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# Downscaling: From Global to Local in the Climate Knowledge Infrastructure

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The climate knowledge infrastructure was built to generate understanding of the global climate system. Its deep history, as well as its more recent role in climate politics, coupled it to national governments in both scientific and political terms. This infrastructure is currently challenged to “downscale” climate knowledge to meet the demands of city, county, and state agencies, as well as a wide variety of non-governmental organizations.

Downscaling means much more than producing higher-resolution climate data. It requires building technical, social, and institutional gateways that permit the smooth transfer of knowledge — forecasts, causal theories, data, and interpretive or translational information — both to and from other knowledge infrastructures. This chapter argues that although the focus on a planetary scale matched the character of the problem as initially conceived, the same features that made it effective at the planetary scale are now inhibiting use of climate knowledge for local, state, and regional planning. Processes now in play are likely to resolve these infrastructural mismatches, at least in part, but the legacy of knowledge built to serve global and national needs will remain a stumbling block for years to come.

## What is a “knowledge infrastructure”?

Why should we think about knowledge in terms of “infrastructure,” a term that normally conjures up roads, bridges, and sewer systems? Precisely by drawing the analogy between material constructions and well-grounded (note the metaphor) understandings of the world, the phrase helps to destabilize the sense of abstraction and disembodiment that too often cloud thinking about what “knowledge” is. No fact long survives unsupported by people, equipment, instruments, standards, networks, and/or organizations — often called “actor-networks” — that supply evidence, theories, and connections to other facts and other infrastructures or actor-networks (Callon and Latour, 1981; Latour and Woolgar, 1979; Latour, 1983; Latour, 1987; Latour, 2005). This is as true for indigenous or alternative knowledge as it is for Western science, though only the latter will concern me here (Jackson et al., 2008). In short, the phrase “knowledge infrastructures” captures the stabilizing effects of historical and material commitments.

From its origins in the 1980s with scholarship on “large technical systems,” and blossoming in the 2000s following the seminal work of Leigh Star and Geoffrey Bowker, infrastructure studies has articulated a well-developed theory of how infrastructures develop and change (Bowker and Star, 1999; Chandler, 1977; Edwards et al., 2007; Edwards et al., 2009; Edwards, 1998; Hughes, 1983; Hughes, 1987; Mayntz and Hughes, 1988; Star and Ruhleder, 1996). In a nutshell, the theory goes something like this: infrastructures are enduring sociotechnical assets that support basic human needs or goals such as transportation, communication, and energy. They often originate as sociotechnical *systems*. “Systems,” in this conception, are centrally designed and controlled, typically in the invention and development phases of new techniques and technologies. At that point, they remain the province of their developer, whether a single individual, a team, or an organization. Once these systems begin to travel, they also begin to vary. Both users and other developers modify or extend them, and competing or alternative technologies and enterprises arise.

This variation is the norm rather than the exception: consider the many similar, but incompatible devices and techniques built during the early days of railroads, electric power, or computers. Consequently, when a need arises to link heterogeneous systems into *networks*, devices and/or social apparatus known as *gateways* must be developed to connect systems’ varying social, technical, legal and other elements (Egyedi and Spirco, 2011; Egyedi, 1996). Gateways such as AC/DC converters are technical, but many — perhaps most — gateways consist of codified, embedded social agreements: legal arrangements for interstate or international trade, standard dimensions for shipping containers, or published APIs (application programming interfaces that act like plugs and sockets for software). The network phase of development involves many actors, and it signals that a growing community is increasingly committed to particular functions and norms of interaction.

In later phases, *webs* or *internetworks* — networks of heterogeneous networks — may develop. For example, shipping, rail, and trucking networks developed symbiotically yet independently, but starting in the 1960s these networks gradually became integrated into a global internetwork. A tipping point in this integration was the rise of the ISO standard shipping container, a classic example of a gateway — all the more so because the container is not so much a device or invention as a standard, i.e. a social agreement, limiting the shapes, sizes, and structures of packaging for large-scale transport (Busch, 2011; Egyedi, 2001; Klose, 2015). Networks and internetworks exhibit more decentralized control. Since they are made up of many independent systems and networks, they can only rarely (if ever) be designed, controlled, or standardized from above (Bowker and Star, 1999; Edwards et al., 2007). Instead, infrastructures are complex ecologies whose component systems must continually evolve to match the changing characteristics of the related systems around them. In a final phase, infrastructures can splinter into more specialized elements, or die altogether (Graham and Marvin, 2001). As a rule, then (though with exceptions), infrastructures are not systems, but networks or webs.

