Flat Organizations for Earth Science

Jesse H. Ausubel*
and John H. Steele+

Abstract

The institutions that made American science famous figure less and less in the leadership and management of American science. Causes for this decline, especially evident in ocean and atmospheric sciences, include large programs that cut across institutions, the volume of federal funds, the scale of scientific instruments and facilities, easier travel and telecommunications, and time horizons of entrepreneurial science. The pattern emerging results not from a deliberate policy of bypassing major institutions and their management, but from radical changes in the structure of scientific activity. Science is matching industry in a trend toward flatter management and functional, rather than geographic, organization. Some risks and needs arise with the new balance—or imbalance—of power.

1. Introduction

American science assumed world leadership in the 1920s and 1930s with the arrival of top scientists in all fields from Europe, their mingling with the first large cohort of students trained in the system of American universities that had burgeoned in the nineteenth century, and the emergence of a flexible set of research-oriented institutions. These institutions included Johns Hopkins University (1876), Cold Spring Harbor Laboratory (1890), California Institute of Technology (1891), University of Chicago (1892), Rockefeller Institute (later University, 1904), Institute for Advanced Study in Princeton (1930), and Woods Hole Oceanographic Institution (1930). Over the next decades, these new institutions, along with expanding centers for graduate education and research such as Harvard, Columbia, Berkeley, Illinois, and the Massachusetts Institute of Technology, would become identified with particular scientific fields, practically inventing them. The fields included infectious diseases, genetics, advanced computation, information theory, physical oceanography, solid state physics, and high energy physics.

Scientific questions are continually redefined by new ideas and the techniques to address them. For a period the scale and structure of individual U.S. institutions matched the questions. Over the last few decades, the scale and complexity of the questions have increased. In consequence, research programs have required a new management structure for many aspects of American science. The pattern is especially evident in earth and environmental sciences, where global issues lead the agenda.

2. Trends in organization of ocean sciences

The classical picture of ocean science at midcentury was an individual investigator with a small technical team and robust, simple instrumentation. Investigators necessarily worked in oceanographic institutes or marine laboratories that provided direct access to ships, which were the only means to obtain data. Obtaining data required lengthy periods at sea. Research vessels were controlled by the individual institutions. Much of the funding of the institutions was by block grants, often from the Office of Naval Research (ONR). Direction of research was determined by the heads of the institutions in discussions with their staff and the funding agencies. Decisions about patronage were made privately by a small number of individuals.

Over the last two to three decades the scale and nature of the scientific questions in ocean science have changed considerably. Often given as a textbook example of a "scientific revolution," development of the theory of plate tectonics provided substantive impetus. The integration of diverse studies of seafloor spreading led to striking new ideas and, by about 1960, to a large program in drilling of the deep seafloor to test and elaborate the ideas. Initially the program was managed for the community by the Scripps Institution of Oceanography. By the mid-1970s, political and other considerations elicited a broader U.S. organizational base, and Joint Oceanographic Institutions (JOI) Incorporated was formed with a board of leaders of the major U.S. oceanographic institutions and university departments involved in the Deep Sea Drilling Program. The prime funder, the National Science Foundation (NSF), contracted with JOI, and JOI spawned an infrastructure of panels that guided the program. The international aspects of the drilling program were promoted through JOI, and so through the management of the major U.S. institutions.

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*The Rockefeller University and Carnegie Commission on Science, Technology and Government, New York, New York.
+Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Meanwhile, the International Decade of Ocean Exploration (IDOE) had begun in 1970. Although earlier programs such as the International Geophysical Year (IGY, 1957–1958) brought together scientists from different institutions for joint work, the IDOE was notable for stimulating and sustaining such links and spanning ocean chemistry and biology as well as physics and geology. IDOE managers at the NSF had increased budgets and involvement in the structuring of the scientific program compared with the traditional programs that emphasized unsolicited proposals. The scheduling of research ships was put on a national basis to provide fuller utilization and to ease access for researchers outside the major oceanographic institutions. Meanwhile, new electronics, including moored instrumentation, acquired data automatically and faster, increased the efficient use of research ships, and conversely decreased dependence on large amounts of ship time.

