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6 Predicting the Weather: An Information Commons for Europe and the World

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Weather affects virtually everything people do: where and how we live, what we eat, what we can and cannot do on any given day. A shared resource when it brings sunlight, warmth, and water, it is a shared risk when it brings floods, droughts, or extremes of temperature. Weather affects agriculture, urban planning, government, insurance, and much else. It even gets inside us. We routinely describe moods, sensations, and relationships as "stormy," "foggy," "cold," or "sunny." We can't change the weather (at least not on purpose), so to escape its tyranny we go indoors. Architects design buildings that protect us from it, yet even their best designs too often succumb to hurricanes, tornadoes, floods, snow, or heat. One thing we *can* do about the weather is to try to predict it, enabling us to prepare for its worst effects and to take better advantage of its best ones.

Weather prediction is an ancient pursuit, the province of sailors, farmers, and shamans long before it became an object of science, and of science long before the advent of practical forecast technology. In this chapter, I will focus mainly on weather forecasting in the modern era. Today's weather prediction system collects weather data from countless sources and blends them into coherent data images via computerized data analysis. Using computer simulations, it then creates weather forecasts for large areas from those data, and it broadcasts both the forecasts and the treated data. I call this form of forecasting "technoscientific" in order to signal that it binds devices (computers, weather instruments, satellites), large-scale information and communication infrastructures, and scientific understanding (meteorological theory, simulation modeling).

I begin by outlining a case for viewing the global weather forecasting system as an information commons—an interpretation that is partially at odds with the more common picture of forecasting as a public good. I then briefly survey the history of the international weather prediction system before moving on to the chapter's main subject: a history of the European

Centre for Medium-Range Weather Forecasts. The ECMWF opened its doors at Shinfield Park, England, in 1974 as a joint project of sixteen European nations. Its primary goal—at the time a highly ambitious one—was to supply credible weather forecasts for a period four to ten days in the future: the "medium range." By the mid 1980s, the ECMWF had already achieved remarkable success. Within a decade after its first operational forecast in 1979, it had built a reputation as the world's most important weather forecasting center, supplying not only Europe but also the rest of the world with data, analysis, and forecasts and contributing substantially to the science of climate change. This episode highlights the technical and political challenges of building a cosmopolitan information commons. Throughout the chapter, I point to tragic possibilities—ways in which the commons can be unintentionally disrupted or destroyed by the withdrawal of data or the privatization of public resources.

Weather Information Systems as Cosmopolitan Commons

Elsewhere I have described the technoscientific weather forecast system as a global knowledge infrastructure comprising the physical, organizational, and knowledge elements that underlie the practice of forecasting.[1] In this chapter, I want to look at it from another angle, thinking of it instead as a cosmopolitan information commons. This perspective complements a widely held and largely correct view of weather forecasting as a pure public good.

Early conceptions of public goods (as discussed in chapter 2 of this volume) defined them as resources that are both non-excludable (i.e., people cannot be prevented from consuming them) and non-subtractable or "non-rivalrous" (i.e., people can consume them without leaving less of the resource for others).[2] National defense, lighthouses, and scientific knowledge were classic examples. By contrast, common-pool resources were described as non-excludable *but subtractable*. This combination of properties was held to be the basis for "tragedy of the commons" effects—that is, overconsumption, such as the depletion of ocean fisheries or grazing lands. More recent scholarship has emphasized, however, that common-pool resources have rarely been entirely non-excludable in practice. Each chapter in this volume, including this one, describes ingenious ways—from physical barriers to customs and legal systems—that people have found to restrict access to and use of common-pool resources. It can be argued that this also applies to public goods. Even national defense and scientific knowledge can be rendered excludable under certain conditions. For example, when the Confederate army defended the seceding states of the antebellum American

South, the African slaves living within the Confederacy could hardly be considered its beneficiaries. Similarly, the "patent thickets" that effectively privatize numerous scientific and technical innovations have been called a "tragedy of the anticommons" in reference to the deleterious effects of the labyrinth of conflicting rights and rights holders they establish.[3]

What about subtractability, often held to distinguish public goods from common-pool resources? Unlimited numbers of people can certainly "consume" (read, view, hear) a weather forecast without diminishing its value for anyone else; it is even the case that the more people consume some kinds of weather forecasts (such as those for hurricanes or tornadoes), the *greater* their value for everyone.[4] Indeed, the head of the World Meteorological Organization once called public weather forecasting "the ultimate example of a pure public good."[5] Yet this chapter will show that the weather data and computer modeling on which forecasts are based depend on contributions from many quarters, which can be, have been, and still are threatened by rivalrous alternatives. Considered as a cosmopolitan commons, technoscientific weather forecasting comprises (a) a shared resource-space, (b) a set of "tragic" possibilities that could diminish or destroy the commons, and (c) a moral economy that governs both contributions to knowledge production and consumption of its outputs. Weather forecasts are much more than costless, abstract information that could be produced anywhere by anyone. Instead, they are inextricably tied to the physical phenomena they predict, and they require data from all over the world. Acquiring knowledge of these phenomena demands that information creators, including people, equipment, and institutions, span numerous international boundaries. As a result, the technoscientific forecasting system is inherently enmeshed in political structures and choices whose vicissitudes make weather forecasts a precarious resource at certain times.

Consider the idea of a "resource-space" (presented in chapter 2). Cosmopolitan commons theory contends that the scale at which and the ways in which resource-spaces are organized and exploited depend not only on the geophysical characteristics of the spaces (the radio frequency spectrum is a very different kind of resource-space from the North Sea, for example), but also on available technologies, techniques, and theories, and on how these are organized into functioning commons. A weather forecast describes physical phenomena for a certain area over some time period. Because weather moves, the longer the time period, the larger the physical volume the forecast must assess. Today, with satellite imagery available at the click of a mouse, we see quite readily that weather systems are huge (often larger than most European nations) and that they move swiftly (often traversing the entire European continent in a day or two). Yet as recently as the 1950s, these systems could not be seen directly. Before high-altitude photography from rockets and satellites, images of weather systems had to be constructed by painstakingly plotting individual data points on maps, then connecting those points according to principles that began as visualization techniques before they gained support from scientific theory.

In seeking to make better, longer-term weather forecasts, the weather forecast infrastructure—the resource-space that is organized and exploited to produce weather forecasts—has expanded from essentially local dimensions to regional and national scales, and in the last thirty years to a global scale. Thus, weather forecasting now is carried out within a *human-constructed* resource-space, rather than within a naturally existing resource-space such as the Rhine or airspace. In fact, weather forecasting is carried out within a constructed "resource- space/time," we might say, since the speeds of data transmission and processing determine how much data can be collected and used, while the quality of computer models determines how far into the future usable forecasts can look. Obviously weather itself occurs in geophysical space, whether we predict it or not. The "resource-space/time" I am talking about is, rather, the space/time of weather knowledge—i.e., the space/time that is exploited to produce modern weather forecasts, and the space/time of those forecasts' validity, which today runs to about 10 days in the northern hemisphere.

