen had made this point in 1874, when he pointed out that the Aristotelian use of the wind rose was flawed. Knowing the direction from which the wind blew was not enough to tell you the character of the wind. One also needed to know the surrounding pressure distribution, as he demonstrated with reference to data from Siberia.[7]

This was the motivation behind Hann's painstaking analysis of the distribution of pressure in central and southeastern Europe, averaged over the

first thirty years of the operation of the ZAMG's network (1851–80). This was a daunting undertaking. Obtaining precise, standardized measurements of pressure over a wide region was not straightforward. Pressure differences between neighboring locations at the same altitude are far smaller in magnitude than differences of temperature; in fact, they were on the order of the systematic error of the barometric measurements of Hann's day.[8] Fortunately, the Austrian network had established the necessary conditions to produce suitable data. At each station the barometer was calibrated against a standard instrument, thanks to the inspection tours carried out every six years. And the elevation of each station was known with precision due to the geodetic measurements of the Imperial-Royal Military-Geographic Institute. What remained was the long and arduous task of averaging thirty years of data by hand.

Hann admitted that he had often spent a week or more deciding whether to adjust the average pressure at a single location by a tenth of a millimeter in either direction. "Many may well wonder if it is even worthy of a serious man to devote so much time and effort to such a minor result." Certainly, he wrote, there had been times when he doubted it was worth it. But anyone prone to such doubts for long, he insisted, was simply not fit to be a natural scientist, and he quoted Francis Bacon to that effect.[9] Just as Bacon had dedicated his empiricism to his queen, Hann's work was dedicated to governing a kingdom. In fact, Hann's *Distribution of Air Pressure* (1887) responded to the same representational challenge as did his chapter for the Austro-Hungarian Monarchy in Word and Image, which happens to have appeared that same year. In both cases, the goal was to keep fine-grained deviations in focus while constructing a total view of the empire. The isobaric maps and accompanying descriptions explained local peculiarities in relation to regional trends. Thus, for instance, the wintertime isobars showed an area of high pressure with its center on the south side of the eastern Alps. This corresponded to a "cold island" in the valleys, with a temperature increase or capping inversion above, which explained why warmer air from the south didn't penetrate into central Europe. The same phenomenon could be found in eastern Hungary and Transylvania. Meanwhile, the center of low pressure over the eastern Mediterranean and the Adriatic set up a pressure gradient that explained the strength of the downslope bora winds on the Dalmatian coast.[10] Hann looked forward to the day when the significance of such a map could be appreciated in relation to a complete description of the climatic conditions of Austria-Hungary. Only then would it be possible to use pressure differences "to explain the differences of wind conditions and their consequences."[11]

FIGURE 25. Postcard showing the weather house in the city park in Graz, 1898. Weather houses like these cropped up in city parks and public squares in spa towns throughout central Europe in the late nineteenth century.

DYNAMIC CLIMATOLOGY FOR ALL

Even as it was being worked out, the new dynamic climatology began to circulate to a broad audience. Under Hann's directorship of the ZAMG (1877–97), the number of observing stations in the network rose from 238 to 444.[12] Teachers, physicians, innkeepers, and telegraph operators were well represented among those who volunteered their time to take note of the state of the atmosphere at prescribed hours daily. Even those without access to their own meteorological instruments could participate in this ritual, thanks to the "weather houses" installed in parks and town squares (see figure 25). All the major Austrian spa and resort towns boasted such an edifice, "which tend to be of a very luxurious and tasteful design and are extremely popular with locals and visitors."[13] These volunteer observers and spa-goers were among the educated readers eager to hear of the latest progress in the sciences of weather and climate.

Hann's popular *The Earth as a Whole* (1872) introduced the basic principles of the application of thermodynamics to the atmosphere, explaining, for instance, the physics of sea breezes and the origins of the trade winds. A more application-oriented presentation could be found in the 1874 *Textbook of Climatology, With Particular Attention to Agriculture and Forestry*. It included the first climatic map of Austria-Hungary, which displayed the empire as a transition zone between "oceanic" and "Pontic" climates, between the West and the Orient, in which abrupt contrasts would immediately be smoothed into continuous transitions. On the large scale as on the small, the

book explained, circulation was driven by "oppositions between warmer and colder neighbors"—a claim we will examine below.[14] Josef Roman Lorenz had almost completed the book when he was called to the agricultural ministry in Vienna; the last touches were left to Carl Rothe, a high school instructor in Vienna, who received the assistance of experts like Jelinek and Hann. Thus while many of the book's explanations incorporated the latest thermodynamics, other passages fell back on Dove's older account of a "struggle" between polar and tropical air, including his view of cyclones as *Ausnahme* (exceptions or deviations) within the general circulation.[15] In fact, the seventy-one-year-old Dove contributed the book's preface. One reviewer, attesting to the book's accessibility, deemed it just as useful for physicians as for farmers.

The press also helped to keep the public up to date on progress toward a dynamic understanding of climate. In 1880, for instance, a series of articles in the *Teplitz-Schönauer Anzeiger* (northern Bohemia) announced that "knowledge of the factors that determine air currents and their trajectory and speed has been quite a recent achievement. It was not long ago that we had no more correct idea of these relations than the ancient Greeks, who simply assumed that the allmighty Zeus had appointed one of his ancestors, the skilled sailor Aeolus, to be the guardian of the winds. . . . Now we know that the wind system of the Earth is governed on the whole by two dominant currents, which have their origin in the uneven heating of the earth's surface by the sun." From there the article went on to sketch the Hadley model of the general circulation (see chapter 8). Finally, the author explained that "the strength as well as the direction of the winds appear to be dependent on differences of air pressure and its distribution." A subsequent article in this series worked through an example, tracing the life cycle of a cyclone based on reports from the ZAMG.[16] In the *Wiener Landwirtschaftliche Zeitung* (a popular, illustrated, agricultural magazine), readers learned in 1885 how they could subscribe to the ZAMG's daily forecasting service. They also received a lesson in the "basic principles of modern meteorology," including the relationship between the distribution of pressure and the direction of winds. As the author explained, this would allow readers to decipher synoptic charts themselves, so that they "can form a judgment for themselves of the influence of the general weather situation on the local weather of their place of residence."[17]

By the 1880s, dynamic climatology had already found its way into at least one high school textbook. Students were taught to view their local weather as a link in a planetary chain of events: "For the most part, our weather is not determined by local conditions and circumstances, but rather by the course of the air-pressure minima and air-pressure maxima. The air-pressure minima originate in the Atlantic Ocean and mainly travel over Scotland and northern Europe. If such a depression center approaches us in central Europe, then we have south and southwesterly winds, and as these arise clouds cover the sky; west and northwesterly winds follow, from which the moisture falls as rain."[18] This text also conveyed the difficulty of predicting the outcome of such a synoptic situation: if the pressure minimum continued on its path, central Europe could experience a clear sky with winds from the northeast; but if a second minimum separated off from the first, the result could be storms in southern Europe, whether sirocco, foehn, or bora. By 1899, the subject of "isotherms, isobars, winds" had been incorporated into the physics curriculum of Austrian Realschulen, even if appropriate textbooks weren't always available to teach it.[19] In short, in the course of the last decades of the nineteenth century, an educated German-speaking public was gaining access to elements of a dynamic theory of climate.

COLD SPELLS, FROST SAINTS, AND NATIVE HUNGARIANS

Dynamic climatology was presented to students and newspaper readers not only as a signature achievement of modern science, but also as a bridge between science and folk wisdom. As we have seen, folk knowledge was built into the new atmospheric dynamics through scientists' engagement with local accounts of phenomena like foehn and mountain inversions. Presentations of dynamic climatology for a general audience highlighted this convergence between expert and lay perspectives.

