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BOOK REVIEW

Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*

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Gabriele Gramelsberger

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Meteorology is a global endeavor consuming vast resources for keeping an eye on the entire world. Thereby it not only detects the present state of the atmosphere, but also envisions its possible futures. Thus, the knowledge instruments of meteorology are permanent remote sensing, worldwide nets of weather stations, world data archives, and global circulation models computing weather and climate phenomena on supercomputers. No other scientific discipline provides such a data-intensive, global cyberinfrastructure and not many other areas attract more public attention than meteorology. Climate change and extreme weather events are challenging for meteorologists as well as the global public.

How does this vast machine of global meteorology work? Which institutions, theories, methods, and infrastructures drive scientific development? Paul N. Edwards gives a well written review of this vast machine on more than 500 pages. Within fifteen chapters he outlines the development of 20th and 21st century meteorology based on its roots in the studies of natural scientists since the 17th century. Edwards begins his narration with the establishment of global space and time. Natural scientists like Edmond Halley, George Hadley and later Alexander von Humboldt, Heinrich Wilhelm Dove and William Ferrel have measured global space and thus constructed it scientifically–followed in the 19th century by international organizations, which have increasingly coordinated and standardized global space and time. For meteorology, the year 1873 marked the beginning of coordinated international exchange when the first International Meteorological Congress was held in Vienna and agreed to prepare for an International Meteorological Organization (IMO). Meteorologists organized themselves as an international scientific community and they started to exchange weather data

G. Gramelsberger (✉)
Department of Philosophy and Humanities, Institute of Philosophy, Freie Universitaet Berlin (FU),
Habelschwerdter Allee 30, 14195 Berlin, Germany
e-mail: gab@zedat.fu-berlin.de

internationally using telegraphy. Already in 1882/83 the very first international measurement campaign was launched by the First Polar Year.

These activities increased the amount of available data enormously and new tools of representation like synoptic weather maps had to be developed. Paul N. Edwards' study is focused on the "making of global data." It is worth mentioning that Edwards is a professor of information at the University of Michigan and thus interested in the creation of data. However, the data flood and the new representation tools increasingly unveiled the global patterns of atmospheric processes and the meteorologists became aware that local weather is influenced by global processes and that reliable weather forecasts require sufficient understanding of these processes. These developments changed the epistemic direction of meteorology and transformed it from a descriptive into a theoretical science increasingly based on physics. Edwards describes this development within five chapters as the precondition for today's mathematical models and simulations in weather forecast as well as climate research on global warming. In the words of Vilhelm Bjerknes (1904), one of the major proponents who turned meteorology into the physics of the atmosphere, "the state of the atmosphere at any point in time will be determined meteorologically when we can calculate velocity, density, pressure, temperature and humidity of the air for any point at that particular time. Velocity is a vector and therefore represented by three scalar variables, the three velocity components, which means that altogether, there are seven unknown parameters to be calculated."[1] In order to compute these seven variables, Bjerknes proposed a model based on seven thermo- and hydrodynamical equations, which constitute the core of each weather and climate model up until today. However, the computation of such a model for a global, three-dimensional grid requires electronic computers. In 1950, Jule Charney and John von Neumann calculated the very first weather model on ENIAC, a barotropic model for a prognosis on air pressure at 500 mbar for a limited region, and in 1955 Norman Phillips calculated a first computerized general circulation model for one hemisphere. Edwards calls Phillips' model "the prototype" including all the chief features of the general circulation known at that time.

This emerging research style of meteorology, named dynamic respectively numerical meteorology, is the precondition to study climate as the global and averaged weather. Although the thermo- and hydrodynamic equations are the same for a weather and a climate model, the shift in spatial and temporal perspective marks the difference. While weather refers to local and regional atmospheric phenomena of several days, climate is the globally averaged picture of weather for minimum 30 years–according to the definition of the World Meteorological Organization (WMO), the successor organization of the IMO. The global, annual temperature has become the most prominent measure for climate change and its development has been reconstructed from paleo data, its future has been projected with general circulation models. Against this backdrop, the need for global data, in particular for upper-air data, became the driving factor for reliable models and simulation runs and Edwards describes in detail the methods and international

[1] See Vilhelm Bjerknes (1904).

activities to gain a full picture of the atmosphere as a three-dimensional object. Since the 1970s national governments as well as the WMO have increased their efforts. In particular, the remote sensing activities of the WMO World Weather Watch (WWW), the US-American Joint Numerical Weather Prediction Unit (JNWPU) and the European Center for Medium-Range Weather Forecasts (ECMWF) are introduced in the volume. However, remote sensing data are gained indirectly and their proliferating quantity requires advanced data assimilation and retrieval techniques, but the methods of collecting and interpreting data differ. Each climatological station calculates their own figures and averages. Thus, overcoming the lack of data by remote sensing led to a deluge of heterogeneous data. Meteorologists had to develop methods for dealing with these heterogeneous data and the idea was to homogenize the records by reanalyzing the data with a frozen data assimilation system, thus rebuilding climate statistics from the scratch. Edwards devotes an entire and very informative chapter solely on reanalysis as the “do over” of given data. Since the 1980s three major reanalysis data sets have been created: The ERA-15 (1979-1993) and ERA-40 (1957-2001) data set of the ECMWF, the GOS-1 (1980-1995) data set of US-Goddard Laboratory for Atmosphere of NASA, and NCEP-NCAR (1948-2008) data set of the US-National Center for Environmental Prediction (NCEP) and the US-National Center for Atmospheric Research (NCAR). Reanalyses of multi-decadal series of past observations have become standard data sets for the entire climate research community. These records are used to initialize simulation runs, to evaluate model results, and to run standardized in-silico experiments. It becomes evident that reanalysis data are one of the cornerstones of today’s climate research. In addition to the methods and activities of the reanalysis projects, Edwards gives some insights into the “data wars” behind the scenes. Already in the previous chapter he illuminates the struggle about how to standardize weather and climate data.

