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METHOD, SCALE AND SOCIO-TECHNICAL NETWORKS: PROBLEMS OF STANDARDIZATION IN ACID RAIN, OZONE DEPLETION AND GLOBAL WARMING RESEARCH

Much sociological research on the environment has focused on how certain conditions of nature have come to be recognized as environmental problems. This type of research identifies how environmental problems are defined through public claimsmaking and other largely social activities. Less research has focused on processes involved in the development of scientific techniques for monitoring the environment and how these techniques are embedded within social networks. This is the general topic for this paper. I will describe how certain monitoring techniques became accepted and standardized in the case of acid rain and ozone depletion, and, more importantly, how their standardization helped shape some dimensions of these problems.

The question of the social underpinnings of various monitoring techniques in particularly timely in the case of global warming. Current scientific and public debate address, among other things, how to empirically confirm global warming. What are the signals of global warming? What sort of socio-technical networks are being constructed to identify climate change? How will these networks shape the environmental problems itself? This paper focuses on a specific aspect of the problem of standardization of the monitoring technologies: their scale. Will global warming/climate change be constructed solely as a global problem, or will there be sufficient flexibility for its scale to be reduced to regional or local problems as well, if warranted? Flexibility surrounding the global scale of measurement techniques is potentially consequential for the size and dynamics of the climate change problem.

Implications of current climate monitoring techniques for the assessment of global warming are as yet unknown. However, it

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may be useful to look at other related environmental problems to analyze the importance of monitoring networks. Two problems which provide a good comparison are acid rain and ozone depletion. We will examine how, in each case, the process of establishing standardized monitoring networks influenced the scale and particular dynamics of the problem. These two cases will then be used to address potential consequences of the choosing on of the existing techniques, such as "fingerprinting" or measurement of temperature increases, in the current scientific controversy over techniques for detecting global warming.

Actor/Network Theory

My analysis draws upon some insights from actor/network theory (Callon 1986; Latour, 1987). Actor/network theorists distinguish between "global networks" and "local networks". Global networks persist beyond individual laboratories, consisting of a set of relations between an actor and its "neighbors" and also among the neighbors themselves (Law and Callon 1992). Global networks allow for the acquisition of space, time and resources (a "negotiation space") so that projects can be undertaken within "local networks" (e.g, a scientific laboratory). Actors must perform "balancing acts" to maintain stability between the "outside" or actors within the global network and the "inside" or actors within the local network (Callon and Law 1989). Scientists may enroll actors into a network in an attempt to make their own activities or laboratory an "obligatory passage point" for these other actors to reach their goals (Law and Callon, 1992). For example, scientists or other network builders may attempt to persuade foundations or governmental actors that they might only or more easily achieve their agendas by supporting scientists' activities: the scientific laboratory becomes an obligatory point of passage for governmental actors to reach their goals.

The standardization of monitoring technologies can be a significant feature of scientists' networks. As machines are used in laboratory work, they may become standardized through the process of successfully passing "trials of strength" and through their negotiated acceptance among other scientific and non–scientific actors. That is, the standardized technologies are stabilized and "black–boxed" so that the data they produce are generally accepted without question as representative of nature. The technology becomes an important actor in linking together global and local networks because it, and the data it produces, can easily pass back and forth. Data produced by a geiger counter, for example, can easily pass from a local site to national and international arenas.

Coupled with the pertinence of actor/network theory for examining standardization of monitoring technology is its possible relevance for comparative studies. Thus far, there have been many case studies of individual technologies, programs of research or scientific knowledge–claims which employ actor/network theory; however, there have been far fewer comparative analyses. With analyses of case studies, a researcher typically can draw conclusions about the processes involved in building a network and why it was successful or unsuccessful. Comparative analyses, on the other hand, may help to more easily visualize both the scale of networks and how they "could have been otherwise" given a contrast with another somewhat similar case.

A comparative analysis may be especially useful in analyzing the current network building surrounding the controversy over techniques for detecting a global warming signal. The analysis below focuses on both the acid rain and ozone depletion cases and draws out some implications for the current controversy surrounding global warming. As will be shown, some significant differences fell along the lines of scale and flexibility built within the networks in the acid rain and ozone cases, which may be relevant for the global warming case.

