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The Significance of Research Platforms for Future Advances in the Earth Sciences

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Article abstract

Scientific advances in recent decades in space exploration, satellite observations, and super computing have resulted in an ability to undertake global studies that were formerly impossible. The change in applied earth sciences from supporting the resource exploration sector to including the environmental conservation and protection sectorhas added new requirements for regional and global baseline environmental studies. Many new initiatives have been launched as international collaborative programs in which Canada — given its large land area and its front age on three oceans — has commonly had a special responsibility to play an important scientific role.

The means by which such science is under taken has likewise adjusted tothese changes in the discipline. In particular, the need for sophisticated scientific research platforms has become essential. These range from space platforms (space stations, satellites), to atmospheric research platforms (balloons, aerosondes, mobile field stations), to ocean research platforms (ships, ice islands, tethered and autonomous underwater vehicles, drill ships),to continental research platforms (fieldstations, drilling platforms, seismic platforms).

The management and funding of such research platforms is usually difficult and not well accommodated by institutions or granting agencies. The cost istypically more than can be recovered by user fees from individual researchers, yet below the special funding levels secured by some "big science" projects. It is argued that a new grant category {i.e., for NSERC grants) of Major Logistic Grants is required to balance the existing areas of support, such asEquipment Grants and Research (Oper-ating) Grants. This would provide notonly greater equity in proposed lines ofinquiry, but would allow for more cost-effective long-term planning of complex interdisciplinary international programs.

the emission of methane from the Hudson Bay lowlands over a full annual cycle. A special (Summer 1992) issue of the *Journal of Geophysical Research* devoted to papers describing the results of this joint Canada-United States project is an interesting early example of the sort of focussed collaborative effort that is a sure harbinger of what the research future has in store.

CONCLUDING REMARKS

The above discussion of future research trends in the atmospheric sciences has, of necessity, been less than exhaustive and is probably less well balanced between experimental and theoretical research than I would have liked. It should be seen as an attempt to convey something of the flavour and the range of considerations that are now shaping the research agenda in this area of science. If atmospheric science is to continue to advance vigorously in Canada, it is important that certain conditions be met. These conditions would include the delivery of adequate supercomputing capacity to university-based scientists, a deepening of the involvement by the Canadian Space Agency in funding the application (as well as the collection) of atmospheric data from space, and a strengthening of the funding base of the Natural Sciences and Engineering Research Council research grants program in environmental earth sciences. The investment by the Canadian Climate Centre in the development of a Network for Climate Research should play an important role in the immediate future by way of galvanizing work across the community on large-scale climate-related problems. It is an example of the sort of initiative that will be required to more fully link scientists in government laboratories with those in the universities in order that the country may continue to deliver the leadership in the atmospheric sciences that has most often characterized its contributions in the past.

REFERENCES

Boer, G.J., McFarlane, N.A., Laprise, R., Henderson, J.D. and Blanchet J.-P., 1984a, The Canadian Climate Centre Spectral Atmospheric General Circulation Model: Atmosphere-Ocean, v. 22, p. 397-429.

Boer, G.J., McFarlane, N.A. and Laprise, R., 1984b, The climatology of the Canadian Climate Centre spectral atmospheric general circulation model as obtained from a 5-year simulation: Atmosphere-Ocean, v. 22, p. 430-475.

Broecker, W.S. and Denton, G.H., 1989, The role of ocean-atmosphere reorganization in glacial cycles: Geochimica et Cosmochimica Acta, v. 53, p. 2465-2501.

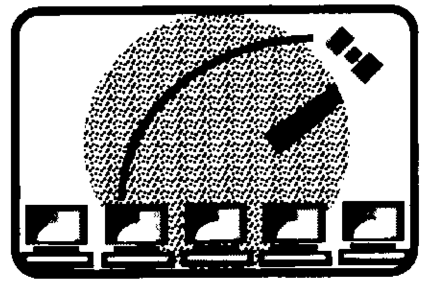
Drummond, J.R., 1989, Novel correlation radiometer: the length modulated radiometer: Applied Optics, v. 28, p. 2451-2452.

Intergovernmental Panel on Climate Change, 1990, Climate Change: The IPCC Scientific Assessment, *in* Houghton, J.T., Jenkins, G.J. and Ephraums, J.J., eds.: Cambridge University Press, Cambridge, 365 p.

McFarlane, N.A., 1987, The effect of orographically excited gravity-wave drag on the circulation of the lower stratosphere and troposphere: Journal of Atmospheric Science, v. 14, p. 1175-1800.

Stewart, R.E., 1991, Canadian Atlantic Storms Program: Progress and plans of the meteorological component: American Meteorological Society, Bulletin, v. 72, p. 364-371.

Accepted 1 September 1993.



The Significance of Research Platforms for Future Advances in the Earth Sciences

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ABSTRACT

Scientific advances in recent decades in space exploration, satellite observations, and supercomputing have resulted in an ability to undertake global studies that were formerly impossible. The change in applied earth sciences from supporting the resource exploration sector to including the environmental conservation and protection sector has added new requirements for regional and global baseline environmental studies. Many new initiatives have been launched as international collaborative programs in which Canada — given its large land area and its frontage on three oceans — has commonly had a special responsibility to play an important scientific role.

The means by which such science is undertaken has likewise adjusted to these changes in the discipline. In particular, the need for sophisticated scientific research platforms has become essential. These range from space platforms (space stations, satellites), to atmospheric research platforms (balloons, aerosondes, mobile field stations), to ocean research platforms (ships, ice islands, tethered and autonomous underwater vehicles, drill ships), to continental research platforms (field stations, drilling platforms, seismic platforms).

The management and funding of such

research platforms is usually difficult and not well accommodated by institutions or granting agencies. The cost is typically more than can be recovered by user fees from individual researchers, yet below the special funding levels secured by some "big science" projects. It is argued that a new grant category (*i.e.*, for NSERC grants) of Major Logistic Grants is required to balance the existing areas of support, such as Equipment Grants and Research (Operating) Grants. This would provide not only greater equity in proposed lines of inquiry, but would allow for more cost-effective long-term planning of complex interdisciplinary international programs.

