Academic-Government Partnerships in Atmosphere-Related Research

A focus paper for strategic planning for the Working Group on Atmosphere-Related Research in Canadian Universities (ARRCU).

Written by the ARRCU Academic-Government Partnerships Committee:

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Contents

Abstract

This focus paper outlines a strategic plan for partnership between Canadian academic and federal government researchers in atmosphere-related research (ARR) as part of the broader strategic planning effort of the working group on Atmosphere-Related Research in Canadian Universities (ARRCU). The plan identifies partnership research priorities as well as the need to enhance research planning, infrastructure coordination, international connections, and education and training aspects of ARR. We propose to establish the Panel for Atmospheric Related Research in Canada (PARRC) to lead this partnership effort and move rapidly on the most urgent priorities.

Introduction

This focus paper on academic-government partnership in atmosphere-related research (ARR) represents part of the strategic plan of the working group on Atmosphere-Related Research in Canadian Universities (ARRCU).[1] The overarching purpose of this strategic plan is *to configure university-based ARR to most benefit Canada in a time of rapid environmental and socio-economic change*. The specific aims of the strategic plan are:

- To build university-based research capacity and excellence;
- To make university partnerships with government and industry more effective;
- To improve the sustainability of fundamental research support in ARR; and
- To enhance our community's efforts in education, training, and engagement with the broader Canadian public.

This focus paper is part of a strategic plan that will also cover academic-industry partnerships; education, training, outreach, and communication; and the role of fundamental science research in support of ARR. This strategic planning effort will produce a single document covering this series of topics, and is intended to be relevant to our activities over a *strategic planning horizon* of five to seven years.

The authors of this document comprise the ARRCU Academic-Government Partnerships (AGP) Committee. We are university and federal government colleagues working in ARR who believe we can work more effectively through coordinated planning of our research activities. This committee was struck by the ARRCU Working Group in September 2016 to create a focus paper mainly concentrated on partnerships between universities and federal government agencies. For this domain, a decades long history of collaboration exists, a need for better planning and coordination is critical, and university networks that cross provincial boundaries can be developed. However, we are hopeful that this document will provide guidance on effective planning with other levels of government (provincial, territorial, municipal) as well as non-governmental organizations engaged in ARR such as Ouranos and the Pacific Climate Impacts Consortium (PCIC). Some of our planning ideas are also relevant to partnerships between academia, government, and industry.

While universities already partner well with government in many aspects of Canadian ARR, strategic planning of this nature will increase the effectiveness of our partnership, will remove barriers between our research efforts, and thus will ultimately better benefit the Canadian public. This strategic planning is required to justify ongoing public investment in

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[1]ARRCU comprises Canadian university faculty working in weather, climate, and air quality under the general framework of atmosphere-related research (ARR). For an introduction to ARRCU, please see Kushner et al. (October 2016, *CMOS Bulletin*), and for a more in-depth discussion see our White Paper posted under the documents tab at the website www.ARRCU.ca.

our collaborative research. Such funding is urgently needed, given the importance of this research and the track record of effective partnership we have already demonstrated (see ARRCU White Paper). This focus paper is intended to communicate our strengths, challenges, and needs to our research colleagues across all sectors, to Canadian university leadership, to those in policy and planning who rely on ARR for their decision making, to agencies that fund ARR, and to other stakeholders.

Academic-government collaborations occur in many areas of ARR: development, validation, and use of observational and computing infrastructure; research involving field campaigns, modeling and data analysis; and education, training, internships, and professional development. In this focus paper, we will first address the general framework of academic-government research partnerships (see next section), including a description of the *Innovation Chain* from Research to Services; research priorities identified by government agencies; and mechanisms for the support of these priorities. The subsequent sections will discuss research infrastructure, international partnerships, and academic-government collaboration in education and training. Then, to enhance our partnership and establish strong Canadian leadership in ARR at an international level, we propose the creation of a joint academic-government advisory body [tentatively named the *Panel for ARR in Canada* (PARRC; see Appendix A for Terms of Reference)]. We will conclude with a summary of recommendations and next steps. Many of the details of planning, including mechanisms for partnerships, infrastructure, international programs, and education/training fall outside the scope of this focus paper. Our proposal to set up PARRC will provide a mechanism to continue our planning on an ongoing basis. We will conclude with a discussion of next steps and recommendations (summarized in Table 2). A list of acronyms is included in Appendix B.