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The 1980s saw further major developments in technology at sea, in space, and ashore. Ships remain a needed component but are no longer a sufficient basis for most research programs. Satellites provide new global data on sea level, surface temperature, and ocean color. Costs of satellites can be justified only on a national or international basis. The time from concept to flight is a decade or longer and thus requires durable working groups to advise and supervise. Advances in computation couple with the increasing data flows from space platforms and other sources. Numerical simulation modeling is now a dominant feature of most programs. "Modelers" appear to determine the pace and priorities in research. The "observer" is perceived to play a lesser or more routine role.

Computing technology has moved from central locations to large networks, from Crays to workstations. Add to this the enhanced communication by electronic mail and fax. These permit nearly immediate exchange of data, technical information, and reports, and so are ideal for rapid interchange, especially among researchers with the easy familiarity created by common disciplinary backgrounds.

While technology developed, so did scientific and political interest in greenhouse warming and other global problems. The key role of the oceans in understanding and predicting climate change emerged, and oceanography became "big" science. The concept for the World Ocean Circulation Experiment (WOCE) originated around 1981, followed by proposals for a global ocean flux study (GOFS) in 1984, both triggered by satellite capabilities. Global-scale oceanography was absorbed into the "Global Change Research Program" (International Geosphere–Biosphere Program, IGBP) which took shape in the late 1980s. This program emphasizes integration of marine, atmospheric, and terrestrial sectors, as well as physical, chemical, and biological research.

The principal agencies funding ocean science, the ONR, NSF, and National Aeronautics and Space Administration (NASA), have built and maintained their basic organization along disciplinary lines. Program managers accept proposals in physical oceanography, chemical oceanography, marine biology, and marine geology/geophysics. The simple disciplinary structure has been efficient for handling the small scale of most proposals. The extension of this form of organization to the larger programs can be attributed to the persistence of existing structures. It also accords with the desire of scientists to have national and international discipline networks—invisible colleges—as the first level of organization of science rather than a hierarchy based on institutions.

In American oceanography these "colleges" usually develop from informal discussions by a small group, leading to a larger study arranged by JOI, or the National Research Council (NRC), the principal nongovernmental organization advising government in all fields of science. The resultant report must define a focus for a national program and demonstrate a consensus within a discipline such as WOCE for physical oceanography and GOFS for chemistry/biology. "Offices" funded by the federal agencies and independent of any particular institution are established to operate the programs. The interesting feature is that traditional research institutions, as management entities, figure little, if at all, in the process. The aim of the leaders of these programmatic groups is to secure funds for themselves and their colleagues across the country, who are generally on soft money.

Three-quarters of the funding for oceanography now comes from federal grants. Thus, it is not surprising that investigators have come to see the program managers in the government agencies in authoritative roles. The relation of researchers and program managers has always been close; as program initiatives become larger, more complex, and more costly, the program managers become more directly involved in designing and implementing them. Some argue that the relationship between principal investigators and program managers now determines the direction of research (Mukerji 1989). Empirical analysis could determine the extent to which the role of the unsolicited proposal coming in "over the transom" has decreased relative to negotiated multi-investigator, multi-institutional programs. In the latter, the program managers and division directors have a much more active stance.

3. Trends in organization of atmospheric sciences

Many developments in atmospheric sciences resemble and converge with those in ocean science. These include globalization, decreased reliance on proximity to a particular piece of machinery, growing federal role, large-scale planning, program offices independent of traditional institutions, and equivocal relations with other disciplines.

The modern transformation of atmospheric sciences is traceable to the recognition by John von Neumann and others in the 1950s that mathematics and computation could significantly advance weather prediction, in short, make it "numerical" [for a helpful retrospective, see Fleagle (1992)]. Accustomed by World War II to working with the military, the scientists usually turned for funds for post–World War II meteorology to the air force. The role of the ONR was filled for the atmosphere by the Cambridge Research Laboratories and other air force units.

By the late 1950s, new institutions were created to capitalize on the possibilities for enhanced prediction, for example, the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton and the National Center for Atmospheric Research (NCAR) in Boulder. In marked contrast, oceanography formed no new national centers. Funding came, respectively, from the National Oceanic and Atmospheric Administration (NOAA) and NSF, reflecting the changing justification for research from military to civilian purposes. The institutions were built around the idea that computers sufficient to crunch the data would be too costly for an individual investigator or university department. Moreover, the world community in these fields was small, and it was felt that centers of excellence on a larger scale were needed. A consortium of university departments of atmospheric sciences and like organizations, the University Corporation for Atmospheric Research (UCAR), was established to govern NCAR.