*Knowledge* infrastructures follow a similar pattern. They are “robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds” (Edwards et al., 2013; Edwards, 2010). They, too, evolve from systems to networks to webs. Like “hard” infrastructures, their stability, reliability, and transparency stem from historical and material commitments made over long periods of time.

Like other infrastructures, knowledge infrastructures are complex ecologies that can shift and change over time. Rarely is anything we call “knowledge” perfectly certain or stable; instead, knowledge consists of coherent claims — today, often expressed as probabilities — warranted by established evidentiary systems. Probabilistic knowledge can be both useful and actionable. Demographic and labor statistics; international disease tracking and rapid vaccine development; evidence-based medical protocols; and daily weather forecasts are all products of knowledge infrastructures. No weather forecast is perfectly accurate, yet the range of error is small enough that people and industries rely on forecasts, which in recent years are right far more often than they are wrong over the large majority of the globe. Similarly, neither flu vaccinations nor flu tracking are perfectly reliable, yet their consistently high success rates justify social confidence.

People rely on mature knowledge infrastructures as part of their daily routines. Precisely for this reason, over time these infrastructures (like others) become invisible to users, except when they fail. Further, while they enable and empower, knowledge infrastructures also constrain. The routines of thought and action they facilitate can obscure other potentially valuable approaches, sometimes with serious consequences.

## Measurement and climate knowledge: a little history

“Climate” refers to average weather patterns on time scales from years to decades to centuries and beyond. Such patterns include the seasonal cycle, the El Niño/La Niña cycle, and the ice ages. Particular places have their typical climates, but the physical systems that create those climates are global and interactive. Understanding of this fact dates to ancient times. Historically, scientific studies of climate examined both regional climates and the global climate system. Before the 19th century, however, very few investigators had access to data about the entire planet, so *detailed* climate knowledge first developed as descriptive (rather than causal) accounts of local and regional geography. With world empires and the rise of science came increasing access to global data, and scientific climatology — seeking to understand causes as well as consequences — slowly turned in that direction.

The historical pattern described in the previous section can be readily observed in the case of climate knowledge. Detailed understanding of global climate requires observations of the world’s atmosphere, its oceans, and its ice. Records of these phenomena, built up over time, constitute the basic data of scientific climate studies. Following the invention of thermometers and barometers in the 17th century, scientists created the first formalized observing networks, sharing their data by mail. Astronomical observatories often recorded meteorological observations (viz. the root word “meteor,” which originally referred to both celestial and atmospheric phenomena). The telegraph’s arrival in the mid-19th century made possible, for the first time, near-real-time mapping of weather over large areas, as well as the first efforts at weather prediction based on those maps. This spurred the formation of government-sponsored national weather services — wide-area observing *systems*, with standards and routines for mapping and predicting weather — in Europe and the United States. Such systems joined isolated observing stations into national networks with partially standardized observing hours, instruments, recording forms, and reporting techniques. Stations reported by telegraph to central offices, which mapped their observations and distributed weather predictions. Weather services faxed weather maps to newspapers for daily publication as early as the 1870s.

National weather observing systems quickly formed international *networks* — and faced the typical problem that the national systems each had their own, sometimes incompatible standards for observing hours, units, instruments, and so on differed widely. In 1853, the American naval scientist Matthew Maury organized a conference in Brussels, where he secured agreements from the world’s major shipping nations to record weather observations at sea on standard recording forms. These forms were sent to the US Naval Observatory for plotting and redistribution worldwide, thus creating the oldest continuous quasi-global weather record. Several European nations participated in a telegraph-based weather data network as early as 1857. The earliest meeting of what would become the International Meteorological Organization was held in 1871. Before the end of the 19th century, the concept of a telegraph-based Réseau Mondial (global network) for real-time weather data collection had been floated. Technical and organizational inadequacies, not to mention two world wars, delayed the full realization of such a network until the 1960s, when the postwar World Meteorological Organization (operating now under United Nations auspices) initiated the World Weather Watch.