RÉSUMÉ

Les découvertes scientifiques des dernières décennies dans les domaines de l'exploration spatiale, de l'observation par satellites, et de l'informatique des super-ordinateurs nous ont permis de lancer des recherches à l'échelle du globe, recherches jadis impossibles. Les sciences de la Terre ne trouvent plus seulement leur application comme support à l'exploration des ressources, mais elles sont aussi utilisées dans le domaine de la protection et de la conservation de l'environnement, et cela exige que des levés environnementaux de base à l'échelle régionale et à l'échelle du globe soit produits. Un grand nombre d'iniatatives ont été lancées sous forme de programmes conjoints internationaux, et en général, le Canada y a joué un rôle scientifique important étant donné ses trois fenêtres océaniques et sa grande superficie.

Les outils nécessaires pour entreprendre de telles recherches scientifiques ont également changés selon les disciplines. Et en particulier, les besoins de plateformes de recherche scientifique de pointe sont devenus essentiels. Il s'agit tantôt de plateformes spatiales (ballons-sondes, sondes atmosphériques, stations mobiles au sol), tantôt de plateformes de recherches océaniques (navires, îles de glaces, véhicules sous-marins captifs ou autonomes, bateaux de forage), ou encore de plateformes de recherche terrestres (stations de terrain, plateformes de forage, plateformes séismographiques).

L'administration et le financement de telles plateformes de recherche sont choses difficiles généralement et leur support est mal assuré par les organismes ou institutions subventionnaires. Les coûts excèdent généralement les montants qui pourraient être récupérés sur las base d'un tarif utilisateur qui serait appliqué aux chercheurs individuels, mais ils sont inférieurs aux niveaux des subventions octroyées pour les «grands projets scientifiques». Nous soutenons que la création d'une nouvelle catégorie de subventions importantes (c.-à-d. subventions du CRSNG) visant la logistique viendrait équilibrer l'aide existante dans les domaines de l'équipmement, et du fonctionnement des projets de recherche. Non seulement cela entraînerait-il une répartition des demandes plus équitables selon les catégories de soutien, mais cela permettrait également d'améliorer la rentabilité à long terme pour l'organisation de programmes interdisciplinaires internationaux complexes.

INTRODUCTION

For their investigations, scientists require an office and, typically, a specialized laboratory for observation, experimentation, curation, analysis and preparation of reports. A century ago, much science was of an observational nature with emphasis on understanding natural laws and phenomena. For field work, many scientists travelled on foot, some supported by field parties with horses and canoes. In the present century, experimental science has flourished, requiring much instrumentation and large laboratory complexes: molecular biology surpassed systematic taxonomy, and geochemistry and geophysics displaced the formerly pre-eminent geological mapping. Advances in microscopy and analytical instrumentation led to new research programs and redeployment of resources in examining the scientific frontiers of small-scale phenomena (atomic structure, mineral physics, computational analysis, geochemical reactions, skeletal ultrastructure). This trend has continued to the present and has generated many of the "big science" proposals in other disciplines (supercollider, superconductors, supercomputers; in Canada, the Sudbury Neutrino Observatory (SNO) and the KAON factory).

In the natural, environmental and observational sciences, a number of developments occurred during the last three decades which have resulted in a revolution in scientific approach and concepts. Key among these developments have been space exploration, satellite observatories, and supercomputers in science, together with the broad range of environmental threats and concerns on the social-economic-political agenda. Space exploration and the images of planet Earth from the moon led to a chilling appreciation of the insignificance of Earth within the universe. Satellite images and data have revealed the scale of forest destruction and burning in the Amazon forests, the size of the ozone hole over both polar regions, and the limited areas of high phytoplankton productivity in the world's oceans. The power of satellite data was revealed most recently by the pattern of drifting smoke from the burning oil wells and by the horrifyingly surgical air attacks during the Gulf War. In January 1992, a lead article in the Victoria Times Colonist newspaper included two colour satellite photographs showing the dramatic rate of removal by logging of the old growth temperate rainforest on Vancouver Island. The illustrations were released by an environmental group (the Sierra Club), demonstrating how sophisticated data can be widely used. The development of space exploration and satellite technology is intimately related to advances in computation. The continuing evolution of the supercomputer, in particular, has allowed for immense data storage, and complex and rapid numerical analysis. This, in turn, has generated new avenues of inquiry in areas such as seismic tomography, basin modelling, and coupled ocean-atmosphere global circulation modelling.

This connection between space exploration, satellite technology, and supercomputers has enabled scientists to develop global databases and to pose a wide range of theories, design new studies, and to better understand processes and predict reactions within highly complex natural systems. The progressive interaction between the solid earth sciences, ocean sciences, and atmospheric sciences has led to the new concept of earth system science: the study of the past, present and future dynamic systems operating on our planet, with particular emphasis on the consequences of anthropogenic environmental forcing factors (*i.e.*, National Aeronautics and Space Administration, 1988; National Research Council, 1993).

The extent of anthropogenic environmental forcing effects has become more apparent in the last decade. There have been numerous dire warnings of environmental degradation and ecosystem collapse, with proposals more toward new types of social and economic policies that would produce sustainable economic development. Such proposals were advanced in the United Nations Bruntland Report (World Commission on Environment and Development, Our Common Future, 1988) and, more recently, in the Agenda 21 Report following the 1992 Rio Conference. The concerns remain acute, given the predictions of a doubling of the world's population by approximately 2030. They have refocussed the directions of many of the sciences, and created an urgency to develop regional and global databases, to monitor short- and long-term environmental change, to understand the complexities of natural and forced systems, and to develop improved predictive capabilities. In this broad context, there is evolving a need for a wide range of research platforms, no longer to just examine natural phenomena in more exotic locales away from the laboratory, but to systematically and rigorously monitor and probe complex environmental systems. Data recovered using such platforms will be essential for programs such as the International Geosphere-Biosphere Program (IGBP; Global Change) and the International Ocean Drilling Program (ODP), and is required for incorporation by new programs, such as the International Decade of Natural Hazard Reduction (IDNHR).