Weather forecasts are, of course, based on data. A moral economy of freely shared, widely disseminated data originated in the seventeenth and eighteenth centuries, when such data were not only inexpensive to acquire but also entirely devoid of economic value. Remarkably, this moral economy remained in place even after the advent of computers and satellites, which multiplied the costs of forecasting (and its power) many-fold.

The "tragic possibilities" that attend the weather information commons stem from challenges to this moral economy. For example, each of the world wars resulted in a temporary collapse of global data sharing. In a more recent example, movements to monetize publicly produced weather data and to privatize major elements of forecasting arose in the 1990s. Some monetization and some privatization did in fact occur. Yet, thanks to defensive action by the World Meteorological Organization and others, basic weather data and forecasts remain freely shared public-domain resources. We will return to each of these points below. First, though, let us look briefly at the historical trajectory of technoscientific weather forecasting since its earliest days.

Topographies of Weather Information: Weather Telegraphy

Meteorology is among the oldest examples of scientific internationalism. This fact is due at once to the large physical scale of weather systems and to the technological means required to produce information and knowledge about those systems. Italian scientists developed thermometers and barometers, the basic instruments of weather observation, in the 1640s. Seeking an understanding of how weather moves, scientists established observing networks almost immediately. From 1654 to 1667 the Accademia del Cimento oversaw a pan-European network consisting of ten weather stations ranging from Florence to Paris, Warsaw, Innsbruck, and Osnabrück. James Jurin published European data (and some data from the British colonies in North America) in the British Royal Society's *Philosophical Transactions* from 1724 to 1735. In the late eighteenth century, the Societas Meteorologica Palatina, based in Mannheim, organized a network of 37 weather stations scattered across Europe and the United States.[6]

Before the advent of the telegraph, however, these observing networks could share data only long after the weather in question had passed. Such forecasting as there was took place locally and was based chiefly on the barometer, whose imprecise predictions were valid only for 12–24 hours. Dependent on patronage and unable to offer forecasts of much practical value, these early networks all collapsed after a decade or two. Surprisingly, until the nineteenth century they almost never used maps, relying instead on tables that mixed instrument readings with qualitative descriptions that lacked a standard vocabulary. Still, these early observing networks established the idea that wide-area data analysis might reveal patterns that could be used for prediction.

Even the earliest meteorologists dreamed of an ability to "see" the weather of the entire world. Scientific understanding of Earth's atmosphere as a global system dates to Edmund Halley's articulation of the mechanism of the trade winds in 1686, which was accompanied by a map of those winds across the Atlantic, the Indian Ocean, and part of the Pacific.[7] The Prussian meteorologist Heinrich Dove mapped global temperature averages from the equator to the middle latitudes in 1853.[8] By 1856, the American William Ferrel, using a combination of theory and observation, had produced a remarkably modern diagram of the large-scale global atmospheric circulation.[9] However, all of these were climatological features derived from data recorded over many years, and were of little use in forecasting weather in the immediate future.

At an 1839 meeting of the London Meteorological Society, John Ruskin spoke of meteorology's desire "to have at its command, at stated periods, perfect systems of methodical and simultaneous observations; it wishes its influence and its power to be omnipresent over the globe so that it may be able to know, at any given instant, the state of the atmosphere on every point on its surface."[10] The arrival of the telegraph in the 1840s seemed to bring Ruskin's goal of meteorological omniscience within reach. For the first time, meteorologists could share weather data over large areas within hours of making observations.

In 1849, Joseph Henry of the Smithsonian Institution established an American weather telegraph network, with government support. Henry secured the agreement of commercial telegraph companies to transmit weather data free of charge. This agreement brought a commercial enterprise and a new communications medium into the moral economy of forecasting under the same arrangement as meteorology's previous no-cost data-sharing regime, such as it was.[11] Europe soon followed suit. In 1854, during the Crimean War, a disastrous storm destroyed a French fleet near Balaklava on the Black Sea. Since observers had seen the same storm moving across the Mediterranean the previous day, they realized that advance warning (by telegraph) might have prevented the debacle. As a result, in 1855 France established a national weather telegraph service and an international meteorological center. Other European nations followed suit, arranging national weather telegraph networks within their borders. By 1857 Paris was receiving and forwarding daily telegraph reports from Russia, Austria, Italy, Belgium, Switzerland, Spain, and Portugal.[12] This transformed the resource-space of forecasting from an essentially local topography to one largely coextensive with telegraph networks. In Britain, in the United States, and elsewhere, many of these networks used railway lines as convenient rights-of-way, leading to overlapping topographies of large technical systems.

Weather telegraphy permitted meteorologists to map the weather over very large areas within a few hours of observations. The resulting "synoptic" maps functioned like snapshots.[13] They charted pressure, temperature, and other weather conditions at each observing station. Wind direction and speed told which way the weather was moving, and how fast. By the end of the nineteenth century, weather maps looked much like those in use today, showing isolines of temperature and pressure and indicating the direction of motion of weather systems. These maps provided a basis for at least a rational guess at what would happen next, and where. Yet the complex motion of the atmosphere—a turbulent, chaotic, global system—means constant change. Meteorologists struggled in vain to find consistent patterns in the behavior of weather at local and regional scales. In the absence of an understanding of atmospheric dynamics and an observing system in the vertical dimension, synoptic maps added little to the quality of forecasts beyond 24–36 hours. Their principal benefit lay in advance warning of the approach of major storms.

By 1865, some twenty European nations had formed the International Telegraph Union to promote and develop technical standards for international telegraphy. Weather services created simple telegraph codes for reporting basic data using a minimal number of characters. The telegraph agencies generally agreed to transmit these weather bulletins at no cost, as a public service. Certain special characteristics of weather data made this information-commons approach sensible at a time when telecommunication was quite expensive. First, basic weather data are quite simple and compact, requiring only a few words of telegraph code. For example, the entire report from a New York City station in the 1870s, coded for telegraph transmission, read simply "York, Monday, Dead, Fire, Grind, Himself, Ill, Ovation, View." Expanded, this report translates into the following.

York: New York (station)
Monday: 30.07 (barometer corrected)
Dead: 29.90 (corrected barometer for temperature and instrumental error)
Fire: 70° (thermometer)
Grind: 75 per cent (humidity)
Himself: west, fair (wind and weather)
Ill: 6 miles (velocity of wind)
Ovation: 1/2 cirrus clouds, calm (upper clouds)
View: 67° (minimum temperature during night)[14]

The compactness of the data, further reduced by ingenious codes, made it feasible for the telegraph operators to carry weather reports without charge. Had many more variables been required, this might not have been possible. A second unique characteristic of weather data is that their value decays rapidly. Before World War II, data more than a day old were of no use in forecasting. A third characteristic is that a *collection* of weather data, suitably mapped, has vastly greater value than individual data points alone. In general, all parties gained by sharing data, and none benefited from keeping them secret—except in certain circumstances, as we will see below. These special characteristics of weather data and forecasting structured both the push to enroll telegraph operators and the operators' acceptance of that task on a no-cost basis.

