Meteorology as Infrastructural Globalism

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ABSTRACT

This chapter explores the history of a global governance institution, the World Meteorological Organization (WMO), from its nineteenth-century origins through the beginnings of a planetary meteorological observing network, the WMO's World Weather Watch (WWW), in the 1960s. This history illustrates a profoundly important transition from voluntarist internationalism, based on shared interests, to quasi-obligatory globalism, based on a more permanent shared infrastructure. The WMO and the WWW thus represent infrastructural globalism, by which "the world" as a whole is produced and maintained (as both object of knowledge and unified arena of human action) through global infrastructures.

INTRODUCTION

Intense debates about the nature and trajectory of globalization have consumed historiography and international relations theory in recent years. Is globalization really global? Is it new or old? What are its causes and consequences? No one who has followed these debates can fail to notice the prominence of information and communication technologies (ICTs) in virtually all accounts. For example, Manuel Castells defines the global economy as one "whose core components have the institutional, organizational, and technological capacity to work *as a unit in real time, or chosen time, on a planetary scale*" via ICT infrastructures,[1] and every chapter of *Global Transformations: Politics, Economics and Culture,* a major survey of globalization, discusses the role of communication infrastructures.[2]

In an important variation on this theme, Martin Hewson offered a three-phase notion of "informational globalism": systems and institutions dedicated to the production and transmission of information on the planetary scale. In the first, nineteenth-century phase, national informational infrastructures (NIIs), such as telegraph systems, postal services, and journalism, were linked into interregional and intercontinental (if not yet fully global) networks. Between 1914 and 1960 (Hewson's second phase), the pace of infrastructural linking diminished, and some delinking occurred. Yet simultaneously, world organizations such as the League of Nations and the International

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I thank Kai-Henrik Barth, John Krige, and Gabrielle Hecht for extremely useful comments.
[1] Manuel Castells, *The Rise of the Network Society* (Cambridge, Mass., 1996) (emphasis in original).
[2] David Held, Anthony McGrew, David Goldblatt, and Jonathan Perraton, *Global Transformations: Politics, Economics, and Culture* (Stanford, 1999).

Monetary Fund "established the legitimacy of producing globalist information"—that is, information about the whole world—in such areas as health, armaments, and public finances (although they did not in fact attain that goal). Hewson's third phase brought general achievement of the two previous eras' goals, beginning with the establishment of worldwide civil communication networks (from the 1967 inauguration of the Intelsat system) and global environmental monitoring (from the UN Conference on the Human Environment, 1972). Throughout, Hewson sees global governance institutions such as the United Nations and the International Telecommunications Union, rather than an autonomous technological juggernaut, as chiefly responsible for informational globalism.[3]

In this chapter, I explore the history of one such global governance institution, the World Meteorological Organization (WMO). The WMO's story confirms the pattern Hewson discerned, but it also has special characteristics. Arguably, the weather data network and its cousins in the other geophysical sciences, especially seismology and oceanography, are the oldest of all systems for producing globalist information in Hewson's sense. When the young John Ruskin wrote, in 1839, that meteorology "desires to have at its command, at stated periods, perfect systems of methodical and simultaneous observations . . . to know, at any given instant, the state of the atmosphere on every point on its surface,"[4] he was only giving voice to his contemporaries' grandest vision. By 1853, the Brussels Convention on naval meteorology had created a widely used standard meteorological logbook for ships at sea; these logs constitute the oldest continuous quasi-global meteorological record.

By 1950, the informational-globalist imperative of planetary monitoring in meteorology was already far stronger than those of many other putatively global systems emerging around that time. When computerized weather forecasting arrived later in the decade, ambitions quickly grew for *real-time* planetary data to feed the forecast models. Achieving these became the early WMO's fundamental goal. To meet them, in the 1960s it extended and linked existing data networks to form a global information infrastructure (GII). Decades before the World Wide Web, this became the first WWW: the World Weather Watch, a global network for the automatic collection, processing, and distribution of weather and climate information for the entire planet.

I contend that the WMO and the WWW illustrate a profoundly important, though messy and incomplete, transition: from voluntarist internationalism, based on an often temporary confluence of shared *interests,* to quasi-obligatory globalism based on a more permanent shared *infrastructure.* Therefore I will speak not only of informational globalism but also of *infrastructural globalism.* By this I mean the more general phenomenon by which "the world" as a whole is produced and maintained—as both object of knowledge and unified arena of human action—through global infrastructures.

THE INTERNATIONAL METEOROLOGICAL ORGANIZATION AND THE *RÉSEAU MONDIAL*

In the 1850s, telegraphy permitted meteorologists for the first time to create synoptic weather maps, that is, "snapshots" of observations taken simultaneously over very

[3] Martin Hewson, "Did Global Governance Create Informational Globalism?" in *Approaches to Global Governance Theory,* ed. Martin Hewson and Timothy J. Sinclair (Albany, N.Y., 1999), 97–113.

[4] Quoted in Napier Shaw, *The Drama of Weather* (Cambridge, 1939).

large areas. Quite suddenly, it became possible to "watch" storms and other weather phenomena develop and move, as well as to warn those downwind. Empirically based synoptic forecasting did not achieve great accuracy, but its dramatic God's-eye views brought new visibility to meteorology. States—especially their military and agricultural services—began to take a strong interest in weather science. By the end of the nineteenth century, most nations with telegraph networks had established national weather services responsible for charting and predicting the weather.

As Frederik Nebeker has shown, theoretical meteorology diverged from the more practice-oriented national weather services, developing separately in mostly academic institutions. Until the 1920s, theory provided little guidance to forecasters. Well into the twentieth century, the major predictive technique was a form of pattern matching: forecasters hunted through huge libraries of past weather maps, seeking similar situations and making their predictions based on how those patterns had evolved. Really it was not until the 1940s that meteorological theory and forecast practice began to converge.[5]

For over a century, then, national weather services focused principally on collecting and charting data. Beginning with existing networks of military, astronomical, and amateur observers, they added professional observers of their own and built operational data networks. Issues of calibration and standardization immediately became salient. To be useful in synoptic forecasting, data must be collected by instruments calibrated to a single standard, and recorded in similar units (of temperature, velocity, pressure, and so forth). Therefore, national weather services established standards. However, in a story endlessly repeated throughout the history of infrastructure, agreement on and enforcement of standards proved remarkably difficult, even within a country.[6] Implementing international standards was even more problematic.[7]

The relatively small nations of Europe soon understood that because weather moves quickly, data from within their own borders would never be enough for really useful prediction. With international telegraphy, national data could be easily shared. By the 1860s, the first of Hewson's phases of informational globalism was already well under way. Naval weather logs were being collected and shared, while Paris served as a hub for Pan-European telegraphic data exchange. Wherever national standards differed, however, these data exchange systems posed new problems.[8] To address them, in 1873 national weather services throughout Europe and the United States founded an International Meteorological Organization (IMO). The new organization's chief agenda was to coordinate international standards for meteorological measurement and data exchange. Despite hiatuses during the world wars, when virtually all international data exchange ceased, the IMO persisted until 1949.

[5] The Bergen School developed the crucial theory of polar fronts around 1920, but the same school's actual forecast techniques remained chiefly empirical. See Robert Marc Friedman, *Appropriating the Weather: Vilhelm Bjerknes and the Construction of a Modern Meteorology* (Ithaca, 1989); and Frederik Nebeker, *Calculating the Weather: Meteorology in the 20th Century* (New York, 1995).

[6] On implementing a uniform time standard for meteorological observations in the United States, see Ian R. Bartky, "The Adoption of Standard Time," *Technology and Culture* 30 (1989): 25–56.

[7] On problems with the Brussels Convention standard naval logbook, see James R. Fleming, *Historical Perspectives on Climate Change* (New York, 1998).

[8] For example, some nations used British units, while others used the metric system. Standard observing hours, methods of sea surface temperature measurement, and a myriad of other seemingly small details produced tremendous headaches for those trying to integrate data sets across national borders.