For instance, one could expect to find climate-themed articles in local newspapers throughout much of central Europe during the second or third week in May. After the first warm weeks of spring, it often happened that the weather suddenly turned cold. This phenomenon was so familiar that an elaborate mythology had arisen around it. In popular speech, a temperature drop between the twelfth and fourteenth days of May was known in German as the *Eisheilige* (frost saints) or *Eismänner* (frost men), or the *strenge Herren*, the strict lords. In Czech, it went by the name *Pan Serboni* (Mr. Serboni), formed from the first syllables of the names of the saints associated with these dates: Pankrác, Servác, Bonifác. Hence the saying, *Pan Serboni pálí stromy*, Mr. Serboni withers the trees. In Polish, the phrase was *Pankracy, Serwacy, Bonifacy to źli na ogrody chłopacy*, suggesting that these saints were bad boys when it came to gardens. These frost saints were a source of great fear in central Europe, because they were capable of destroying entire crops at the very start of the growing season. Weather lore like this, passed down from one generation to the next, reminded farmers to take appropriate precautions. Many communities had devised tactics to protect their crops when a freeze threatened, most often by blanketing their fields in smoke.[20]

Whether or not this weather pattern occurs more frequently in mid-May than at other times of year has never been clear.[21] Already in the 1870s and 1880s, some scientists attributed the reports of a regular mid-May cold spell to faulty statistics and stubborn superstition.[22] As an 1887 article in the *Innsbrucker Nachrichten* put it, "Cases in which the effect is absent are forgotten, since, as Kepler already knew, one retains the occurrence, forgets the absence, since it's nothing special after all."[23] Nonetheless, much of the population of central Europe at the time was united in expecting a cold snap in mid-May, and newspaper editors aimed to address their concerns.

Hence the appeal of the frost saints as a research topic for scientists was, in part, the wide audience for results of any kind. The *Eisheilige* was also a tempting nut to crack for physical reasons. Here, after all, was a clear confrontation between air masses of different temperatures, as Dove had been the first to point out. Dove understood the frost saints as the last gasp of the polar current in its springtime struggle against tropical air. It carried such a chill, he said, because it blew from the region of melting ice in Labrador and Greenland.[24] An alternative explanation emerged in the 1870s, as scientists working in a dynamic framework became intent on explaining typical wind patterns according to average pressure distributions. The new theory (due to Wilhelm Bezold and W. J. von Bebber in Germany) started from the observation that, as winter passes into spring, land warms faster than water. Over a large landmass like the plains of Hungary and southeastern Europe, the warmer air will rise and create a low-pressure center at the surface. This low will allow cold air from the north to flow in, across central Europe, bringing a cold snap as it goes. Noting that these episodes were preceded by unusually warm temperatures in Hungary, Bezold nicknamed the cold spells "native Hungarians" (*geborene Ungarn*), a name that German-speaking scientists in Austria couldn't resist repeating.[25]

The theory of the "native Hungarians" became a hit with the popular press. Local German-language papers in Tyrol, Upper and Lower Austria, Bohemia, and Moravia carried articles that affirmed the reality of a phenomenon previously known only from popular lore. The *Linzer Tagespost* declared that explaining the *Eisheilige* was "one of the most difficult tasks of modern meteorology."[26] And the *Innsbrucker Nachrichten* reported that here for once was a case in which scientists had decided to take popular lore seriously.[27] In Transylvania, Ludwig/Lajos Reissenberger (1819–95) brought the dynamic perspective to his neighbors at the local Natural Scientific Society. Reissenberger was a Berlin-educated gymnasium teacher and meteorologist in Hermannstadt/Nagyszeben/Sibiu and had been a corresponding member of the ZAMG since its founding. He took an active role in organizing local scientific societies and in stimulating popular interest in meteorology. In his research, he took a particular interest in correlations between temperature variability and mortality. In taking up the question of the *Eismänner*, Reissenberger explained that what had been missing until recently was an understanding of how the pressure distribution governs flows of air—precisely the question on which Hann was working.[28]

These articles invited readers to consider their local climate from a synoptic perspective: to track the course of a cold spell as it swept across Europe from Sweden to Russia. As we will see in further detail below, the dynamic theory of climate offered nonscientists not only a compelling interpretation of a familiar phenomenon like late spring cold spells; it also provided a way to imagine central Europe as a physical unit, a space of atmospheric flows.

"HE DIED OF FRESH MOUNTAIN AIR, BIRD SONG, AND THE SCENT OF ROSES"

Climatology captured the attention of many middle-class Habsburg subjects in the late nineteenth century as a means of taking control of personal health. Medical climatology placed heavy emphasis on the collection of empirical data, including the climatic characteristics and physiological effects of mountains, seacoasts and the open sea, steppe and desert. Textbooks in the field gave detailed accounts of the workings of meteorological instruments and insisted that the medical man must carry out his own climatic measurements. Climatology, in this view, was about firsthand observation, not theoretical study. Wilhelm Prausnitz, whose research and teaching at the Hygiene Institute in Graz included the health effects of indoor climates, insisted that "it is not possible to 'study' hygiene from a book. Hygienic research methods in particular must not only be seen but also tested out."[29] In 1901 the Austrian Society of Apothecaries took a field trip to the ZAMG, where members were fascinated by the profusion of instruments on display:

> It will certainly be of interest to everyone to know the climate of his place of residence and to pay closer attention to it. However, the climate can only be determined if one investigates precisely and at regular intervals the current state of the atmosphere—that is, the size and variation of air pressure, temperature, humidity, electrical and optical phenomena, as well as the air currents produced by the air pressure, the winds, the various and distinct forms of water vapor (clouds, fog, frost, dew) and the aqueous forms of precipitation (rain, snow, hail, sleet).[30]

While the pressure of the atmosphere may seem to be a factor that escapes direct human perception, changes in air pressure were widely believed to affect physical and mental health. This belief was supported by evidence collected by researchers of the ZAMG, who studied the effects of changing air pressure on the health of students, workers, and hospital patients.[31]

The results of medical climatological research were widely disseminated to both physicians and their patients. The *Österreichische Badezeitung* (later *Österreichisch-Ungarische Badezeitung*) launched in 1871 and published continuously for a quarter century. It was followed by the shorter-lived *Vierteljahrschrift für Klimatologie, mit besonderer Rücksicht auf klimatischer Kurorte*, the *Bade- und Reisejournal*, the *Illustrierte Fachzeitschrit für Kurorte, Hotels, Sanatorien, Reise und Sport*, and other periodicals with a similar orientation. These aimed to communicate the latest research on medical climatology to experts and nonexperts alike. As the *Vierteljahrschrift für Klimatologie* announced in its first issue: "The support and dissemination of our knowledge of climate, above all of its effects on human life and health, forms the charge of this quarterly journal. The scope and importance of this knowledge in its present stage of development more than justifies its compilation in its own periodical, and one intended not only for physicians but for educated readers in general."[32] Atmospheric dynamics was also introduced in reference works like Enoch Kisch's *Klimatotherapie* and Wilhelm Prausnitz's *Grundzüge der Hygiene*.[33]

This was an era when medical thinking was torn between environmentalist and contagionist explanations of disease. It's worth noting that the Habsburg state had reason to resist contagionism, since it implied the necessity of quarantine during outbreaks of cholera in southeastern Europe. Austria's commercial class lobbied against quarantines, as barriers to commercial exchange. Thus Austrian medical experts pursued public health alternatives to quarantines in the Balkans and the Levant—for instance, overseeing a trial program of sanitary reform and medical education in Constantinople.[34]