Acid Rain: Taking Local Measurements Seriously

Separate acid rain monitoring networks exist in the U.S., Canada, Europe and Scandinavia. My analysis will focus on the U.S. network for reasons of brevity and familiarity. This network is called the NADP/NTN (National Acid Deposition Program/National Trends Network) precipitation chemistry network which now consists of about 200 sites. The construction of this network was important for how acid rain itself became constructed as an environmental problem and for the types of scientific research focused on it. The idea for a U.S. acid rain monitoring network was first propagated in the early 1970s by Ellis Cowling of North Carolina State University who had recently returned from a trip to Sweden where he had met with Svente Oden and other acid rain scientists. Cowling approached other scientists, the Environmental Protection Agency, members of Congress and others to develop support for the network. Initially he was unsuccessful in obtaining federal support, but was able to enlist the interests of several State Agricultural Experiment Station (SAES) leaders. These leaders were interested in interregional projects, especially if they would expand the visibility of SAES by addressing national problems (Cowling 1987). They gave Cowling $12,000 to begin organizational work.

Cowling and others began drawing up plans and held meetings with interested members from SAES. In its early stages, about 15 stations sent representatives. Official sponsorship for the project initially came from SAES in the North Central Region of the U.S., but collection sites were established in other areas as well (Galloway and Cowling, 1978). The project was called the National Atmospheric Deposition Program (NADP). A decision to join the program and construct a monitoring site was initially on a voluntary basis. A scientist had to raise sufficient funds(about $4000–$5000 per site) and agree to the terms of the research protocol. In exchange, data about precipitation chemistry from their site and others were available for analysis. Though originally in 1978 there were 15 sites, the network expanded rapidly and by the mid–1980s included about 200 sites (Bowersox, Sisterton and Olsen 1990).

At first, each site contained only a wet deposition collector with a dry collector listed as optional equipment. When NADP scientists first began meeting, they reached quick consensus about the high quality of wet deposition data because of the availability and widespread use of wet deposition collectors. This technology consisted of a sterile bucket, which would open and close with each precipitation event, with a precipitation gauge attached to the bucket to confirm that the lid was working properly. Each Tuesday morning at 9 a.m., precipitation samples were collected and conductivity and pH tests were performed at each site. The weekly samples were then sealed and sent to a central analytical laboratory located at the Illinois Water Survey (IWS) in Champaign, IL. Scientists there already had in place extensive facilities supported by the U.S. Department of Energy and their site was chosen for analytical procedures because of their alleged high quality work and their interest in taking on the task. Scientists at each individual site were responsible for paying IWS for the analysis conducted on their samples. This analysis included measurements for volume, pH, conductance, sulfate, nitrate, chloride, phosphate,calcium, magnesium, sodium, potassium, ammonium and any other tests requested by individual scientists. The IWS eventually published a manual documenting their analysis procedures (Illinois Water Survey, 1986) and NADP and other scientists have accepted their work as of high quality.

The collection of dry deposition, on the other hand, was much less straightforward because of the importance of surface for dry deposition (McFee 1986). The atmosphere interacts variably with different surfaces yielding, all else being equal, different levels of dry deposition. Initially, scientists at some sites put out an open plastic bucket to collect dry deposition (one that would close during a precipitation event). However, this practice was criticized because of the surface problem: a plastic bucket is simply representative of a plastic surface which is quite rare in nature. There was significant debate about this problem in the late 1970s and it was eventually agreed that monitoring of dry deposition would be optional at each site. This decision helped strengthen the network by making an unruly actor unnecessary for its survival.

Once formed, the network expanded in the late 1970s and received a major boost in the 1980s with the creation of the National Acid Precipitation Assessment Program (NAPAP). NADP served as a sort of model for NAPAP but the latter brought extensive federal funding to acid rain research. NAPAP expanded the monitoring network created through NADP with a new network called the National Trends Network (NTN). This network established sites (using the same protocol and central laboratory as NADP) with attention given to better representation of the diverse ecoregions across the U.S., especially those particularly susceptible to the effects of acid rain (Bowersox et al. 1990). NTN also added a new sophisticated dry deposition collector to the network.