The IMO case was typical of pre–World War II scientific internationalism. For seventy-five years, the organization remained a cooperative nongovernmental association of national weather services. The principle of interaction was explicitly voluntary. As a result, IMO standards and policies functioned only as recommendations, which nations were at liberty to refuse or simply ignore. In practice, national identity and independence often mattered more than international standards, though the polite language of scientific exchange muted national rivalries. Each national weather service chose its own balance between IMO standards and its own, sometimes diverging techniques. Ambivalence about intergovernmental status among national weather service directors, who feared bureaucratic meddling, kept the organization frozen in this state until just before World War II.

The tension between national technical systems and internationalist aspirations frustrated early efforts to build a global meteorological data network. At the IMO's founding in 1873, U.S. and Swiss delegates pressed for, and received, general acceptance that existing data networks should be extended into a complete global observing network—in other words, they endorsed the principle of informational globalism. Christophorus Buys Ballot advocated "an International Fund for the establishment of meteorological observatories on islands and at distant points of the Earth's surface."[9] Buys Ballot's proposal failed, but in 1875, under the IMO's aegis, the U.S. Army Signal Office began publishing a regular *Bulletin of International Meteorological Observations Taken Simultaneously,* containing worldwide synoptic charts based on sporadic national contributions. However, coverage beyond the United States and Europe was poor, especially in the Southern Hemisphere.[10]

The first, rudimentary, but partially successful, *global* effort began in 1905, with French meteorologist Léon Teisserenc de Bort's proposal for a telegraph-based global weather data system rather grandly named the *Réseau Mondial* (worldwide network).[11] Simplifying Teisserenc de Bort's ambitious vision, the IMO decided that the network should collect, calculate, and distribute monthly and annual averages for pressure, temperature, and precipitation from a well-distributed sample of meteorological stations on land—creating, in effect, a global climatological database. The distribution standard was two stations within each ten-degree latitude/longitude quadrangle, an area about twice the size of France. Ultimately, the network comprised about 500 land stations between 80°N and 61°S. Seemingly modest in concept, in practice this early project proved ferociously difficult.

Why was it so challenging to gather data from 500 stations and calculate a few averages? The explanation lies in the lack of settled standards, the limited reach of communications infrastructure, and the voluntary, essentially private mode of scientific

[9] Howard Daniel, "One Hundred Years of International Co-Operation in Meteorology (1873–1973): A Historical Review," *WMO Bulletin* 22 (1973): 164.

[10] U.S. Army Signal Office, *Bulletin of International Meteorological Observations Taken Simultaneously* (Washington, D.C., 1875–1884).

[11] Similar efforts to build very large-scale data networks began around the same time in other geophysical sciences, including seismology and oceanography. All of them suffered from standardization problems and long publication delays. See R. D. Adams, "The Development of Global Earthquake Recording," in *Observatory Seismology,* ed. J. J. Litehiser (Berkeley, 1989), 3–24; Elisabeth T. Crawford, Terry Shinn, and Sverker Sœrlin, *Denationalizing Science: The Contexts of International Scientific Practice* (Boston, 1993); Robert Stoneley, "The History of the International Seismological Summary," *Geophysical Journal of the Royal Astronomical Society* 20 (1970): 343–9. I am grateful to Kai-Henrik Barth for drawing this literature to my attention.

internationalism prior to World War II. Although telegraph services relayed weather data free of charge, the network's technical capabilities were not yet robust enough to support Teisserenc de Bort's vision of global, real-time data collection. Instead, the *Réseau* collected most data by mail. The problem of nonstandard observing and recording techniques remained considerable. Retrieving and confirming information from remote observers required great effort. As a result, the *Réseau Mondial's* first annual data set, for 1911, did not appear until 1917. Delays of up to thirteen years marked the publication of subsequent volumes, which ceased with the data for 1932. Without governmental commitments, IMO backing provided little institutional leverage.[12]

Prior to World War II, governmental powers *were* invoked to promote international standards in one particular area: aeronautical meteorology. The rise of international air travel after World War I led to the Paris Convention Relating to the Regulation of Aerial Navigation, which laid out the legal basis for international air traffic and effectively codified the vertical extent of the nation-state. Under the 1919 convention,[13] each nation retained sovereign rights over its own airspace. This would later become a crucial object of cold war maneuver and diplomacy regarding overflight by earth-orbiting satellites.[14] Among other things, the convention specified guidelines for international meteorological data exchange, to be carried out several times daily by radiotelegraph.

In the same year, the IMO established a Technical Commission for the Application of Meteorology to Aerial Navigation. But the Paris convention ignored it, establishing a separate, *intergovernmental* International Commission for Air Navigation (ICAN), charged in part with implementing the convention's meteorological standards. Participating governments officially recognized only ICAN. By 1935, this led the IMO to transform its technical commission into an International Commission for Aeronautical Meteorology (CIMAé) *with members appointed by governments.* CIMAé thus became the first, and until after WWII the only, IMO entity to acquire official intergovernmental status. In the event, most CIMAé members also sat on ICAN; the former functioned more as an IMO liaison than as an independent organization.[15]

This episode reflects both the IMO's endemic institutional weakness and the relative infancy of professional meteorology. Despite the vast scientific, technological, and political changes sweeping around it, the IMO administrative structure constructed in 1889 remained largely unchanged until after WWII. Throughout, the Conference of Directors of national weather services did most of the detail work, supplemented by IMO technical commissions covering specific areas. The larger, broadly inclusive International Meteorological Committee met infrequently to discuss general policy and directions. Both of these bodies met as scientists and forecasters, rather than as government representatives. The IMO had no policy-making powers, serving only as an advisory and consensus body. Between its infrequent meetings, the organization itself did little. The IMO did not acquire a permanent Secretariat until 1926, and the latter's annual budget never exceeded $20,000.[16]

[12] Great Britain Meteorological Office, *Réseau Mondial, 1910: Monthly and Annual Summaries of Pressure, Temperature, and Precipitation at Land Stations* (London, 1920), iv–v.

[13] Part of the Treaty of Versailles, the convention entered into force in 1922.

[14] Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York, 1985).

[15] Daniel, "One Hundred Years" (cit. n. 9).

[16] Ibid.

In this era—before the advent of heavy state investment in scientific research—meteorologists themselves remained divided over the desirability of government involvement. In part this reflected the conflicting loyalties of national weather service directors. Though serving national governments, they saw their primary identity as scientists, and IMO meetings as apolitical spaces for scientific discussion. Intergovernmental status, they feared, might change this, turning them into representatives of their governments, reducing their independence and prerogatives, and perhaps subverting IMO proceedings toward the fulfillment of political agendas. For this group, in other words, scientific internationalism served as a way to *bypass* the nation-state and keep science separate from politics. Another faction, however, saw governmental commitment as the only road to the permanent, fully integrated international data exchange that would aid forecasters and climatologists, especially in Europe. As long as the IMO lacked official status, its decisions could not bind government weather services. As a result, many standardization problems remained unresolved or progressed only slowly toward solutions. For this second group, the road to better science lay *through* political commitment.

There were at least four reasons for the increasing dominance of this view within the IMO. First, as we have just seen, ICAN had challenged the organization's control of meteorological standard setting and threatened its status. Second, by the 1930s a breakthrough—the Bergen School's polar front theory—had focused meteorologists' attention on the hemispheric dynamics of weather.[17] As a result, global information became more than a far-off, abstract goal; reports from the whole Northern Hemisphere above the tropics could be used directly in national weather forecasts.

Third, rapid technological change in the interwar period vastly expanded the possibilities for, and geographic reach of, real-time data exchange. Throughout Europe and the United States, weather services traded data via Teletype, a kind of automated telegraph widely adopted in the 1920s. In the 1930s, data from more remote locations began to arrive via shortwave radio broadcasts, from ships at sea, remote island and land stations, and other locations beyond the reach of the telegraph network. "Bounced" off the ionosphere, shortwave allowed instantaneous data transmission over thousands of kilometers—even across the oceans, under some conditions—though noise in the broadcasts frequently caused errors and incomplete transmission. Telegraph and radio authorities prioritized weather data. By the late 1930s, a rudimentary real-time weather data network covered the Northern Hemisphere between the Arctic Circle and the tropics.