This paper summarizes input from consultation with the Canadian ARR community that has included workshops, video conferences, and extensive email communication (see the ARRCU.ca website for documents[2]). It is understood that coauthors from government agencies [Environment and Climate Change Canada (ECCC), the Natural Science and Engineering Research Council (NSERC), and Canadian Space Agency (CSA)] represent the institutional view of their agencies.[3] Viewpoints expressed here are advisory and not binding; they do not commit coauthors or their institutions to any specific action.

[2] Ideas specific to this focus paper were developed through a webinar in November 2016 where the document outline was laid out, a face-to-face workshop discussing a first draft of the document in January 2017, and follow on communications.
[3] We welcome additional endorsements or expressions of interest from other government agencies and departments and non-governmental organizations.

Academic-Government Research Partnerships

The Innovation Chain and Roles for Academic ARR

Government scientific organizations active in ARR provide science-based services to the public, to private and public-sector clients, and to other stakeholders. These organizations, of which numerical weather prediction agencies such as the Meteorological Service of Canada (MSC) provide perhaps the best-known example, often operate through what could be called an *Innovation Chain* of scientific teams that transfer knowledge and innovation from Research, to Development, to Operation, and to Service. The Research link is the furthest *upstream* component of the chain; it transfers innovation to Operations with the help of the Development team. The Service link is the furthest *downstream* component of the chain that interacts on a day-to-day basis with clients.

Although government ARR is based on fundamental first principles, it strongly focuses on its mandated mission and will seek relatively quick development and impact downstream. Knowledge and innovation transfer from Research to Services might take three to ten years. Of course, longer time horizons might be required for full implementation of important changes. (For example, the numerical weather prediction system based on the Global Environmental Multiscale modeling framework in MSC was initiated in 1990 but was only fully implemented operationally by 2005.). At this time, academic ARR in Canada typically connects upstream with the Research link rather than downstream towards Service. Academic ARR tends to be higher risk, longer-term, and more oriented towards fundamentals and discovery than government research activities. Scientists in ARR might tackle fundamental problems that could eventually end up as an innovation, and these could easily take more than two decades to impact on services. But academic ARR can lead to rapid advances in knowledge, disseminated through high impact literature, that can rapidly impact all aspects of the Innovation Chain.

Experience has shown that ideas, innovation, and initiatives are generated by all teams in the Innovation Chain, from the researchers upstream to the clients and stakeholders downstream. Bearing in mind all links in the Innovation Chain in our strategic planning will help coordinate our partnership research. Academic-Government partnership research can be made more effective if we take into account the push from clients and stakeholders at many points along the Innovation Chain.

Priority areas for academic-government partnership

The mandates of several federal government agencies require input from ARR taking place in universities and industry in addition to the ARR taking place within the government itself. These agencies include, for example, ECCC, the Department of Fisheries and Oceans (DFO), Natural Resources Canada (NRCan), Agriculture Canada (AgCan), Department of

Defense (DoD), and the National Research Council (NRC).[4] In this section we outline the range of ARR priorities of interest to the Government of Canada (GoC). Figure 1 represents the priorities identified by the parties to this document, but more input is required to extend this initial list to better represent the range of AGP research. The Canadian university community is already actively engaged in many of these areas, or has the immediate capacity to undertake research in them. Our current capacity for research in these areas were identified in the ARRCU White Paper's *Priority Areas for Partnership*[5]. Opportunities will arise that require additional investment and coordination to be realized. These new priorities could include emerging areas of applied or policy concern or significant technological advance anticipated for the strategic planning horizon.

Key priorities in which ARR is required that will be undertaken by the Government of Canada (GoC) over the planning horizon are listed in the blue shaded row of Figure 1. These priorities will inform delivery of predictions and warnings, regulatory reporting, climate sensitive infrastructure, climate resilience, and disaster-risk reduction. The scientific ARR required to support these priorities is listed in the green shaded row in the figure. As in the ARRCU White Paper (see Figure 1 of that document), we emphasize the two-way connection between fundamental and applied research (*Application to Discovery* and *Discovery to Application*).

GoC activities take place within national and international regulatory frameworks, and in particular its science activities are coordinated with international programs where practicable. These aspects will be discussed further in the *International Connections* section.

Mechanisms: Research partnership programs

Effective academic-government research partnerships require strategic planning on how to structure partnership programs. In Canada, ARR partnerships between government and universities range from smaller projects led by individual or small teams of investigators, with typical budgets of less than $100K/year, to large projects and networks with budgets in the range of $1M/year or more. These projects are supplemented by research infrastructure funded either directly by the project, available as in-kind support through a

[4] Other agencies like NSERC and CSA serve to support research across government and academia, even if they do not define strategic research priorities themselves. The mandates of such agencies also extend to the areas of industry partnership and education/training, which will be the subject of subsequent focus papers.