At the same time, ideas of what might constitute a "healthy climate" were shifting. By the close of the nineteenth century, Habsburg physicians agreed that the healthiness of a climate was relative rather than absolute. There was no single cure-all location. A given climate could be salubrious for some individuals but not for others, beneficial in some seasons but pernicious in others. As the medical director of the spa at Marienbad, Enoch Kisch (1841–1918) wrote in 1898, the last decades of the nineteenth century had seen a striking expansion in both the variety of diseases for which doctors advised climatic cures and the range of climates seen as potentially therapeutic. Earlier in the nineteenth century, taking a climatic cure had meant traveling to a "southern" land. Now, cold climates were almost as likely to be prescribed, even in winter.[35]

What's more, physicians often specifically recommended movement between one climate and another. For respiratory disorders, for instance, the best thing was "a change of climate," whether that might mean a "lengthy stay in the valley and in the mountains, in the south and on the coasts, in a mountain forest and the open sea." This advice built on the Hippocratic principle, *in morbis longis solum mutare* (in tedious diseases to change the place of residence). Variety rather than constancy of climate was recommended for a host of other diseases as well—scrofula (a skin disease associated with tuberculosis), diabetes, arthritis, heart and nerve ailments, "as well as various illnesses of the nervous system and the sexual organs." Exposing the body to multiple climates was said to serve the fundamental purpose of "enhancing organ function and improving total nutrition." In short, "change of climate is to be regarded as a common foundation of all climate cures."[36] Often, what a sick body needed was a change of air, any change. To be sure, this could cause the body strain, but after a few days the process of acclimatization was usually complete.

The most important factor to consider was the climatic character of a health resort *relative* to the patient's most recent abode. "Therefore what must be considered is not so much the absolute temperature of the climatic resort to which an invalid is sent, but the difference between the temperature from which he is departing and the one to which he will arrive." In this sense, there was a kernel of medical truth in a verse about the hypochondriac who "died of fresh mountain air, bird song, and the scent of roses." This school of thought was not without influence even among military men. Take, for instance, the Habsburg naval officer Karl Weyprecht, who led the Austro-Hungarian Polar Expedition of 1872–74. Weyprecht argued counterintuitively that his crew of sailors from the Adriatic was uniquely well prepared for their Arctic journey, having been seasoned for abrupt climate change by the inherent variability of their native climate.[37]

In this way, climate became a dynamic and relational concept, and the relocated body of the patient became a register of geographic difference. The relational character of climate was accentuated by medical textbooks of the day that explained climate therapy in terms of basic atmospheric dynamics. The new dynamic climatology taught that local conditions were not sui generis; they depended on prevailing winds and thus on the large-scale pressure distribution.[38] In this way, climate therapy furnished the patient with a kinesthetic experience of Austria-Hungary's natural diversity. Between the ocean and the steppe lay the many therapeutic climates of the Habsburg lands, endlessly diverse and yet in perpetual interaction with each other. "Thus it is the winds," wrote Kisch in Marienbad, citing Julius Hann, "that erase climatic borders and maintain neighboring climatic regions in constant communication."[39]

"STRIVING TOWARDS THE BALANCING OUT OF EXTREMES"

Dynamic climatology was quickly integrated into the geographical surveys of Austria-Hungary that publishing houses churned out with increasing frequency starting in the 1870s. In his widely read accounts of the climate of the Habsburg lands, Josef Roman Lorenz showed how local contrasts of temperature and pressure formed and were then "balanced out" by means of moving air currents: "The movements of the atmosphere derive from the same causes as those of the fluid envelope of the earth. In the atmosphere, temperature differences between horizontally and vertically adjacent layers of air are the stimulus to the drive towards the balancing out of extremes." Consider, for instance, Lorenz's account of the bora, a cold, dry wind that blows along the Dalmatian coast, on the Monarchy's southern periphery, where Lorenz had spent six years teaching high school and studying the coastal climate and its flora and fauna (see figure 26). The bora arose from the confrontation between two masses of air representing "the starkest opposition": a stationary mass of cold, dense air in the interior and the warm air on the Adriatic side of the Dinaric Alps. The strength of the bora depended on the magnitude of this contrast and the size of the air masses.

> If the opposition lasts for a while and is significant along a fair distance, then an inland current will flow for a period of time and draw as its replacement air masses from ever more distant regions to the north; in this way, in a Bora lasting several days, the temperature drops ever lower. . . . If the opposition is either merely local, or insignificant, then a narrow or weak inland wind will suffice for the equilibration, and a short local Bora or a moderate Borino will arise.

From a physical perspective, this analysis was rudimentary, neglecting the rising and falling motion of the air as it crossed the mountains. As a framework

FIGURE 26. The Dalmatian coast during a bora wind.

for geography, however, it was revelatory. Suddenly, the Dinaric Alps—long regarded as the dividing line between an oceanic climate and a continental one, between coastal civilization and mountain backwardness—no longer seemed quite so stark a barrier. The bora represented a sign of the true "interdependence" of regions across apparent borders.[40]

One of the most influential popularizers of geography in Austria-Hungary was Friedrich Umlauft (1844–1923). A protégé of Friedrich Simony, Umlauft was a gymnasium instructor who shared Simony's commitment to "whole-state" geography and the communication of scientific research to the public. The stated aim of his 1876 "Geographical-Statistical Handbook" of the Monarchy was to illustrate the interdependence and mutual determination of *Land und Leute*, or nature and culture. Austria-Hungary was characterized by "the harshest [*grellste*] oppositions with respect to physical conditions, population, and intellectual culture—which is why the Monarchy is rightly called a state of contrasts."[41] To do justice to such multiplicity without losing sight of the whole, Umlauft divided the territory according to Lorenz's system of climatic zones, based on rainfall and temperature. In this way, each region "maintains its position within the great climatic provinces of Europe," while "peculiarities are highlighted that are revealed under closer observation." In general, he explained, climate was the result of prevailing winds, and winds were the effect of a "balancing out" of differences of air pressure: "The distribution of air pressure, when disturbed by the uneven distribution of heat, are the stimulus to the drive towards the balancing out of extremes, to air currents." Umlauft applied these same images of natural flows when he turned to ethnographic description. He saw no hard-and-fast divisions among Austria's peoples, which included representatives of "all the main cultural groups of Europe." "Thus Austria's history converges with that of Germany, Hungary, and Poland, similarly to the confluence of different streams at different stages in a large riverbed, which then carries these waters along collectively." The Monarchy was thus a space of circulation and mixing, whether one attended to air, water, or human populations. "The nations mentioned do not occupy sharply defined and enclosed areas, but rather are interspersed in many regions. Thus in such border districts one often finds a uniquely mixed population. Indeed, nowhere in Europe can the intermixing of various nationalities be observed as strikingly as in our fatherland."[42] Umlauft's physical analogies served to naturalize his ethnographic observations.

While Dove and the later Norwegian school of meteorology chose images of "struggle" and "battle" to describe confrontations between divergent air masses, Austrian climatologists preferred the language of mixing, equilibration, exchange, and mutual dependence. Thus, as Dr. Kisch explained in his medical guide, winds were a force for "interdependence" and the "erasure of borders." To describe this interaction between contrasting air currents—and to circumvent the question of how their contrasts were maintained—Austrian climatologists even revived the Romantic concept of an *ausfüllende Bewegung* or self-fulfilling movement. Felix Exner, for instance, employed this archaic term in his otherwise highly technical 1925 textbook *Dynamic Meteorology*.[43] The concept of self-fulfilling movement was associated with the highly influential early nineteenth-century geographer Carl Ritter. It expressed a Leibnizian view of the cosmos simultaneously as a totality and an evolving configuration of moving parts. Ritter argued that the geographic relations among physical elements, as among human cultures, are always in flux, thanks to new technologies of observation, communication, and transportation. "What formerly was distant and unreachable, now approaches into closer contact, even into the realm of daily interaction." Thus for Ritter, the category of self-fulfilling movement included all manner of atmospheric and oceanic circulations and the organic responses they called forth, as well as the migrations of peoples and the intentional transformations of spatial relations wrought by human agency.[44] Analogously, an Austrian treatise in dynamic climatology posited that an air current with a component in the direction of the pressure gradient "strives to attenuate the contrasts; it is a 'self-fulfilling movement.'"[45] Readers of the day would have recognized this allusion to a Romantic cosmology of continuously regenerating variety. In this way, climatology lent physical plausibility to the Habsburg ideal of unity in diversity.