Meanwhile, the topology of telegraph networks—which rapidly became national systems, in some cases under government control—helped shape the forecasting system that emerged in the second half of the nineteenth century. That system's fundamental unit was the national weather service.[15] National weather services provided both verbal forecasts and weather maps, which could be viewed at weather stations or even, starting in the 1880s, could be transmitted as crude facsimiles over telegraph lines and published in newspapers—a practice that was routine in some places by 1900.[16] As both system builders and network users, the national weather services experienced conflicting pressures. Because they were answerable to their governments, they gave the highest priority to improving their services within their respective countries' borders. Yet as forecasting techniques improved, all nations needed data from beyond their own borders. This was especially true in Europe, with its relatively small nations. Even countries on Europe's western edge, such as Britain and Norway (whose weather comes primarily from the North Atlantic), needed data from Canada, from the United States, and from ships at sea. The heads of European and American national weather services joined forces in the 1870s to form an International Meteorological Organization that was oriented toward standardizing weather observations and telegraph codes for international data sharing. By 1900, the IMO had articulated the goal of a Réseau Mondial—a worldwide network—that might one day report weather data from across the globe in hours over the telegraph network that by then covered much of the world.

Elsewhere I have described the International Meteorological Organization and its successors as engaged in "infrastructural globalism." This phrase emphasizes the deliberate project of global infrastructure building in meteorology. The well-defined and persistent focus on the planetary scale of weather, especially after 1950, created a clear trajectory for the sociotechnical systems needed to monitor the weather and to model its processes.[17] Cosmopolitan commons theory complements the idea of infrastructural globalism. Nineteenth-century meteorology explicitly conceived weather forecasting as a public good, properly supplied by national governments to their citizens, and made weather data freely available to forecasters. Meteorologists saw global data sharing as desirable not in some abstract or political sense, but because the physical phenomena in question are global in scale. The resource-space of the weather information commons began to grow.

Weather Information, World War, and the Growth of a Global Network

The long-term goal of a global weather information infrastructure, the moral economy of freely shared data, and the notion of weather forecasts as public goods were widely accepted by professional meteorologists. Yet until after World War II the institutional basis for an internationalized forecasting system remained extremely weak, and it conflicted with the political structures on which meteorology depended. Each national or imperial weather service established its own standards for data formats, telegraph codes, units of temperature (Fahrenheit vs. Celsius), units of pressure (pascals vs. millibars vs. pounds per square inch), observing hours, and so on. As a result, there were many thousands of slightly different national standards. In the pre-computer era, converting one format, code, or unit into another required significant work. This chaotic state of affairs constrained forecasters, in practice, to use only a small subset of the available data.

A major goal of the International Meteorological Organization was to standardize data, formats, codes, units, and so on. But the IMO had no governmental status or authority. From 1871 to 1939 its activities consisted of little more than occasional meetings of the heads of major national weather services and the publication of suggested standards. Between meetings, the IMO did very little. It didn't acquire a permanent secretariat until 1926, and even then the secretariat's annual budget never exceeded $20,000. The IMO did make slow progress on international standards. But getting dozens of national weather services to agree on and conform to common standards and techniques often cost more in time, money, and aggravation than it seemed to be worth. Therefore, as in many situations where national sovereignty conflicts with internationalist or globalist goals, the national weather services often behaved in contradictory ways, sometimes guarding their existing standards and systems against "outside" interference and at other times urging the adoption of international norms. The one thing on which all agreed was that the national weather services retained sovereign rights to work as they wished. This tension between meteorological nationalism and internationalism severely limited the IMO's potential well into the Cold War era.

The two world wars did nothing to improve the situation, and in fact illustrate the precarious nature of the weather knowledge commons. During each war, the combatants did their best to cut off each other's access to the global flow of weather data in order to reduce their enemy's forecasting capability. As soon as hostilities ceased, access was restored. The world wars inhibited data sharing, but they also advanced meteorological science in numerous ways. The armies of World War I made meteorology central to military affairs, promoted the growth of dense observing networks and upper-air observation by aircraft (largely in order to overcome the loss of data that otherwise would have been shared), and led indirectly to a conceptual revolution in weather forecasting spearheaded by the Norwegian

Vilhelm Bjerknes and his so-called Bergen School.[18] The World War II story of the weather forecasts for Operation Overlord (the landing at Normandy) makes for exciting reading. The invasion succeeded in large part because Allied forecasts showed a brief period of calm weather in the midst of a relentless series of storms in the English Channel. German forecasts had failed to predict the lull.

Military meteorology underscored the national orientation of weather forecasting infrastructures. Nations could not necessarily rely on other nations for the weather information their armed services needed in wartime, when that information suddenly ceased to be seen as a common resource and became a tool of conflict instead. As a result, the military forces of the major world powers established their own, largely separate meteorological services, which established independent networks of weather stations around the world. In peacetime these networks shared data with the civilian weather services, but they stood ready to operate independently in the event of war. These separate infrastructures demonstrate a flaw in the public-good perspective on forecasting, which sees forecasts only as an abstract knowledge product. By contrast, the cosmopolitan-commons perspective highlights the sociotechnical systems that shape the character and the extent of commons. In the case of forecasting, the commons can be damaged by withholding of data (as in wartime), and forecasts can also be created by restricted, non-public systems (such as military weather services).

The vicissitudes of the interwar period prevented major change in the structure of international meteorology, except in one important area. At the 1919 Paris Peace Conference, signatories adopted a Convention relating to the Regulation of Aerial Navigation (discussed in detail in Eda Kranakis' chapter in this book). This convention laid out the legal basis for international air traffic, but it also specified guidelines for international meteorological data exchange, to be carried out several times daily by "radiotelegraph." Finally, the Convention established an International Commission for Air Navigation (ICAN), a body with supranational decision-making authority (based on a system of qualified-majority voting) charged in part with implementing these meteorological standards.[19] This put ICAN several steps ahead of the International Meteorological Organization, which could claim neither a legal mandate nor any official governmental status. The IMO staked a competing claim to "aeronautical meteorology," establishing its own Technical Commission for the Application of Meteorology to Aerial Navigation. But participating governments officially recognized only ICAN, not the IMO's technical commission. By 1935, this led the IMO to transform its technical commission into an International Commission for Aeronautical Meteorology (known by its French acronym, CIMAé) with members appointed by governments. CIMAé was the first, and until after World War II the only, IMO entity to acquire official intergovernmental status. In the event, most CIMAé members also sat on ICAN, so it functioned more as a liaison than as an independent organization.[20]

Meanwhile, in the first half of the twentieth century the telegraph-based weather data network rapidly became an amazingly complicated web. New technologies arrived in rapid succession. The weather network had to integrate not only new instruments, such as radiosondes (weather balloons carrying radio transmitters), but also new communications media, such as telex and shortwave radio. By the 1920s, both aircraft data and maritime (ship) data provided new data streams. New airports became observing stations, increasing the density of the network.[21] Radio eliminated the need for fixed cables, permitting cheaper, faster data exchange both within and among nations. Radio also mattered enormously in distributing weather forecasts, both as broadcasts to the public and as targeted forecasts for aviation and shipping. During this period, most of the development was driven by the internal system-building dynamics of national weather services. Even though the national services of Europe depended on each others' data, rationalizing *international* data networks remained a secondary priority. IMO standards served only as guidelines, routinely violated yet producing considerable convergence.