RESEARCH FRONTIERS

Prior to examining specific research platforms, it is pertinent to consider, in more detail, some of the societal pressures that are driving new research programs, and to outline some of the scientific proposals that require support of research platforms.

With a growing world population and the voracious appetite for natural resources of many developed countries, this century has witnessed the escalation of an unsustainable rate of resource consumption and the transfer to future generations of a substantial environmental debt (*i.e.*, the future clean-up costs for today's inadequately regulated activities that generate long-term detrimental effects).

Many rich and diverse natural resources have been depleted or destroyed during the last 200 years: mineral and petroleum resources; fish, whales, turtles, elephants, rhinos and a variety of other marine and terrestrial animals; massive clear-cutting of the tropical and old-growth temperate forests, with a reduction of biodiversity at a scale resembling some of the major paleontological extinction events of the geological past; chemical pollution of lacustrine and coastal marine environments; chemical alteration of the atmosphere to create large holes over the polar regions through partial destruction of the protective ozone layer; soil erosion and loss with urban development, deforestation and poor agricultural practices; and reduction of soil productivity through monocultural practices and excessive reliance on chemical fertilizers.

These are a few examples to illustrate how much social and economic gain has been derived by converting a rich and diverse natural endowment into human wealth, but commonly at the expense of the environment and through systems that are unsustainable. If the world population were shrinking, it might be argued that the reduced future yields would be shared between fewer people to maintain or improve current standards. However, given the anticipated population doubling within the next 40 years, it is evident that many natural systems will be drastically modified, depleted or will collapse, with the possibility of similar profound change in societal structures.

Two examples in Canada seen in recent years may suffice to illustrate the current rates of change: the east coast fishery and the west coast forest industry. An abundance of fish on the Newfoundland Grand Banks sustained a small population in Newfoundland, together with a rich export trade to the United States and Europe, for more than four centuries. A combination of poor knowledge of the ecosystem, possible changes in ocean temperatures, enhanced fishing technology (especially factory fishing vessels), and an inability to control over-fishing in international waters has led to the collapse of much of the fishery. Scientific study of the natural environment and resource was inadequate compared to the application of advanced scientific and engineering knowledge applied to detecting, catching and processing the fish. The loss suffered in the fabric of Newfoundland society — of bankrupt fishing companies and of welfare payments from other Canadians — is surely not worth the short-term gain induced by over-fishing. With the collapse of the wild fishery, there are increasing attempts to develop the aquaculture industry. This, in turn, has suffered several serious setbacks, including an early decimation of Newfoundland salmon aquaculture stocks by disease. Attempts to replace the wild fishery by aquaculture in coastal waters that may no longer be pristine in environmental quality may have severe limitations.

The Canadian forestry industry has experienced similar serious questions about sustainable yields. In central Canada, the magnificent white pine stands were cleared early, with only a few remnants left in some corners of northern Ontario. In western Canada, the coastal temperate rainforests, rarely affected by fires, have value to the industry in vast quantities of wood, but also to some of the public and environmental groups as a unique recreational and inspirational setting. In the last few years, the bark of the Pacific yew, never harvested by the clear-cutting methods, has been processed to produce the promising cancer drug taxol. Medical, ecological, recreational and spiritual values of the rainforest have challenged the former largely economic values, and have led to a re-evaluation of forest management practices, especially in British Columbia (and elsewhere in the Pacific Northwest and Brazil, if not in Myanmar (Burma), Haiti and Indonesia). Similar land-use issues have involved mining, such as the recent decision by the British Columbia government to deny the development of the Windy Craggy mine by establishing a vast new provincial park in the Tatshenshini area near the border with Alaska.

Such fundamental changes in resource industry operations have begun to encourage new directions of scientific inquiry by both industry and government regulatory agencies. In both cases, the expanded use of research platforms will be necessary to better understand complex earth systems and to develop improved remotely operated environmental monitoring systems.

In addition to over-exploitation, the combination of increased population, resource consumption, environmental degradation, and the combustion of fossil fuels has led to several broadly based international research programs. Two, each with several subprograms, may be illustrative. The International Geosphere-Biosphere Program (IGBP; hereafter, the Global Change Program) has an expanding range of core programs involved with the present and past conditions of the atmosphere, oceans and solid earth and, in particular, with climate change and its consequences for agriculture, forests and sea-level change (IGBP, 1990). Humankind will have consumed, largely over a period of some 300 years, most of the world's extractable total subsurface reservoirs of fossil fuels (coal, oil, natural gas) and, through combustion, will have transferred vast quantities of CO_2 and other emissions into the atmosphere. The anticipated greenhouse effect is predicted to raise the mean global temperature by between 1.5°C and 4°C by the end of the next century, and potentially raise sea level by an average of some 60 cm (with a doubled CO_2 scenario) (IPCC, 1991). Recent studies of the long Greenland ice-core record of climate variability have shown amazing shifts in annual temperature of up to 8°C within less than five years during the last interglacial period (Dansgaard *et al.*, 1993). Others have noted the important role of the oceans, particularly the stability of the thermohaline circulation, as a control on climate variability (*e.g.*, Weaver and Hughes, 1992; Weaver, 1993). It is now apparent that the highly stable global climate pattern that has existed for the last 8000 years (most of the Holocene Epoch) is anomalous, and that the earth's climate is normally more highly variable. During the next century, humankind may need to monitor the rate and scale of anthropogenic forcing to offset swings in natural or forced variability in climate in an attempt to maintain stable climate regimes.