By the early 1960s, Jule Charney and Edward Lorenz were systematically exploring the limits of predictability. They quickly realized that for forecasts to extend 7–10 days, global observations were needed. Technology, particularly satellites, promised such observations. President Kennedy set the machinery in motion in his speech to the General Assembly of the United Nations in September 1961: "With modern computers, rockets and satellites, the time is ripe to harness a variety of disciplines for a concerted attack. . . . we shall propose further co-operative efforts between all nations in weather prediction . . . [and] . . . a global system of satellites linking the whole world."

The concept was operationalized during the 1960s through the creation of the World Weather Watch and the associated Global Atmospheric Research Program (GARP), intended to extend the range, scope, and accuracy of weather forecasts. The experiments of GARP required satellites, aircraft, balloons, international fleets of vessels, and other platforms, operating in tight synchrony. United States funding came primarily from NSF, NOAA, and NASA.

Meanwhile, interest in world weather was joined by concern about global climate. The IGY marked the establishment of the actual monitoring of atmospheric carbon dioxide levels. By the late 1970s the measured rise was drawing political as well as scientific attention. Moreover, the general circulation models (GCMs) developed in connection with GARP could also calculate climate change.

As GARP came to a close in the early 1980s, the World Climate Program sprouted from it. Long-range numerical weather prediction required dynamical meteorologists to reach out to colleagues in space science and technology and oceanography. Climate required a reach much deeper into the oceans and to the sun, as well as cooperation with geologists, ecologists, geographers, and others. The broadening ambition for identification and prediction of "global change" was symbolized by the emergence of the IGBP, funded by a dozen federal agencies.

The point is that a generation of scientists has grown up whose institutional vocabulary consists of network operations: GARP, GATE, TOGA, WCRP, IGBP, OIES, NIGEC, and CIESIN.[1] To a considerable measure, these have superseded the universities and other traditional bricks-and-mortar institutions as the identity cards of atmospheric researchers. Although this is less true in mesoscale meteorology, it is not for

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[1] GARP Atlantic Tropical Experiment (GATE), Tropical Ocean Global Atmosphere Program (TOGA), World Climate Research Program (WCRP), International Geosphere–Biosphere Program (IGBP), Office of Interdisciplinary Earth Sciences (OIES), National Institute of Global Environmental Change (NIGEC), Consortium for International Earth Sciences Information Network (CIESIN).

lack of trying, as efforts such as SESAME, HIPLEX, and STORM have been mounted.[2]

4. Issues

The changing balance of power among research institutions in American science raises a host of issues.

a. Integration of research across disciplines

One approach to interdisciplinary cooperation is through the committees of the NRC, whose main purpose is to advise federal agencies. The NRC has committees for disciplines such as ocean, solid earth, and atmospheric sciences. To cope with global environmental change, the NRC has formed committees whose terms of reference include land, sea, and air sectors, and sometimes social as well as natural sciences. In their reports, such multidisciplinary groups often revert to disciplinary divisions. Within a campus or research institution, the incentives for interdisciplinary cooperation are overpowered by centrifugal forces. Is only the surface of modern earth science interdisciplinary?

JOI illustrated an earlier strategy for coordination and integration with reliance on the component institutions, whereas the emerging network technologies move scientists toward disciplinary groupings. Is there JOI without drilling? UCAR illustrates a disciplinary network strategy but one increasingly confronted with the limitations of a discipline.

b. How to achieve large scale at acceptable cost

In the 1950s and 1960s a favored response in many fields to increasing scale of concepts and technology was the establishment of large national centers, such as NCAR. These have proven to be awkward partners in distributed, national, and global programs. They tend to become internally segmented themselves and ineffective at integration. The new institutional preference is for consortia, joined temporarily in a specific search or mission. The limits of large networks will be tested in coming years.