Overall, this standardized collection network was important for the construction of acid rain as an environmental problem.[1] The network brought about accepted scientific data which identified the existence of acidic precipitation and showed its regional distribution. It also made acid rain more visible as organizations, collections of scientists, maps of acid rain, claims by scientists and other inscriptions were made available for public dissemination.

Also, this particular network opened the acid rain problem for construction and research at several levels of scale. The network was flexibly a local, regional and/or national phenomenon according to scientists' interests. Data could be linked to and used for analyses of research problems at particular sites (e.g., spruce decline on Camels Hump Mountain in Vermont (Scherbatskoy and Klein, 1983), mobilization of aluminum and poisoning of fish (Schofield, 1976)), for regional research problems (e.g., acidification of lakes and streams in New England (Cogbill and Likens, 1974), transport of acid rain precursors in particular areas) and more national–scale research problems (e.g., transport of acid rain precursors from the midwest to northeast). The network was flexible and constructed in such a way that scientists' *attention* was directed at different levels.

The flexibility of scale in the network also impacted different publics' perceptions and use of the acid rain phenomenon. By the early 1980s in the U.S., the concept "acid rain" was multiply interpreted to mean different things in different contexts. Farmers and fishermen, for example, localized acid rain to explain crop failure and lack of fishing success; environmental organizations regionalized and nationalized the phenomenon to reinforce arguments for more stringent national clear air laws. Other groups, such as representatives of the electric power industry, could flexibly vary the scale of acid rain to draw attention to uncertainties in knowledge. Consequentially, the flexible scale of the acid rain phenomenon helped delay formation of acid rain policy in the U.S. precisely because this flexibility could be used by various social groups holding opposing political interests. So whereas the data gathering network was formed by scientists to fulfill diverse research interests, it was less suitable for producing quick legislative policy.

Ozone Depletion: The Construction of A Global Scale Phenomenon

In contrast to the acid rain case, stratospheric ozone depletion was quickly defined as a global environmental problem even as ozone monitors, which were then in place (early 1970s), were largely local (vertical column) indicators of ozone levels. As the environmental problem gained increased attention, there was a concerted effort within the scientific community to globalize an ozone monitoring network, both through a standardized network of Dobson stations and through monitoring technology aboard satellites. These separate networks were impeded by three main problems. First, the definition of (and consequential actions of defining) ozone depletion as a global phenomenon created a setting in which atmospheric scientists overlooked extreme regional variability. Second, there was less tightly controlled data handling and upkeep of measurement instruments than in the U.S. acid rain network, which led to mistrust of data that did not meet prior model–based expectations. Third, the overlap of data collection procedures (though generally beneficial) helped produce, in a particular instance, an ambivalence in reporting and analyzing key data in a timely manner.

In the early 1970s, several scientists published theories on the potential effects of nitrous oxides and chlorine in the destruction of ozone in the stratosphere (Crutzen, 1970; Johnston, 1971; Nicolet, 1971; Stolarski and Cicerone, 1974; Molina and Rowland, 1974). These theories, coupled with a proposed SST fleet and rising levels of chlorofluorocarbons (CFCs) production, helped drive the construction of ozone depletion as a new environmental problem and led to calls for elimination of the SST fleet and production and use of CFCs.[2] They also stimulated an interest within the atmospheric scientific community both to develop atmospheric models that predict future ozone loss and a means to measure actual ozone depletion. Since CFCs are highly stable compounds (providing for multiple uses), once emitted, they remain in the atmosphere for many years and eventually rise into the stratosphere. In the stratosphere, they eventually break apart in the presence of solar radiation, releasing chlorine atoms which act as a catalyst in the break–up of ozone molecules. Because CFCs were emitted world–wide (though with major international disparities) and, more significantly, because of their long–term presence and global dispersion in the stratosphere, atmospheric scientists quickly labeled ozone depletion as a global problem.