There is much scientific and public debate on the global warming issue and on these specific estimates, hence, much new research is required. Since CO_2 is resident in the atmosphere for approximately one century, remedial actions have little effect in the short term. The nature and scale of buffering systems (cloud formation, absorption by the oceans, oceanic and terrestrial carbon sinks) in the carbon and methane cycles are poorly understood. The Global Change Program is likely to exist for well over a decade, during which time the People's Republic of China alone will have built at least 60 new major coal-fired electrical generating stations. The global scope of scientific investigations demand substantial resources, international collaboration, satellite databases, and a variety of research platforms. As humankind overpopulates the Earth and encourages static or fixed structures and activities (migration to urban conurbations, with specialized agriculture, silviculture and aquaculture in surrounding areas), it places itself in jeopardy by not being able to respond to changes induced by anthropogenic forcing. There is considerable concern about future pressures on immigration and migration of people across existing national boundaries if existing agricultural and water resources are disrupted by anthropogenic forcing or the rapidity of natural climate change noted above. As a small example of the costs involved, Hydro Quebec lost some $800 million within a recent three-year period by underestimating waterflows into the vast northern Quebec hydro-electric dams. In the same three-year period, the Canadian scientific community has been trying to secure sufficient funding to develop its contribution to the international Global Change Program, and to date has secured approximately $3 million annually. A significant investment in science and technology must be accepted as a requirement to understand such complex systems and to temper the financial losses incurred by variabilities in the systems.

A second major research program being developed through this present decade is the United Nations International Decade of Natural Hazard Reduction (IDNHR) (Press *et al.*, 1987). This program accepts that many of the environmental threats outlined above will come to pass, and is concerned about their human consequences in the heavily populated developing countries that can scarcely afford the recovery costs of major disasters. This program will attempt to identify potential hazards for various regions (*e.g.*, earthquake, tornado, hurricane, volcanic, sea-level change, climate change, soil erosion) and help develop basic plans to mitigate the potential damage of such hazards. The tornado in Trinidad in 1989 caused more than $11 billion damage, a cost the country could scarcely afford. The tornado could not be avoided, but the prediction and warning systems, the building code standards, the emergency measures, and land use planning could all be improved to mitigate the level of destruction. The devastation of recent floods in Bangladesh is another example of the consequences of a burgeoning population that seeks to colonize all available space, despite the obvious high risk. The predicted 60 cm sea-level rise by late in the next century would be especially hazardous to low-lying countries such as Bangladesh, Mauritius and the Netherlands, not to mention many of the world's major ports.

With the predicted global climate changes, an area in Canada destined for greater aridity is the prairies (southern Alberta, Saskatchewan, Manitoba). At present, the cumulative cost of soil degradation in Canada is anticipated to grow from $3 million in 1985 to $43 million in 2005 (Science Council of Canada, 1986), and subsidies to wheat farmers total billions annually. With a significant change in rainfall, soil moisture, and salinity, what level of investment in scientific inquiry is appropriate to provide a predictive capability, new strains of wheat, new irrigation methods, management of groundwater resources, preservation of soil quality, and productivity?

The brief examples given above for the state of the Canadian fisheries, forestry and prairie agriculture suggests that more investment in science and technology at an earlier stage and on a continuing basis would have led to more adequate knowledge for resource management, and would have paid for itself many fold. The slow, but progressive reduction in research and development funding in Canada as a percentage of the Gross Domestic Product (GDP) has slipped from 1.69% in 1965 to 1.34% in 1992, significantly weakening Canada's international economic competitiveness. What is required is a doubling, at least, of base budgets for research (*e.g.*, NABST, 1991; Larkin *et al.*, 1991; Sparrow *et al.*, 1991; AUCC, 1991). A portion of this funding must be allocated for large-scale collaborative research and support for Canadian or international research platforms.

In the section that follows, some research platforms are discussed in terms of their capabilities, scientific significance, limitations, costs and lifespan, and role in collaborative research. The list is not exhaustive, and restraints on space do not allow a full discussion on all facets of each platform. In total, those selected give some idea as to the need and priority of such platforms in the new range of scientific inquiry, especially in the environmental sciences. They have also been considered recently in the United States (National Research Council, 1993, Table 7-14). Such platforms will typically be available for multidisciplinary studies, so that examples noted in this paper are not confined solely to the earth sciences.

RESEARCH PLATFORMS

A variety of research platforms are reviewed which are categorized arbitrarily as exploring or operating in space, the atmosphere, the oceans, and on land.

Space Research Platforms

The last three decades have seen a progressively sophisticated and successful exploration of first, the moon and then, the solar system. More recently, studies have involved the atmosphere, surface topography and environment of Venus, the nature of the rings of Saturn, and details of the moons associated with the outer planets. Attempts to launch and utilize the Hubbard telescope to operate above the limiting influence of the earth's atmosphere have suffered technical problems. Canadian scientists have been involved, typically in co-operation with National Aeronautics and Space Administration (NASA) programs, and have contributed certain components (of which the Canad-arm on the Challenger Shuttle has been most noteworthy) in a number of critical tasks and experiments in space.

Much activity is now focussed on the deployment of the space station. This will be large enough to support occupation, for extended periods, by scientists who will have sufficient area and facilities to conduct various experiments for which the lack of significant gravity provides an opportunity not possible on Earth. A specific Canadian scientific responsibility will be research on microgravity. This scale of research platform is extremely costly. Canada's contribution to the program through the new Space Agency is approximately $2 billion, although some scientists are concerned that only a small fraction of this cost will be devoted to actual scientific experiments.

Satellites represent another form of research platform operating in space and in the upper levels of the atmosphere. Several nations have launched their own satellites or participated in joint programs. For some, the data are made publicly available after acquisition; others are secret military missions. Many different images are available using various spectral wavelengths. Landsat images have been perhaps the most widely used. The disciplines of remote sensing and geographic information systems (GIS) have emerged as powerful techniques in the spatial sciences. Scientists working in the field may now carry a small backpack or pocket personal locator beacon instrumented to relay to orbiting satellites that provide a global positioning system (GPS) to give their position on the Earth's surface, accurate to within a few metres. Both size and cost of such portable GPS receivers is being rapidly reduced. A series of Landsat satellites has been launched, of which Landsats 4 and 5 continue to function nominally. Landsat 6 construction is scheduled for a launch in the near future. Construction of Landsat 7 is proposed for 1994, with the cost of a clone of Landsat 6 being approximately $250 million US. Canada will soon launch Radarsat, which will emit radar signals to provide images of the Earth's surface independent of cloud cover. This feature is particularly important for coastal and polar areas where extensive cloud cover is the norm.