Finally, technoscientific changes had begun to overwhelm the institutional and organizational context. Data traveled widely, even globally—but in a bewildering variety of forms. As late as 1945, the *Handbook of Meteorology* declined to attempt a worldwide survey of meteorological data transmission and coding because

> the currently used codes are far too numerous. There are many reasons for the complexity in weather codes and reports: the diversity of elements to be observed, the various techniques of observation, variation in the information desired by analysts in different

[17] Tor Bergeron, "Methods in Scientific Weather Analysis and Forecasting," in *The Atmosphere and the Sea in Motion,* ed. Bert Bolin (New York, 1959), 440–74; Friedman, *Appropriating the Weather* (cit. n. 5); Nebeker, *Calculating the Weather* (cit. n. 5). The polar fronts, a marked feature of the global atmospheric circulation, are the boundaries between polar and mid-latitude air in each hemisphere. Their locations vary seasonally between about 30° and 60°.

> parts of the world, and lack of uniformity in the codes adopted by separate political units are some of the reasons . . . [M]any political units use International [IMO] codes, [but] others use portions of these codes or have devised forms of their own.[18]

Multiple data transmission techniques exacerbated the problem. Fast, reliable Teletype was the gold standard, but standard telegraph, shortwave broadcast, point-to-point microwave links, and other technologies were also in widespread use. In the pre-computer age, collecting and integrating data from all these channels and media remained slow, labor intensive, and error-prone.

In hopes of conquering this meteorological babel and regaining central control of standard-setting processes, IMO leaders came to agree on the need for powers like those of ICAN. In 1929, the organization posted a letter to governments seeking intergovernmental status. Arriving on the eve of the Great Depression, this proposal was generally ignored. The IMO revisited the issue with renewed vigor at its 1935 meeting in Warsaw. This time, in an attempt to acquire government endorsement by stealth, the group decided to submit future meeting invitations directly to governments, asking them to appoint each weather service director as an official government representative. At the same time, led by France and Norway, the organization began drafting a World Meteorological Convention that would secure intergovernmental status.

A preliminary version of this convention was presented to the 1939 meeting of the IMO before World War II—held, ironically, in Berlin. IMO president Theodor Hesselberg's comments reflected the general frustrations with the IMO's unofficial status:

> In view of the steadily increasing practical importance of meteorology, it is desirable that governments . . . should have a greater influence on the work of the Organization. The resolutions of the Organization should be binding on the countries to a greater extent. The Organization must be able to rely on adequate resources so that efficient cooperation should not be hampered by financial difficulties. It is abnormal for one of the Organization's commissions [the intergovernmental CIMAé] to have a more official status than the Organization itself. Similar organizations [such as CIMAé rival ICAN] have a more official status than IMO, a circumstance which has its drawbacks.[19]

The conferees forwarded the draft World Meteorological Convention to a committee for refinement. Plans called for final approval at a 1941 Conference of Directors, and the stage seemed set for meteorology's transformation. War, of course, intervened.

FROM INTERNATIONAL TO GLOBAL: THE WORLD METEOROLOGICAL ORGANIZATION

The IMO could not meet again until 1946. Already primed for a major change by its prewar activism, the organization worked at a furious pace, building on the draft convention written seven years earlier. Agreement was by no means unanimous; many participants remained skeptical of the value of intergovernmental status. The key, perennial issues were whether the change might lead to control of meteorology by politicians rather than professional meteorologists and whether the new organization would reduce the prerogatives of national weather services to function as they saw fit.

[18] G. R. Jenkins, "Transmission and Plotting of Meteorological Data," in *Handbook of Meteorology,* ed. F. A. Berry Jr., Eugene Bollay, and Norman R. Beers (New York, 1945), 574.

[19] Quoted in Daniel, "One Hundred Years" (cit. n. 9), 174.

Nonetheless, in the postwar atmosphere of optimism, conferees resolved the major outstanding questions in just over a year. Reassured by negotiators that professional status would remain primary, that nations would retain equal rights as members, and that governments would not control its deliberations, the final drafting conference in Washington, D.C., drew to a close in October 1947.

The new organization would be one among many "specialized agencies" of the United Nations, so it would have to conform to UN rules of membership. As a result, during the final proceedings an important change occurred. American legal experts advised the conferees that membership in the new organization should be accorded only to "sovereign states," as recognized by the UN. Defined in Article 3(c) of the World Meteorological Convention as a nation's "being fully responsible for the conduct of its international relations," this criterion excluded from full membership not only divided nations such as Germany—the major issue immediately after the war—but also the People's Republic of China (PRC), colonial territories, and individual Soviet republics. As Clark Miller has observed, for meteorologists this "new vocabulary of 'States' instead of 'countries' superimposed a *geopolitical* imagination of the world over the *geographical* imagination that had previously organized meteorological activities."[20] These debates mirrored those occurring simultaneously in the UN itself. In the end, representatives of thirty-one governments signed the World Meteorological Convention in October 1947. The convention entered into force in early 1950, and in 1951 the International Meteorological Organization officially became the World Meteorological Organization (WMO).

The explicit and fundamental purpose of the new organization was informational globalism. As outlined in the convention's opening paragraphs, WMO goals were:

(a) To facilitate world-wide co-operation in the establishment of networks of stations for the making of meteorological observations or other geophysical observations related to meteorology . . . ;
(b) To promote . . . systems for the rapid exchange of weather information;
(c) To promote standardization of meteorological observations and to ensure the uniform publication of observations and statistics;
(d) To further the application of meteorology to aviation, shipping, agriculture, and other human activities; and
(e) To encourage research and training in meteorology and to assist in co-ordinating the international aspects of such research and training.[21]

Although these goals differed little from those of the IMO, now meteorologists could call upon the power of government, via the authority (and the finances) of the UN, to implement them.

Committed as they already were to informational globalism, those drafting the convention must have been struck by the irony of a "world" organization that excluded some nations. The convention did specify a mechanism by which states not belonging to the UN could apply to join the WMO; approval required a two-thirds majority

[20] Clark A. Miller, "Scientific Internationalism in American Foreign Policy: The Case of Meteorology, 1947–1958," in *Changing the Atmosphere: Expert Knowledge and Environmental Governance,* ed. Clark A. Miller and Paul N. Edwards (Cambridge,, Mass., 2001), 167–218.

[21] World Meteorological Organization, *Basic Documents (Excluding the Technical Regulations)* (Geneva, 1971), 9.

vote. Territories (i.e., colonies and protectorates) could also join, under the sponsorship of their governing states. Membership grew quickly. By the mid-1960s, most nations were represented.[22]

The exceptions to this rule remained, however, extremely significant, and the issue of sovereign statehood as a requirement for membership would dog the new organization for decades. The First World Meteorological Congress, in 1951, immediately moved to soften the rebuff of the PRC's exclusion by inviting that nation to participate as an "observer." This decision became a general policy: any nonmember nation could send official observers to World Meteorological Congresses. Further, the director of the nation's meteorological service could attend or be represented at technical commission meetings.

This uneasy compromise avoided overt conflict with UN policy and the United States, but it did not satisfy the desire of many states for full recognition. Only five nonmember nations sent observers to the Second World Meteorological Congress, in 1955.[23] For many years the second-class "observer" status and the exclusion of divided nations provoked anger. For example, during the 1971 sixth congress, held at the height of the Vietnam War, Cuban delegate Rodriguez Ramirez insisted on reading into the minutes a statement denouncing the exclusion of "the socialist countries" from full membership. Ramirez accused the WMO of hypocrisy:

> The World Weather Watch would have more amply fulfilled its objectives had the WMO opened its doors to all countries. . . . The WMO . . . is rejecting UN agreements on the peaceful uses of the World Weather Watch. Viet-Nam, in particular, has suffered the destruction of nearly half of its meteorological stations, loss of the lives of more than 100 scientists and meteorological workers, terrible destruction of its forest wealth by the use of chemical products which have altered its ecology and biology . . . , at the hands of the armed invasion forces of the United States and its allies. This declaration, Mr. Chairman, has been supported by the socialist countries of Byelorussia, Bulgaria, Czechoslovakia, Hungary, Mongolia, Poland, Romania, Ukraine and the Soviet Union.[24]

U.S. representative George Cressman responded heatedly that such statements "served no purpose other than to interrupt the proceedings with political propaganda." Still, he could not resist venting some propaganda of his own, justifying the U.S. intervention in Vietnam as an invited response to "coercion, organized terror and subversion directed by North Viet-Nam."[25] Though such confrontations remained rare at WMO meetings, they marked the subterranean antagonism between the informational globalism inherent in the organization's scientific and operational goals and the conflicted, voluntarist internationalism inherited from the IMO.