By the end of the 19th century, climatologists had begun making use of the growing number of long-term, semi-standardized records to plot monthly average temperatures and other variables at all subpolar latitudes. Although most 19th century climatology was purely descriptive, emerging climatological theories comprehended major global features such as the tropical, mid-latitude, and polar circulatory cells, and correctly assessed their causes.

As new instruments and instrument platforms appeared, and as understanding grew of the links between terrestrial, marine, polar, and upper air phenomena, international data *internetworks* emerged. By the 1970s, these webs brought information from satellites, instrumented buoys, ships, airplanes, weather balloons, radar, and dozens of other platforms to central processing facilities. These were true internetworks — rather than merely extensions of existing networks — because some platforms and instruments functioned very differently from older devices and were managed by different institutions. For example, unlike ordinary thermometers and barometers, which take periodic measurements at fixed points, ground radars produce continuous images of moving clouds and precipitation, while satellites measure large volumes of air beneath them. Weather forecasters took decades to find practical uses for radar images and satellite data in forecasting, because connecting them to the traditional representations of temperature, pressure, and winds on weather maps required a long period of experimentation and learning. Radar stations first developed as part of the air traffic control system, and the space agencies responsible for satellites still remain largely independent of weather services or climate science (Cirac Claveras, 2014; Courain, 1991). Weather and climate data internetworks, such as the World Weather Watch and the Global Climate Observing System (GCOS), constructed gateways that linked these independently constructed and managed systems and networks.

## From measurement to modeling: computer simulation

Climate knowledge comes not just from the data these internetworks provide, but from theory and analysis, which lead in turn to the ability to project futures grounded in physical understanding. In the 1950s, computer modeling rapidly took root as the central tool of weather forecasting (Nebeker, 1995). Computerized weather models ingest data from the weather observing web, but they do not simply project data trends forward in time. Instead, they use observations to correct weather simulation models based on physical principles, treating the simulations themselves as a source of data about areas of the globe where instrument coverage is poor. Simulation modeling proved so superior to all other techniques that today, virtually all forecasts begin with global model results, though human interpretation still plays a significant role in local forecasting (Daipha, 2015).

By the 1960s, computer models of climate (as opposed to weather) became the favored tool of climate scientists (distinguished from a previous generation of “climatologists” by their focus on geophysics rather than geography). Global climate models do not use current weather observations at all. Instead, they generate their own, simulated global climates. Although equations of fluid dynamics lie at the core of these models, a great deal of empirically derived information is present in “model physics” parameters such as solar output, air chemistry, aerosol distribution, and many others. The physics of climate are extremely complex, since relevant phenomena occur on scales from the molecular (e.g. the radiative characteristics of constituent gases) to the planetary (e.g. atmospheric “long waves” with wavelengths of thousands of kilometers) and even the solar system (orbital cycles responsible for the periodic ice ages). Oceanic phenomena such as the El Niño/La Niña cycle and the Gulf Stream current also play major roles. Modeling the smaller-scale phenomena in detail would be computationally intractable, so they are “parameterized,” i.e. represented via related, but larger-scale variables that are more easily included. As a result, since the 1970s virtually all climate simulation models, like weather forecast models, have been global in scope.[[1]](#footnote-2)

As time went on, the practice of computer modeling spread throughout the sciences. Meanwhile, in the 1980s and 1990s, emerging climate politics led to increasing research budgets, as well as to scientific interest in elements of the climate system beyond the atmosphere and oceans. As a result, climate models became a point of interaction for many scientific communities, including glaciology, hydrology, ecology, agriculture, atmospheric chemistry, and many others. A slow, imperfect process of infrastructural adjustment ensued, as each science revised its methods of analysis to enable interaction with the others around issues of climatic change. One example is “upscaling” in ecology. A highly fragmented discipline focused on smaller units such as associations and plots with edges the length of their tallest tree — and in experimental ecology, even smaller — ecology took a sharp turn toward much larger, climate-correlated ecological units such as biomes and biome-types in the 1980s and 1990s as ecological modelers puzzled out how to connect with GCMs (Aber, 1992; Kareiva and Andersen, 1986; Whittaker, 1962; Zimmerman, 2003).