The interwar phase of technology transfer and growth resulted in numerous different systems, some linked and others not, all governed by a very loose patchwork of sometimes conflicting national, regional, and international standards. The pre-World War II network made rudimentary worldwide data *available* to forecasters nearly in real time by the 1920s. But forecasters' ability to *make use* of those data remained extremely limited, largely because of the extreme difficulty of sorting out the numerous formats and standards used by various national weather services.[22] Describing the conditions of commercial air travel in the interwar period, Eda Kranakis' chapter in this volume brings home the somewhat primitive quality of forecasting at that time, when international flights were routinely interrupted by "unexpected" weather conditions along the way. The reason for this low quality was that before the computer age forecasting lacked a strong scientific basis, relying largely on experience and intuition instead.

As information commons, mid-twentieth-century weather forecasting systems exhibited a fragmented and unstable character. From the point of view of those who made forecasts, data were widely available and freely shared but often were too difficult to use, owing to a lack of well-established standards. Nevertheless, a shaky, multi-modal, but basically functional data-sharing network existed over land in most of the northern hemisphere, and in a good part of the southern hemisphere too. (See figure 6.1.)

Each national weather service created its own forecasts. Since the value of weather data decays rapidly, the speed of available information and communications infrastructures made international collaboration on forecasting extremely difficult. In the interwar period, then, the prevailing moral economy of weather forecasting held that both data and forecasts should be generated by government agencies as a public service and treated as public goods—except in wartime, when governments halted the trans-border flow of weather data and military services treated weather forecasts as secret assets.

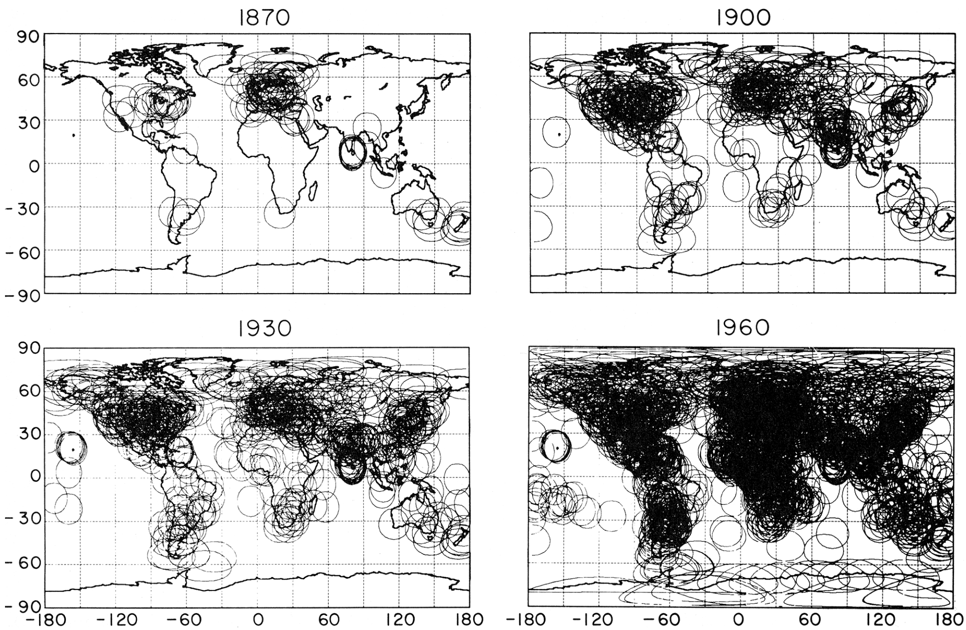

Figure 6.1
The evolution of the surface observing network. Top: Evolution of coverage by surface stations in WMSSC, principally based on World Weather Records and Monthly Climatic Data for the World. Coverage shown as a 1,200-kilometer radius around each station. Bottom: surface stations included in the Goddard Institute for Space Studies version of World Monthly Surface Station Climatology as of 1987. Grid cells demarcate regions of equal area. Numbers in each cell represent the date on which coverage began (top), total number of stations in that region (middle), and a grid cell identifier (bottom right). Reproduced from J. Hansen and S. Lebedeff, "Global Trends of Measured Surface Air Temperature," *Journal of Geophysical Research* 92, no. D11 (1987): 13, 345–372.

Consolidation: The World Meteorological Organization and the World Weather Watch

A unifying theme of this book is the complementary role of nature and technology as agents in the creation and maintenance of commons. Meteorology presents an excellent case in point. As has already been noted, diagrams of the global atmospheric circulation had appeared by the middle of the nineteenth century. Scandinavian meteorologists employed a hemispheric conception of weather in forecasting during World War I, when Vilhelm Bjerknes developed the idea of the "polar front" (an explicitly military metaphor) to describe the interaction of polar and mid-latitude circulatory cells that governs northern Europe's weather. By the time of the International Geophysical Year (1957–58), the "single physical system hypothesis," as it was called in IGY documents, dominated the research goals of meteorology.[23]

A single physical system implied a single, unified weather information system. Consolidation of the pre-World War II network began around 1950 and continues into the present. On the institutional side, the International Meteorological Organization acquired intergovernmental status as a specialized agency of the United Nations, renaming itself the World Meteorological Organization. National sovereignty remained a touchy issue, and Cold War politics sometimes created headaches for an entity that sought to integrate all the world's weather services but had to function under UN rules. Still, the WMO brought considerable new authority to develop and propagate standards and systems.[24]

On the technical side, consolidation was driven by the arrival of computer models for weather forecasting, first used operationally in Sweden in 1954. Instantly perceived as a vastly superior technique, computer modeling brought with it a voracious appetite for data. Weather forecasters began with regional models of the North Atlantic, North America, etc., but the major weather services were already transitioning to hemispheric models by the late 1960s, and to global models by the mid 1970s. These computer models required huge quantities of data, demanding prodigious efforts in standardization, communication systems, and automation. These trends in science and technology shaped the resource-space of forecasting, shifting it to ever larger scales. By 1965, there was no doubt among leading meteorologists that the world weather information infrastructure would eventually be global in scope.