The last chapters are dedicated to the use of global climate models for future projections and the emerging climate policy. One of the problems of global models is the need for subscale parametrization for every process which takes place on scales smaller than the global resolution. But these subscale parametrizations are afflicted with uncertainties. On the one hand, uncertainties lead to major problems for the validation of model results. On the other hand, improving parametrizations drives model development and inspires new measurement campaigns. Particularly the use of climate models for future projections has installed an interesting cycle of model improvement and model intercomparison. Since the 1980s the Atmospheric Model Intercomparison Project (AMIP) and later the Coupled Model Intercomparison Project (CMIP) have been established in the context of the simulation runs for the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), founded in 1988 by the WMO and the United Nations Environment Programme (UNEP). Every global climate model submitting results to the IPCC reports has to pass through the AMIP/CMIP model intercomparison process in order to analyze the strengths and weaknesses of each model. The timeline of the IPCC reports–every five to six years an assessment report on climate change has been published since its first report (FAR) in 1990–has established an international cycle of model improvement and evaluation in climate research. The overall goal of these reports is "to assess scientific information related to climate change, to evaluate the environmental and socio-economic consequences of climate change, and to formulate realistic response strategies" (IPCC website). A precursor to the IPCC reports has been the so-called Charney report on the carbon-dioxide problem from 1979. Since then the possibility of global warming by about 3°C (+/- 1.5°C) due to a carbon-dioxide doubling since pre-industrial age (from 280 ppmv to 560 ppmv) is well known. In 2010, about 390 ppmv were measured. Global efforts for reducing emissions like the Kyoto-protocol (first period 2008-2012) of the United Nations Framework Convention on Climate Change are attempts to respond to the problem of global warming but the future of globally coordinated response strategies is challenged.

Edwards finishes his volume with an interesting conclusion by comparing climatologists with historians. Each new generation discovers new evidence in given data. "Just as with human history, we will never get a single, unshakeable narrative of the global climate's past. Instead we get versions of the atmosphere, a shimmering mass of proliferating data images, convergent yet never identical" (p. 431). This statement unveils that data are not fixed facts but somehow vague entities of information, and the book outlines the difficulties and challenges of making global data. Of course, global campaigns and global models are in the center, disregarding the important question of downscaling the global information to regional and local scales for concrete response strategies. Although the book is well written and gives an informative overview of making global data, the story Edwards tells is not new. The seminal studies of Frederik Nebeker (Calculating the Weather), Robert Marc Friedman (Appropriating the Weather), Spencer R. Weart (The Discovery of Global Warming), Kristine C. Harper (Weather by the Numbers) and others have already reconstructed the history of 20th century meteorology in detail and less US-centered than Edwards.[2] Particularly Kristine C. Harper has outlined the influence of Swedish meteorologists on US meteorology bringing in dynamic meteorology from Europe. The influential work of Japanese climate modelers like Akio Arakawa at the University of California in Los Angeles and Syukuro Manabe at the Geophysical Fluid Dynamics Laboratory could be added. In fact, the model of Manabe and colleagues was one of the two models used for the Charney report. Nevertheless, the book's focus on making global data gives first-hand insights into a data-driven science like meteorology. This is important because the goal of Edwards' study is to take the wind out of the global warming skeptics' sails, insofar as they degrade the scientific case of global warming as "nothing but simulation." They recommend waiting for "real data." However, real data are given as the human induced warming signal can be clearly identified in measurement data for quite some time. The more elaborate answer is given by Edwards when he claims that all our knowledge about climate change is coming from models, also the "real data": simulation models of weather and climate; reanalysis models, which recreate climate history from historical weather data; and data models used to combine and adjust measurements from many different sources. All three types of models

[2] See Robert Marc Friedman (1989), Frederik Nebeker (1995), Spencer R. Weart (2003), Kristine C. Harper (2008). Also Andres Persson (2005).

together constitute global data on climate change and enable research on climate. Thus, meteorology has become a prototype data-driven science creating its knowledge through infrastructures of detection and computation. Understanding this provides understanding the current shift in science towards computational sciences in general. Edwards' book provides an archeology of these developments and his narrative style makes the 500 pages very readable.

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Author Biography

Gabriele Gramelsberger works as a philosopher of science at the Institute of Philosophy at the Free University Berlin. Her research is focused on the restructuring of science as computational sciences, particularly in the field of climate research and cell biology. Her recent works include:

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- Gabriele Gramelsberger: Conceiving meteorology as the exact science of the atmosphere - Vilhelm Bjerknes revolutionary paper from 1904, in: *Meteorologische Zeitschrift*, 18, 2009, p. 663–667.