Anthropologies of the Sciences: Thinking Across Strata

Mike Fortun and Kim Fortun

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> *One cannot look upon the sciences as being only a set of sentences or a system of thoughts. They are complex cultural phenomena, at one time perhaps individual, at present collective ones, made up of separate institutions, separate actions, separate events. Written sentences, unwritten customs, one's own aims, methods, traditions, development. Preparation of the mind, cleverness of hands. A special organizational structure, with its hierarchy, ways of communication and co-operation, an organizational court, public opinion, press and congresses. A distinct relation to other aspects of cultural life, to society, to the state, etc.*
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> — Ludwik Fleck, "Problems of the Science of Science" (1946: 118)

"Shall we go see the equipment?," Huang Wei asked us, before we even had a chance to sit down in her office at Peking University Health Science Center in Beijing, China, to talk about her research on air pollution and health. There really was only one possible answer to this question -- *of course!* -- not only for reasons of politeness and anthropological necessity (we were meeting for the first time, strangers to each other, each harboring far more questions than answers about the others' work and interests), but also because we are as genuinely excited to examine the many and intricate devices of scientific research as the scientists we come to meet are to show and talk about them with us. The bonds between scientists and their technologies are strong and complex; scientific technologies allow scientists to do and know new things, and demand the kind of constant care and attention that produce both skill and affective attachment.

Huang Wei, Peking University Health Sciences Center, Beijing, China, November 2017.

We were at PKU in November 2016 to interview Wei (and other scientists) for a multi-sited ethnographic study of air pollution science and governance in cities around the world, including

Beijing. In each city (five in the United States and six in Asia), we are working collaboratively with local researchers, interviewing and interacting with scientists in different disciplines, government officials, environmental activists, and residents. We want to understand how people are thinking about the problem of air pollution, who is producing air pollution science, how it is commissioned, funded and used, and what historical, political economic and cultural influences shape all of this. We also want to understand the social formations and connections (between scientists in different countries, for example) that engender and empower improvements to air pollution science and governance. And we want to be able to characterize differences among the cities, drawing out what we think of as signature environmental health governance styles. It is a big, sometimes unwieldy, and experimental study, but also designed to mime and enact the very kinds of research collaboration that we are studying. Through this, we hope to develop ethnographic perspective on collaboration itself, as well as on how sciences of many kinds move through different societies. Experimenting in this way with new methods and study designs has been especially important in anthropologies of the sciences -- a response to challenges in adapting traditional anthropological methods to studies of new kinds of communities and practices.

Soon after our arrival at PKU in November 2016, Wei took us down the hall, past her lab space, to a completely unspectacular room harboring only a few instruments, and a towering rack of data storage devices. One key part of Wei's research concerns the health effects of PM2.5 -- "particulate matter" of such a small size (less than 2.5 microns in diameter) that it penetrates deeply into lungs, and from there into blood and other tissues. Sometimes, according to recent research, PM2.5 particles may pass directly from the nasal passages to the brain. It's only within the last decade or so that scientists like Wei have even been able to measure atmospheric levels of PM2.5 accurately and routinely, but the known and suspected health effects are piling up in an international scientific literature documenting effects on not only respiratory conditions like asthma, but also on heart disease, low birth weight, and (most recently) dementia in the elderly. PM2.5, PM10, and larger particles produced by motor vehicles, factories, domestic heating, wood fires, and other sources are all monitored and regulated by national systems of law like the U.S. Clean Air Act and China's Environmental Protection Act (updated in 2014, through what many observers see as a new level of interaction between the Chinese government, academic scientists, NGOs and citizens). As anthropologists of the sciences, we are interested in ways new technologies change the way science is practiced. We are also interested in how scientific findings are exchanged -- between scientists, between scientists and lawmakers, and between professional scientists and other kinds of experts (traditional healers, for example, or citizen scientists). Partly because of newly available and affordable scientific instrumentation (air monitors, for example), "citizen science" has really taken off in recent years in many settings, from pollution monitoring to astronomy.

One of the instruments in Wei's lab is an aethalometer, which converts Beijing's ambient "haze" into daily, hourly, or even minute-by-minute measurements of black carbon (a component of particulate matter). It's an instrument developed initially by scientists at Lawrence Berkeley National Laboratory in California (famous first for its physics research, now also for its research in genomics), now spun-off into a small scientific instruments manufacturing business. Aethalometers are now used in thousands of locations around the world, from Houston to Antarctica (in addition to its health effects, black carbon is also a significant contributor to global warming). Historians and anthropologists trace how technologies like the aethalometer (earlier, technologies like the microscope and the camera) have moved between settings, sometimes resulting in standardized approaches, but often not.