In the 1960s, meteorologists eagerly awaited weather satellites, which can view the entire globe every twelve hours from their polar orbits. Satellites would, they hoped, complete the fully global observing system of which many had dreamed. In private correspondence, the American president, John F. Kennedy, and the Soviet premier, Nikita Khrushchev, agreed to promote weather satellites through the United Nations. The UN General Assembly received Kennedy's proposal for "further cooperative efforts between all nations in weather prediction and eventually in weather control" with great enthusiasm when he presented it in September 1961. In the same speech, Kennedy also announced cooperative efforts in telecommunications satellites. These efforts were major elements of a concerted push to prevent the militarization of outer space, and to characterize it as a global commons. That characterization entailed limits on national sovereignty, since one plausible (even if unenforceable) view of sovereign rights would be that they extend to an unlimited height above a nation's soil.[25]

By 1962 the WMO was directing its principal energies toward systems, standards, and institutional mechanisms for a World Weather Watch—an integrated system of satellites, surface-based observing systems, aircraft, and radiosondes (weather balloons) that would produce coherent global data images through computer processing. Although its name suggests a top-down organization, in practice the World Weather Watch's planners never expected to replace the existing patchwork. Instead, they relied on improved standardization and greater cooperation among national weather services.[26] Today the World Weather Watch remains the WMO's principal activity. It instantiates the realization of Ruskin's dream of a "vast machine" for "methodical and simultaneous observations" all over the world.[27]

The sharing of data from weather satellites and the concept of the World Weather Watch grew directly out of Cold War politics. Both were heavily promoted as counterweights to military and ideological tensions. The principal planners of the World Weather Watch were the US Weather Bureau scientist Harry Wexler and his Soviet counterpart, Viktor A. Bugaev. The International Geophysical Year had established "world data centers" for the participating geophysical sciences. World Weather Watch planners adopted a similar framework, envisioning three World Meteorological Centers: one in the United States, one in the Soviet Union, and one in Australia. These centers were to communicate with six Regional Meteorological Centers—one of which would be in Europe—which would organize communication among National Meteorological Centers.[28]

In the 1960s, the world's most advanced meteorological research centers were in the United States (the US Weather Bureau, the National Center for Atmospheric Research, several NASA facilities, the meteorology departments of the University of Chicago, the Massachusetts Institute of Technology, and the University of California at Los Angeles) and in the Soviet

Union (Guri Marchuk's laboratory at Novosibirsk). In Sweden, an International Meteorological Institute—established by Carl-Gustav Rossby (the foremost meteorologist of the mid twentieth century) in 1955—served as a European hub for meteorologists, but many European scientists preferred the US and Soviet laboratories. The US laboratories, in particular, featured more powerful computers than most of their counterparts in Europe.

The World Meteorological Centers were initially conceived mainly as data centers and communication hubs. They would collect and consolidate global data, then forward relevant subsets of those data to the Regional Meteorological Centers. The idea was to reduce the redundancy that characterized meteorological communication. At the time, each national weather service in a region (Europe, for example) had to collect bulletins from every other country, a process that took hours on the slow communication channels of the day. The data problem, however, was only one piece of the puzzle. In addition, integrating the data would require forecasting tools—computer models—capable of making use of them. Therefore, World Weather Watch planning soon led to calls for a Global Atmospheric Research Program (GARP) that would develop ways to link data systems, to automate communication, and to build computer models capable of analyzing data for the entire world. For several years in the mid 1960s, WWW and GARP planners discussed the idea of establishing a world meteorological research center, probably in Europe. However, it proved impossible to assemble a politically feasible combination of location, computer technology, funding, and leadership for such a center, which would have had to supersede or else compete with the already strong US research system, and the project was abandoned.

A European Meteorological Computing Center

The major European weather services (in Sweden, the United Kingdom, West Germany, and France) had all established computer forecasting centers by 1960. These centers faced financial strains as rapid advances in modeling techniques required ever faster, larger supercomputers. Weather models are essentially simulations of the atmosphere, represented in the models as a grid of points containing numerical values for temperature, humidity, motion, and other conditions in the vicinity of that point. The models recalculate values for every point on the grid at a "time step," typically 10–15 simulated minutes. Reducing the distance between grid points generally improves the simulation, for the same reason that a computer or television screen with more pixels per square inch displays a higher-quality image—but halving the distance between grid points multiplies the amount of computation required by a factor of at least 8 (2^3). The earliest forecast models used a grid spacing of about 600 kilometers. By 2000, global forecast models typically had a one-kilometer resolution and twenty vertical levels, amounting to roughly 1.3 million grid points. Scientists also improve models by simulating additional physical processes, further increasing the computational demands. Finally, in a forecast model, incoming weather observations—data—are injected into the simulation to correct it. These data are not simply dumped into the model, but must be checked for quality, interpolated to grid points, and analyzed in a variety of other ways beforehand. This analysis process also requires computer time. Hence, forecasters' appetite for computer power has been virtually insatiable.

Supercomputers were extremely expensive in the pioneering days of computer forecasting. In 1970, the most advanced supercomputers cost between 8 million and 16 million dollars (roughly equivalent to 47 million and 93 million 2012 dollars), and owing to the rapid improvement of computer technology their effective lifetime was only four or five years. But the machine was only the beginning. Running a supercomputer center required large additional sums for electric power, peripherals, and smaller computers for preparing programs and data. Centers also needed highly trained professional staff to program, operate, and maintain the machines.

In the early 1960s, the absence of a strong indigenous computer industry became a policy concern for major European governments. The principal industrial strategy turned initially on promoting "national champions"—state-supported firms such as ICL in the United Kingdom, Bull in France, and Siemens in West Germany. By 1970 this strategy had failed to make any headway against IBM and Control Data Corporation, which had emerged as the leader in the niche market for advanced supercomputers. The next European approach to regaining market share in computing was a collaborative, government-supported program known as Unidata,[29] begun in 1972 by CII-Bull (France) and Siemens (West Germany) and joined in 1973 by Philips (Netherlands). Unidata proved no more successful than the national champions, however, and it collapsed in 1975.