The quality of climate models can be evaluated by making them simulate past climates. This is done by setting their parameters (such as greenhouse gas levels, continental position, orbital obliquity, and solar output) to those of a particular time period, then comparing the long-term trends in their simulated climates with observations from that period. Like the real climate, models exhibit a certain amount of random variation; only long-term trends, not the day-by-day or even year-by-year details of the simulations, can be compared. While many aspects of the climate system are still not fully understood, the ability of climate simulations to reproduce the 20th century climate, and the absence of any credible alternative theories of climate dynamics, gives reasonable confidence in their capability.

These evaluations require global data. Assembling a *global* data image from the information collected by many parties — national weather services, separate climate observing networks, satellites, ocean observing systems, and others — involves much more than simply gathering the records. Early climatologists used small numbers of records (tens to hundreds), drawn from trusted weather stations with long, stable histories, to calculate trends. The cacophony of differing standards, data formats, and communication technologies around the world made it difficult to make use of more data to create more detailed time series.

Today, computers permit the aggregation of many more records to produce a much more precise picture. Computerized data analysis models use algorithms to reconcile differences in instrument characteristics, observing times, station siting, recording errors, and many other factors. In *A Vast Machine* (2010), I called this process *“making data global,”* pointing to the central role of such models in the climate knowledge infrastructure. The largest of these to date, the Berkeley Earth Surface Temperature project, presently incorporates over 1.6 billion data records from more than 39,000 stations worldwide.[[2]](#footnote-3)

## Global knowledge and the Intergovernmental Panel on Climate Change

As we have seen, climate knowledge “upscaled” over the course of the 20th century, especially after 1950. The nature of the phenomenon justified a focus on the planetary scale. But the planetary focus was not only conceptual and theoretical. It involved material and organizational commitments: institutions, instrument networks and internetworks, and discursive framing of climate problems, as well as to data and models. This *infrastructural globalism*, as I have called it, produced lock-in effects with momentous consequences.

For example, global climate simulations can project future trends, and this is the role in which most people know them. Based on global models, a scientific consensus emerged in the late 1970s: a global warming of 1.5-4.5°C would ensue when carbon dioxide concentrations doubled (to 550 ppm) over those of the pre-industrial atmosphere (270 ppm). These numbers — the global average temperature anomaly[[3]](#footnote-4) on carbon dioxide doubling (again a global average) — became major benchmarks in climate change studies. Framed in this way, scientific concern over global warming reached its first crescendo in 1990 with the first report of the Intergovernmental Panel on Climate Change (IPCC).

The IPCC is an international organization under the auspices of the UN and the World Meteorological Organization charged with assessing the state of climate knowledge on a periodic basis. Over the more than 25 years since its inception, the IPCC has played a critical role in the climate knowledge infrastructure. Unlike more typical scientific institutions, it has no permanent research staff. Instead, the IPCC consists of a loose network comprising thousands of scientists from many nations working in climate-related fields, from paleoclimatology to modeling to human impacts. Its periodic assessments review the relevant research and characterize the quality of knowledge about the past and future of climate change. Dozens of specialists collaborate on each chapter of the multi-thousand-page assessments, which cover not only the physical science of climate change, but also the likely human impacts and potential strategies for mitigation and adaptation.

Flush with the success of global accords on ozone depletion, the most successful global treaty of any kind in world history, the IPCC’s founders — heavily influenced by their conception of climate as a global system and climate change as a global problem — sought to forestall dangerous climatic change by means of a global political process. They designed a knowledge assessment process which they hoped would short-circuit a protracted political debate by front-loading the integration of scientific understanding into climate policymaking. This took the form of an elaborate peer review process in which draft reports are reviewed not only by scientists, but also by national governments and non-governmental organizations. IPCC authors are required to respond to every one of the tens of thousands of peer comments. Since the large majority of all research considered in IPCC reports has already been peer reviewed by scientific journals, this is certainly the most comprehensive review process in the history of science.