Unlike the acid rain case in the U.S., there has been a relatively long history of ozone measurements. The main instrument for measuring ozone (until the 1980s) was the Dobson spectrophotometer originally developed by the physicist Gordon Dobson (Cagin and Dray, 1993). The instrument measures the relative intensities of pairs of wavelengths in the Huggins ozone absorption band (300–350 nanometers). One wavelength in each pair is strongly absorbed by ozone and the other is not. From these differences, one can deduce the total vertical column of ozone from that surface point which is measured in Dobson units (cf. London and Angell, 1982; World Meteorological Organization, 1989). Gordon Dobson was the first to use the spectrophotometer and to place them in different parts of the world. The rather loosely connected network of about a dozen Dobson stations established in the 1930s increased considerably in 1957 during the International Geophysical Year along with increased global geophysical and atmospheric research. In 1957 Dobson published a complete description of and instructions for operating the instrument which facilitated their use (Dobson, 1957). By the early 1980s, there were about sixty Dobson instrument stations in the northern hemisphere and ten in the southern hemisphere (Cagin and Dray 1983).

With the growth of Dobson stations and emergence of the ozone depletion problem, members of the World Meteorological Organization (WMO) attempted to standardize the equipment and develop a more formalized network of global ozone data. For ozone measurement precision, the Dobson spectrophotometer must be periodically recalibrated and maintained and measurements must be adjusted according to several background conditions such as directness of sun, temperature and cloudiness. To minimize variability, the WMO in 1974 designated a World Primary Standard Dobson Spectrophotometer No. 83 (referring to the 83rd instrument built) which was maintained at the World Dobson Spectrophotometer Central Laboratory in Boulder, Colorado (WMO, 1989). Dobson instruments around the world could then be calibrated either directly against No. 83 or indirectly through intercalibrations with Secondary Standard Dobson spectrophotometers calibrated in Boulder in 1977 (WMO, 1989). Coupled with this attempt to standardize equipment, an effort was made to collect and publish global ozone data through the auspices of the International Ozone Commission (established at the UN Conference on the Human Environment held in Stockholm in 1972) and the Canadian Atmospheric Environment Service. If Dobson station operators wished, they could report daily and monthly ozone measurements to one of these organizations which would collect and publish results in the "Red Books" (Cagin and Dray 1993).

Despite these attempts to standardize and globalize the Dobson ozone data gathering network, several problems emerged which inhibited its momentum. One problem related to variations among stations in upkeep of their equipment. Some station operators were more fastidious than others about calibrating and replacing equipment which was notorious for deterioration and drift. Variability in upkeep led to some distrust about accuracy of ozone data, especially measurements that lay outside of levels predicted by atmospheric models. Second, ozone data obtained from each station were dependent upon careful measurements of several background characteristics (noted above). Although standard techniques were developed to factor in these characteristics, there was always some distrust about whether these techniques were followed accurately at each station. Unlike the U.S. acid rain network where most of the analysis was conducted at a central laboratory, ozone measurements were calculated at each separate station. Third, there was an uneven global distribution of Dobson stations. A majority were in the Northern Hemisphere (and on the continents of North America and Europe) which limited their capacity to provide information about global trends. Fourth, most Dobson stations provided total column measurements of ozone (including the troposphere and stratosphere). But these standard measurements gave little information about the vertical distribution of ozone, which was key to measuring two different types of ozone related problems (i.e., presence of ozone in the troposphere and lack of it in the stratosphere). This problem was solved at a limited number of stations with the use of "Umkehr" techniques. This involved using Dobson spectrophotometers to take measurements of radiation at pairs of wavelengths at several angles (60° to 90°) from the solar zenith sky. These measurements were then compared to determine vertical layers of ozone level and, in practice, nine layers from the ground to 48 km. altitude were generally used (London and Angell, 1982; WMO, 1989). However, only a limited number of stations (about 12) have performed umkehr measurements for a sufficient length of time to allow for trend analysis of ozone changes (Reinsel et al. 1984) and these techniques were limited by the same problems noted above at Dobson stations.