Under the Westphalian internationalist model prevailing at the time of the IMO's founding, states retained absolute control over affairs within their territories and had

[22] For membership figures, see Daniel, "One Hundred Years" (cit. n. 9), 187; and Sir Arthur Davies, *Forty Years of Progress and Achievement,* WMO-721 (Geneva, 1990), 151–2.

[23] "Second World Meteorological Congress," *WMO Bulletin* 4(3) (1955), 94.

[24] For Ramirez, as for other members of the Communist bloc, this category included individual republics of the Soviet Union, which were still arguing (unsuccessfully) for separate representation at the United Nations. It also incorporated the Communist governments of divided nations such as Germany (not admitted to the UN until 1973), Vietnam (1977), and Korea (1991).

[25] The Ramirez-Cressman exchange is recorded in World Meteorological Organization, "Sixth World Meteorological Congress, Geneva, April 5–30, 1971: Proceedings," in *Congress Proceedings,* WMO CP-6 (Geneva, 1972), 162–3 (Ramirez), 164 (Cressman).

none whatsoever over the affairs of other states.[26] No state recognized any authority higher than its own. International associations existed simply to promote mutual (and shifting) interests. The paradigm cases were military alliances. Accordingly, the IMO had sought to secure common standards through persuasion via an ethic of shared, universal scientific interests. As in other organizations following the internationalist model, the IMO's constituents had cooperated when it served their mutual interests but readily ignored IMO directives when their goals diverged.

The UN system simultaneously perpetuated and eroded this voluntaristic internationalism. On the one hand, the UN strengthened the nation-state framework by codifying the rights of states against each other and creating explicit criteria for legitimate sovereignty. On the other hand, these very acts also limited sovereign power, implicitly asserting the UN's authority to challenge the legitimacy of governments. Its status as a world organization made withdrawal from the UN system difficult and costly. Contemporaries clearly experienced these contradictions as acute challenges, frequently hedging their commitments to avoid even the appearance of surrendering sovereign powers. Therefore, like most accords in the early years of the post-WWII international order, the WMO convention carefully avoided any claim to absolute authority. Rather than dictate to its member states, the WMO would "promote," "encourage," "facilitate," and so on. Under Article 8 of the convention, members were required to "do their utmost" to implement WMO decisions.

However, members could still *refuse* to adopt any WMO recommendation simply by notifying the WMO secretary-general and stating their reasons. Such deviations instantly became a ubiquitous issue at WMO technical meetings. For example, the Soviet Union and some other countries, "for practical reasons," elected to continue their standard two-hourly observing times of 02, 04, 06 GMT, and so forth, despite a majority view that a three-hourly system at 03, 06, 09 GMT, and so forth, would be sufficient. A compromise "placed emphasis on" the three-hourly times. At its first meeting in 1953, the Commission on Synoptic Meteorology expressed confusion about the contradiction between Article 8 of the WMO Convention and Resolution 15(I) of the First World Meteorological Congress (1951), which spoke of "*obligations* to be respected by meteorological administrations."[27] Debate ensued over whether to frame regulations in terms of "shall" or "should." Ultimately, the commission put off any decision. Nor did the WMO Executive Committee feel ready to impose stronger language. Both bodies deferred to the full World Meteorological Congress.

The Second World Meteorological Congress, in 1955, spent considerable time confronting this problem. Finally, the congress decided to issue two separate sets of WMO regulations. All WMO members were expected to conform, "within the sense of Article 8," to the "standard" regulations, while a second set of "recommended" regulations could be implemented at members' discretion. The criterion dividing these two sets was whether a given practice was considered "necessary" to the collection of a minimal global data set or merely "desirable."[28] Nonetheless, deviations even from "standard" practices remained common for many years.

[26] For a review see Held et al., *Global Transformations* (cit. n. 2), chap. 1.
[27] WMO Commission for Synoptic Meteorology, *Abridged Final Report of the First Session, Washington, 2nd–29th April, 1953,* CSM-1/WMO-16 (Geneva, 1953), 41 (my italics).
[28] "Second World Meteorological Congress" (cit. n. 23), 95.

INFRASTRUCTURAL GLOBALISM

Very slowly, the new WMO chipped away at the Herculean task of integrating the unruly complexity of national weather observing and communication systems into a functional planetary infrastructure. It accomplished this by embedding social and scientific norms in worldwide infrastructures, in two complementary ways. First, as the process of decolonization unfolded, the WMO sought to *align individuals and institutions with world standards* by training meteorologists and building national weather services in emerging nations. Second, the WMO worked to *link national weather data reporting systems into a single, increasingly automated global data collection and processing system.* In the early 1960s, as we will see below, the WMO began explicitly planning a global information infrastructure, the World Weather Watch.

As mentioned above, most theorists of globalization discuss information and communication technologies. Few, however, distinguish between ICTs as nonspecific channels and ICT infrastructures dedicated to specific forms of globalist information. Even Hewson's insightful discussion confounds these. Although the two are clearly related, and both are important, I argue that the latter have special significance. International communication channels, such as post, telegraph, and telephone, facilitate global flows of information, but they neither produce information nor seek to control its quality. Specifying world standards for linking communication systems facilitates globalization, but specifying uniform standards for globalist information *actively produces a shared understanding of the world as a whole.* This is why I believe we should see the meteorological project not only as informational but also as *infrastructural globalism.*

This concept refers to efforts to achieve globalist goals *by building permanent, unified world-scale institutional-technological complexes.* If Hewson's notion of informational globalism captures the emergent idea that knowledge about the whole world has practical value and sociopolitical legitimacy, then infrastructural globalism describes the material dimension of this imperative. The value of the term "infrastructure" here is manifold. Even in everyday usage the word comprehends both institutions and technological systems.[29] It expresses the invisibility that systems acquire as they become embedded in ordinary life and work as well as the reliance placed on them by whole societies. It also captures the endurance of some sociotechnical systems and institutions, whose momentum and long lifespans limit and shape human agency even as they are shaped by it.[30] (We might call this mutual shaping "infrastructuration," suggesting its substantial resonance with Anthony Giddens's structuration theory.)[31] Enduring, reliable global information infrastructures build both

[29] For example, the *American Heritage Dictionary* (New York, 2000) defines infrastructure as "the basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons."

[30] On these concepts, see Paul N. Edwards, "Infrastructure and Modernity: Scales of Force, Time, and Social Organization in the History of Sociotechnical Systems," in *Modernity and Technology,* ed. Thomas J. Misa, Philip Brey, and Andrew Feenberg (Cambridge, Mass., 2002), 185–22; Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out: Classification and Its Consequences* (Cambridge, Mass., 1999); Thomas P. Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems,* ed. Wiebe Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge, Mass., 1987), 51–82.

[31] Anthony Giddens, "Agency, Institution, and Time-Space Analysis," in *Advances in Social Theory and Methodology: Toward an Integration of Micro- and Macro-Sociologies,* ed. Karin Knorr-Cetina and Aaron V. Cicourel (Boston, 1981), 161–74; idem, *The Constitution of Society* (Berkeley, 1984).

scientific and political legitimacy for the knowledge they produce. Similarly, long-term dependency on global information infrastructures can subtly erode expectations of state sovereignty, as many have noted in connection with more recent GIIs such as the Internet and the World Wide Web. Thus infrastructural globalism (to the extent that it succeeds) is a particularly effective agent of globalization.

The WMO began its project in infrastructural globalism by exerting three kinds of institutional power. First, like the IMO before it, the organization served as a central site for negotiating technical standards. WMO technical commissions worked more vigorously than their predecessors, in part because constant effort was required simply to keep abreast of the many new instruments and techniques arriving in the 1950s. The technical commissions and quadrennial World Meteorological Congresses provided the necessary opportunities to resolve differences over standards. Over time, these institutional decisions became embedded in the emerging infrastructure, built into instruments and technological systems—a trend that continues into the present. Weather balloons and automated weather stations, for example, take readings and broadcast them for processing by meteorological centers. WMO standards govern how these instruments are constructed, used, and calibrated, as well as how their data are interpreted.