This process inspires confidence from the vast majority of scientists, who accept IPCC reports as highly authoritative summaries of the current state of knowledge. Yet the political aspect of the IPCC process has not functioned as originally imagined. The strategy of engaging national governments with a view toward a global climate treaty was risky to begin with. Global environmental agreements are few in number, and those which have been very successful — such as ozone accords, or the Partial Test Ban Treaty banning tests of nuclear weapons in the atmosphere — have worked mainly because they affected only a small number of nations and industrial sectors. Unlike those issues, climate change demands massive transitions in energy systems, agriculture, and many other arenas, with potentially profound effects on the livelihoods and lifestyles of billions.

Some governments and NGOs — particularly those with high stakes in fossil fuels and other interests threatened by decarbonization of the world energy economy — have used their power as peer reviewers to reduce the strength of IPCC knowledge claims, often by lobbying to weaken expressions of confidence. Others have repeatedly and disingenuously attacked the organization on both procedural and substantive grounds, attempting to cast it as a scientific conspiracy (Edwards and Schneider, 2001; Hoggan and Littlemore, 2009; Oreskes and Conway, 2010). Following the 2009 “Climategate” incident, a major external review of IPCC procedures concluded that the organization lacked transparency (Shapiro et al., 2010).

Based in part on the first IPCC report, the United Nations Framework Convention on Climate Change was signed in 1992. The second IPCC report declared that “the balance of evidence suggests a discernible human influence on global climate” (Houghton et al., 1996). The third (2001), fourth (2007), and fifth (2013) IPCC assessments refined those conclusions, expressing increasing confidence in the quality of climate knowledge. In science, such expressions almost never get stronger than the fifth report’s statement that “it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century” (Stocker et al., 2013: 15, italics in original).

As we have seen, climate models are necessarily global in scale, and due to the historical limits of computer power, climate model grid cells initially covered areas of around 250,000 km2, i.e. about the size of Colorado, or the entire United Kingdom. At this very low resolution, few scientists were willing to make claims about the future of any particular place — yet this is exactly what political choices normally require. The political question is almost never “what will happen to the world?”, but instead “what will happen to me and my constituents?” As one climate modeler put it to me long ago, “climate models will begin to have political impact when their grid scales reach the size of a Congressional district.”

Thus the globalist historical and material commitments of the climate knowledge infrastructure strongly influenced both the IPCC, a hybrid scientific-political organization, and the FCCC, a global policy process. This state of affairs produced considerable inertia when the FCCC policy process stalled after the 1997 Kyoto accords, widely acknowledged as weak, overly narrow in scope, and ineffectual. Hope springs eternal, but the evidence of the past two decades is that the greatest potentials for climate action no longer lie — if they ever did — in a comprehensive global agreement.

Yet knowledge about the *global* climate cannot easily be mobilized at the regional, national, and urban scales on which policymaking can operate effectively. Even less can global knowledge engage with the temporal and spatial scales on which policy choices are rewarded or punished by their publics. At present, we are witnessing a slow and creaky shift of the knowledge infrastructure toward these smaller scales of governance.

## Downscaling the infrastructure: from useful data to usable knowledge

Infrastructures are extended when new gateways — in actor-network terms, new intermediaries — connect them to other systems or networks. Knowledge infrastructures are no exception. As we have seen, climate simulations provided one such gateway, linking many sciences between the 1970s and the 2000s. Glaciology, ecology, agriculture, soil, atmospheric chemistry, and many others “upscaled” the knowledge they produced in order to join the field now often called “Earth system sciences.”