Because of the inadequacies of the Dobson network in providing global coverage, there was much interest among atmospheric scientists in monitoring ozone by satellite. Similar technology could be used to measure backscattered radiation from the earth, which would identify ozone levels following similar principals used with Dobson technology. Efforts first began during the 1960s with NASA scientists at Goddard Space Flight Center. Their original intention was to use measurements of ozone as information for weather forecasting – ozone levels being a good tracking device for high and low pressure areas (Cagin and Dray, 1993). One NASA scientist – Donald Heath – had a plan for a "backscatter" instrument which would compare outgoing infrared light (which has been "backscattered" off ozone molecules) with incoming scattered ultraviolet light on that same molecule (Cagin and Dray, 1993).

Since both measurements could be performed by the same instrument, one would not have to worry about continual calibration because the two measurements would be relative to each other (WMO, 1989). With the support of Arlin Krueger – another NASA scientist – this instrument was eventually included aboard NASA's Nimbus 4 satellite launched in 1970.

Although the instrument worked, it was not sufficiently sensitive to determine whether ozone was being depleted by chlorine, which was an emerging interest among NASA technicians because of emissions from Space Shuttle flights (Cagin and Dray, 1993). An improved SBUV instrument was placed aboard *Nimbus 7* launched in 1978. This instrument known as the Total Ozone Mapping Spectrometer (TOMS) included an optical apparatus which would provide hundreds of wavelength observations every few seconds as the satellite circled the globe, with slight variation of angle with each orbit, from equator to pole (WMO, 1989; Cagin and Dray, 1993). TOMS measured not only total column and altitude profiles of ozone but also made measurements over a broad geographical area at the same point in time. This produced an immense amount of ozone data with global coverage.

Unfortunately, TOMS was not the panacea that some anticipated. Although the same spectrophotometer was used to measure backscattered radiation and solar UV irradiance at the same wavelengths (thus providing a measure of the amount of radiation absorbed by ozone), a diffuser plate was used to transform solar irradiance into a radiance comparable in magnitude with the backscattered earth radiance (WMO, 1989). This piece of equipment was an important actor in one set of measurements, but not the other, and this plate began to degrade and became less reflective over time. This degradation introduced an element of distrust and uncertainty among atmospheric scientists in data produced by the satellite, especially when these data contradicted predictions from atmospheric models. This distrust was evident when Donald Heath attempted to publish a paper in *Science* in 1981, which reported that global ozone had declined by one percent during the 1970s based upon combined data from *Nimbus 4* and *Nimbus 7*. The paper was rejected based mainly upon the assumed unreliability of the diffuser plate (despite calculations introduced by Heath to control for this degradation) and because this measured decline was far beyond that predicted by stratospheric models (Cragin and Dray, 1993).

A second dilemma emerged partly as a consequence of the success of *Nimbus 7* in providing global coverage of ozone levels. The amount of data produced became overwhelming for scientists and technicians at NASA. To relieve some of this overload (and because of an element of distrust in the instruments), NASA scientists programmed their computers to exclude from cataloguing data points which fell outside of the range of 180 and 650 Dobson units under the assumption that these measurements must result from equipment failure. Although these data were not completely discarded, they were excluded from any analysis until 1984 when a NASA technician noticed some particularly low readings while reviewing the previous year's measurements and brought them to the attention of other NASA scientists. These low readings were checked against the Red Books and upon finding nothing to corroborate them, they were again rejected as due to equipment failure (Cragin and Dray, 1993).

The rejection of these data was also consistent with the main focus at NASA on *global* ozone depletion. Particularly low readings in specific regions were less interesting, given the construction of a global problem, than global averages. Without some provocation to look in a different direction, the combination of the amount of data produced, distrust of anomalous readings and continued attempts to standardize TOMS technology resulted in the reproduction of efforts to globalize the scale of the ozone depletion problem.