THE DYNAMICS OF LOCAL DIFFERENCES

In 1881, Alexander Supan published one of the first major monographs to apply atmospheric dynamics to the explanation of the climatic characteristics of the regions of the globe.[46] Alongside Coffin and Voeikov's 1875 *Winds of the Globe*, it was, in the words of Alfred Hettner, "the first approach to a physiological or genetic treatment of the climates of the earth."[47] Leaning heavily on Hann's observations and interpretations, Supan began by laying out the most recent conclusions concerning the relationship between winds and the distribution of air pressure. From there he moved on to an overview of the major wind systems of the Northern and Southern Hemisphere. Finally, the bulk of the book discussed each region of the world in turn, including tables of average wind frequencies, most of which he calculated directly from the station data, provided by Hann. In each case, he showed how the typical locations of primary and secondary pressure minima and maxima could be used to explain prevailing winds and, on that basis, known characteristics of the regional climate at different times of year—for instance, the typically warm winters along the Norwegian coast, or the extremely cool summers of Novaya Zemlya.

It was shortly after the publication of his treatise on winds that Supan began to reflect on the significance of Hann's insight for the discipline of geography more broadly. These were the years of a contentious struggle among geographers to define their field over and against the disciplines that increasingly encroached on geography's domain—sciences like geology, meteorology, economics, and anthropology. Geographers saw their discipline fracturing into narrow specializations. In the ensuing debates, Supan took a leading role, forcefully defending the unity of his discipline. His methodological pronouncements resonated well beyond Austria-Hungary, influencing future thinkers from Lenin to the Weimar school of geopolitics.[48]

At the German Geographers' Congress of 1889, Supan laid out his vision for the future of geographical research. The key to holding together the physical and human aspects of geography lay in raising the "special" or "chorographic" part of geography to the level of "chorology"—to go, in other words, beyond systematic description, toward causal analysis. The Austrian Problem was not far from his mind, as indicated by his critique of the Austro-Hungarian Empire in Word and Image for its failure to synthesize its multiauthored descriptions into a higher unity, to transcend chorography and achieve chorological insight. Supan proceeded to illustrate what he meant by chorology. Chorology was the study of the reciprocal relations between nature and man. In this respect, it rejected the environmental determinism of Friedrich Ratzel's anthropogeography. The first stage of chorological research was to mark out "geographic localities" that displayed homogenous conditions of orography, climate, vegetation, perhaps also fauna and minerals. Crucially, the influence of any given "geographic locality" on its human inhabitants was contingent on conditions in neighboring "localities." That is, how a human group adapts to its surroundings and exploits its local resources will depend on how those surroundings and resources differ from those of neighboring regions. As relationships of interregional interdependence grow, interactions between man and nature within each region will shift accordingly. Thus Supan's key insight was that natural conditions "guide the social development of their inhabitants in a particular direction"—not in any simple deterministic sense, but by fostering a relationship of interdependence, or potentially conflict, with another locality differing from the first in its natural conditions.[49]

This vision of neighborly difference underlay the research program that Supan prescribed for geography. It consisted in the study of the relationships *between* natural-human regions, their evolving interdependence. As he put it, "The power of neighboring geographic contrasts, which strive to balance each other out, is one of the most significant formative forces in the life of a nation." The mission of geography, Supan insisted, was to characterize these neighboring contrasts and to investigate the relations of dependence and conflict between neighboring societies to which they gave rise.

His choice to refer to these environmental contrasts repeatedly as *Kräfte*, forces, is telling. Supan had been among the first scholars to pursue climatology as the study of the atmospheric motions arising from gradients of pressure or temperature. Only six years later, in 1887, he was turning this program into an agenda for the study of politics and culture. As this suggests, imperial-royal scientists like Supan and Hann found the dynamic interpretation of climate compelling partly because of the analogies it suggested. Indeed, Supan relied on the pressure-wind relationship as the organizing principle of his volume on Austria-Hungary for the Länderkunde von Europa series (1889). Faced with the task of producing an overview of the multinational state, Supan, like Hann, seized on an interpretive method that recast difference as continuity. It was in the context of this overview that Supan penned the programmatic lines: "All living things blossom forth from the balancing out of neighboring contrasts. To ascertain these contrasts and describe their influence on men: this we see as our scientific responsibility."[50]

THE POLITICS OF EQUILIBRATION

To be sure, "the balancing out of neighboring contrasts" was only the roughest first approximation to a description of atmospheric dynamics. Yet it carried the authority of physical science. In yet another play on the terminology of force, Supan argued that his proposed method would give chorology more "wissenschaftliche *Kräfte*," scientific force.[51] He was prescribing for international geography most generally a research program that Austrian scholars had already adopted in the name of imperial unity. As we have seen, it had become a commonplace among imperial-royal scholars that the confrontation between dissimilar social elements set a process of development in motion. In the words of Alois Riegl, "when the unfamiliar meets the unfamiliar in a close and sustained relationship the process of development is set in motion."[52] What should now be clear is that this interpretation of imperial unity rested on an analogy developed among coordinated yet distinct disciplines concerned with the spatial distribution of natural and cultural resources, including climatology, geography, political economy, ethnography, and art history. It was a vision of the empire as a circulatory system, in which energy was released from a tension between local gradients.

Such was the powerful metaphor that coupled dynamic climatology to imperial ideology. When Habsburg scientists discussed the relationship between pressure gradient and wind, a cultural-economic analogy was implicit: difference creates circulation and thus cultural continuity and interdependence—literally, unity in diversity, or "the balancing out of neighboring contrasts."

The analogy was particularly resonant in the wake of the 1867 *Ausgleich* between Austria and Hungary, which granted Hungary domestic autonomy and recreated the empire as the Dual Monarchy. Typically translated as "compromise" or "settlement," the word *Ausgleich* was often used interchangeably with *Ausgleichung*, literally an "equilibration" or "balancing out." It was in this sense that Supan used the term *Ausgleichung* in his 1889 treatise on Austria-Hungary, where he wrote, both literally and metaphorically, of the balancing out of neighboring contrasts.

The slippage between *Ausgleich* and *Ausgleichung* was strategically employed by Habsburg-loyal writers to naturalize the 1867 status quo. The liberal statesman Gyula (Julius) Andrássy, instrumental in negotiating the compromise, lost his seat in the Hungarian parliament because he was perceived as overly sympathetic to Vienna. While out of office, Andrássy published a defense of Hungary's ties to Austria that drew on both historical and geographic arguments. Andrássy portrayed modern Hungary as a "small country" that could not survive independently. Austria was its natural partner because its borders were impossible to defend without Hungary's aid. The *Ausgleich* was the outcome of an increasing intensification of "differences" (*Gegensätze*) between the two countries: "Every human being, every organism composed of a group of human beings, can only survive through the balancing out of differences [*nur durch die Ausgleichung der Gegensätze fortbestehen*]." Andrássy thus presented the *Ausgleich* as the solution to a problem of disequilibrium. The goal remained to reestablish a state of balance: "Who can predict whether the old harmony will ever be reestablished, whether the oppositional drives will result in a new compromise, whether the means can indeed be found with which to bring the impending avalanche to a halt."[53] The pivotal term here was the German word *Ausgleich*. To nineteenth-century ears, it did not simply connote a diplomatic compromise. Far more vividly, it implied a physical process by which opposing forces were maintained in dynamic equilibrium.