A pipe leads to a collector on the roof, where Wei takes us next. We can't help taking notice--not only through our eyes, but *in* our eyes, and noses, and throats, and lungs--of the haze surrounding us mid-morning in the heart of Beijing. She begins to talk to us about her research, gesturing toward the nearby hospital where she collects biosamples and other data (complying with human subjects research guidelines both similar to and different from those in hospitals in the United States and Europe). [1] We're familiar with the broad outlines of Wei's research. To prepare for our interview, we've read many of her articles, easily accessible to us in journals like *PLoS ONE*, the *American Journal of Epidemiology*, and the *Journal of the American Medical Association*. Some of these articles list a dozen or so co-authors, not unusual

Huang Wei and assistants, Beijing, China, November 2017.

for many scientific fields these days, especially the environmental health sciences. These collaborations often cross both national and disciplinary borders, with different people contributing different data sets or helping with the research design, statistical analysis, the interpretation and writing up of results, questions, noting of limitations, and suggested directions for future research. Sometimes Wei is first or last author, the positions to which most credit accrues, but more often, she tells us, she is happy to take the more modest positions in the middle of the list even if doing so may not accurately reflect the value or strength of her contributions. A key goal for Wei -- one we greatly admire -- is to build environmental health research infrastructure in China that can sustain cutting-edge research beyond her own career. Modesty and a deeply collaborative spirit are critical. We've called this kind of work "civic science" (Fortun and Fortun 2005).

Wei also exemplifies the cosmopolitanism that has long characterized the sciences. A Beijinger now returned to live and work in Beijing, she lived for years in the United States, first working toward an advanced degree in environmental health and epidemiology, and then as a researcher at the Health Effects Institute (HEI), an important nonprofit research organization established in the U.S. in 1980, funded jointly by the U.S. Environmental Protection Agency and the motor vehicle industry. HEI was a key player in the now famous "Harvard Six Cities Study," which set the stage for our own multi-city project focused on air pollution science and governance. The Harvard study is famous because it made early claims (in the 1990s) about the health effects of air pollution. The study was challenged by an anti-regulatory, energy industry-funded "think tank," Citizens for a Sound Economy, and HEI was called in to ajudicate. The years-long HEI reanalysis upheld the claims of the original study. But contestation over air pollution science and governance has not stopped. There are many "stakeholders," including scientists, government agencies, polluting industries, vulnerable people (with asthma, for example), and whoever uses motorized transportation -- or just breathes. Anthropologists of the sciences study how these different groups understand problems and controversies like this -- on a huge array of issues with critical scientific dimensions: issues associated with genetically modified organisms in agriculture, for example, or with nuclear power, waste and war.

Anthropologists of science also study how scientists themselves form communities, socialize new members, and link with other scientific communities -- often dispersed around the world. Like Wei, many scientists today circulate globally, working simultaneously in a particular cultural formation, and constantly called to think and move beyond it. To succeed, Wei and other scientists working internationally need to deeply understand the expectations, opportunities, and constraints of their home settings, while also demonstrating a scientific persona that makes them recognizable and credible to scientists from other settings. And even this is not enough. To be a truly effective scientific collaborator, a researcher must understand and respect the conditions that shape the lives, work and perspectives of those they they to collaborate with -- especially if those conditions are very different than their own. Effective scientific collaborators also understand and respect differences across research disciplines -- recognizing that a collaborator from another discipline is likely to have a “thought style” different than their own, with a different sense of how experiments should be run, data should be collected, and results interpreted. The latter makes cross-disciplinary scientific collaboration very challenging -- but it is certainly easier if involved scientists themselves have cross-cultural insight (thus understanding differences across both geography and discipline). Anthropologists of science are interested in how scientists do this work, and how they entrain their students to both follow and go beyond them. In our ethnographic study of air pollution science, for example, a key focus is on the educational programs that create the “pipeline” of scientists available to work on different aspects of air pollution (sources, health effects, mitigation, etc).

Like Wei, many scientists today are intensely interested in and committed to the study of phenomena that cross multiple scales of analysis (like rising PM2.5 levels of air pollution and their health effects), from the molecular to the global, and everywhere in between. It is complex, multi-dimensional research, as full of careful precision and accurate quantitative analysis as it is of uncertainty, modeled parameters and dynamics, analogical thinking and interpretation. One way to think of scientific research like this is as a search for “patterns that connect,” the terms that anthropologist Gregory Bateson used to describe a kind of thinking that stretches beyond simple observation and direct causation to understand connections between things that appear disconnected. The challenge, according to Bateson, is to find and characterize connections -- discerning what connections matter, and why.

Wei uses her equipment to produce enormous amounts of data; her selection of *which* data to produce is critical, and based on her understanding of what isn’t yet understood and needs to be explored, or -- alternatively -- on her understanding of what problems need more science so that they can become more legible to policy makers and other non-scientific audiences. Both science and politics orient what data gets collected, and what science gets done. Anthropologists of the sciences are interested in *how* such selection and orientation come about. In interacting with Wei, for example, we wanted to understand how her current research is oriented by her own previous work, by her reading of scientific findings produced by other researchers, by her understanding of what is politically important and possible, and by a particular “thought style” that she has cultivated through interaction with others in her scientific community. A “thought style” is rather like a cultural frame or worldview. As used in the history and anthropology of science (building on the work of Ludwik Fleck, a microbiologist of the early 20th century and a keen observer and analyst of his own scientific work), a “thought style” develops over time, through interaction amongst scientists (in a “esoteric” circle of specialists), and between scientists and other kinds of people (in overlapping esoteric and “exoteric” circles), all shaped by the dynamics of a particular sociocultural, political-economic context. A thought style directs the perception of scientists, shaping what problems they investigate, what data they produce, and how they interpret those data.