The provocation to focus on particular regions of the stratosphere came in 1985 with the publication of research by a team of British scientists called the British Antarctic Survey (Farman et al., 1985). The Survey, with Joseph Farman as its leader, had been measuring ozone from a Dobson Station in Halley Bay since 1957. Around 1980 they began noticing significant drops in ozone readings during the Antarctic spring. At first, they assumed equipment failure and ordered new Dobson equipment. The next year similar measurements were observed, but again they were not reported (not even to the Red Book) under the assumption that something must have gone wrong. Among other things, members of the British station assumed that if the low ozone levels were real, they certainly would have been identified by TOMS equipment aboard satellites which made many more measurements in the area than their one Dobson station. Farman even prevented a doctoral student from publishing his research which was based upon these particularly low readings. In 1984 their results at Halley Bay were corroborated with those from another British station on Argentine Island and finally in 1985 their data and analysis appeared in the journal *Nature*.

With the publication of these results, NASA scientists retrieved the data discarded by their computers and were able to confirm the existence of an ozone "hole" over Antarctica which appeared each spring. With the TOMS technology, they also constructed maps of the ozone hole (some in brilliant colors) which were widely published in the scientific and popular press. The discovery of the ozone hole led to a rush of scientists attempting to explain the processes behind it and to a reemphasis on the regional peculiarities (mainly a polar focus) of ozone depletion.

The failure of the British team to report the results immediately reflected several features of the emerging science of ozone depletion. Dobson technology was embedded in an actor/network which de–emphasized local and regional variability. This was due to, among other things, the voluntary upkeep of equipment (leading to some distrust of local, specific measurements), voluntary reporting of data, and the assumption that new globally–based satellite technology was replacing the network. These factors were coupled both with the dominance of 1-dimensional models of predictions of ozone depletion, which also de–emphasized regional or local variation, and with the construction of a public *global* ozone depletion problem.

This case demonstrates the significant role which types of monitoring technology and the networks within which they are embedded can play in shaping environmental problems. Dobson technology, though with a potential for local strength, was linked together into a "weak" global network in which local and regional variability was de–emphasized. Satellite monitoring technology, though holding the capacity for either regional or global emphasis, was situated in a network in which the latter was emphasized leading to neglect of regional and local ozone depletion problems. This case differed from acid rain in which monitoring technologies were embedded in a network which emphasized regional problems and within which local measurements were considered to be "strong" because of the strict adherence to standardized protocols.

Global Warming/ Global Climate Change: Problems with Models and Methods

Some of the points raised in these two cases, I would suggest, offer insights into potential outcomes of the contemporary scientific controversy over monitoring techniques in the global warming/ global climate change case. Both acid rain and ozone depletion can be subsumed within the global climate change (GCC) problem, however, the primary component (and what I deal with here) of GCC is the existence and effects of global warming attributed to changes in greenhouse gas emissions. That is, to what extent is planet Earth warming up beyond what may be due to natural fluctuations in global temperature, and what are the consequences?

Although there are many unanswered scientific questions related to global warming, one much debated issue involves the detection of global warming and whether it can be attributed to greenhouse gases. Atmospheric scientists have developed theories and models that predict (within certain parameters of uncertainty) that past, current and future emissions of greenhouse gases will increase global temperatures. But how does one actually measure global warming to determine whether these models and theories are correct?

One approach has been to gather together historical records of temperatures and other indicators of global warming or cooling to detect whether contemporary trends are significantly different than what one might expect from natural variations. This effort has included an examination of world–wide land surface and ocean surface temperatures since the mid–19th century. Data are available prior to this time, but their spatial coverage is considered too poor for scientific usage (Folland, Karl and Vinnikov, 1990). The combined land surface air and ocean surface temperatures indicate a global warming trend of 0.45 0.15°C since the late 19th century (Folland et al., 1990). However, this trend both falls within model predictions for natural global temperature variability (on the upper end) and within model and theoretical predictions for global warming attributed to greenhouse gas emissions (on the lower end), so scientists' do not confirm or refute the global warming theory.

Some scientists have looked elsewhere for historical indicators of global warming. These include precipitation and evaporation variations, tropospheric temperature and moisture variations, sub–surface temperature variations, sea–ice extent and thickness and glacier retreat. These data can provide independent indicators of global warming or lack thereof. Results from these different indicators neither completely confirm nor deny the global warming trend, either because of insufficient data or because of contradictory results. For example, Oerlemans (1994) uses data on the retreat of glaciers in all regions of the world to identify a linear warming trend of 0.66 0.10oK over the past 100 years which is in agreement with land and ocean temperature increases. However, studies of temperatures in the upper troposphere and lower stratosphere show a trend of declining temperatures since the 1960s, which is the opposite of predictions of the effects of greenhouse gases (see Folland et al., (1990) for a review of these data).