In the mid 1980s, NASA developed a major new long-term program for an observatory-class spacecraft referred to as EOS (Earth Observing System; Mission to Planet Earth initiative). This concept is to establish a sequential series of large space-borne platforms which would host an array of down-looking, bore-sighted instruments. EOS-A would be launched in about 1998, with five others during the next decade. A complementary complex system, EOSDIS, is being designed to receive, disseminate and archive the vast amount of data. The budget for EOS will be $271 million US in fiscal year 1992 with the total program costs predicted to be $17 billion US. The total funding in fiscal year 1991 for the United States Global Change Research Program (including an EOS component) was $676 million US. This figure compares to a total annual funding in fiscal year 1991 for all programs of the Canadian Natural Sciences and Engineering Research Council (NSERC) of approximately $400 million US.

Atmospheric Research Platforms

Research platforms operating in the atmosphere take the form of planes, balloons and remotely operated aerosondes. Canada has a few aircraft especially outfitted for airborne observations. Environment Canada routinely observes ice conditions along the east and arctic coasts. Energy, Mines and Resources Canada has recently reduced their airborne capabilities for systematic airborne geophysics (mainly aeromagnetic and gravity surveys, most of which are done under contract; budget cuts have reduced the programs). Canadian industry has led the world in developing and applying airborne geophysical sensing devices.

A significant problem in atmospheric science has been the intensity and repetition of sampling, since both balloon and high-altitude flights are expensive. Differing results between Canadian balloon observations and United States flight recordings led to an initial difference of opinion on the nature of the Arctic ozone hole. A similar disagreement on the origin and scale of acid precipitation in the North American north-east deferred agreements to reduce emissions for more than a decade, at profound environmental cost. One major resolving factor was the elegant, precise and scaled Experimental Lakes work by the Environment Canada research team, led by Dr. David Schindler, using mobile field stations. With the move of Dr. Schindler to the University of Alberta and with budget reductions, this internationally recognized program has been regrettably downsized.

The origin, production rates, and cycling of greenhouse gases such as methane are now under international study. In the recent Northern Wetlands Project, a combination of low-altitude flights and field stations produced measurements of methane generated over a large area of the muskeg swamps of northern Ontario. The relative fluxes of natural and anthropogenic sources of methane must be understood. Some scientists have cautioned that the methane generated by dammed lakes is considerable, and may exceed the equivalent emissions produced if the equivalent electricity was generated through combustion of fossil fuels

(Nisbet, 1989; Moore and Knowles, 1990).

On a more local scale, many anthropogenic emissions are generated in urban environments (car exhaust, power and pumping stations, factories, wood-burning stoves). Several major cities, notably Los Angeles, Mexico City and Beijing, experience severe pollution and high ozone levels. The deteriorating air quality in the lower mainland of British Columbia, where the mountains can trap noxious gases within the Fraser Valley, is considered British Columbia's most important future health hazard. Local platforms are needed, both fixed and mobile, to monitor and detect sources of pollution. New laser devices (*e.g.*, tunable diode laser spectrometer) can now detect accurate variations in noxious gases and open up new potential for both research and regulation. Small, inexpensive, remotely operated aircraft (aerosondes) will become effective platforms for sampling and monitoring a variety of atmospheric situations.

Ocean Research Platforms

Research vessels have long been the standard research platform for oceanography. Facing three oceans and having the largest coastline in the world, Canada has faced a formidable task in understanding its offshore territory and in contributing to international programs. The offshore area represents 30% of Canada's total territory. Nearly all marine research is dependent upon federal research vessels. Only three agencies are mandated to operate a fleet: the Department of National Defence (DND), the Coast Guard (CG), and the Department of Fisheries and Oceans (DFO). Only a modest amount of publicly accessible research (*e.g.*, acoustics) is generated by DND, and little from the CG. In DFO, much emphasis lies with the Fisheries sector, and basic science under the Oceans sector represents a relatively minor budgetary component. This sector has suffered 11 budget reductions in the last eight years. Other federal departments (*e.g.*, Energy, Mines and Resources) and university scientists share the research vessels, mainly those of DFO.

Extended negotiations have occurred recently to improve collaboration; particularly, for CG vessels to be used for research cruises. A truly effective partnership is still a future aspiration. In recent years, despite the increasing environmental concerns and the demise of the fisheries on the east coast, general government budget reductions have resulted in a reduction in the size of the research fleet, reduction in technical staff support and overtime payments, a deferment of new replacement vessels, and a reduction of support for related marine equipment. In 1991, the *DAWSON* and the *BAFFIN* were taken out of service and the *PARIZEAU* moved from the west to the east coast; the PISCES IV submersible operation could not be sustained and, in 1991, it was transferred to DND; the Hysub 5000 remotely operated vehicle (deep ROV; with a capability of use to 5000 m) is presently at risk with too few resources to operate it effectively. Canadian science led the world in the discovery and understanding of the hydrothermal vents and mineral deposits and the exotic "black-smoker" benthic communities, but the progressive erosion of capabilities to work in the deep ocean has crippled further advances and stalled support for the Canadian subsea technology industry. This industry is seeking support for a new generation of tools, such as the autonomous underwater vehicle (AUV), to be remotely operated, untethered, with a specialized fuel source (*e.g.*, hydrogen). The production of a Canadian AUV industry is the concept behind the SPIRIT proposal by a dozen Canadian companies, mainly British Columbia-based, presently seeking $20-30 million to launch the project. Armed with a variety of sampling, detection and photographic devices, such a platform could revolutionize much marine science, together with possessing a wide range of industrial capabilities. Remote, unmanned instrumentation platforms are likely to be the most cost-effective future developments, and are mirrored by the move to unmanned offshore weather stations and coastal lighthouses.