The Unidata joint effort reflected a general trend toward collaborative technology projects. In 1967, faced with an ongoing "brain drain" and withering competition from American technology firms, the Committee for Medium Range Economic Policy of the European Economic Communities had initiated studies to determine the feasibility and cost-effectiveness of cooperative efforts in science and technology. Included in early lists of possibilities were "longer-range weather forecasts" and "influencing weather."[30] The committee accordingly established an Expert Group on

Meteorology under the direction of Erich Süssenberger, president of the Deutscher Wetterdienst (German weather service). In consultation with the weather services of all six European Economic Community countries, the Expert Group generated a long list of potential meteorological collaborations, including an ozone-monitoring network, air-pollution studies, and the manufacture of weather balloons. Süssenberger himself emphasized the meteorological "frontier" of medium-term (four-to-ten-day) forecasts. Achieving usable forecasts at that range would require enormous progress in modeling, supported by the most advanced supercomputers. This emphasis stemmed in part from Süssenberger's involvement in the World Weather Watch program and the Global Atmospheric Research Program, then in the earliest phases of conception and planning.[31]

The European Centre for Medium-Range Weather Forecasts

The Expert Group on Meteorology recognized the extreme difficulty of estimating the precise value of weather forecasts. Still, it noted, an American cost-benefit analysis had calculated that an accurate five-day forecast would be worth about $6 billion per year, which suggested that Europe might anticipate annual savings of several billion dollars. Such an effort might also help Europe to catch up scientifically with the United States and the Soviet Union, which led the world "principally due to the high level of their technology," i.e., computing.[32] Finally, the Expert Group noted that no computer with sufficient capacity to address the problem of medium-term prediction existed anywhere in Europe.

Accordingly, the Expert Group proposed a "European Meteorological Computing Centre" in 1969. Later that year, the Council of Ministers of the European Communities agreed to open the proposal to nine non-EC countries: Austria, Denmark, Ireland, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. Of these, Sweden and the UK were especially important owing to their historical strengths in meteorology; in fact, the UK initially reacted skeptically to the EMCC idea, apparently viewing its own programs as superior to those of the other countries.[33] Meanwhile, the absence of Eastern Europe from the proposal—as from all 49 other EC cooperative technology projects—reflected the political realities of the Cold War.

By 1971 all other concepts for cooperation in meteorology had been swept aside by the idea of a computing center. Planning then proceeded rapidly. First, the Expert Group commissioned an economic study of the potential benefits of more accurate medium-term forecasts, which might reduce weather-related losses in agriculture, shipping, air travel, construction, and a myriad of other weather-dependent industries and activities. Lacking standard numerical data and operating under tight time constraints (only a few months were allotted), the economic study group employed an unusual method, interviewing 156 experts in fifteen countries about potential benefits in a variety of economic sectors. From these interviews and some basic data for various economic sectors, the economists estimated that reasonably accurate four-to-ten-day forecasts for Europe would produce a benefit of at least 200 million u.a. (units of account, a standard measure of value) per year—at least 25 times the center's projected operational costs of 7.5 million u.a. The report concluded that, despite uncertainties in its calculations, "the mere money value obtained is so considerable that no more than a partial realization of the benefits expected would largely justify the creation of EMCC."[34]

As with the World Weather Watch, relations between the proposed EMCC (renamed European Centre for Medium-range Weather Forecasts in late 1971) and the national weather services required a delicate touch in order to avoid the perception that some pan-European monolith would take over the national weather services' functions. In a bow to the meteorological nationalism described earlier in this chapter, initial discussions emphasized that the ECMWF would not provide forecasts directly to consumers, but would instead hand off its forecasts and data to the national weather services, which then would process them further and provide national forecasts. By then, the EC program Cooperation in the Field of Scientific and Technical Research program (abbreviated COST) had received financial authority to implement its recommendations, so planning proceeded swiftly. Süssenberger noted the unusual nature of this situation: "Normally, meteorologists develop programmes and then ask the Finance Minister for funds, which usually leads to complex discussions. In the case of the ECMWF, however, the financial means were made available first with a request to plan appropriate projects."[35]

The decision to create a European center entailed the thorny question of where such a center would be located. COST explicitly considered the technical, the economic, and the human factors, but implicitly considered political ones as well. The technical and economic issues of computer power and telecommunications links played a very considerable role in this choice.

One way to acquire sufficient computer power would have been to colocate the ECMWF with a national meteorological center, where it could share computer facilities and thus possibly offset some operating expenses. COST roundly rejected this idea, noting that "approximately 10 hours computing time are needed on a 50 MIPS [million instructions per second] computer to carry out a 10 day forecast. Since these tremendous requirements exceed by far the total capacity of all European meteorological centres (only the British centre will reach 10 MIPS in the near future, the others ranging in the order of 1 MIPS or less), the possibility to place EMCC within a national centre is not a feasible solution."[36] Another solution might have been to use computer time from many centers over a network—an idea much like today's concept of "cloud computing." COST concluded, however, that "it is not at present possible to aggregate computing power from different sources in a liaison network and to concentrate this accumulated capacity on one single problem,"[37] and that only a dedicated, stand-alone computer center could achieve the intended goal.

Furthermore, despite a nod to its sister "Working Party on Data Processing" (tasked with improving the competitive position of the European computer industry), COST did not expect any European computer supplier to be able to handle the ECMWF's needs until 1980 or later. The group suggested a Control Data machine and estimated the likely operational cost of computers, software, and associated maintenance at 4.8 million u.a. per year.[38] Furthermore, the sophisticated computer equipment would require maintenance. This implied a need for proximity to technical support from the computer manufacturer, most likely to be available in or near a major European capital.

The telecommunications issue involved how raw meteorological data would reach the ECMWF, and how the latter would, in turn, distribute processed data and forecasts. The cost of telecommunication depended on prices in the eventual host country: "a central location of EMCC will generally minimize the network costs . . . ; a peripheral location of EMCC could . . . raise the annual network costs from u.a. 650.000 to u.a. 1.000.000." Cost was not the only consideration, however. The amounts of data required for regional and global forecasting were so large that the capacity of data transmission lines had to be taken into account. In the 1970s—long before the Internet's many-to-many connectivity became the norm—a few major data and forecasting centers (hubs) were connected by dedicated long-distance "trunk lines" with the highest available data rates (then around 2,400 bits per second). Smaller centers were connected to a regional hub via spoke lines with lower data rates, at lower costs. For the proposed EMCC, this implied a trunk connection:

> [EMCC] requires a considerable amount of input data for its operations to be obtained mainly from European WMO centres situated on the 'Main Trunk Circuit' of the WMO Global Telecommunication System, i.e. London, Frankfurt, Paris. In order to speed up and to secure the operational data inflow direct and relatively short

connections between EMCC and these 3 centres are desirable; this condition suggests a central location for EMCC.[39]

Planning thus focused on the London-Frankfurt-Paris "triangle," but other locations were not ruled out.

Human factors also entered into the placement decision. The plan envisaged regular, long visits (months to years) by considerable numbers of scientists from all over Europe, and they would need available, affordable, high-quality housing, schools for their children, and easy transport to and from their home countries. Urban amenities and a pleasant environment would also make it easier to attract top scientists.