The inability to confirm or deny a historical global warming trend attributed to the greenhouse effect has led atmospheric scientists to look for other techniques which might quickly identify future warming trends. The best data to confirm or deny the trend are mean global temperatures. This would involve monitoring temperatures until global warming or lack of it can be statistically supported. The problem with this approach is the potentially long period of time that might be required to obtain data sufficient for statistical significance. Fifty years of data may be necessary if warming is sufficiently slow; if global warming proceeds more rapidly, the detection time will be reduced but it may be too late for preemptive action to prevent catastrophic effects.

To avoid these scenarios, some (e.g., Wigley and Barnett (1990) and Santer, Wigley and Jones (1993)) have proposed the use of a "fingerprint" method. This involves identifying a multivariate signal of global warming by comparing the structure of changes in several indicators (or one indicator at several places) with the structure of change predicted by models of the greenhouse effect. In practice, this would typically involve comparing changes in indicators across regions (such as mean temperatures and precipitation levels) and/or seasons. The appeal of the fingerprint technique for some scientists is that multiple data sources might provide the statistical power to confirm or deny the greenhouse effect/ global warming theory much earlier than univariate techniques.

Recently, the fingerprint method has come under critique by Schneider (1994) and others. They argue that such a fingerprint technique would require a greenhouse model (for comparative purposes) that is sufficiently sensitive to many different regionally heterogeneous climatic relationships, time–evolving and able to distinguish between natural climatic variations (that are different across regions) and the effects of anthropogenic emissions. Such a model, Schneider (1994) argues, is still a decade away. Consequentially, he proposes (for policy purposes) the use of univariate methods such as global mean temperature trends while eliminating the requirement of statistical significance levels normally used in scientific research.

Conclusion: The Consequences of Methodological Choice

This current controversy bears watching in social studies of science and might be informed by the acid rain and ozone depletion cases. These cases suggest that the consequences of the outcome of this controversy (if there is one outcome) may entail more than merely resolving how quickly global warming is confirmed or refuted. One important area of focus is the emerging social networks (and potential battles between them) around global climate change monitoring techniques. The fingerprint method requires significant work by the atmospheric modeling community to develop computer models (or a major model). The univariate method requires specific climatic measurements, especially historically based, such as temperature trends, glacial retreat, sea ice volume, thickness of ice sheets, etc.. This research would be conducted by other scientists from diverse fields. This method also potentially requires acceptance of a reduction in levels of statistical confidence (save some major finding), which increases the possibility in the future of being wrong.

More significantly, the acid rain and ozone depletion cases suggest that what becomes accepted as standard procedures for detecting global warming may influence the scale of the environmental problem. The fingerprint method, while potentially contributing to confirmation or denial of global warming, also may be useful for identifying more locally based environmental peculiarities that are likely to occur with global warming. The fingerprint technique brings with it some scientific attention to regional specifics, while also making possible a comparison of regional data. Univariate techniques, on the other hand, are directed to the global scale, which may foreclude early identification of locally or regionally–based climate problems and solutions. As with ozone depletion, a univariate approach to global warming could gloss over regional, potentially catastrophic, climate changes. On the other hand, if sufficient flexibility and strength is built into local networks in the global climate monitoring network (as with acid rain), these changes may not escape attention.

This scientific controversy over global warming detection is ongoing. Which monitoring techniques win out (or whether any of them do) is yet to be determined. As social analysts of science, it behooves us to employ an actor/network perspective to watch this controversy, but also to bear in mind comparisons with other controversies and problems. The important issue is not only how particular socio–technical relationships result in one monitoring technique winning out over another, but how the winning technique may shape the nature of this and other environmental problems.

NOTES

1. I have discussed the construction of the acid rain controversy in more detail elsewhere (see Zehr 1994).
2. See Roan (1989) for a review of the development of the ozone depletion controversy.

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