THEORIES OF CIRCULATION

Dynamic climatology illustrated how diversity could be the motor of circulation—and how circulation could in turn "even out" the starkest of oppositions. This proved to be a fertile point of view for the field of political economy. It offered a vivid, physical analogy for the hope that Austria's natural oppositions would generate economic interdependence and therefore political unity.

The rise of dynamic climatology coincided with a spatial turn in central European political economy. This new departure leaned on the ideas of Johann Heinrich von Thünen (1783–1850), a north German landowner and agricultural improver. In 1811 von Thünen had attempted to derive the optimal geographic distribution of economic production. He assumed the existence of a single city with a single road leading out of it and a uniform natural environment. Based on the transport time from the site of production to the urban market, von Thünen posited that zones of agricultural production would develop as rings of increasing radius from the city center: first a zone of vegetable gardens, then zones of forestry, grain farming, and distilleries. Beyond a certain radius, agriculture would no longer be profitable, and the land would be useful only for hunting. Crude as this model may have been, central European scholars developed it as a tool for thinking through the expanding scale of trade in the nineteenth century. Their interest lay in the dynamic relationship between environmental, technological, or demographic change and the expansion or contraction of the economy.[54]

This line of inquiry led, for instance, to some of the first attempts to visualize Austria-Hungary's position within what the Vienna-based economic geographer Franz Neumann-Spallart (1837–88) called the "world economic organism."[55] From his start as an expert on Austro-Hungarian trade statistics, Neumann-Spallart moved on to developing methods for achieving an international economic "overview." To that end, Neumann-Spallart suggested that economics model itself on climatology. In both cases, the question was how to "represent statistically" "the economic situation of a state in its entirety over a certain time interval":

> This is a task that may be compared to the one that meteorology has to solve when it is supposed to determine the climatic character of a region. Just as the climate is in a certain sense the complex result of the interactions of a great number of interdependent elements, likewise what we call the economic situation [*wirtschaftliche Lage*] is the totality of a series of individual facts that express the degree of strength and health of the material life of a given population. In both cases . . . it is a matter of the analytical groundwork for the disaggregation of a holistic impression into its essential constitutive factors. However, meteorology finds factors such as air pressure, temperature, humidity, direction and strength of the wind, etc., which are genuine elements or factors of the situation, for which it possesses precise measuring instruments; and, by generalizing on the basis of a causal law, it can draw a conclusion from a single series of observations for all similar cases. Economic statistics, on the other hand, must rest content with surrogates for these natural-scientific methods.[56]

Otherwise put, climatology furnished political economy with an exemplary model of multicausal reasoning. Although economists did not have precise, causal laws to work with, nonetheless they too could analyze a complex state of affairs into its causally significant component factors.

Climatology also offered economics a model of spatial analysis, as Emanuel Herrmann argued in 1872. At that time, Herrmann was a docent at the Vienna Commercial Academy and an adviser to the imperial education ministry; from 1882 to 1902, he taught as a full professor of national economy at the Technical University in Vienna. Historians of economic thought have associated Herrmann with the subjectivist turn, because he explicitly sought to model economics on natural science. Yet Herrmann's model was not Newtonian physics but rather the empirical, geographical, historical, and statistical fields of natural history and climatology. Like a naturalist in pursuit of the diversity of life, Herrmann was fascinated by the variability of economic life across time and space. Like the naturalist, he sought to interpret the geography of economic activity in terms of interactions among general laws, local conditions, and historical trajectories. Indeed, he viewed the discipline of economics as continuous with evolutionary biology and human anthropology. Thus Herrmann noted that there was a telling affinity between von Thünen's circles of uniform economic production and Alexander von Humboldt's lines of equal temperature or "isotherms." "The lines of equal conditions of production in relation to an urban market form isotherms of a sort."[57] Herrmann noted that these two representational devices had been introduced to the world within a decade of each other.[58] He went on to construct an elaborate analogy between economic and climatic geography, likening "demand" to heat in its capacity to create "tropical" zones of economic growth.[59] Physical geography thus supplied Austrian economists not only with empirical data and statistical methods, but also with a new model for the spatial analysis of economic relations. Once von Thünen's rational approach had been adapted to allow for geographic variability, it suggested how economics could be transformed into a science: not as an abstract mechanics, but as an observational discipline modeled on physical geography.

Another exponent of this new spatial economics was Emil Sax, an independent-minded member of the circle around Carl Menger in Vienna. Like Neumann-Spallart, Sax set out to adapt von Thünen's analysis to the "new scale of global commerce" and analyze the impact of new modes of transportation. Before the coming of the railway and steamship, Hungary had been in the fifth or sixth von Thünen zone from Vienna. Subsequently, Hungarian cattle farmers now had to compete with those in Galicia; at the same time, it became easier to transport grain from Hungary to Vienna. So Hungarian farmers turned increasingly to grain, and the price of grain in the Alpine lands fell accordingly. As Sax interpreted these shifts, improvements in transportation had increased "the value of these natural regions" by raising the "marketability" [*Absatzfähigkeit*] of their products.[60] Thus the modern transportation network allowed Austria-Hungary to profit fully from the complementarity of its natural regions. In this vein, from 1900 to 1904, the liberal prime minister Ernst von Koerber promoted a vast program of economic development and integration, including a broad network of canals and railways—all intended, in his words, to "reduce the nationality strife" by paving a "road . . . free for the spiritual and economic development of the State."[61]

Liberals like Sax and Koerber were not alone in developing this spatial perspective on the economic life of the Monarchy. Karl Renner, one of the leading minds of the Social Democratic Party, disagreed with Sax about the railway's impact on Austria-Hungary, but he too emphasized the crucial significance of physical geography for the socioeconomic life of the Monarchy. The very possibility of imperial unity depended on the physical form of the territory.[62] More importantly, Renner echoed Sax on the value of natural diversity for the economic health of the state:

> To a superficial gaze it seems natural and adaptive that a commercial center lies at the center of a homogeneous region. Nothing is falser than this. Trade is the exchange of what a homogeneous region has in excess, in return for what it lacks; [trade therefore] always thrives on the region's periphery—that is, the space where contact is made between soils of one type and another, between one nation and another. . . . There, where mountains give way to plains, where the mouth of a river connects land and sea, where industrial land borders agricultural land, there the city arises.

Renner interpreted this geographical interdependence dialectically: "Dissimilarity of the parts and autarchy of the whole is the characteristic of all state formation, particularly of the large state. . . . Thus, opposites are incorporated into its being [*Dasein*] in order to be transcended [*aufzuheben*]." Applied to Austria-Hungary, this became an Austro-Marxist argument for the advantages of the supranational state in terms of the value of natural diversity: "Here are united not only agricultural and industrial land but also agricultural lands of the most different structures: forest, pasture, fields of rye, wheat, barley, beets, and animal feed, vineyards and orchards, land for horses and cattle."[63]

Although neither Sax nor Renner referred explicitly to dynamic climatology, all these analyses, economic and climatological alike, derived from the same "whole-state" discourse that assumed local contrasts to be a motor of circulation and, therefore, a force for unity. Climatic diversity, in particular, figured as the basis for a spatial division of labor that set trade in motion. As an article in the *Militärzeitung* from 1866 awkwardly expressed this atmospheric analogy:

> World trade in its broadest significance is the law of the flows that have as their medium the unevenness of nature and of cultural productions that are determined by climates and soils, and that have as their stimulus the compensatory [*ausgleichend*] efforts of man within the confines of his nature and needs—efforts whose geographical and historical origins, due to the infinitely complex composition of these needs, are almost as difficult to fathom as meteorological phenomena, which even today often have the appearance of hieroglyphs.[64]