The various national delegations volunteered sites in Belgium, Denmark, Germany, the Netherlands, Italy, and the United Kingdom. The eventual choice of Shinfield Park (near Reading, and less than 50 kilometers from London) reflected political factors as well as other factors described above. Shinfield Park lay near Britain's Met[eorological] Office College and to the Met Office's headquarters at nearby Bracknell, but it lacked international schools and other amenities. However, the COST negotiations in 1972 coincided with Britain's buildup, under Prime Minister Edward Heath, to membership in the European Economic Community, which it joined on January 1, 1973. According to Austin Woods' history of the ECMWF, Heath—an amateur meteorologist—was easily persuaded of the ECMWF's benefits, but also saw its near-term political utility:

[A] strong memorandum was sent from the Government of the UK to COST detailing the technical advantages of having the Centre at Shinfield Park. It went on: 'There are also political considerations. Her Majesty's Government considers that at the time of our entry into the EEC it is particularly important that we should be in a position to be able to announce publicly that an important European scientific institution is being set up in the United Kingdom.'

In the final COST vote on placement in early 1973, the UK proposal competed chiefly with one from Denmark, backed by Germany (which had withdrawn its own bid in order to make way for Germany to obtain the European Patent Office). The UK forced the issue, hinting strongly that it might not participate in the ECMWF if it failed in its bid to host the center.[40] This arm twisting may or may not have influenced delegates' votes; in any case, the UK bid succeeded and the project moved swiftly to fruition. In 1973 fifteen nations signed the Convention establishing the European Centre for Medium-Range Weather Forecasts.

Activity began almost immediately. The ECMWF's first director, Aksel Wiin-Nielsen, launched the Centre in January 1974 at temporary facilities in Bracknell. Wiin-Nielsen, a Dane, had begun his career at the Danish

Meteorological Institute and moved to the International Meteorological Institute in Stockholm in 1955. Another move, this time to the US Weather Service's Joint Numerical Prediction Unit, followed in 1959. Soon afterward, he joined the US National Center for Atmospheric Research during its earliest years. In 1963 he was named the first chairman of the Department of Meteorology and Oceanography at the University of Michigan. His personal career thus embodied the frequent and international movement of people and ideas that was typical of meteorology during this period—as well as the flight of excellent meteorologists from Europe to the United States in the 1950s and the 1960s, one of the conditions that COST hoped the ECMWF might reverse.

The ECMWF leased its first computer, a CDC 6600, in 1975, and immediately began work on building a global general circulation model (GCM). The US National Meteorological Center had introduced a GCM for hemispheric forecasting several years earlier, but after periods beyond a few days this and other hemispheric models became unstable owing to their artificial methods of handling computations at the models' equatorial "edge." Using a global model would eliminate this instability, but would require advanced numerical techniques as well as much greater computer power. Rather than construct the ECMWF's global forecast GCM from scratch, Wiin-Nielsen contacted his friend Joseph Smagorinsky, leader of the Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton University, and Akio Arakawa and Yale Mintz, two professors of Meteorology at the University of California at Los Angeles. Though neither group had an operational forecast model, they had the world's best-developed global GCMs. Wiin-Nielsen requested working copies of these models, and they agreed. Neither group imposed any conditions other than appropriate credit—an impressive generosity considering that each group's model had taken more than a decade to develop. Acquiring the model codes called for in-person visits. In 1975, Robert Sadourny, a French modeler who had studied with Arakawa and Mintz in the 1960s, spent four weeks at UCLA. Meanwhile, an Irish meteorologist, Anthony Hollingsworth, made his way to Princeton's Geophysical Fluid Dynamics Laboratory. Both returned to the ECMWF bearing code and documentation, as well as personal knowledge gained during the visits. After extensive comparison, the ECMWF settled on the GFDL scheme. Soon, however, the ECMWF replaced part of the GFDL model (known as the "model physics") with a new package of its own, retaining only the GFDL dynamical core (the part of the model that simulates atmospheric motion). Later this too was replaced with a spectral core coded "from scratch."[41] After four years of research and development, the ECMWF commenced operational medium-range forecasting in August 1979.

Six years later, in 1985, the ECMWF's global forecasts outdid the British Met Office forecasts for the northern hemisphere on some measures. (The ECMWF's performance in the southern hemisphere was slightly worse than that of the Met Office model.) According to B. J. Mason, former head of the Met Office, the accuracy of forecasting had advanced by a full day: "[T]he 72-hour, 500mb forecast is now as good as the 48-hour forecast was 7 years ago, and the 48-hour forecast is now as good as the 24-hour forecast was then."[42] In fact, by 1985 the ECMWF had achieved the objective imagined by the 1971 cost-benefit analysis: producing six-day forecasts of about the same accuracy as the two-day forecasts of 1971.[43] By comparison with all earlier technoscientific forecasting, in which the limit of accurate forecasting had advanced from about 24 to about 48 hours, this was an astonishing achievement.

At a seminar commemorating the ECMWF's first ten years, in 1985, Joseph Smagorinsky—a towering figure both in computer modeling and in the creation of a global weather data infrastructure—told the assembled representatives of European national weather services that the ECMWF "commands the awe and admiration of the meteorological world." By the time I began interviewing climate scientists in the early 1990s, most of my interviewees described the ECMWF as the best forecast center in the world. The ECMWF's global and regional forecasts and its thousands of "data products"—subsets of collected, analyzed and processed data—were, and are, widely used by weather services not only in Europe, but all over the world.

At the same 1985 seminar, Ernst Lingelbach, former head of the Deutscher Wetterdienst, noted that of about fifty large projects sponsored by COST, each with numerous "sub-programmes," "only one . . . has led to the establishment of a great common research institute, namely the ECMWF. All other [COST] actions are being implemented by coordinating the research efforts of individual national laboratories."[44] Concerning the role of the ECMWF in European integration, Lingelbach went on to say:

> The fathers of the idea of European unification still have many things to hope for. However, in the meteorological community, their ideas have been realized with the integration of the work of seventeen European states [through the ECMWF]. The lead over other countries has been re-gained in this area and many industries in Europe have become aware of the great use that they can make of the Centre's ever improving medium range weather forecasts.[45]

With the demise of communism, the ECMWF expanded its membership. Today 34 European states support its operations.

In the late 1980s, the ECMWF's role expanded to encompass climate change analysis. The ECMWF produced a highly cited "reanalysis" of fifteen years' weather observations. This was an entirely new way to trace the evolution of Earth's climate during the period of instrumental records. Rather than the *average* temperatures, pressures, etc. pre-calculated at individual weather stations used in most climate datasets, reanalysis would begin with unanalyzed data: *every available instrument reading* for some long period. Then it would pipe those data through a state-of-the-art forecast model. The forecast model would fill in gaps in the observational data. This would overcome the serious problem of incomplete climate data, on the one hand, and a constantly changing observation and forecasting system, on the other. The result would be a continuous, consistent, and complete data image of the weather over the entire Earth.