Wei, for example, is measuring the mix of black carbon, sulfur dioxide, nitric oxide, ozone, and road dust in Beijing’s air, trying to connect these (together and separately) to patterns of urinary biomarkers and exhaled gases in the bodies of the city’s residents, particularly schoolchildren.   And she is comparing these things across time, using the 2008 Olympics as a “natural experiment” in public health since especially strict pollution controls were in place during the Olympics, allowing her to set up a comparison between that period and more routine, less controlled periods. Wei is working to discern patterns that connect air pollution and health -- in ways conditioned by many, interlaced factors and forces -- historical, sociocultural, political economic and technological. Our challenge as anthropologists of the sciences is to discern patterns that connect Wei and her work to her (ever evolving) cultural context.

As our opening quote drawn from Fleck expresses, the sciences are complex cultural phenomena, and call for study as such.   We refer to this as *anthropologies of the sciences* to highlight the need to recognize methodological and cultural differences across scientific fields geographies, and historical periods (diverting reference to “science” as a monolith). Reference to *anthropologies of the sciences* also highlights the need to cultivate methodological diversity within anthropology itself -- recognizing, as the best of contemporary science shows, that different angles on and ways of thinking about any phenomena together create more insight than one approach alone.

SCIENCE IN TIME, SPACE, AND POLITICS

On Earth Day 2017, people joined marches for science around the world, calling upon their governments to support “scientific research and education, evidence-based policy-making, and the upkeep and public accessibility of data needed to understand societal problems” (Society for Social Studies of Science 2017).   The American Association for the Advancement of Science was a lead supporter of the 2017 march in the United States, along with the American Geophysical Union, and American Sociological Association, and other scholarly societies --

including the American Anthropological Association. Universities and scholarly organizations in other countries also played leading roles, as did environmental groups, churches, and citizens of all ages. Anthropologists of the sciences both participated in and critically observed these organizations, and the diverse social and political movements of which they are part.

March for Science, Albany, New York, 22 April 2017.

What did marches for science in 2017 signify, and what do they tell us about ways contemporary sciences are different from the sciences of earlier historical periods?

Science circa 2020, it is fair to say, has come to study increasingly complex phenomena (like climate change and air pollution, gene-environment interactions, and emerging infectious diseases), and has itself become more complex in its internal social organization, and interaction with the broad social formations in which which it operates. Science circa 2000 is complex in every dimension.

It isn't that the sciences were ever simple, unidimensional, and insular; complexities of many kinds have always been the "pattern" in the sciences themselves. But In trying to characterize what makes contemporary science different from, say, the science of Galileo in 17th century Venice, many historians often trace our current moment to changes that accelerate with World War II, when increasing investments (largely driven by military concerns) by the state result not only in what came to be known as "Big Science" (primarily in physics) but in a deeper commingling between many sciences and nearly all aspects of social life. In the U.S., the National Science Foundation was formed as part of this post-war push, as well as the National Institutes of Health, which funds most biomedical research in the United States; although more economically and infrastructurally damaged by the war, the U.K., Germany, France, the Soviet Union, Japan and India also began to grow, in different ways and at different paces, their national support for "basic" scientific research. (The distinction between basic and applied research is, it almost goes without saying, much more complicated in actuality than it is often assumed to be, but for our purposes here these broad-brush strokes suffice.) Since then, developments in many scientific fields have led to fundamentally new knowledge about biological processes, ecological dynamics, the atmosphere, chemistry and materials, electronics, evolutionary theory, and so on. Sometimes these developments in basic science are translated into applied sciences and technologies (which also have their own independent development trajectories) with far-reaching social consequences. At other times, sciences are "translated" into policy and law.

Some social scientists refer to the re-organization of science and its sociocultural norms that took shape over the second half of the 20th century as "normal science," echoing Thomas Kuhn's terminology from his influential 1962 book *The Structure of Scientific Revolutions*. For Kuhn, "normal science" was what most scientists did most of the time: fitting pieces of a puzzle together within established and reliable frameworks or paradigms, as opposed to the paradigm-busting "revolutionary science" done by a few extraordinary figures. The more recent usage of "normal science" refers more to the established framework that we've developed to make sense, not of the natural world, but of the world of science itself as that new postwar system congealed: normal science is "pure" basic science, definitive and determined, disinterested and objective because it is supported by a modern nation-state, in which scientists are left free to pursue the logics (often only curiosity-driven) of their scientific fields, and only entering into the different world of politics and policy when asked for their advice, on limited issues relevant to their formal expertise.

The "normal science" of an earlier century is now transforming into what is sometimes called "post-normal science": sciences of complex and even chaotic systems; sciences that are riddled with uncertainties and ambiguities, highly dependent on computer simulations and deeply entwined theories; sciences that are produced in numerous public, corporate, and in-between organizations, and so thoroughly imbricated in matters of political, social, and indeed planetary importance that they defy normal attempts to draw those traditional and comforting lines cleanly separating the natural from the cultural and political. Climate change science is probably the best and most well-known example of a "post-normal science."