[5] The ARRCU White Paper's *Priority Areas for Partnership* with universities are: *Prediction*, *Arctic and Cold Regions*, *Regional Climate and Hydroclimate*, *Air Quality*, *Atmosphere-related biogeochemical cycles*, and *Applied Research*. The last category is a catch-all for product and service development activities carried out within universities, for partnership with government and industry.

larger facility (e.g. aircraft or ship time, surface long-term monitoring networks, satellite data, computing or modelling resources) and/or by prior industry contracts. The smaller government projects are funded through various mechanisms, such as the NSERC Strategic Projects, Collaborative Research and Development Grants, government-industry partnerships (MITACS) and the Grants and Contributions programs of individual federal agencies. The larger projects are typically, although not always, administered by NSERC but supported by contributions from one or more federal agencies. Such projects can also attract industry support. Space-based observational infrastructure projects are typically supported by the CSA.

Small-project and large-project programs provide distinctive advantages and challenges. Smaller projects (e.g. on the $80-100K/year) provide fast turnaround on specific research questions that can lay the groundwork for longer-term scientific advance. They are suitable for higher risk exploration for which the outcomes are more uncertain. Their cumulative impact is perhaps somewhat harder to measure than is the case for network and other large projects. Larger projects and networks [e.g. NSERC Climate Change and Atmospheric Research (CCAR) Networks, on the scale of several hundred thousand dollars per year] allow for comprehensive investigations on broader research or applied areas, or ongoing development of technological capacity. They can be challenging for university and government scientists to co-develop and for university faculty to administer. They tend to concentrate a large fraction of research resources over long periods of time.

One current example of large network-based partnership is the Climate Change and Atmospheric Research program (CCAR) of NSERC, which funded seven networks at the $1M/y level for 2013-2018. The CCAR program called for partnership between university researchers and federal government departments in areas of 1) understanding Earth system processes and their representation in weather, climate, and atmospheric chemistry models, 2) advancing weather, climate, and environmental prediction, and 3) understanding recent changes in the Arctic and cold region environments. A midterm review of the CCAR program suggests that its partnership model has been successful in advancing GoC priorities. Other examples of such partnership programs include the MEOPAR and ArcticNet Networks for Centres of Excellence, which feature several partnership projects between government and universities. These Networks are not typically oriented towards satisfying core government priorities to the same extent as CCAR.

Academic-Government partnership in Canadian ARR: Priority Applications

- To develop weather and air quality prediction and warning systems.
- To inform air pollutants, toxics, and greenhouse gas regulations and reporting (frameworks including: CEPA, Canada/US Air Quality Accord, UN ECE LRTAP and the UNFCCC, and GoC Enforcement).
- To develop climate prediction and projection systems to provide input into climate services. Inform the Pan Canadian Framework for Clean Growth and Climate Change: The mitigation and adaptation goals related to the Paris agreement.
- To reduce disaster risk related to weather and climate change as guided by Public Safety Emergency Management.
- To advance climate resilient infrastructure under the Green Infrastructure program and to assess Canada's general climate resilience.
- Environmental monitoring in support of and in partnership with government agencies for characterization of pollutant and greenhouse gas trends and source characterization.

Application to Discovery

Academic-government research partnerships on weather, climate and air quality to benefit Canada in a time of rapid change.

Discovery to Application

Academic-Government partnership in ARR: Research priorities

Under the general framework of the development of fundamental knowledge of the atmosphere and related systems:

- To develop and apply Earth-system models (integrated weather, climate, chemistry, biogeochemistry) for weather, air quality, and climate forecasts and projections.
- To advance utilization of space based observations through development of data assimilation systems for physical and chemical atmospheric parameters and land surface conditions.
- To develop and apply methods for atmospheric monitoring, emissions measurements, including development of observation-model fusion methods for regional and facility-scale emission source characterization.
- Priorities in environment and agriculture: strengthening water resource sustainability in agriculture, adapting agricultural production systems to climate change, disaster mitigation for climate extremes.

Figure 1: Research Priorities and Priority Applications for Government-Academic Partnerships over the Strategic Planning Horizon

Our consultations suggest that a suitable balance of partnership opportunities that encompass small projects, large projects, and larger networks would best serve the overarching goal of configuring ARR to most benefit Canada. While there continues to be a range of research opportunities available, the ARRCU community has nevertheless noticed a decrease in the availability of small-project partnership support over the last 10-15 years. We thus encourage the support of programs that seed smaller project opportunities in areas that align with government priorities.