In the Arctic during the last decade, Soviet and Canadian scientists have successfully exploited huge natural ice islands. These mobile segments of pack ice have been somewhat modified to receive Hercules aircraft supply flights and to host near-permanent field stations, and perforated to allow geophysical soundings and sampling of water, biota and sediment beneath. The Canadian ice island was some 20 km across and 40 m thick (GEOS, 1989), and revealed many new scientific discoveries, including formerly unknown large shell banks and sponge reefs beneath the ice. This particular ice island unfortunately travelled back into the coastal pack ice rather than conducting a circuit of the Arctic Ocean, when United States and Soviet scientists would have adopted it when it passed through their territories. The recent news of the scale and extent of pollution and toxic dumping by the former Soviet Union into the Arctic Ocean underlines the need for wide and sensitive ocean monitoring.

The deep ocean is now known to be among the most complex and important of environments. It hosts major conveyer-belt currents that transfer dense saline, oxygenated waters over vast distances; it provides areas of carbon sinks in restricted anoxic basins; and it is the site of both new ocean crust along ridge systems and subducted crust in the deep trenches. Its biota is still largely a mystery, with speculation on potential exploitation of its genetic material by the biotechnology industry; yet there are serious discussions of disposal of toxic or radioactive wastes in the deep ocean. Japan, in particular, is considering how to dispose of CO_2 in the deep ocean. Deep sampling by physical, chemical and biological oceanographers is still in its infancy, and the deep ocean represents one of the principal frontiers (both geographic and scientific). Many such issues were addressed at the 1991 Dahlem Conference on the Use and Misuse of the Seafloor (Hsü and Thiede, 1992).

Perhaps the greatest understanding comes from the geological oceanographers following a decade of scientific drilling through the Deep Sea Drilling Project (DSDP), followed by the current replacement phase, the Ocean Drilling Program (ODP), which operates a state-of-the-science drilling research platform, the *JOIDES RESOLUTION*. This Canadian-built drilling vessel had seven stories of laboratories installed, has a modern sophisticated GPS system, and an ability to drill in high seas down to more than 1000 m in over 8000 m of water. In 1991, Leg 139 to the Juan de Fuca Ridge off Canada's west coast drilled several cores, up to 90 m, of massive polymetallic sulphide ore associated with the oceanic spreading ridge. In 1992, for Leg 146, the ship returned to the west coast to investigate the expulsion of fluids and methane, and the deeper gas hydrate layer (solid methane) in the Cascadia accretionary prism above the subducting plate. In 1993, the *RESOLUTION* will be drilling in the North Atlantic, with two port calls arranged for Canadian east coast ports.

In these last two decades, the use of these sophisticated research platforms has sampled the two-thirds of the Earth's surface that lies beneath the oceans and inaccessible to normal geological investigation. The nature of the ocean crust, the processes of sea-floor spreading, rifting and subduction, the record of change in oceanographic circulation and climate, and the evolution of the marine biota for the last 200 million years is being revealed. This type of exploration is, of necessity, a long-term venture, given the vast area to be covered and the relatively small volume of drill core recovered. The present ODP program costs approximately $40 million US annually. It involves collaboration of scientists from more than 20 participating countries and has seen a wide array of technical advances applicable to industry. Its future work will become more thematic in focus, and the vessel can contribute significant data to many of the issues embraced by the Global Change Program. Canada now belongs to the Program, in a partnership with Australia, at an annual membership fee of $3 million, and contributes nearly 10% of the international scientific effort. In December 1992, Canada's position in this successful partnership with Australia changed when both the Geological Survey of Canada (GSC) and Industry Science and Technology Canada (ISTC) indicated their unwillingness to continue their contribution level. Rather precipitous decision making with limited partner or ODP Council consultation created a crisis for future Canadian participation in ODP. Currently, Canada appears to have most of a one-third share (reduced from a two-thirds share) and is seeking, with Australia, a third partner for a new membership consortium. The lack of commitment to long-term science and to supporting one of the world's leading research platforms is of major concern.

Continental Research Platforms

Fixed research platforms on land take the form of field stations operated by both governments and universities. They may be highly specialized and equipped to investigate local conditions, or operate more as a base for wider regional studies with supporting fly-camps. The Natural Sciences and Engineering Research Council (NSERC) supports a number of field stations through infrastructure grants that are representative of both marine and terrestrial stations.

Marine field stations deal largely with nearshore marine biology, may have ocean water pumped into research aquaria, and may include a wide variety of marine research, but commonly with a biological focus. They possess small boats and diving capabilities, and typically play an important role in graduate and undergraduate training. Some are operated by a single university (*e.g.*, Logy Bay Marine Lab by Memorial University of Newfoundland) or by a consortium (*e.g.*, Bamfield Marine Station operated jointly by three British Columbia and two Alberta universities on Vancouver Island). Other field stations focus on particular local/regional settings, *e.g.*, Hudson Bay (Grand Baleine Station), Rocky Mountain foothills (Kananaskis Station), and northern Rocky Mountain glaciers (Kluane Station). Some stations are located outside of Canada (Bermuda Field Station, McGill University). Without such bases, the logistic operational costs for research in remote areas would be prohibitive, and new researchers would fail to gain the skills and training involved in field research. Many field stations also play critical roles in public awareness programs. The Arctic remains a vast area with only a few field stations. Some logistic bases (*e.g.*, at Resolute, Eureka) are present, and Polar Continental Shelf Project (PCSC in the Department of Energy Mines and Resources) provides logistic and funding support for some Arctic researchers and plays an important co-ordination, communication and safety role. PCSC was a key player in the success of the Canadian Ice Island referred to in the ocean research platforms section.