Cultures are dynamic and always changing, to put it somewhat differently, and science as part of culture is no exception. What counts as science, how sciences are done, by whom, where, and for what reasons are all matters of culture. And what counts as "anthropologies of the sciences" is similarly context-specific; anthropologists who engage with sciences and scientists now face, in significant ways, different demands, possibilities, and questions than those that shaped the anthropologies of sciences of an earlier generation.

Most basically conceived, anthropologies of the sciences work to make sense of the different ways different people make and use different kinds of knowledge, in different times and places. Inevitably, some things and people count more than others. What counts as scientific knowledge also has important social consequences. How things are named and categorised is never a neutral affair, and *always* carries limitations and bias. The politics of naming and categorizing human difference as "racial" is one especially important example – that has been well studied by anthropologists.

Recently, the politics of naming and categorizing has also provoked fanfare in the earth sciences, with some scientists arguing that our current epoch needs to be re-named to acknowledge the profound, destructive effects that humans have had on earth systems and environments. The Holocene, they argue, has transitioned to the "Anthropocene." So far, the scientific bodies (specifically, the International Commission on Stratigraphy and the International Union of Geological Sciences) with the authority to name divisions in geologic time have not approved the name change. But arguments are flying, and many acknowledge the profound importance of what "the Anthropocene" signifies – scientifically, politically, and culturally.

Earth systems--soils, waters, energy and natural resources, ecological webs, species biodiversity, and an all-encompassing atmosphere--used to be conceptualized as a strictly natural order, "in balance," independent of humans. No more. Though the beginnings of the Anthropocene continue to be debated – using different data sets and different modes of interpretation – most scientists acknowledge the import of the "Great Acceleration" driven by the industrial revolution, kicked into even higher gear after the 1950s. In this period, human consumption (of food, natural resources, and especially petroleum based energy) escalated dramatically (in some places much more dramatically than in others),as did use of industrial chemicals (pesticides to drive up agricultural yields, for example). Nuclear bomb tests also left an indelible, scientifically discoverable imprint (in children's teeth, for example). This is what scientists want to capture in denoting our current epoch as "the Anthropocene."

Naming and categorizing are never innocent acts, as "normal science" would have cast them, and naming our contemporary era "the Anthropocene" sparks disagreement not only among earth scientists but among anthropologists too, some of whom argue that something like "the Capitalocene" would be a more fitting name, assigning causality and responsibility to a more accurately delimited entity than "humans." It's a lively and important conversation in disciplinary circles, but one which we defer here for the sake of aligning with those "post-normal" earth scientists challenging the still powerful "normal science" trends of their own scientific communities. This apparently small and unimportant insistence on a change of scientific nomenclature from the Holocene to the Anthropocene is an acknowledgment by these earth scientists that their actions are simultaneously acts of science and acts of politics--that the bonds between these two cultural domains are so immediate and strong as to be practically indistinguishable, just as the deep and extensive linkages between "humans" and "the planet" have also become practically indistinguishable. This points to an exciting and demanding dimension of the anthropology of science, its relevance and indeed importance to wider publics, including scientists themselves, and to wide and urgent political problems.

SCIENCE ACROSS STRATA

So what do anthropologists of the sciences actually study when they are studying "science"? Of course, like other anthropologists, they study people: we are interested in the lives of scientists, how they came to be interested in what they study, what influences their work, and how they understand what influences their work. We are also interested in all those who think about and are shaped by science -- on the ways science operates in and as culture. We study what science becomes in courtrooms, in schools, in the media, and in the lives of citizens in many different settings--how the sciences themselves become powerful forces in society. To learn about this, we talk to people, and observe their practices (and the ways these two things are sometimes different). Attention to practices and material culture has been especially important in anthropologies of the sciences (as it has been in the closely related fields of history and philosophy of science) because of the important role of technologies in science. Because of this, many anthropologists of science refer to what they study as "technoscience."

In our own work, we often use a geologic image of striated rock to imagine and think through the many "strata" where science occurs and can be studied (see Figure 3). An image of many layers, forcefully squeezed together, also reminds that all strata influence all others. As anthropologists have long said: it is a complex whole; context matters. There are, of course, many other ways of visualizing what anthropologists of the sciences study. Many like Donna Haraway's image of a cat's cradle, for example, pointing to the orchestrated tangle of influences from which knowledge emerges. We like the image of striated, shale rock because it also points to ways geophysical conditions -- and human exploitation and destruction of these conditions through petroleum-based prosperity -- are at the center of scientific and political concern today.