Although the ultimate conduct of large research programs may be decentralized and relies on voluntary actions of many individual scientists, the funding decisions remain concentrated in Congress and especially the executive branch of the federal government. Within and across the agencies, a "big" concept is needed to gain funds. Individual program managers are territorial, as is characteristic of hierarchical, compartmentalized organizations; their divisions and directorates normally compete as well. In the bureaucracy, large scale is achieved through formally constituted groups nested at each level. The Committee on Earth and Environmental Sciences (CEES) established by the White House–based Federal Coordinating Council for Science Engineering and Technology (FCCSET) is the highest level of integration and also defines priorities. Transaction costs, such as time spent in meetings, are high. So are pressures for science to set goals, respond to economic priorities, and account for itself.

c. The interface between the bureaucratic structures that fund most science and the research enterprise itself

As suggested above, the bureaucracies are essentially hierarchical in structure, while science has a highly individualistic and distributed character. The NRC seems to provide a reasonable interface, when the organization of the NRC and the structure within agencies are congruent. Funding for NRC activities is provided by the agencies on the same general soft money basis as the research programs, and usually by the same program managers, who are thus in a position to shape the NRC structure.

d. Goals for research

The funding agencies, driven by missions and overseen by Congress, want to set goals for the research system and design it to match their purposes. Congress has strongly supported the linking of research to national goals (see, for example, Committee on Science, Space, and Technology 1992). Science, on the other hand, has no objectives at all, but explores stochastically the realm of contiguous possibilities, moving in the direction of certain gradients in an optimization space. Setting objectives, even if a posteriori correct, may forbid the system the exploration of potentially fruitful routes and so may constitute an inferior form of strategy. This clash of cultures will never cease. It may intensify in coming years as the buffer provided by traditional institutions thins.

e. The locus for the gestation of new projects

In the past, individual research institutions have borne new projects, providing security and support within their own structures. The new systems for initiating projects, relying on federal funds, may be more democratic but less secure and independent.

f. Mismatched time horizons and research problems

The federal budget is almost entirely operated on an annual basis; capital budgeting and other multiyear

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[2] Severe Environmental Storms and Mesoscale Experiment (SESAME), High Plains Experiment (HIPLEX), Stormscale Operational and Research Meteorology program (STORM).

commitments are notoriously difficult. Yet, time for initiation of large projects is usually 5–10 years, and longer if satellites are involved. Meanwhile, the field-oriented scientists in the independent research institutions and in university departments depend on soft money for three-quarters of their salaries and research expenses. The time horizon for such investigators is necessarily 2–3 years, or even less. The soft money scientists cannot afford to spend much time on research that will not pay off in publishable results for a decade or more. Both long-term planning and research requiring patience are hard to fund through the grants economy.

g. Shifting dependency between the professorate and their institutions

Administrations encourage their research staff and faculty to seek external funds. In fact, institutions rely on the revenue streams generated from overhead on contracts and grants. Recovery of staff or faculty salaries is even more important than overhead for many institutions because it is a long-term commitment whose cost the institution is legally obligated to assume. Hiring practices at universities and other research institutions to an increasing extent depend on the money an individual brings to an institution. As long as external collections increased, institutional leadership may not have noted or missed their diminishing autonomy.

h. Reliable development and maintenance of human and logistical resources that are not immediately salable

Not only in science, but in our society as a whole, individual professionals are functioning as itinerant journeyman. This is not new in academia. Abelard and other medieval professors traveled from university to university collecting fees at the door for their lectures. In business, professionals have been urged recently to think of themselves as "consultants" to their employers, constantly rejustifying their presence and ready to shift to alternative employers when opportunity strikes.

It may be that the classical large, stable research institutions are becoming endangered or even extinct, like many department stores and other businesses. In their places are the networks that gather, focus, and allocate shifting pools of human, physical, and financial resources. A few phone lines and a PC enable one to perform almost all intellectual work. The favorable view is that a healthy, economical "flattening" of organizations is taking place. *Business Week* (8 February 1993) highlighted this trend in a cover story on "the virtual corporation" which it introduced this way: "Big, complex companies usually can't react fast enough. Small, nimble ones may not have the muscle. What's the answer? A new model that uses technology to link people, assets, and ideas in a temporary organization. After the business is done, it disbands. It's called the virtual corporation. Just another management fad—or a vision of the future?"