It was not just that diversity propelled commercial exchange. Forms of circulation—atmospheric, economic, migratory—in turn served to smooth out stark contrasts. This was the image of the Monarchy evoked by the Ljubljana-based commercial geographer Franz Heiderich at the opening of the International Economics Workshop for economists and entrepreneurs, held in Vienna in 1910. Tasked with instructing the foreign guests on the "natural conditions" of Austria-Hungary's "economic life," Heiderich began with the obligatory description of the Monarchy's "pronounced geographic and economic contrasts." Yet nature and man had conspired to moderate these contrasts and stitch together the parts:

> By means of deposits from the rivers and the Ice-Age glaciers, the mountains have acquired gentler slopes along the plains, and the wind-blown deposits as well as the sediments from slowly shrinking bodies of water have further diminished the vertical difference in height and have connected differently formed regions. In this way Nature itself has erased the sharp tectonic borders and replaced them with gradual transitions and wide border zones. Across these flow, from one natural region [*Landschaftsgebiet*] to the next, cultural, economic, and political forms of life, at first distributed in colonies and then gradually coalescing. . . . The Monarchy can thus be regarded as a unity in a physical sense, its various parts solidly cemented together just like a giant breccia.[65]

Here Heiderich introduced two geological metaphors for Habsburg unity: one, the image of the Monarchy as a giant breccia—a rock formed of angular fragments, cemented together by the flow of debris. Its components retained their individuality, yet were bound together by a natural, irresistible process. The second image was a geological variant on a climatological metaphor: the equilibration of neighboring contrasts. In this case, gradients of elevation rather than pressure are evened out by a natural process of weathering. In this way, Heiderich cast empire-building as a natural process, akin to erosion, as unstoppable as the flow of wind and water.

Climate's economic significance was thus both literal and figurative. On the one hand, climatic oppositions set trade in motion. On the other, atmospheric circulation was an apt metaphor for the conciliatory effects of trade: "The exchange of goods and money is colorless like waves of air."[66]

Finally, the convergence of climatology and political economy in late imperial Austria cast new light on the future of industrial Europe. As Herrmann put it, modern man tended to think only in terms of immediate causes. But the earth sciences suggested a more appropriate scale for economic thought. The universe itself was a system of sustainable production, an "enduring economy [*Wechselwirthschaft*, literally crop rotation] of light, heat, gas, earth, waters." "The coal that warms our ovens was a verdant tree hundreds of millions of years ago, which, with so many others, was suddenly destroyed by a storm and washed over by the sea. The petroleum in our lamps derives from the fat of a fish. . . . But the earth must have compressed these stocks for millions or at least thousands of years like a protective container for us to be able to consume them unthinkingly today."[67] Even the milk and butter of a European breakfast must be seen as the product of millions of years of mammalian evolution. Alarmed at the rapid pace of resource exhaustion in the 1880s, Herrmann called for a worldwide organization to survey the earth's stocks and agree on their allocation.

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In short, climatology can be said to have contributed a kinesthetic basis to the imperial ideology of unity in diversity. That is, familiarity with the observation of atmospheric phenomena and with the mapping of meteorological elements offered an intuitive, embodied way for scientists and nonscientists alike to imagine the space of the empire. The atmospheric dynamics communicated in atlases, newspapers, and medical guides taught Habsburg subjects to experience the wind as a force for the balancing out of oppositions. The idea that nature decreed the *Ausgleichung* of local differences lent support to the ongoing politics of *Ausgleich* in the late nineteenth century, as Bohemians, Galicians, and South Slavs each demanded their own "settlement"/"equilibration" with Vienna. In the fields of medicine and political economy, appeals to the "balancing out of neighboring contrasts" grounded arguments for the benefits of the multinational state to the health and prosperity of its inhabitants. By the 1890s this simple model of atmospheric dynamics had captured the imagination of Habsburg citizens, expert and lay. It provided a vivid physical image of the emergence of unity out of diversity.

Much of the work of Habsburg climatology after 1900 went into refining this idealized picture of atmospheric circulation in order to understand how it resulted in the sensible characteristics of local climates. However, "the balancing out of neighboring contrasts" was but a first approximation to a description of atmospheric dynamics. As scientists today would put it, the pressure gradient only determines the winds under the simplifying conditions of geostrophic flow. Only in this case can the pressure difference be maintained and the wind remain constant, since the wind blows perpendicular to the gradient.[68] By the 1890s, however, the ideological force of this model made it seem self-evident. As we will see in the next section, it would take an outsider to question it.

A "UNIQUELY ODD FELLOW"

Of all the accomplished individuals working at the ZAMG circa 1900, Max Margules is, ironically, the only one whose name is commonly remembered today. Among atmospheric physicists, Margules is best known as the author of the "tendency equation," a cornerstone of early computerized weather forecasting, and the inventor of the concept of available potential energy, long central to the work of climate modelers.[69] Some textbooks of atmospheric physics will tell you that Margules worked in Vienna circa 1900, that he was known as something of an oddball, and that he met a tragic end. In fact, he left behind few clues to illuminate the mysteries of his life. The irony of Margules's fame today is that in his own lifetime he was a liminal figure in the circles of imperial-royal science. A Jew in a casually anti-Semitic academic world, he was never a contender for a high-ranking post. Socially awkward by some reports, Margules has gone down in history as a loner, as someone who worked, to quote one textbook, in "intellectual isolation."[70] There is indeed evidence that he was an intensely private man. The archives hold no more than a few terse manuscripts on physical chemistry, the topic he took up after abandoning atmospheric physics in 1906. Even his published papers are dense with equations, short on words. And yet the claim that Margules was isolated from his milieu remains to be evaluated. His story must be pieced together from government records and the posthumous recollections of his colleagues.

FIGURE 27. Max Margules (1856–1920).

Margules was born to a Jewish family in the primarily Jewish town of Brody, in eastern Galicia, in 1856. He moved to Vienna for his last two years of gymnasium, where he lived in the Jewish quarter of Leopoldstadt. He studied physics at the University of Vienna and then, in 1879–80, at the University of Berlin. The chair of physics at Berlin was then Hermann von Helmholtz, who had recently returned to the study of atmospheric discontinuities. Margules was not well prepared to contribute to this inquiry, having trained as a mathematical physicist with a focus on electromagnetism. Nor had he experienced the leisurely childhood in the Alps that had set many of his colleagues on the path to a geoscientific career. Nonetheless, he turned his focus to the science of the atmosphere.

For twenty years, interrupted only by his stay in Berlin, Margules served as an assistant, adjunct, and then secretary at the ZAMG. He was hired in 1877 in part to work on the institute's yearbook, which had fallen far behind its publication schedule due to the arduous labor of reducing data from the fast-growing station network. Margules succeeded so well that by 1885 the yearbook for 1883 was in press. Likely due to his knowledge of a Slavic language, he was put in charge of maintaining communication with the weather stations in the eastern and southern portions of the Monarchy.[71] As we saw in chapter 4, the ZAMG's network was unevenly spread across the crown lands, and its early directors made it a priority to increase the density of observations from regions like Galicia, Bukovina, and Dalmatia. Margules made this goal his own. He expressed satisfaction at seeing stations established in poorly represented areas.[72] By 1888, he was responsible for reviewing the observations submitted by all the stations of the network and preparing them for publication. He was also in charge of inspecting stations in Galicia, Bukovina, Dalmatia, and Bosnia and Herzegovina—to which was soon added Austrian Silesia, Upper Hungary, and Transylvania.[73] These inspection tours took Margules to the distant reaches of the empire, from where he reported on the quality of observers and observations. Back in Vienna, he took pains to stay in contact with observers in these parts.[74] Margules also took charge of reducing vast amounts of raw data.[75] Not one for collaboration, he would nonetheless occasionally surprise colleagues with a sheaf of measurement values, on which observations relevant to their research had been highlighted with his signature red pen.[76]

Although Margules is thought of as a "fundamental" researcher who worked "in isolation," his research questions were firmly embedded in the program of imperial-royal science. His most lasting contributions began as an interrogation of the central metaphor of Habsburg climatology: the potential of local differences to power an integrative circulation.