Querying the Strata of Science

STRATA OF ACTIVITY	EXEMPLARY ANALYTIC QUESTIONS
meta dominant discourses	What discourse traditions shape the way science is talked and thought about—in the media, in schools, in informal conversation? How is science compared to and used along with other knowledge forms?
macro governance, political economy	What events and problems provoke calls for science? How is science used in courtrooms, and by policy makers? How is science itself governed? What drives science in different settings, and how does science drive social and economic change?
meso organizations	What government agencies conduct, sponsor, and disseminate scientific research? What is the organizational culture of labs in different disciplines and places? How are NGOS, businesses, and citizens' organizations involved in the production, use, and authority of science? What social networks connect and control scientists?
micro practices	What do scientists actually do in their laboratories and field research, and what orients their attention? Who is doing science, and whose science has more authority
edex education, expertise	How are scientists educated, formally and informally? How do they learn to design experiments, and to think about problems that haven't yet been problematized? What gives scientists and other experts authority, and what hierarchies of authority have been established in different settings?
techno equipment, infrastructure	What technologies do scientists use in their work, and how do these technologies shape the questions they ask, what they regard as an answer, and who else will be persuaded? How do scientific technologies circulate, and to what effect?
data infrastructure and visualization	What data and data infrastructure enables science, and its use in governance and other social activities (commerce, education, etc.)? How is data shared, or privatized? How have data visualizations changed over time, and how are they persuasive (or not)?
nano language, subjectivity	What methods and data do different kinds of scientists learn to use and love, and what are their different thought styles? What, and how, do scientists think about ethical and political responsibility? How does science figure in the ethical and political thinking of non-scientists?

Thinking in terms of layered strata on and through which the sciences operate first directs attention to what we have called the “meta” strata, the strata where we can observe and analyze how science is operating discursively, as part of dominant discourse, laced into the stories people tell about their lives and worlds. In many settings, what can be called modernist ideas about science are still very powerful: “science” is regarded as a uniquely objective, methodical, rigorous, quantitative, empirical, materialist, neutral, disinterested, and authoritative way of knowing, Other knowledges--humanist inquiry, for example, or “traditional ecological knowledge” about plants and animals – are, by contrast, characterized (and negatively so) as subjective, non-methodical, non-systematic, variable, and thus “soft,” unreliable, or at least non-neutral, rendering them idiosyncratic, irrational, culture-bound, or simply inferior. Anthropologists of the sciences can identify where such discourse and binaries operate (in school books or legal decisions, for example) and where alternative discourse have emerged (among scientists working to understand the Anthropocene, for example).

Tracking where modernist ideas about science are in play is important, not least because of political implications. In modernist constructs, science is cast as pure, modern, and “Western” but also as universal, grounded and “hard“--and more suited to men, although that usually goes unstated. Mathematics is seen as the the privileged language of science because it was the language of nature (indeed the language that God, according to Galileo, used to write nature), geometric in its clarity and determinism. In contrast, interpretation (“hermeneutics”) becomes the language of culture, values and aesthetics -- imaginative rather than empirically grounded, subjective, and hard to pin down. In this way of thinking about science, science is largely imagined as somehow outside of culture, politics, and other domains of human life—as a “culture of no culture,” in the memorable phrase of Sharon Traweek, one of the earliest anthropologists of science. (Traweek studied physicists and physics, usually accorded exemplary status in the sciences as the purest of the pure, the closest to the ideals of reason, logic, and math.)

Different ways of thinking and talking about what science *is* – especially “good science” (or “sound science,” as some say, often with an anti-regulatory ideological edge) is particularly visible today when the topic is climate change. Indeed, often what is at issue is whether a particular kind of science – computer model-based science, as is needed to capture the many interlocking processes and timescales involved in climate change – is *sound* science. Peter Huber, a well-known advocate for “sound science” (almost always in opposition to regulation) has referred to model-based science as “faith-based,” presuming that scientific computer models and “actual observations” are polar opposites. Scientists, historians, and philosophers have all explained otherwise – drawing out how scientific computer models can both integrate and be cross-checked with "actual" monitoring data. This debate over what counts as good science recurs across issues today, particularly those with environmental dimensions – showing what a difference between the ideas of normal science and post-normal science look like in action.

We see similar oppositions in the discourses that carry debates over the connection between air pollution and health. One basic opposition pits air pollution regulation against economic prosperity, arguing (implicitly or explicitly) that regulation undermines economic productivity, and that this is a surer means to physical health and prosperity. (Over the last decade, especially, those arguing against this position have been able to make increasingly fine-grained claims about both the health impacts of air pollution, and associated economics costs.) Another opposition – which clearly reflects a difference between normal and post-normal ideals – is between claims that are causal, and claims that are associative or suggestive. Many who don't want to regulate air quality insist that the evidence of health benefits must be directly causal—with a clear and linear pathway from source to human exposure to a specific health outcome. This kind of claim is difficult if not impossible to make when dealing with many environmental health issues, if only because of "confounding" factors – the facts that people are surrounded by a variety of health stressors (smoking, or poor diet, for example) which can't be ruled out as contributing to a particular health outcome. Insistence on direct causal connections between air pollution and ill-health as the basis of air pollution regulation thus makes it almost impossible to regulate. The way people think and talk about science thus has very practical effects.

What counts as authoritative knowledge thus has implications for what we've called the macro strata -- the strata where laws are passed, or not, industries and products are regulated, or not, and economies are ordered -- always benefiting some people and regions more than others. In our air pollution governance study, for example, we are examining the development of laws regulating industrial activity, energy use in homes and transportation, and urban planning -- and the various kinds of data and science used to design and legitimize these laws. In the United States, for example, federal law mandates protection for vulnerable communities to offset environmental injustice (resulting from uneven distribution of pollution and associated health impacts). This calls for scientific studies that *demonstrate* pollution distributions and health disparities. It also calls for science that can direct air quality improvements.