5. Discussion

For several reasons, traditional research institutions have a decreasing role in the formation and management of research programs. Their faculty, directors, chairs, and deans accordingly have little opportunity to provide scientific leadership within their own confines, other than through service in national and international planning efforts. It is no longer true that institutions obtain funds for research. The institutions recruit (or host) the scientists, and the scientists obtain the funds. Funding agencies support projects. Institutions support people, but also live off the funds they raise. The major function of institutional leadership is in quality control through selection and training of scientific staff.

An analogy can be drawn with health care, where it has been said that hospitals do not have patients; hospitals have doctors, and doctors have patients (Fuchs 1986). As the cost and complexity of the enterprise increase, the management task enlarges, but the responsibility and accountability of the institution for its ultimate products and services diminish and change. This shift might matter little if funding were still based mainly on diverse, unsolicited proposals from individual investigators. It may matter more when in many branches of science, "bigness" and much greater interaction with the government agencies prevail.

The changes in the organization of research appear to match the development of ideas and techniques. The impetus for the particular pattern of restructuring appears to have come from the scientists themselves, from the emergence of global (geo)science, the larger scales, the higher costs, and from the preference for multi-investigator, multi-institutional groups allied in a broad discipline and occasionally across disciplines. The approach seems to be preferred to multidisciplinary programs within a single institute. It may be the most direct way to couple working scientists, the generators of ideas and technology, with sources of funds. Yet, it may also move program decisions more to persons in an administrative rather than scientific culture, who are longer steps from the actual performance of research.

These comments derive from ocean and atmospheric sciences, but all fields of science have participated in the modern revolutions in transport of people and bits. High speed at low cost has collapsed physical distance and intellectual time lags. Americans increased the number of miles they traveled and messages they sent by about a factor of ten between 1950 and 1990. Scientists probably exceeded this rate of increase and appear to be at the forefront of a new surge of growth in network operations. The ease of operation of the global colleges may be an underestimated factor in determining the character of recent large programs, such as the World Climate Research Program and Human Genome Project, which are predominantly within disciplines and across institutions and nations.

What appears to have been lost is a countervailing power (Galbraith 1984). Poised between the actual performers of the research and the funders, the research institutions with their diverse locations and traditions provided independent approaches to priorities. Historically, they had an ability to maintain distinctive institutional cultures over decades. Rare qualities of individual leadership were needed to sustain societal trust without elaborate scrutiny and procedures or the direct consent of taxpayers.

The increased role of the federal agencies in determining priorities may be viewed as a major consequence, rather than a primary cause, of the shifting balance of power. However, many would claim that the balance of power in the system is now unduly weighted in favor of its federal components. Early in the life of the American republic there was an intense debate about whether to establish a national university. The idea, proposed by Benjamin Rush in 1787, was approved by Thomas Jefferson, but never gained sufficient support (Madsen 1966). Two hundred years later the United States appears close to realizing the notion through the NSF, NIH, and other major funders of research, who de facto operate branch campuses across the country.

How general is the organizational trend? It would seem to be occurring in numerous fields of research and in other countries as well. In Britain, the directors of the oceanographic institutes have quite formally been downgraded in relation to the headquarters staff at the National Environmental Research Council. Severe constraints on funding in Britain complicate the comparison.

Research institutions, as places with laboratories, workshops, and offices, will always be necessary. We can argue about sizes and locations, and sources of comparative advantage in a world of easy communication. But will these places retain their individual styles of operation, their intellectual diversity, and an appropriate share of power? It seems unlikely that they can return to an earlier pattern. Perhaps fresh concepts of research institutions, emphasizing a few core structures and services and a complex of loosely held organisms existing around them will help. Ways can be sought within the context of the new technologies and funding patterns to build healthy ties between individual researchers and their host structures.

The organization of science should be continually changing. Increase in the number and scale of geographically dispersed, disciplinary networks as organizational and fiscal units is refreshing. Now may be the time for the virtual university. But the distribution of power and energy among the diverse institutions that house and enable science will surely shift again. In fact, the dynamic provides the heterogeneity of preferences, skills, and expectations that ensures that the whole system evolves in innovative ways. We should not expect the organizational map of earth science to remain flat.

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