The second institutional power exerted by the WMO was simple peer pressure. Its founding members clearly hoped that the organization's new status would produce conformity to standards almost by force. Instead, as we have already seen, the process took considerable time. Lacking any kind of police power, the WMO exerted peer pressure chiefly through meetings and official publications. At first, like its predecessor, the central organization in Geneva maintained only a skeleton staff. Except for the congresses, most efforts coordinated by the WMO took place elsewhere. The Secretariat conducted no research and played no part in managing data networks; all of that was still done by national weather services. Its only activities were to facilitate meetings and to print and distribute WMO publications.

However, the organization's budget grew rapidly in its first two decades. Annual spending, only about $300,000 in the early 1950s, had quadrupled to about $1.3 million twelve years later, and by 1968 the annual budget was nearly $4 million. The WMO Secretariat acquired permanent offices in Geneva in 1955, moving into its own building in 1960. On a symbolic level, the increasingly substantial presence of a central organization mattered enormously. The series of WMO-coordinated international ventures beginning with the International Geophysical Year (IGY), 1957–1958, and culminating in the 1970s with the World Weather Watch and the Global Atmospheric Research Program placed increasingly stringent requirements for standardized observations on participants.

The third and most direct of the WMO's institutional powers was its technical assistance program. At the time of the First WMO Congress, in 1951, the impending independence of Libya, formerly an Italian colony, created the possibility of a break in meteorological services there as the existing weather service was staffed mainly by non-Libyan personnel. The congress directed the WMO Executive Committee to propose a plan for continuing services and "to express the willingness of the WMO to provide all possible technical assistance within its available resources."[32] From mod-

[32] World Meteorological Organization, *Final Report: First Congress of the World Meteorological Organization, Paris, 19 March–28 April 1951* (Geneva, 1951), 10.

est beginnings—$23,000 contributed to four countries in 1952—the Voluntary Assistance Program (VAP) soon became one of the WMO's most significant activities.

Decolonization, accelerating after 1955, created some forty new nations, multiplying the problem posed by Libya manyfold. Newly independent, poor countries, with inexperienced leaders and shaky governments, typically had few resources and less attention for meteorology. Throughout the decolonization period, the United Nations Expanded Program of Technical Assistance for the Economic Development of Under-Developed Countries (EPTA) invested in a variety of meteorological assistance projects under WMO guidance. (EPTA, established in 1950, was absorbed into the larger United Nations Development Programme [UNDP] in 1966.)[33] Though hardly the most substantial of EPTA/UNDP expenditures, neither were these projects negligible, typically comprising 1–3 percent of EPTA/UNDP's overall budget.[34]

Initially, the WMO had hoped to rely entirely on EPTA for funds, but the latter's small budget and shifting priorities made it an unreliable ally. Therefore the WMO established its own Voluntary Assistance Program in 1956. Although the majority of funding continued to flow from EPTA, between 1956 and 1959 the WMO's own VAP contributed some $430,000 in aid to thirty-four countries, mostly in the form of on-site expert assistance and fellowships for meteorological training. In the next WMO financial period, 1960–1963, this figure reached $890,000; in 1964–1967, it rose to $1.5 million, with EPTA and its successor, the UNDP, contributing another $6.5 million. By 1972, the WMO and ETPA/UNDP together had spent a total of about $55 million on meteorological assistance to developing nations, including some 700 expert missions, 1,500 fellowships, and numerous seminars and training courses in some 100 nations.[35] Wealthier WMO members also donated large amounts of equipment to less-developed nations.

Who paid for all this? Contributions to the VAP varied from year to year, but as a rule the large majority of the WMO portion came from the United States. The Soviet Union typically provided roughly half the U.S. contribution (almost all of it in kind rather than in direct financial aid). The United Kingdom and France were the third and fourth largest contributors, each donating amounts roughly one-tenth of the U.S. amount. Sweden led the list of other European countries that provided most of the rest. Altogether, some fifty nations—including some of those that also received aid—made monetary or in-kind contributions to the fund during the 1960s.[36]

The WMO perceived these activities as purely technical. As Miller has argued, however, at a larger level they formed part of a new politics of expertise. Recipients, particularly those engaged in nation-building, often understood them as part of a political program. For example, by helping the new Israeli state to provide expert advice to its (mostly immigrant) citizens, WMO assistance to the Israeli weather service simultaneously promoted the legitimacy of the new state.[37]

It would be absurd to claim any major role for the WMO in nation-building. Yet the organization certainly helped to construct an international community of civil servants,

[33] Ruben P. Mendez, *United Nations Development Programme,* http://www.yale.edu/unsy/UNDPhist.htm.

[34] Miller, "Scientific Internationalism" (cit. n. 20).

[35] Daniel, "One Hundred Years" (cit. n. 9).

[36] See, e.g., *Consolidated Report on the Voluntary Assistance Programme Including Projects Approved for Circulation in 1971,* WMO-323 (Geneva, 1972).

[37] Miller, "Scientific Internationalism" (cit. n. 20).

science and technology administrators, scientists, and engineers who carried the banner of their native countries. The Voluntary Assistance Program furthered the representation of weather expertise as a basic *and apolitical* element of the infrastructures furnished by modern sovereign states to modern citizens. Multiplied across many forms of scientific and technical expertise, this representation promoted the integration of expert institutions into emerging liberal states. Additionally, by creating channels and even requirements for the two-way flow of scientific information, the practice helped reduce the chance—much feared by early cold warriors—of being "scooped" in critical areas of science or technology by insular or secret state-sponsored Communist institutions. Ultimately, these and the myriad of similar intergovernmental scientific and technical bodies that arose after World War II heralded "a significant shift of foreign policy responsibilities from Departments of State to other government agencies as the participation of experts in international institutions has become central to international affairs."[38]

The technical assistance program also served as a key conduit for the WMO's standardization efforts. The training and expert advisory programs accomplished this not only through their educational content but also by building human relationships and participatory norms. WMO documents on training frequently stressed the importance of communicating to newly trained meteorologists the value of their contribution to the global effort. Efforts were made (and also resisted) to standardize syllabi for WMO-sponsored training courses.[39] Equipment donated through the VAP functioned to carry WMO standards, embodied in the machines, from donors to recipients.

In summary, the early WMO did not immediately fulfill the expectations of its founders. Instead, joining the UN system actually inhibited the WMO's informational globalism by preventing all nations from joining on equal terms, and it involved the organization in cold war politics in ways its leaders probably did not anticipate. However, cold war geopolitics *also* worked in the organization's favor in several important ways. First, the superpowers themselves began to seek global information in arenas that included weather. Second, two of the cold war's most central technologies—computers and satellites—would become the most important tools of meteorology as well. Finally, international scientific cooperation would become part of the cold war's ideological dimension.

METEOROLOGY, COLD WAR POLITICS, AND NEW TECHNOLOGY

The geopolitical context of post-WWII geophysics was the desire of both superpowers for a multidimensional form of global reach. This necessarily involved the collection of certain kinds of globalist information. As I showed in *The Closed World,* the United States' foreign policy of "containment" conceptualized the cold war as a global struggle, reading all conflicts everywhere in the world as part of the contest for military and ideological advantage. Containment strategy materialized in specific technological forms. High-technology weapons, in the form of thermonuclear bombs, long-range bombers, nuclear submarines, and missiles, would project U.S. power across the globe, while computers, radar, and satellites would enable centralized, real-

[38] Ibid.