In Albany, New York, for example, scientists working for New York State's Department of Environmental Conservation are conducting a study to discern the sources of air pollution impacting a mostly African-American community near the Port of Albany. These scientists have been surprised to learn that particular routes and patterns of truck traffic are a key pollution source. We, in turn, were surprised to learn how difficult this is to change. Trucks in this area are en route to a federal highway, to which they have a "right-of- access." The rights of trucks is thus something at odds with the rights of people living in the communities that they drive through. But there are different kinds of solutions, and, as anthropologists of science, we are also interested in these. Trucks coming in and out of many ports have been required to retrofit their engines so that they pollute less. At the ports of Los Angeles and Long Beach (the largest, most active ports in the United States), truckers have borne the cost of these retrofits -- and have recently gone on strike in protest. Port managers insist that the retrofits are a critical component of new commitments to better address climate change. Retrofitting trucks around the Port of Houston has played out differently. Through a program designed and led by Environmental Defense (a large NGO), truckers have received loans to help them transition to cleaner fuels. We've interviewed many of the actors in these controversies (scientists, truckers, environmental activists), working to understand their social and political economic positions, the knowledge they produce and rely on, and their perspective on what needs to happen and why. This kind of controversy analysis is a recurrent thread in anthropologies of the sciences.

We also examine dynamics at what we think of as the meso strata – the strata of organizations and social networks. We want to understand how researchers like Huang Wei in Beijing were influenced by and remain connected to key air pollution organizations like the Health Effects Institute in Cambridge, Massachusetts (USA), for example. We also want to understand the organizational culture in state/province-level environmental agencies: in Indian states, Pollution Control Boards; in Texas, the Commission on Environmental Quality (TCEQ). We have learned, for example, that TCEQ is a powerful advocate for industry, and often pitted against both the US Environmental Protection Agency and the City of Houston. A key index of their differences in recent years has been the controversy around federal regulation that put stricter limit on ozone levels in cities. There is a wide, deep, and highly regarded scientific literature demonstrating the negative health effects of ozone, particularly for vulnerable groups (like children and asthmatics). Texas's state toxicologist nonetheless opposed stricter standards, arguing both on scientific grounds (claiming the health data and analyses were "insufficient" and "inadequate") and on political grounds (claiming the burden on industry would be too severe). As anthropologists of science, it is our job to parse how and why such arguments are made, and what weight they carry in the ecology of actors that together govern air pollution in Houston.

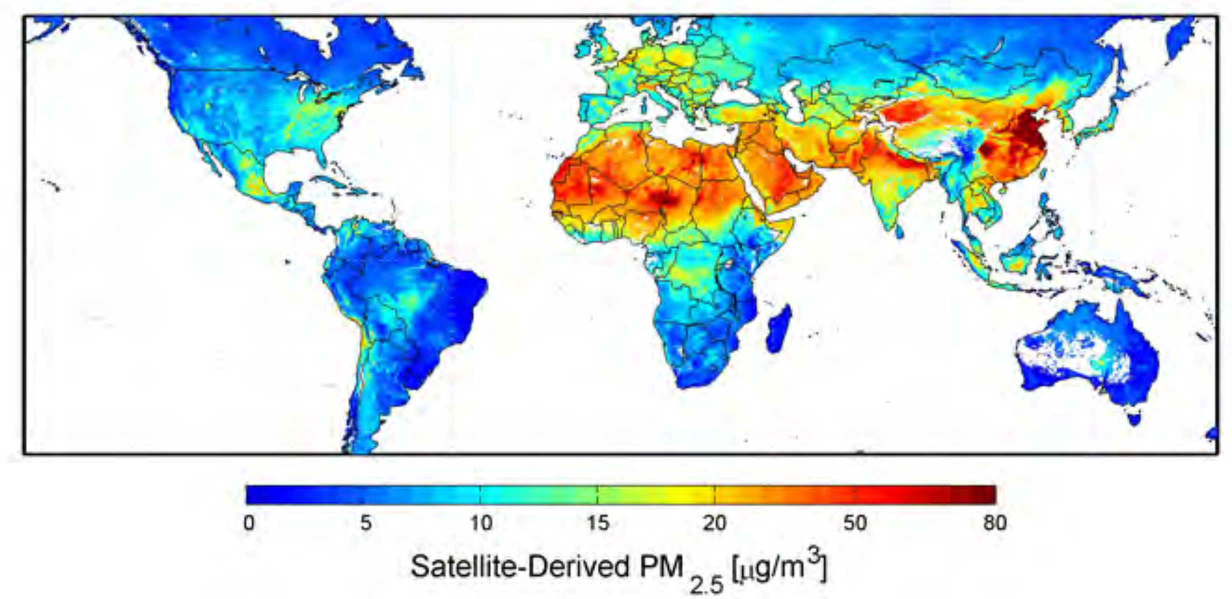
We also need to understand the daily practices that result in scientific claims and controversies – watching what science looks like at what can be called the micro level. In the Albany effort to understand pollution from truck traffic, for example, scientists have taken to the streets, with an air monitoring backpack. The data they will collect will be compared to a stationary monitor (that runs continuously, generated huge amounts of data, which is averaged for usability). Alternatively, the backpack data may show air pollution hotspots at particular street intersections, or at particular times of the day. This is a new kind of scientific practice, and the DEC scientists are well aware of this. (Earlier, this same group of scientists did vehicle emissions testing – testing the pollution created by different kinds of vehicles when put on the (very large) equivalent of a treadmill.) The backpack monitor generates a new kind of data, which they will have to learn to interpret and use. With their backpack study, these scientists are also situated much more personally in the community they are studying, walking the streets alongside community members, trying to learn from their experiences. This recognition of the value of community knowledge in scientific studies has been a key development in the environmental health sciences over the last two decades. Anthropologists of the sciences have both documented and tried to support this development, critically attuned to the value of "explanatory pluralism" – a concept developed to account for the value of gender, race and class as well as disciplinary diversity in knowledge making.