In the early 21st century, as the pace of warming continued unabated[[4]](#footnote-5) and the FCCC policy process proved unworkable, attention shifted from mitigation (preventing or limiting anthropogenic climate change) to impacts and adaptation. Regions, states, and cities may potentially become agents of mitigation, but all will need to adapt. Today, city planners, health officials, water managers, military services, and disaster response agencies are beginning to use climate data in their planning processes (Bierbaum et al., 2013; Bulkeley, 2010; Howard et al., 2011; Lepore, 2014; Lutsey and Sperling, 2008; US Department of Defense, 2014; Wheeler, 2008; Yerkovich et al., 2012).

These trends place new demands on the climate knowledge infrastructure. While climate data are already being used to address critical planning issues, a yawning gap generated and the knowledge systems most commonly used by policy-oriented planners currently exists between the forms in which climate knowledge is typically. knowledge of *global* trends does not translate automatically into usable knowledge at the local, state, or even the regional scale. Planners are mainly concerned with what will happen in the geographic area for which they are responsible. Some users, such as watershed managers making contingency plans for droughts, floods, and changing precipitation patterns, or health professionals concerned with heat waves, already have considerable climate-related expertise, especially with respect to local, regional, or national climate patterns. They would like detailed information about likely future trends *for their own areas,* but global trends are unimportant to them, and they are not interested in every aspect of climate change. Heat waves, water supplies, and extreme weather events such as hurricanes and floods top the list of cities’ concerns.

As a result, these user groups differ from climate scientists in their understanding of what climate data are, how they can credibly be used, and how the inevitable uncertainties can be communicated and managed. I now describe two examples of how this problem occurs “on the ground.” Both examples come from a masters-level course on climate change informatics, which I co-taught with climate scientist Richard Rood at the University of Michigan (to whom I owe many of the insights in this chapter) in 2014 and 2015. In 2014, two our student teams worked with scientists at the Centers for Disease Control, who were interested in improving community readiness for health-threatening heat waves. Two other teams worked with Tampa Bay Water, responsible for managing the watershed for that part of Florida. We chose these groups partly because some of their members had attended Rood’s 2013 summer workshop on “downscaling” climate data.

Downscaling is a set of techniques for increasing the resolution of climate data. Applied to historical data, downscaling can generate more detailed, synthetic data for areas that were not well instrumented. Simulated future data from climate models can also be downscaled; in one technique, a high-resolution regional model is embedded in a lower-resolution global model.[[5]](#footnote-6) Since each grid cell (essentially a single data point) in a typical modern climate model covers an area of around 2500-10,000 km2 — as large as some US states and European countries, and far larger than most cities and counties[[6]](#footnote-7) — higher-resolution climate data are highly desirable for planning and policymaking.

None of the available downscaling techniques produces perfectly reliable data, largely because no climate model can do so either. Each of the dozens of global climate models has virtues and vices. Some underpredict polar warming, while many do poorly in coastal West Africa and western South America, where upwelling ocean currents create complex atmospheric effects. As a result, climate scientists rarely if ever take downscaled data at face value. Instead, just as with the original climate model output, they prefer to analyze carefully chosen ensembles (sets) of downscaled data. There is currently no standard “recipe” either for choosing or for analyzing such an ensemble. Instead, downscaling remains the province of expert judgment, and stirs controversy among climate scientists. In other words, downscaling has not yet been routinized, standardized, and integrated into the climate knowledge infrastructure.

These problems and controversies are of little interest to users from other domains, who would simply like to get the “best” available climate data for their area. Both professional groups we worked with were highly sophisticated data analysts, and since both had attended the downscaling workshop, they also understood the reasons behind climate scientists’ reticence to offer any single “best” dataset. Yet this was only the beginning of the litany of problems they encountered in trying to make use of climate model output. Arcane filenames such as “arrm\_gfdl\_2.1\_min\_tnxmminm\_september\_1971-2000” are readily comprehensible to climate scientists, but gibberish to others.[[7]](#footnote-8) Data conventions and software libraries that are common in climate science, such as CIM (Common Information Model) and netCDF (Network Common Data Form), are completely unknown in many other areas. Climate models use numerous grid schemes, including not only standard latitude-longitude grids but triangular, icosahedral, and other unusual forms; very little climate data is published in the GIS (Geographic Information System) file formats now commonplace in other geographically-oriented sciences as well as government and commercial mapping services. None of these hurdles are impossible to overcome, but all of them increase the friction involved in translating climate data into forms usable by other fields.