INTERROGATING THE CENTRAL METAPHOR

What Margules realized in the 1890s was that existing scales of observation failed to capture the phenomena of relevance to a quantitative evaluation of this model of atmospheric motion. The stations of the ZAMG's network were irregularly spaced, and even at its densest in Carinthia there was no more than one station for every three square miles.[77] This made it impossible to track phenomena like squall lines, with dimensions of roughly one hundred kilometers. And so Margules defined a new scale of observation. That is, he constructed climatology's first purpose-built *meso*scale observing network, comprising four stations arrayed at a sixty-kilometer radius from Vienna.[78] Observations from this network would be used to determine the relationship between observed pressure gradients and the force of a squall—that is, a localized storm or violent gust of wind.

Here was an infrastructure suited to studying the question at the top of the institute's research agenda: the strength of winds to be expected from what Supan had called the "balancing out of neighboring contrasts." The data from the stations' barometers and anemometers indicated that bigger pressure differentials did not, in fact, correlate with stronger winds—"not even approximately." Margules began to suspect that pressure contrasts were not the driving force behind atmospheric motions—that they were a "mere cogwheel in the machine," as he would later put it. Here was empirical evidence that the model of a circulation powered by pressure differentials didn't quite work. Refining it became the new agenda of Habsburg climatology.

In his theoretical work, Margules sought to understand this situation from first principles. Take the example of his "tendency equation," still taught in introductory courses in atmospheric physics today and a governing equation of many computerized climate models. The tendency equation relates a change in pressure to the movement of air. Margules derived it in 1904 from basic considerations about the incompressibility of air and the relationship between air pressure and altitude.[79] The pressure of the air at any point is determined by the weight of air above it. Margules's tendency equation (equation 1) gives the relationship between the change in pressure at a given point and the wind blowing toward or away from that point (neglecting friction and the rotation of the earth). The first term is the rate of change of air pressure; the second and third terms are the divergence of air in the horizontal plane; and the fourth term is the air's vertical motion. The equation says that as air flows horizontally away from a point, the pressure at that point will fall, unless balanced by a vertical inflow of air.

$$(1) \quad \frac{\partial p}{\partial t} + \frac{\partial (pu)}{\partial x} + \frac{\partial (pv)}{\partial y} + g\mu_h w_h = 0.$$

Historians of meteorology have described the equation as an early attempt at weather forecasting. The goal would be to *predict* a rise or fall of the barometer from observation of the wind field. The equation showed Margules that a small error in the measurement of the wind field will skew the forecast significantly. In the 1940s, this problem came to be dealt with by means of "quasi-geostrophic" theory. This approach, developed by Jules Charney, used vorticity, a measure of rotation, to arrive at approximate calculations of the divergent flows that worried Margules. These, in any case, tend to be small outside of the tropics. Back in 1904, however, Margules's analysis reinforced the skepticism with which he and his colleagues at the ZAMG already viewed the job of weather forecasting. As Felix Exner would argue, mathematical models of atmospheric processes were of use for explaining, not forecasting.[80] Margules was unequivocal: forecasting, he said, was "immoral and dangerous to the character of the meteorologist."[81]

How then should we interpret Margules's work toward the tendency equation? Was this an attempt to prove the practical impossibility of forecasting? Or was he perhaps after knowledge of a different kind? Consider next a very similar expression that Margules had published three years earlier. In this case (equation 2), he began by balancing the work performed by an expanding parcel of air against the work exerted by the surrounding air pressure. Equation 2 allows for a similar calculation as equation 1, assuming the change in pressure to be small and the movement of air to be only in the horizontal plane.

$$(2) \quad \frac{1}{2}(V^2 - V_0^2) = RT\frac{p_0 - p}{p_0} + \frac{RT}{p_0}\int(\partial p/\partial t)\,dt\,.$$

It is telling that equation 2 states the equivalence in the opposite order as equation 1: now a change in wind speed is to be calculated from a pressure gradient. In other words, the interest is not in forecasting a clear or stormy day. Instead, the question is how much motion is generated when air flows from an initial location to a final location at which the pressure, though lower, is not constant. Rising pressure will produce a greater final wind speed; falling pressure will produce a lower final wind speed. Here, the motivation, as the title of the 1901 paper indicates, is to understand the "Energy of a Pressure Distribution." In other words, equation 2 is an expression of the motive force produced by what Margules's contemporaries referred to as "neighboring contrasts."

THE ATMOSPHERE'S STORE OF ENERGY

The second key concept for which Margules is remembered today is that of "available potential energy" (APE), which played an important part in the first general circulation models of the 1960s and 1970s and remains central to the analysis of the instability associated with regions of the atmosphere where temperature varies abruptly (baroclinic zones). We can define "potential energy" as the energy stored in a system; "available potential energy" then designates the fraction of that energy available to do work—that is, to generate motion. In the atmosphere, this is only a small fraction of total potential energy. Margules showed that APE (or what he called "available kinetic energy") could be calculated as the difference between the potential energy of an initial configuration of a gas and that of a final state in which the potential energy of the gas is

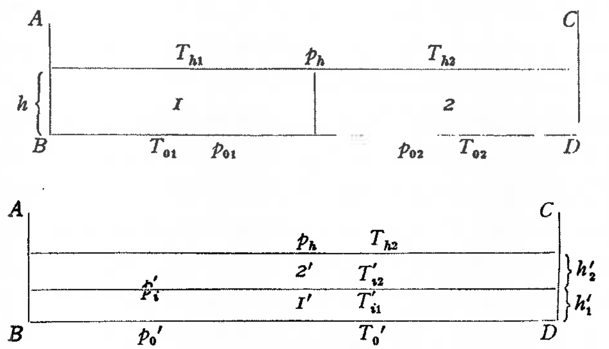

FIGURE 28. Calculating available potential energy: initial and final states of a chamber of gas with dividing wall removed.

reduced to a minimum, without adding or subtracting heat. A very simple case is illustrated in figure 28. The initial state consists of air at different temperatures separated by a vertical wall. The final state is layered horizontally: gas with higher pressure and higher temperature above, lower pressure and lower temperature below. It is instructive at this point to note the difference between APE and total potential energy. Imagine a horizontally stratified atmosphere like this stable final state. It would still have gravitational potential energy, since the molecules are above ground height. However, the system can do no work: it cannot move to a state of lower potential energy (all molecules at ground level) without removing heat.[82]

The significance of APE is that it allows one to calculate accurately something new and important: it measures the energy stored in different states of the atmosphere and *available* to generate motion. This gave Margules a way to test the presumed power of neighboring contrasts. Suppose a room five meters high is divided in two by a sliding wall. Assume that the air on one side is at a higher pressure than the air on the other side, with a difference of ten millimeters of mercury at ground level. Gradients of this size are often observed during strong winds. What happens when you remove the sliding wall? According to Margules's calculations, the redistribution of air would generate a wind of only 1.5 meters per second: no more than a gentle breeze. No matter how big the room is, the answer is the same. Now consider the case in which the room is again divided in two, but the two sides are maintained at different *temperatures*: 0°C (32°F) in one half, and 10°C (50°F) on the other. Remove the sliding wall, and you'll have a wind of .67 meters per second, somewhat lighter than a light breeze. Not very impressive, to be sure. However, if the height of the room were six thousand meters, the height of mid-level clouds, the speed achieved would be twenty-three meters per second—close to a storm-strength wind.