A new role for some existing field stations or a requirement for some additional stations is in ecological monitoring. In the United States, a program has been established for long-term ecological monitoring of a score of specific sites. At each small location, the changes in the physical and biological aspects are routinely recorded. These are designed to give a long-term environmental data base. For North American coverage, clearly Canada needs to establish a similar array of sites, perhaps using the system of national and provincial parks where existing trained staff can take the recordings and even develop results into public exhibits and brochures. This has been proposed by A.R. Berger within a TERRAMON project in Newfoundland and Labrador. This could be extended to some of the new marine parks. Phenomena such as the seemingly worldwide reduction in frog populations may then become better understood, and global environmental modelling would be much better constrained. Such monitoring sites are only successful if there is a commitment to long-term support; the termination of a variety of activities under the Canadian Wildlife Service a few years ago is an instance where such long-term observations are regrettably disrupted. In the important deep sea environment, some of the ODP drill hole sites could be used as monitoring stations.

There are a wide variety of mobile research platforms which, again, can be expected to diversify with the pressures for systematic environmental monitoring. Subsurface exploration is partly achieved by seismic surveys and the deep crustal studies using a large mobile Vibroseis facility under the LITHOPROBE Program. The latter program is now in its fourth grant period and has generated a wealth of important scientific discoveries (*e.g.*, Clowes, 1993). Mobile geochemical laboratories are used for river and lake geochemistry studies (*e.g.*, acid rain, mineral exploration, environmental health). In Australia, special acid labs are used in the desert for micropaleontological studies, as geologists may be in the field for periods of 3-6 months and need the data immediately to structure their later work schedule and ongoing geological interpretations.

Subsurface drilling from mobile, but locally fixed drill rigs (on land and at sea) is a widely used technology in the mineral and petroleum exploration industries. For research programs, scientific drilling is expensive and has been typically deployed in shallow soft sediments (*e.g.*, glacial sequences). Recently, more ambitious programs have been established. Those in the marine realm (DSPD, ODP) are discussed above. On land, the Continental Scientific Drilling Program (CSDP) has been established as part of a wider international program. Early pioneering work by the former Soviet geologists and engineers on the Kola Peninsula ran into numerous technical problems, but penetration to more than 14 km has been achieved. Later deep drilling projects were launched in Germany, the United States, and formatively in Canada. Some are tackling strictly scientific targets. In Canada, for example, the first main proposal was to drill in the Kapuskasing area, northern Ontario, into the ancient lower crust to test many intriguing features revealed in the LITHOPROBE seismic transects. Another recent target was to drill and sample across the Cretaceous-Tertiary boundary in Alberta to focus on the biological extinction event and the evidence for a bolide impact. In the United States and Germany, the drilling work is closely related to the need for information about the proposed deep disposal of hazardous waste (including nuclear wastes). The high pressures and temperatures and the highly saline brines commonly encountered pose new technical and engineering difficulties for traditional industrial drilling; new tools and technologies are required. Certainly, probing further into the third dimension of the subsurface will be at the forefront of future geoscience research. As details of surface geology are understood, the extension of the structures into the subsurface, the role of fluids, and mechanisms of solute transport and contamination are frontier elements of geoscientific inquiry. Both the mineral and petroleum exploration industries will be forced progressively into deeper crustal levels to seek new reserves as the more readily found surface or shallow discoveries are depleted. Hence, deep drilling research will find increasing future application by industry, and appropriate drilling platforms are needed for government and academic researchers.

SUMMARY

Research platforms of various types are becoming increasingly sophisticated and diverse. As concerns for the global environment are heightened, the need expands for new techniques, platforms and monitoring programs. Advances in fuel cell technology and data recording and transmission will result in a wider array of remotely operated, highly instrumented platforms. As research in the natural and environmental sciences probes into the frontier areas of the deep crust, the deep ocean, the upper atmosphere, and space, different research platforms will evolve. Issues such as environmental degradation and monitoring, resource depletion and exploration, waste production and disposal, pollution emissions, and climate change all demand additional knowledge, especially to understand the complexity and interrelationship of natural and anthropogenically forced systems.

Research platforms are merely necessary structures to help scientific inquiry, and may be fixed or mobile; located in space, the atmosphere, the ocean, or on land; and may penetrate up, down or laterally. Some are strictly for research, some are for long-term monitoring, others provide for specialized training and for public education (*e.g.*, field stations). This paper considers, in brief, the nature of a wide range of research platforms, considers some of the costs and logistic problems, and describes some of the recent and projected scientific advances.

Although the logic, purpose and success of research stations is widely recognized, a nearly ubiquitous problem is that of funding. Costs are typically large and maybe unpredictably variable. Research platforms typically support collaborative and often multidisciplinary research. Funding is for diverse activities, research teams, multiple institutions, and with variable annual operating and maintenance requirements. Therefore, they pose problems to managers and to funding agencies. Those platforms operated for university researchers are a special problem, since NSERC does not have a clear program for supporting such platforms. Field stations are covered under Infrastructure Grants, some platforms are supported under the new Collaborative Special Projects Grants, or as special programs (LITHOPROBE; Sudbury Neutrino Observatory). With the majority of scientific work covered by Research (formerly Operating) and Equipment Grants and some by the Collaborative Research Initiatives Program (*e.g.*, CSP awards), a new category of Major Logistics Grants is required by granting agencies such as NSERC. Under this category, funding for, and research involving the use of a wide variety of research platforms could be applied for in an open competitive system. As noted in the introduction, as scientific inquiry has evolved, it has diversified from individual investigations (Research (Operating) Grants), through to complex laboratories (Equipment and Infrastructure Grants), to collaborative research (Collaborative Special Projects Grants), to now exploiting a wide range of research platforms for which there is no adequate grant category for competitive support, and for which only a few opportunities are covered, mostly inadequately, by existing grant categories. Given the anticipated growth in research platforms in the future, agencies such as NSERC, working with federal and provincial parties, should endeavour to seek new solutions in a systematic collaborative manner for the stable, but competitive funding of research platforms.