[39] J. Van Mieghem, *Problem of the Professional Training of Meteorological Personnel of All Grades in the Less-Developed Countries,* WMO TN-50 (Geneva, 1963).

time surveillance and control. Heavy investment in military equipment would reduce reliance on men under arms, something the American public was never keen to support. The extremely rapid improvement of computers between 1945 and 1960 owed much to cold war goals. By enabling centralized command and control on a vast scale, computers and ICT infrastructure also helped to shape American global ambition.[40]

Mathematician John von Neumann, one of the major figures in both computer and nuclear weapons development, promoted the new machines for "numerical weather prediction" (NWP), or weather forecasting by means of mathematical models. Von Neumann helped found the Joint Numerical Weather Prediction (JNWP) Unit, which brought operational computerized forecasting to the United States starting in 1955. "Joint" here meant combined support from the U.S. Weather Bureau, the U.S. Air Force, and the U.S. Navy, with the military backers providing the lion's share. The idea of weather *control*—techniques such as cloud seeding and hurricane steering—was frequently deployed (not least by von Neumann himself) to justify NWP, receiving about half the total U.S. government budget for weather research throughout the 1950s.[41] The prospect of using weather as a weapon remained very much on the military agendas of both superpowers well into the 1970s, when it was finally abandoned.[42]

Military technological change also increased the superpowers' appetites for global weather data and forecasts. High-flying jet aircraft needed information on the jet streams and other high-altitude weather phenomena, which could also affect ballistic missiles. Tactical nuclear strategy depended on knowing the likely path of fallout clouds and the distances they might travel on the wind. In the 1950s, the U.S. Air Force Air Weather Service (AWS) grew to be the world's largest weather agency, employing an average of 11,500 staff. During this period, approximately 2,000 of these AWS personnel were officers with some degree of formal training in meteorology. By the end of the decade, military officers accounted for over half of the total enrollment in meteorology programs at American universities.[43]

Geostrategy and technological change—mutually reinforcing—thus aligned military interests with the informational globalism of scientists involved in NWP research. Global data procurement grew into a joint, unified effort of the Weather Bureau and the navy and air force weather services and (later) of NASA as well.[44] American military weather observations, especially from radiosondes and reconnaissance aircraft

[40] Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass., 1996).

[41] In practice, NWP and weather control remained separate research tracks. See Paul N. Edwards, "The World in a Machine: Origins and Impacts of Early Computerized Global Systems Models," in *Systems, Experts, and Computers,* ed. Thomas P. Hughes and Agatha C. Hughes (Cambridge, Mass., 2000), 221–54; James R. Fleming, "Fixing the Weather and Climate: Military and Civilian Schemes for Cloud Seeding and Climate Engineering," in *The Technological Fix,* ed. Lisa Rosner (New York, 2004), 175–200; Kristine C. Harper, "Research from the Boundary Layer: Civilian Leadership, Military Funding, and the Development of Numerical Weather Prediction (1946–55)," *Social Studies of Science* 33 (2003): 667–96; Chunglin Kwa, "The Rise and Fall of Weather Modification: Changes in American Attitudes towards Technology, Nature, and Society," in Miller and Edwards, *Changing the Atmosphere* (cit. n. 20), 135–66; John von Neumann, "Can We Survive Technology?" *Fortune* (June 1955): 106–8, 151–2.

[42] Kwa, "Weather Modification" (cit. n. 41).

[43] John F. Fuller, *Thor's Legions: Weather Support to the U.S. Air Force and Army, 1937–1987* (Boston, 1990); Committee on Atmospheric Sciences, U.S. National Research Council, "The Status of Research and Manpower in Meteorology," *Bulletin of the American Meteorological Society* 41 (1960): 554–62.

[44] Gerald L. Barger, *Climatology at Work* (Washington, D.C., 1960).

flying from remote Arctic and Pacific island airbases such as Alaska, Greenland, Hawaii, the Philippines, Midway, and Guam, became very important sources of upper-air data in sparsely covered regions. Bases in France, Germany, Japan, and Korea provided coverage of the surrounding regions independent of national weather services. The increasingly worldwide forays of American military vessels supplemented coverage of the oceans. A key purpose of this military network in the 1950s was to monitor atmospheric tests of nuclear weapons and the spread of fallout.[45]

Military observing networks freely shared most of their synoptic data, but they also produced their own separate, secret forecasts and data.[46] Still, there is little evidence that these were any better than those produced by their civilian counterparts. Indeed, military weather services experienced ongoing threats to their survival from commanders who found them redundant or sought to cut costs by relying on civilian forecasts instead. Around 1960, both the U.S. Air Weather Service and the Royal Swedish Air Force in fact discontinued some internally produced forecasts in favor of publicly available results.[47] But the separate military weather networks had another purpose: to provide an independent basis for forecasting in case war stopped the flow of data through the civilian network. In the end, international cooperation in data sharing continued with few interruptions throughout most of the cold war. Even at the cold war's most dangerous moment—the Cuban missile crisis of 1962—the weather services of the opposing nations (i.e., Cuba and the United States) continued their routine exchanges of data.[48]

Cold war politics did sometimes impede the free exchange of weather data from civilian weather services. Before 1956, the People's Republic of China—excluded from full WMO membership—shared no weather data at all. The Soviet Union did provide most information but withheld the locations of some weather stations near its northern borders, presumably for military reasons. The U.S. Air Weather Service was able to determine the probable location of these stations by modeling their fit to several months' worth of weather analyses.[49]

By the end of the 1950s, the most pressing weather-related military issues involved satellites. Intelligence has always been crucial to military strategy. During the cold war, it reached new levels of urgency as well as technological sophistication. Uncertainty about the other side's real capabilities drove an accelerating race to build ever more, faster, and longer-range bombers and missiles. The United States, in particular, found it difficult to penetrate the closed Soviet society with human agents, while the Soviet propaganda machine produced convincing images of that nation's rapidly advancing high-tech armed forces. From 1956 on, American knowledge of Soviet military capabilities came largely from secret reconnaissance flights by high-altitude U-2 spy planes. These flights were illegal under the 1922 Convention Relating to the Reg-

[45] Fuller, *Thor's Legions* (cit. n. 43); David M. Hart and David G. Victor, "Scientific Elites and the Making of U.S. Policy for Climate Change Research," *Soc. Stud. Sci.* 23 (1993): 643–80.

[46] For example, the Defense Meteorological Satellite Program (DMSP) operated independent military weather satellites—nearly identical to their civilian counterparts—from 1962 until 1994, when the civil and military meteorological satellite programs were combined. R. Cargill Hall, "A History of the Military Polar Orbiting Meteorological Satellite Program," *Quest* 9(2) (2002): 4–25.

[47] Fuller, *Thor's Legions* (cit. n. 43).

[48] Gerald S. Schatz, *The Global Weather Experiment: An Informal History* (Washington, D.C., 1978).

[49] Richard Davis, U.S. National Climatic Data Center, interview with author, 1998, Asheville, N.C.

ulation of Aerial Navigation, which reserved sovereign rights to national airspace. When a Soviet antiaircraft missile shot down a U-2 over Svedlovsk in May 1960, finding another way to spy from above became an urgent United States priority. Satellites offered a bulletproof alternative, more difficult to detect and virtually invulnerable to attack.

The first proposals for intelligence satellites, in RAND Corporation studies of the late 1940s and early 1950s, almost immediately noted the tight links between military satellite reconnaissance and weather forecasts. To have intelligence value, photographs from space would have to be taken on clear days, with little or no cloud cover. How better to improve forecast quality than with satellites? Explorer VII, launched in 1959, carried both the first meteorological instruments for measuring radiation balance and the first camera from which film was successfully recovered for the secret CORONA spy program.[50] As on many other occasions, public meteorological purposes thus provided cover for secret military ones. The famed U.S. Television and InfraRed Observation Satellite (TIROS) weather series began life in 1956 under an army "weather reconnaissance" program, but it became a "civilian" project after being transferred to NASA.[51] In the end, the U.S. Weather Bureau received responsibility for the TIROS operation, with NASA retaining responsibility for engineering and launch.[52] By 1966, thirteen TIROS satellites had been placed into orbit, and other meteorological satellite programs were underway.

Would spy satellites violate the sovereignty of nations they overflew? International law did not specify an upper limit to national airspace. Perhaps there *was* no limit, although no nation then possessed the ability to intercept a foreign satellite. Walter McDougall has shown that a covert purpose of John F. Kennedy's proposals for "peaceful uses of outer space" was to preempt legal challenge on this issue. A world reaping the daily benefits of weather and telecommunications satellites would be much less receptive to objections against satellite photography of airbases and missile silos. In the event, the Soviets never raised the issue, probably because they had the same objective. Both American and Soviet satellite programs continued on their dual course, with large, secret military programs looming quietly behind the huge fanfare accorded the public, peaceful space race, in which weather and telecommunications satellites led the way.