Margules was challenging the reigning theories of cyclone formation. Hann's thermodynamic theory of the origin of foehn had inspired an idea that, ironically, Hann would fight hard to disprove: the thermal theory of cyclones. This held that the churning energy of a cyclone derives, like the foehn's warmth, from the latent heat released by a rising current of moist air. This view came easily in an era obsessed with the new industrial engines, since it cast steam in the role of motive power. As Gisela Kutzbach has recounted in a masterful study, the thermal theory of cyclones became orthodoxy in the 1860s. But Hann had never bought it. He had focused instead on the motive power of the pressure distribution, but had been unable to explain what maintained that distribution. Margules went further. Both his observations and his theoretical calculations had suggested that pressure gradients were not responsible for storm winds. So what was?

Inspired by studies of inversions and other stark temperature contrasts in the atmosphere, Margules hypothesized that strong winds could be produced by horizontal gradients of *temperature*. He reasoned that such temperature differences create a situation in which small air currents might displace parcels of lighter (warmer) air into colder regions, and parcels of heavier (colder) air into warmer regions. These parcels would then experience a strong gravitational force tending to restore them to their original positions. According to this interpretation, storm winds are the result of conditions of instability in the atmosphere that accrue gradually until they are suddenly released by a small movement of air. Margules introduced the fiction of the sliding wall because, as he admitted, he was unable to explain how such unstable conditions were maintained in the free atmosphere. He concluded that the forces "set free" when an unstable equilibrium is disturbed "are greater than those corresponding to the largest horizontal pressure gradients that have been observed in the atmosphere."[83]

Upon publication in 1903, Margules's theory was overlooked by many and met resistance from some who made the effort to read it. Thus his colleague Trabert had to defend him for having ignored vertical air currents.[84] Particularly controversial was Margules's claim that the latent heat of condensation contributes little to the energy of most storms.[85] Sir Napier Shaw contended that Margules had set an arbitrary limit on the vertical convection of warm, moist air, the driving force of the cyclone according to the thermal theory.[86] In fact, Margules's fundamental contribution to atmospheric dynamics would not be recognized outside of the German-speaking world for several decades.[87]

In 1954 the pathbreaking American meteorologist Edward Lorenz seized on Margules's concept of APE as the quantity that would make it possible to track the flow of energy in the atmosphere.[88] Lorenz tweaked the concept in two ways. First, he applied it not to an individual storm, as Margules had, but to the atmosphere as a whole (which could more properly be regarded as a closed system, in which a fixed mass of air would be redistributed within a fixed volume). Second, he renamed it. "Available potential energy" made clear, in a way that Margules's "available kinetic energy" did not, that the energy in question was stored in the form of a tension in the atmosphere. Lorenz then showed how APE could be used to track the exchange of atmospheric energy between large scale and small, "between zonal winds and the eddies." In this way, it became possible to show that larger eddies—that is, cyclones—play a vital role by transferring enough angular momentum to the zonal flow to compensate for the energy dissipated as friction. The concept of APE thus helped to confirm a picture of the general circulation that Julius Hann had already begun to imagine in qualitative form circa 1900, as we will see in the next chapter.

A TRAGIC END

For his hard work and "excellent knowledge," Director Hann repeatedly petitioned the ministry to promote Margules and give him a raise.[89] In 1890, Margules was made an adjunct, and in 1901, he was promoted to the institute's secretary, the first to hold that post. Many years later, he expressed gratitude to Hann for all that he had learned from him.[90] Then, in 1897, Josef Maria Pernter succeeded Hann as the ZAMG's director. Pernter was a staunch and politically active Catholic conservative, a Tyrolean patriot, and very likely an anti-Semite. Ficker recalled: "Anyone who got to know Pernter without knowing who and what he was, would never have guessed that this lively, combative South Tyrolian had been captured by science. . . . This product of a Jesuit education looked more likely to be a politician or a pugnacious cardinal than the director of a scientific institute. And if one had to write the life story of this extraordinary man, one would have to reach the conclusion that political and religious controversies occupied him at least as much as the problems of science." In Ficker's judgment, "Anyone who knew Pernter and Margules would find it lamentable but not incomprehensible that these two men could not bear each other."[91]

Pernter must have made Margules's life at the ZAMG unbearable. It became all too clear that he would never rise above the position of assistant. Two years after publishing his concept of APE, Margules quit his post as secretary of the ZAMG and abandoned meteorology for good. He explained to the education ministry that he had fallen into conflict with his colleagues, pointing out as well that he had been passed over repeatedly for promotions.

Director Pernter agreed to his request for early retirement, adding that Margules was an *eigenartigen Sonderling*, a "uniquely odd fellow." He was "overly sensitive," perceived himself to be always under attack, and did not respond well to efforts to improve his situation.[92]

Other colleagues described Margules far more fondly. Ficker wrote:

> I had the great good fortune to arrive at the ZAMG when Margules was still active there—and had the even greater good fortune to develop a closer relationship with him. I remember very well . . . how he looked me over with his gray eyes, how he then said, 'I've read your Föhn study. I have here a couple years of data charts from the Sonnblick and a valley station that I've prepared for you. You can always come and tell me what you've found. But I won't give you any advice. And he stuck to that while I put together the study of the transport of cold air masses over the central Alps. That by the way was the first meteorological investigation that was carried out with a view to his new ideas. Only after it went to press would he give criticism. He sure wasn't a teacher. Once he said to me, "You should really deal with the theoretical side now. You'll get the math soon enough!"[93]

From Felix Exner, we have the following account of Margules's tragic fate:

> In the last years, when I had the privilege to visit Margules from time to time, I found in him an enlightened, amicably disposed wise man, with no trace of bitterness, who had given up on all the joys and vanities of the world and who was leading the life of an urban recluse. I never left him without being deeply impressed by the greatness of his soul. In the last years of his life there literally was no one with whom he would communicate on a regular basis; he was a bachelor, living alone in a small, undecorated flat without house help. Margules, who preferred independence and freedom to everything else, wrote to me once that he had almost nothing to eat and asked if I was still alive. Afterwards, patrons were found both in and outside Austria, who sent him some food; and still it was not an easy task to persuade him to accept it. And so Margules died a hungry death in complete consciousness, unwilling to become a burden to others and to take anything that was not his due.[94]

As much as Margules's colleagues valued his contributions, they could not or would not welcome him into the social world of imperial-royal science. Margules died with the empire, another faithful Jewish servant of Franz Josef.

And yet, in the years around the turn of the century, Margules had made the Austrian Problem his own. He had worked to expand the imperial observing network both extensively and intensively and had nurtured relationships with its observers. He was not, as is often supposed, a "lone wolf."[95] But he had retained enough intellectual autonomy from the ideology of imperial-royal science to put its central metaphor to an empirical test. Other Austrian researchers would follow his lead.

CHAPTER 8

Planetary Disturbances

Habsburg contributions to dynamic climatology elucidated phenomena at scales ranging from the planetary down to those of agriculture and human health. Far from being disconnected investigations, these studies built on each other, working toward an understanding of interactions between phenomena of such disparate dimensions. To this end, between 1903 and 1921, researchers affiliated with the ZAMG, including Margules, Schmidt, and Defant, developed two essential tools of scaling, described in this chapter: small-scale fluid models of atmospheric motion, and a quantitative measure of turbulent motion, applicable to flows of any dimensions.[1] Putting these together with Margules's concept of APE (chapter 7), they were able to estimate the contribution from turbulent eddies to the flow of heat and angular momentum between equator and poles. This added up to a revolutionary idea. Cyclones and smaller eddies no longer appeared as "local disturbances" superimposed on steady planetary currents. Rather, these disorderly motions came to be seen as essential components of the atmospheric system.

MODELS OF THE ATMOSPHERE AND ITS "DISTURBANCES"

The historian of meteorology Hans-Günther Körber has suggested that the opening to a "dynamic" science of the atmosphere came with the adoption of the Copernican system in the seventeenth century. For the first time, winds could be explained in terms of the movement of the earth. Galileo, in fact, cited the easterly winds in the tropics as evidence of the earth's rotation.[2] And yet