In terms of knowledge infrastructures, these are gateway problems. Data relevant to users’ problems exist and can be accessed, but lack the metadata and/or interpretive frameworks that could permit them to travel outside their original disciplinary settings. Users want to create bridges between their own knowledge infrastructures — watershed management, public health — and climate science, but they cannot find straightforward (or even convoluted) ways to make use of climate data directly. Experience in many work environments suggests that where some alternative exists to frustrating, unfamiliar forms of information, users will often seek alternatives, even if their quality is known from the outset to be lower. In this case, the easy alternative for historical information is the weather record from the local airport, the most familiar, stable, and long-term record available in many cases. Airports — wide-open, flat areas located far from city centers — are often unrepresentative of the conditions of interest downtown, or elsewhere in the region. Yet they are trusted, so they are used.

Studies of successful knowledge integration efforts routinely conclude that gateway-building across divides like these requires considerable, and ongoing, human effort. A review article summarizing some of these studies found that “…climate science usability is a function both of the context of potential use and of the process of scientific knowledge production itself. …[N]early every case of successful use of climate knowledge involved some kind of iteration between knowledge producers and users” (Dilling and Lemos, 2011). A key organizational dimension of this iterativity is the need to create a sense of individual and organizational “ownership” of problems, methods, and solutions (Kirchhoff et al., 2013; Kirchhoff, 2013; Lemos et al., 2012; Lemos et al., 2014).

In a media environment filled with bedazzled hype about “big data,” it is easy to forget that making knowledge is always work. Translating knowledge into new frames, for new purposes, is work too. The rapidly increasing availability of climate data has not been matched by a concomitant increase in translational information, nor by software or social systems capable of choosing and processing climate data for a vast variety of potential users and uses.

Global CO2 concentrations topped 400 ppm in 2015. Most observers expect the 550 ppm mark to be surpassed around the middle of this century, and there is currently little reason to expect that it will stop rising then. If climate sensitivity to greenhouse gas doubling is around the middle of the projected range, this means global warming of 2.5-3°C within a few decades. The consequences will affect every place in the world, but not in the same ways. Downscaled climate knowledge, coupled more closely to the knowledge systems of cities, states, and regions, as well as to particular knowledge needs, may help them reduce or prevent some of the worst outcomes.

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1. Regional climate and weather models exist and can add detail to global simulations, but they are all dependent on global models for inputs at the edges. [↑](#footnote-ref-2)
2. berkeleyearth.org/about-data-set/ [↑](#footnote-ref-3)
3. For technical reasons, climate scientists focus on the difference (anomaly) between two average global temperatures (a baseline and some perturbed state), rather than on their absolute values. [↑](#footnote-ref-4)
4. A perceived hiatus in *atmospheric* warming after 1998 was belied by measurements of ocean heat content, which continued to rise throughout the supposed “pause.” At this writing, new adjustments to global data sets, incorporating more station records and more complete metadata for sea surface temperature measurements by ships, seem to show that the hiatus never really occurred. [↑](#footnote-ref-5)
5. At this writing, in 2015, global weather forecast models use grid cells as small as 170 km2 for 10-day forecasts. The supercomputer power these high-resolution global models require prohibits using them for the multi-decade runs needed to simulate climate. Embedding a higher-resolution model of a chosen region in a lower-resolution global model is one way around this problem. [↑](#footnote-ref-6)
6. For comparison, the city of Los Angeles is 1300 km2, urban London is 1740 km2, the US states of Rhode Island and Connecticut are 3140 km2 and 14,360 km2 respectively, and the country of Kosovo is 10,890 km2. [↑](#footnote-ref-7)
7. Decoded, the filename refers to the Asynchronous Regional Regression Model of the Geophysical Fluid Dynamics Laboratory, version 2.1, output of the variable “minimum highest daily minimum temperature” for the month of September for each year 1971-2000. [↑](#footnote-ref-8)