Infrastructural globalism in meteorology also benefited from the IGY. Scientists from some 67 nations conducted global cooperative experiments to learn about world-scale physical systems, including Earth's oceans, ionosphere, magnetic field, and geologic structure. The IGY's atmospheric component claimed even broader participation, from some 100 nations. The IGY served significant ideological purposes for both superpowers, which used their scientific collaboration to promote their technological prowess and their commitment to peaceful coexistence.[53] Internationalism may have

[50] John Cloud, personal email, July 7, 1997.

[51] Abraham Schnapf, "The Tiros Meteorological Satellites—Twenty-Five Years: 1960–1985," in *Monitoring Earth's Ocean, Land, and Atmosphere from Space: Sensors, Systems, and Applications,* ed. Abraham Schnapf (New York, 1985), 51–70.

[52] Margaret E. Courain, *Technology Reconciliation in the Remote-Sensing Era of United States Civilian Weather Forecasting: 1957–1987* (Ph.D. diss., Rutgers Univ., 1991).

[53] Miller, "Scientific Internationalism" (cit. n. 20); Clark A. Miller and Paul N. Edwards, "Introduction: The Globalization of Climate Science and Climate Politics," in Miller and Edwards, *Changing the Atmosphere* (cit. n. 20), 1–30.

been indigenous to science, but in the IGY it would be used, in a marriage of convenience, to help guarantee American (and more broadly Western) political interests.[54] As Ron Doel has observed, this argument implies a kind of co-optation.[55] Instead, the situation was one of what I have called "mutual orientation."[56] Science would be used to promote a particular vision of world order, but in exchange scientists could better promote their own. Their involvement in government and governance would, in the long run, produce pressures to which governments would be forced to respond. Ozone depletion and climate change are major cases in point.

The WMO became heavily involved in early IGY planning. A general consensus emerged across the many sciences represented that the IGY's overarching purpose should be to study the Earth as a "single physical system." This fit well with meteorology's increasing orientation toward large-scale, hemispheric or global atmospheric motion. Hence the IGY's meteorological component focused most of its attention on observations of the global general circulation. Three pole-to-pole chains of observing stations were established along the meridians 10°E (Europe/Africa), 70°–80°W (the Americas), and 140°W (Japan/Australia). Dividing the globe roughly into thirds, these stations coordinated their observations to collect data simultaneously on specially designated "regular world days" and "world meteorological intervals." In addition to balloons and radiosondes, an atmospheric rocketry program, initially proposed by the Soviet Union, retrieved information from very high altitudes. In addition to Sputnik—nominally an IGY experiment—six other satellites were successfully launched, though the meteorological data they returned had little value. Here as elsewhere, the IGY marked a transition that would be fully achieved only later. Extensive efforts were made to gather information about the Southern Hemisphere from commercial ships, as well as (for the first time) from the Antarctic continent. In total, the IGY meteorological network claimed some 2,100 synoptic surface stations and 650 upper-air stations—far more than the networks for ionospheric and magnetic studies, which counted only about 250 stations each.[57] The program proved so popular that many of its operations were extended through 1959 under the rubric of an International Geophysical Cooperation (IGC) year.

A look at the WMO's data strategy during the IGY reveals the cusp of change from voluntarist internationalism to infrastructural globalism. Plans called for depositing complete collections of IGY/IGC meteorological data at three world data centers (WDCs): one in the United States (WDC-A), the second in the Soviet Union (WDC-B), and a third at WMO headquarters in Geneva (WDC-C).[58] Each WDC would be funded by the host nation. The data centers did not undertake to process the data but merely

[54] Ronald E. Doel and Allan A. Needell, "Science, Scientists, and the CIA: Balancing International Ideals, National Needs, and Professional Opportunities," in *Eternal Vigilance? Fifty Years of the CIA,* ed. Rhodri Jeffreys-Jones and Christopher Andrew (London, 1997), 59–81; Allan A. Needell, *Science, Cold War, and the American State: Lloyd V. Berkner and the Balance of Professional Ideals* (Amsterdam, 2000).

[55] Ronald E. Doel, "Constituting the Postwar Earth Sciences: The Military's Influence on the Environmental Sciences in the USA after 1945," *Soc. Stud. Sci.* 33 (2003): 635–66.

[56] Edwards, *The Closed World* (cit. n. 40), chap. 3.

[57] Aleksandr K. Khrgian, *Meteorology: A Historical Survey,* 2nd ed., ed. Kh. P. Pogosyan and trans. Ron Hardin (Jerusalem, 1970).

[58] Comité Spécial de l'Année Géophysique Internationale, "The Fourth Meeting of the CSAGI," in *Annals of the International Geophysical Year,* ed. M. Nicolet (New York, 1958), 297–395; Sir Harold Spencer Jones, "The Inception and Development of the International Geophysical Year," in *Annals of the International Geophysical Year,* ed. Sydney Chapman (New York, 1959), 383–414.

to compile and distribute it. Each national weather service and research group was responsible for reporting its data to the WDCs.

In an echo of the prewar *Réseau Mondial,* merely collecting and compiling these data took years. The full set was not completed until 1961. Though planners knew that electronic methods of data processing would soon become the norm, standardization in computer storage techniques remained in the future. Therefore the IGY data sets were produced and distributed on microcards, a miniature photographic reproduction method similar to microfiche. This choice, based chiefly on economy and convenience, reflected the WMO commitment to informational globalism as it allowed more members affordable access to the IGY data.[59] At the same time, the lack of a standard format for electronic data processing reflected the continuing technical challenges to infrastructural globalism.

This lack, and the enduring internationalist ethic of voluntarism, profoundly affected the fate of the IGY data infrastructure. Instead of continuing with centralized global data collection, the WMO urged each national weather service to publish its own data. Centralized data collection, opponents feared, might reduce the resources available to national services and duplicate effort. As an official WMO history rather delicately put it, at the Third World Meteorological Congress in 1959,

> some delegates expressed the view that the WMO Secretariat should continue to discharge the functions of the IGY [Data] Centre on a permanent basis. The prevailing view was however that the responsibility for the regular publishing of meteorological observations, and thus for making them readily available for research workers, should be in the hands of national Meteorological Services.[60]

Instead, the organization undertook to catalog all the data residing in national repositories around the world. These immense volumes took years to compile. The data catalog for the IGY appeared in 1962. Two fat volumes listing various additional data sets from around the world arrived in 1965, while a third—"meteorological data recorded on media usable by automatic data-processing machines"—did not see print until 1972.[61]

CONCLUSION: THE FIRST WWW

During the 1950s, dramatic new possibilities for informational globalism emerged as a result of both scientific and technological change. The advent of digital computers meant that physics-based simulations of weather could be performed fast enough to be useful in forecasting. By the end of the decade, computerized forecasting was planned or operational in the United States, the United Kingdom, the Soviet Union, Japan, Sweden, Israel, West Germany, Belgium, Canada, and Australia. Computer-forecast models required data from regular three-dimensional grids over very large

[59] Davies, *Forty Years* (cit. n. 22), 74–5. A full set of 16,500 IGY microcards cost about $6,000. The same data set required about 10 million punch cards, weighing approximately thirty tons. See Barger, *Climatology at Work* (cit. n. 44).

[60] Davies, *Forty Years* (cit. n. 22), 75.

[61] *Catalogue of IGY/IGC Meteorological Data,* IGY-4//WMO-135 (Geneva, 1962); *Catalogue of Meteorological Data for Research,* parts 1 and 2, WMO-174 (Geneva, 1965); *Catalogue of Meteorological Data for Research,* part 3, *Meteorological Data Recorded on Media Usable by Automatic Data-Processing Machines,* WMO-174 (Geneva, 1972).

areas. Initially regional or continental, by the end of the 1950s forecast models were already moving to the hemispheric scale.