Portable Ultrafine Particle Detector (PUFP) in use in the Ezra Prentice Homes, Albany, New York, 29 April 2017.

Practice (what happens at micro strata) always, of course, need to be understood in context – as emerging from particular historical conditions. Anthropologists of the sciences thus also examine what we've called the edex strata – the strata where we can observe where and how people are educated, formally and informally, and what credentials experts *as experts.* In our pollution study, for example, we observe the built effects of particular ideas about how cities should be designed, built and function. And we are observing the emergence and increasing authority of new kinds of city planning expertise, focused more on environmental sustainability and even "just sustainability" (which keeps wealth stratification in mind, designing against the way city greening often leads to gentrification and the displacement of poor residents). Alternative ideas about city planning are often rooted in particular educational institutions – the School of Planning and Architecture in Delhi and the JJ School of Architecture in Mumbai, India, for example – and almost always involve interdisciplinarity, bringing together urban planners, ecologists, transportation engineers, biking advocates and residents. Anthropologist Sharon Traweek has argued that innovation often happens at these "fault lines" where people with very different ways of viewing the world come together.

Anthropologists of the sciences work to understand how established expertise shapes the world (inevitably delimiting what is seen as a problem, and what is seen as a possible solution), and how new forms of expertise (and supporting education) emerge, gain social standing, and sometimes fundamentally challenges the order of thing.

Education and expertise, in turn, is enabled and shaped by the technologies available to power them. Consider, for example, the way electronic computation has changed how people are educated, and the way people carry out many different kinds of work. We've thought of this as occurring on the techno strata – the strata where we can observe technological change and the distribution of technology, and how this shapes how and what people know, are interested in, and worried about. The availability of air quality monitors affordable to independent citizens is one of the most important technological developments that we've observed in our air pollution study, for example. Some government actors are skeptical of this kind of "citizen science," but others – like the US National Aeronautics and Space Administration (NASA) -- strongly supports it, seeing it as a source of data that won't replace but can supplement the kinds of data produced by more expensive equipment and professional scientists. NASA and other supporters of citizen science also see it as a way to draw citizens into scientific inquiries, encouraging their support for scientific research and the use of science in decision-making. Other technical developments have also transformed air pollution science and governance. Satellite images, for example are now used to track pollution distributions, as well as the way pollution crosses borders – profoundly challenge governance-as-usual.   Efforts to effectively govern air pollution in Singapore and elsewhere in Southeast Asia from fires in Indonesia are largely regarded as another (legal and political) disaster, for example.



Global satellite-derived map of $PM_{2.5}$ averaged over 2001-2006. Credit: Dalhousie University, Aaron van Donkelaar. Image courtesy of NASA: https://www.nasa.gov/topics/earth/features/health-sapping.html

Technologies of the sciences are important in many different ways, not least because they produce the data on which science turns. Anthropologists of the sciences thus spend a great deal of time examining what we call the data strata – watching what data is collected, how, why, and to what effect. Indeed, a key part of characterizing the “thought style” of a particular scientist or scientific community is in delineating their data practices, infrastructure and sensibilities – what can be called their “data culture.” We are thus interested in how data is shared, or not, and in ethical as well as epistemological reasons many scientists are committed to “open data.” Some scientists see open data as a necessary condition of the “reproducibility” often said to be what make scientific knowledge robust. Other scientists see open data more as a means to leverage previous knowledge in the making of new knowledge – because open data allows reanalysis of data from a study of air pollution impacts on the health of rats, for example, with newly available software and statistical techniques. Here, especially, one can see how all the strata we’ve described press and shape one another. Data cultures are both shaped by and drive scientific technologies, which are available and circulate because of supporting law, economies, and social networks, for example. Data practices and culture also powerfully shape narratives about what sciences is, and what kinds of social resource science is – observable at what we earlier called the meta strata.