The ECMWF completed a 15-year reanalysis in 1996, covering the years 1979–1994. In 2000 it initiated a 40-year reanalysis, then extended that to 50 years.[46] Other agencies also created reanalyses, but the outstanding quality of the ECMWF's reanalysis model garnered profound respect from the climate science community. Reanalysis has not displaced traditional data analysis in the study of climate change, and for various technical reasons it may never do so. Nonetheless, reanalysis is widely regarded as a major benchmark for understanding and measuring global climate change, and the ECMWF as among its pioneers.[47]

Conclusion

Benedict Anderson famously argued that maps contribute to the "logoization of political space."[48] He also liked to say that people encounter such "logos"—simplified maps of their own nations—most frequently while watching the weather report on the nightly news. Yet although people naturally care most about the weather at their own location, modern weather reports no longer focus only on the nation. Instead, they offer a nested series of views at various scales. Continuous reporting of weather around the world occupies entire television channels. Even in ostensibly national news, European weather reporting typically zooms out to the scale of the entire North Atlantic, then zooms in to a smaller transnational region before focusing down to the national level. An information commons built from instruments, computers, and arcane mathematics thus joins global natural systems with multiple levels of political identity—globe, region, nation, city—in the everyday consciousness of people around the world. Weather information plays a major supporting role in activities and infrastructures of the modern world: agriculture, air travel, shipping, managed waterways, and others far too numerous to mention. The advance warning we now have of storms, snowfall, heat waves, floods, and other extreme weather events saves hundreds of billions of dollars and thousands of human lives each year, yet the total annual cost of the world weather forecast system has been estimated at just $10 billion. Many people routinely check the radar on smart phones or computers before heading out the door. Weather forecasts for the next few days—long enough for weather systems to travel from central Canada to Germany (though this is not exactly what happens)—strongly influence planning of weather-related events.

Like other chapters in this volume, this one has emphasized the joint contributions of nature (weather itself, a structurally global phenomenon) and technology (observing systems and computer models) to the construction of this commons. Among other things, we have seen how building the European Centre for Medium-Range Weather Forecasts required the pooled scientific, financial, and technological resources of an entire continent, yet soon provided benefits not only to the European region but to the whole world.

The moral economy of this commons is rooted simultaneously in the natural phenomena of which it provides knowledge, in the institutions that generate weather data and forecasts, and in the scientific knowledge and technological systems that permit those forecasts to be created and shared. Weather data were freely shared first as scientific curiosities; later as nationally produced quasi-public goods, most beneficial when widely shared; and finally as products of an international enterprise, as global public goods. The ECMWF has been this chapter's primary example, but a number of other entities (including the US National Aeronautics and Space Administration and the European Organisation for the Exploitation of Meteorological Satellites) contribute equally to this widely used information commons.

Are there tragic possibilities that could affect the weather information commons? Yes—not because of overconsumption, which cannot occur, but through the withdrawal of major contributors (as in wartime), or through the privatization of weather information. Beginning in the 1980s, private companies such as Accuweather began to challenge the public monopoly on weather forecasting.

An extreme version of this challenge arose in 2005, when US Senator Rick Santorum sponsored a "National Weather Service Duties Act" that would actually have *prohibited* the US Weather Service from issuing routine weather forecasts, since such forecasts were available from commercial weather forecasters—who use data produced at public expense, and provided to the commercial forecasters at no cost, by the Weather Service. Instead, the bill would have required the Weather Service to release only forecasts of severe storms and other dangerous weather events—a task it could not possibly fulfill without creating routine forecasts as well.[49] The act garnered no co-sponsors and died in committee. Yet it was only one in a long series of similar efforts by private-sector forecasters to wrest partial control of the weather forecast infrastructure from public agencies.

This issue is more complex than it appears, however. Basic weather forecasts and severe weather alerts clearly belong in the public domain, but there is a large category of "value added" forecast products, such as targeted forecasts specially produced for individual clients, that arguably should not be the responsibility of public agencies. For example, a burgeoning industry in "weather risk management" uses publicly available data in combination with proprietary models and methods toward such purposes as "management of the financial consequences of adverse weather for [firms and organizations] with natural exposure to weather, [and] commercial trading of weather risk, both in its own right and in conjunction with a variety of commodities." The expense of these efforts is best borne by the private entities that require them and profit from them.[50]

As for weather data themselves, it is most ironic—after all I have said about Europe's pivotal role in building the global weather information commons—that the single most direct challenge to a global data commons also came from Europe. By 1995, many European national weather services had gradually introduced commercial operations, selling specialized forecasts and data in order to recoup some of their costs as well as to stave off private competition. These operations had engaged in a "gentleman's agreement" not to sell products outside their national borders—but with European integration in the then-new European Union, this arrangement could not hold.[51] A coalition of European weather services pressed the World Meteorological Organization for the right to charge fees for data. They succeeded in pushing through a compromise, WMO Resolution 40, which altered the long-standing WMO policy that weather data should be freely shared. "Recognizing . . . the requirement by some [WMO] Members that their National Meteorological Services initiate or increase their commercial activities," Resolution 40 created two tiers: "essential" data, which must be freely shared, and "additional data and products," for which fees could now be charged.[52] Today the ECMWF still provides many kinds of data and forecasts freely or at cost, especially to scientific researchers—but, like the European national weather services, it now also sells many of its data products, for fees that can run to tens of thousands of euros.[53]

Probably the single most controversial action in the history of the WMO, Resolution 40 remains severely contentious. John Zillman, the WMO's president from 1995 to 2003, strongly opposed the introduction of high fees for data, and wrote several papers and presentations on the subject. In one address, he said:

> The widespread trend towards implementation of competition policy at the national level, and governments' increasing tendency to open up many former government functions to competition and the operation of market forces, represents a full-frontal assault on the most fundamental principle of meteorological service provision worldwide—its reliance on cooperation rather than competition and its dependence on free and open exchange of information and knowledge in the overall global public interest.[54]

When I interviewed Zillman in 2001, he told me this had been "his number one cause over the last decade and a half."[55]

Ironically, the practice of charging high fees for weather data produced at public expense has actually hobbled Europe's competitive position and reduced the potential value of weather data to European economies. A 2002 study found that European private-sector meteorology is only one-tenth as large as the same industry in the United States. "Given that the US and EU economies are approximately the same size," that study concluded, "the primary reason for the European weather risk management and commercial meteorology markets to lag so far behind the US is the restrictive data policies of a number of European national meteorological services."[56] The weather information commons thus remains a precarious resource, one that highlights the crossroads humanity currently faces with respect to virtually all scientific data and information: open and freely shared, common resources for all to use, or proprietary and reserved for private gain.

Notes

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36. COST/136/71 (III/1118–71-E), “Project Study on European Centre for medium-range weather forecast (ECMWRF),” Secretariat of the program on European Cooperation in the Field of Scientific and Technical Research, Brussels, 5 August 1971, p. 51.

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39. Ibid., p. 81.

40. Woods, *Medium-Range Weather Prediction*, pp. 65–66.

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