For technical reasons, data voids mattered much more to these models than they had to the human synoptic forecasters who preceded them.[62] This made improvement in data networks imperative. Real-time data exchange on a planetary scale would require better infrastructure—not just better technology, but more uniform conformance to WMO standards, better coordination, and more widely distributed knowledge and skills in weather services across the globe. The IGY, conceived as a temporary collaboration, came up short of building a permanent infrastructure, though it represented an important "proof of concept."

By the end of the decade, however, meteorologists were explicitly conceiving an infrastructure to support their informational globalism. Satellites were the spur. In 1959, the WMO convened the Panel of Experts on Artificial Satellites, consisting of U.S. and Soviet representatives. In 1961, as the panel was completing its first report, U.S. president Kennedy delivered an unrelated address to the United Nations General Assembly. He outlined an arms control agenda that included the demilitarization of outer space and promised soon to bring forward new proposals for "further cooperative efforts between all nations in weather prediction and eventually in weather control." These words were soon backed by action. Kennedy's national security adviser, McGeorge Bundy, directed the secretary of state and numerous relevant U.S. government agencies to pursue this objective actively.[63]

In December 1961, the UN General Assembly approved Resolution 1721 encouraging all nations to participate, via the WMO, in efforts "to advance the state of atmospheric science and technology so as to provide greater knowledge of basic physical forces affecting climate and the possibility of large-scale weather modification," as well as to improve weather forecasting.[64] The WMO satellite panel's report, along with a U.S. National Research Council proposal, were rapidly integrated into the World Weather Watch. The project envisaged automatic, global data collection; a global telecommunication system; and computerized data processing for forecasts and climate studies. Implementation began in 1967, following an intensive planning process. Planning focused on making the system as automatic and as global as possible.[65] From that point on, the World Weather Watch has been the WMO's central *raison d'être* and its primary activity.

[62] Jule G. Charney, R. Fjørtoft, and John von Neumann, "Numerical Integration of the Barotropic Vorticity Equation," *Tellus* 2 (1950): 237–54; P. D. Thompson, "A History of Numerical Weather Prediction in the United States," *Bull. Amer. Meteor. Soc.* 64 (1983): 755–69.

[63] McGeorge Bundy, "National Security Action Memorandum No. 101: Follow-up on the President's Speech to the United Nations General Assembly on September 26, 1961," available in the Federation of American Scientists' Intelligence Resource Program online archive of official documents (Washington, D. C.), http://www.fas.org/irp/offdocs/nsam-jfk/index.html.

[64] Available online via the "Index of Online General Assembly Resolutions Relating to Outer Space," United Nations Office for Outer Space Affairs, Vienna, http://www.oosa.unvienna.org/SpaceLaw/gares/.

[65] N. G. Leonov, H. P. Marx, and WMO, *Requirements and Specifications for Data-Processing System,* WWW Planning Report No. 8 (Geneva, 1966); T. Thompson, *Telecommunications Problems in Computer-to-Computer Data Transfer,* WWW Planning Report WWW-PR-3 (Geneva, 1966); U.S. Weather Bureau, *The World Weather Watch: An International System to Serve All Nations* (Washington, D.C., 1965); WMO, *Planning of the Global Telecommunication System,* WWW Planning Report No. 16 (Geneva, 1966); idem, *The Role of Meteorological Satellites in the World Weather Watch,* WWW Planning Report No. 18 (Geneva, 1967); idem, *World Weather Watch: Status Report on Implementation* (Geneva, 1968).

The World Weather Watch *could* be understood simply as a series of incremental improvements in an existing global network, driven by an inexorable process of technological change (and some of its planners have described it this way). But this is to misconstrue its significance as a technopolitical achievement. It marked the successful transfer of key standard-setting and coordinating powers from national weather services to a permanent, globalist intergovernmental organization. Unlike its many predecessors, this global data network has persisted now for four decades, gathering momentum as it grows. It is a genuinely global infrastructure that produces genuinely global information. Virtually all nations contribute data and receive, in turn, WWW data products.

Has infrastructural globalism in meteorology limited the power of national governments? Generally, the answer must be yes. The globalization of data networks makes it almost unthinkable, not to mention unaffordable, for most nations to develop separate, independent networks or standards. Even military meteorology now relies heavily, though not exclusively, on data provided by public, civilian networks. As an example, in the 1990s some European governments began to contemplate recovering costs by selling meteorological data (in contravention of centuries-old traditions), draining data from the WWW. In response, the WMO—prodded by the United States—defined "basic" data that member states are required to share freely.[66] Despite some ongoing resistance, most governments are complying.

A different question is whether this particular project for infrastructural globalism actually matters outside the meteorological community. Here the politics of global warming provide a unique metric. For three decades, scientific predictions of anthropogenic climate change were resisted by political leaders from many countries, who argued that such predictions were based on theories and computer simulations—not on observations, which still failed to show a convincing signal against the noise of natural climatic variation. From the late 1980s on, the Intergovernmental Panel on Climate Change (IPCC), established jointly by the WMO and the UN Environment Programme, began providing state-of-the-art reports on climate change. By the time of its *Second Assessment Report,* released in 1995, the organization could state that "the balance of evidence" supported the theory of anthropogenic climate change.[67] The 2001 IPCC report went further, claiming "new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."[68] These conclusions were endorsed not only by the IPCC's scientists but also by most IPCC member governments. The 2005 ratification of the Kyoto Protocol solidifies this acceptance.

I would argue that this consensus has come about precisely because the weather data network has grown into a well-developed, highly standardized GII. As it improved and endured, measurements accumulated. Uncertainty was reduced. Seemingly contradictory sets of observations from different instrument sets were reconciled. At the

[66] WMO Resolution 40, adopted at the Twelfth World Meteorological Congress (1995), reafffirms the principle of free exchange of basic data and defines a set of shared "supplemental" data that cannot be used commercially in the country of origin. For example, French supplemental data cannot be used to make French forecasts that are sold instead of freely distributed.

[67] *Intergovernmental Panel on Climate Change, IPCC Second Assessment—Climate Change 1995: A Report of the Intergovernmental Panel on Climate Change* (Geneva, 1995), 5, http://www.ipcc.ch/pub/sa(E).pdf.

[68] *Climate Change 2001: Synthesis Report,* ed. Robert T. Watson and the Core Writing Team (Geneva, 2001), 5, http://www.ipcc.ch/pub/un/syreng/spm.pdf.

same time, virtually all nations were enrolled, first at the agency level, through weather services, and then, via the IPCC, at the executive and legislative levels as well. Linking *governments* to environmental *governance* by means of a global data-producing infrastructure has made it increasingly difficult for the former to ignore the latter. The IPCC's conclusions are not ones that any nation or its political leaders would ever seek to reach. Barring heroic and extremely costly changes to the world's energy economy, anthropogenic global warming cannot be easily controlled. Yet even the ideologically driven George W. Bush administration finally abandoned its wait-and-see position, acknowledging that global warming is real and is caused in significant part by human activity even while declining to ratify the Kyoto Protocol.[69]

Of course, I am not arguing that scientific evidence by itself determined this change in a key political position. Global scientific organizations cannot force political action on the issue. Yet their extraordinary success in promoting highly unwelcome conclusions shows how infrastructural globalism has helped transfer power from states to global science-based organizations.

No one who has studied the global warming debate can ignore the long-term convergence of the observational evidence. This convergence has everything to do with the increasing precision, power, and scope of the global weather data network. No infrastructure this complex or this large will ever be perfectly integrated or seamlessly smooth.[70] Debate will continue over the quality of the data it generates. Nonetheless, it has established global warming as an accepted, highly consequential fact. Without the infrastructural globalism that produced it, this knowledge would remain far more heavily contested.

[69] *U.S. Climate Action Report* (Washington, D.C., May 2002).

[70] Thomas C. Peterson, David R. Easterling, Thomas R. Karl et al., "Homogeneity Adjustments of *In Situ* Atmospheric Climate Data: A Review," *International Journal of Climatology* 18 (1998): 1493–517; Thomas C. Peterson and Russell S. Vose, "An Overview of the Global Historical Climatology Network Temperature Database," *Bull. Amer. Meteor. Soc.* 78 (1997): 2837–49.