REFERENCES

Association of Universities and Colleges of Canada, 1990, Canada's universities and the new global reality: AUCC pre-budget submission to the Minister of Finance.

Clowes, R.M., Cook, F.A., Green, A.G., Keen, C.E., Ludden, J.N., Percival, J.A., Quinlan, G.M. and West, G.F., 1992: LITHOPROBE: new perspectives on crustal evolution: Canadian Journal of Earth Sciences, v. 29, p. 1813-1864.

Dansgaard, W., Johsen, S.J., Claussen, H.B., Dahl-Jensen, D. Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbörnsdottir, A.E., Jouzel, J. and Bond, G., 1993, Evidence for generall instability of past climate from a 250-kyr ice-core record: Nature, v. 364, p. 218-220.

Hsü, K.J. and Thiede, J., 1992, Use and misuse of the seafloor, Proceedings of the 1991 Dahlem Conference: John Wiley and Sons Ltd., New York.

Intergovernmental Panel on Climate Change, 1990, Climate change: The IPCC Scientific Assessment, *in* Houghton, J.T., Jenkins, G.J. and Ephraums, J.J., eds., Cambridge University Press, Cambridge, 365 p.

International Geosphere-Biosphere Programme, 1990, A study of global change, The initial core projects: International Council of Scientific Unions, Report No. 12.

Larkin, P.A. (Chair), 1991, Realizing the potential: a strategy for university research in Canada: The Royal Society of Canada, 37 p.

Moore, T.R. and Knowles, R., 1990; Methane emissions from fen, bog and swamp peatland in Quebec: Biogeochemistry, v. 11, p. 45-61.

NASA, 1988, Earth system science: a program for global change: National Aeronautics and Space Administration, Report of the Earth System Sciences Committee, Washington, D.C., 208 p.
National Advisory Board in Science and Technology, 1988, University Committee Report, 84 p.
National Research Council, 1993, Solid Earth Sciences and Society, Committee on Status and Research Objectives in the Solid-Earth Sciences: A Critical Assessment: National Academy Press, Washington, D.C., 346 p.
Nisbet, E.G., 1989, Some northern sources of atmospheric methane: production, history, and future implications: Canadian Journal of Earth Sciences, v. 26, p. 1603-1611.
Science Council of Canada, 1986, A growing concern: soil degradation in Canada: Council Statement, Ottawa, 24 p.
Sparrow, B.J. (Chair), 1990, Canada must compete: Report of the Standing Committee on Industry Science and Technology, Regional and Northern Development, Ottawa.
Weaver, A.J., 1993, The oceans and global warming: Nature, v. 364, p. 192-193.
Weaver, A.J. and Hughes, T.M.C., 1993, Stability and variability of the thermohaline circulation and its link to climate: Trends in Physical Oceanography, v. 1, p. 15-70.
World Commission on Environment and Development, 1987, Our Common Future: Oxford University Press.

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Health of the Discipline Statement for Earth Science

The NSERC
Earth Sciences Committees

OVERVIEW

The solid Earth, the land surface, the hydrosphere, atmosphere and their constituent organisms are strongly interacting systems. For the past 200 years, there has been a steady growth of subdisciplines working within each of these systems. However, it is only in the past decade that quantitative integrated study has become feasible. Four factors have caused this recent development. Firstly, the global theories of plate tectonics and mantle convection have provided a theoretical framework for subdisciplinary work. Secondly, the deployment of remote sensing systems has revolutionized our view of the Earth; the surface of the planet is mapped at moderately high resolution, and the floors of oceans, seas and great lakes are also known at scales adequate for many purposes. Thirdly, increased computing power has stimulated global modelling in such areas as heat flow, climate and ocean circulation. Lastly, and perhaps most potent, is the realization that anthropogenic processes may be forcing overly rapid and unnatural change to many of the more fragile environments.

There are other themes of national significance. Canada is the largest country in the world. Half of its land area is Arctic and sub-Arctic, constituting 25% of all ice-free Arctic and sub-Arctic terrain on the planet, and exhibiting geological and ecological features that are truly unique. We cannot afford to waste the scientific opportunities offered by these resources; to do so would be globally irresponsible. In addition, we have a small population in a vast country; the most tangible evidence of sovereignty is the scientific study of the land that is Canada. This should have high national priority.

The recognition that Earth systems are not independent of each other raises the spectre that human activity may trigger disastrous and irreversible change. Ozone depletion, acid rain, loss of agricultural land, deforestation, groundwater contamination, oceanic pollution, global warming, and sea-level rise are not simply matters of scientific study, they are matters of deep concern for the future of the human race. Only scientific study can provide an understanding of these systems; without this, it will be impossible to predict and manage future change.

In order to respond to the challenge of society and its interaction with the Earth, a three-pronged attack is required:

1) We must be able to characterize environmental change as it occurs. Consequently, extensive field programs with sophisticated field instrumentation are essential; without them, we lack even the basic data. The geographic and climatic ranges of Canada mean that we are in an ideal position for such programs, but their magnitude provides significant logistical and financial problems.

2) Extensive field sampling requires extensive supporting analytical facilities, particularly in the areas of trace-element and isotopic analysis. We have the expertise, but we do not have the necessary instrumental resources or supporting infrastructure.

3) Amelioration or prevention of environmental degradation involves being able to predict the results of specific actions or processes. This involves building models based on the field and lab results of 1) and 2), and then using these to simulate numerically the effects of system perturbations. The community has the expertise, but the massive computational requirements of such a program far outstrip our current capabilities.

This effort needs significantly increased multi-disciplinary work on a large scale if the earth sciences are to develop a truly integrated view of the Earth, and to respond to the scientific and social demands posed by the increasing impact of society on the environment.

DETAILED REVIEW

The Earth consists of six principal units: the core, the mantle, the crust, the land surface, the oceans, and the atmosphere. Historically, studies of these units have evolved as separate disciplines. However, the advent of plate tectonics as a unifying theory of the Earth, together with the current concern about global-scale environmental issues, have led to the integration of geological