All, also, come together in what we've called the nano strata – a strata especially familiar to anthropologists, where subjects are formed and performed, where language ideologies are harbored and enacted, where ethical imaginaries come together. Anthropologies of the sciences focus here to draw out the thought styles of the scientists they study and to figure out how public discussion and media representation of the sciences (meta discourses) are actually taken up in the imaginations of all kinds of peoples. In our air pollution study, for example, we want to understand how many different kinds of people on the streets of India – auto rickshaw drivers, truck drivers, drivers of personal vehicles, street vendors – understand the (scientific) claims that it is necessary to restrict their movement to improve the air to protect their health – even through restrictions on vehicle mobility will change and possibility undermine the way they do or get to their jobs.

How all these people understand new air pollution laws is, of course, not only a matter of science; it is tangled up in how people think about the actual and legitimate role of the Indian government in their lives, about how and where they can making a living wage, and about how health is best protected and sustained. Anthropologists of the sciences are interested in what people see as usable and valuable knowledge, as expertise, and as appropriate uses of knowledge, data and other forms of evidence in decision-making, dispute resolution, and planning for the future. A key challenge in our air pollution study, for example, is to figure out how the many kinds of experts involved think about the public good and civic responsibility. We also need to understand the many different ways people in different settings, with different social standing, think about "governance," and about the kinds of data and knowledge that legitimately orient governance – aware that this is shaped by the history of ideas and politics in a given setting, by media dynamics, and by the intricacies of individual life histories. Envisioning all the strata where science is in play helps us gets at these entanglements.

Interactively, the many strata we have described produce what science becomes in society and culture. There are many possible ways of focusing work in anthropologies of the sciences, and many reasons why such work advances both anthropological theory and the contributions that anthropology makes to public life. Anthropologies of the sciences address basic theoretical questions about social hierarchies and legitimacy, about how power is distributed within and between societies, about how globalization plays out on the ground, and about how social change happens. Anthropologists of the sciences also speak to many issues of urgent practical concern – offering perspective on how investments in education and research advance societal development, prosperity and distributions of wealth, on how knowledge can move through social formations and into new laws and norms, on how different forms of knowledge can be brought together and leveraged to re-image future possibilities. Anthropologists of the sciences thus provide an especially exciting place to work within anthropology writ large, both as a space of its own and as a dimensions of many different kinds of anthropological projects.

Conclusion

In our opening story we alluded to the slight awkwardness one often feels at the start of an anthropological engagement with scientists. Often the scientists recognize that anthropologists are fellow *researchers*, and respect them as such, but don't fully understand what the anthropologist is up to and why they want to talk to -- and analyze -- *them.* "So we're your guinea pigs, right?" We've heard this many times. Usually the question isn't hostile, just curious and a show of hesitancy -- a call for explanation. Anthropologists of science thus have special demands on them to describe what anthropology is, how and why we do it, and how we move from listening and observation to analysis, interpretation and the making of (scientific) claims ourselves. Anthropologists of the sciences explain themselves and their work in different ways, and there is a healthy debate among them about whether anthropology itself is a science. Most all, however, at some point have to explain how anthropology moved from the the study of low-tech, other-than-modern societies in far away places to the study of people, practices and issues at the heart of high-tech, ultra-complex, globally connected societies. "People are people," although logically impeccable, asks for a bit more anthropological explication, when it comes to anthropologies of the sciences.

In our experience, the relative newness of the anthropology of science has made it an exciting place to work, in part because its newness has made it methodologically challenging. The methods, concepts, and theories developed in anthropological research over time and around the world are critical guides to the anthropology of science, but they always have to be translated -- becoming something new in process -- when focused on the sciences in practice and in culture. In a move that was highly controversial at the time (1969), anthropologist Laura Nader described the challenge as one of "studying up." Nader argued that it was critical to do this not only because people at the top of social hierarchies are indeed part of the "whole picture" that anthropologists strive to capture, but also because this hierarchy organizes and emanates *power*, shaping the lives of all within in -- in ways that are more or less fair, healthy, and meaningful. Emphasizing the importance of studying lawyers, bureaucrats and other elites (including scientists), Nader pushed anthropologists toward "'study of the colonizers rather than [just the] the colonized, the culture of power rather than the culture of the powerless, the culture of affluence rather than the culture of poverty."

Nader's early call for studying up literally upended established approaches to anthropological research, foreshadowing the methodological challenges and innovation that would come to be associated with anthropologies of the sciences. Nader's call also reaffirmed Ludwick Fleck's insights (in the epigraph), that anthropologies of sciences are also the anthropologies of politics. In studying how science is produced, circulated, legitimated, used and imagined, anthropologists draw out *who* counts as knowledgeable, *what* counts as knowledge, and *how* knowledge claims shape everyday lives, law, policy, and public discourse -- in turn shaping next generation education, science, and social reproduction writ large. Anthropologies of science are thus best seen not as a topical subfield but as a critical layer in all anthropological research, though depth and scope of attention to different layers will of course vary across projects. Anthropologies of science should also be seen as deeply political in form as well as through specific arguments. In recognizing and exploring *different* knowledge forms -- within the sciences, and in comparison with other knowledge forms -- anthropologies of science analyze what comes to be seen as important and obvious, and why, who and what gets cut out, and how people are pushing back, reaching for new knowledge forms, attuned to emerging as well as stubbornly enduring problems. Anthropologies of the sciences are thus about how people have, and might in the future continue to, in Michael Fischer's phrase, "figure things out."

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