In addition, effectiveness of academic-government partnerships in ARR could be increased by ensuring that as much funding as possible is made available through competitive proposal processes open to the entire academic community as potential partners.

To enhance international competitiveness of Canadian ARR, we recommend ensuring that partnership calls are well coordinated with international programs and available on similar timelines to these programs. A past example of a limited window opportunity, for example, is the range of activities leading up to the Year of Polar Prediction (2017-2019). This theme will be further explored in the *International Connections* section.

Finally, our consultations revealed support for reviewing how the current structure and regulations of Federal Tri-Council funding mechanisms impact the efficacy of academic-government partnerships. For example, it would be useful to review the impact of the two-year limitation on the length of postdoctoral fellowships, rules about the location of tenure of HQP being outside government labs given the context of academic-government partnership funding, and the rules for support of research costs related to management and administration of networks.

Overall, *we encourage increased engagement by both the academic and government research community in the design and delivery of partnership programs*, such as CCAR and the NSERC Strategic Projects. It is important that such planning involve those who are directly involved in the research as well as those who make use of its outcomes. Greater engagement by both sides of the partnerships at the design stage will improve the shared understanding of and commitment to these programs. This, we believe, will enhance the effectiveness and impact of the programs, make them more predictable and consistent, and make them more transparent for purposes of accountability and evaluation.

Key recommendations in the area of partnership priorities and programs:

- The academic and government ARR communities should be aware of and provide input into the partnership research priorities outlined in Figure 1.
- Future partnership calls should be designed in collaboration between academic and government partners. Such calls should feature a range of project funding levels.
- Future partnerships should be well coordinated with international activities and enable timely engagement in these activities. And, vice versa, international activities should be seen as a trigger for a Canadian funding or call for engagement.

- A review of the regulations concerning tri-council funding in partnership calls should be undertaken.

Partnership in Research Infrastructure

Partnership and coordination in research infrastructure is an important component of strategic planning in collaborative ARR between government and academia. Partnerships might include joint University/government applications to obtain the resources needed to develop and operate infrastructure, collaboration in using the infrastructure to carry out cutting edge ARR science, and partnerships for maintenance and ever-greening of these facilities and associated resources. The operational lifetime of ARR infrastructure often exceeds that of individual projects (three to five years) and thus requires a longer planning horizon (five to ten years or longer). The key issue is how to make most effective use of limited resources for infrastructure in ARR to address shared goals.

ARR is a highly interdisciplinary endeavour that rapidly responds to technological development. Thus, the infrastructure needs of ARR are wide ranging. A partial list of existing infrastructure categories in which partnership will help advance our shared goals is presented in Table 1. This is provided to give a sense of the scope of infrastructure we use and is not intended to be comprehensive.

Table 1: Infrastructure Categories and Examples for Academic-Government Partnerships in Canadian ARR

Infrastructure Type	Examples
Space-based infrastructure for global remote sensing of atmospheric composition and dynamics for process studies, assimilation in models, monitoring trends, and air quality assessment.	ACE-FTS spectrometer on SCISAT (2003), cloud radar on Cloudsat (2006), radiometer on SMAP (2015), wind lidar on ADM-Aeolus (2017), interferometric radar on SWOT (2021), and other international satellite missions
Ground-based infrastructure, including unique field stations, in-situ long-term monitoring networks.	CCAR CCRN, PEARL/PAHA, CHARS, SPARTAN, CAPMoN, NAPS, GHG Network.
Field campaign infrastructure (instruments, airborne platforms, ships, moorings) – includes deployment platforms and equipment to be deployed. Such equipment will include both equipment deployed for an extended period in the field (e.g. moorings) as well as equipment mounted just for the experiment.	NETCARE, PEARL/PAHA, Alert Global Atmosphere Watch Observatory, Whistler Site, CSA-CNES stratospheric balloon program
Advanced research computing and other information technology resources, covering hardware, software, computer cloud systems, and datasets. Hardware	Compute Canada resources (SciNet, SHARCNET, WestGrid, etc.), ECCC/DFO/DoD/university

includes CPU and mass stores. Software includes models (Earth system models, NWP models, chemical transport and air-quality models), retrieval workflows, analysis software for large complex data sets (e.g. climate, satellite, remote sensing).	models, climate and atmospheric composition data records from ECCC and terrestrial data records from NRCan, etc.

For larger facilities operating over the longer term, it is likely that it will be the government partners who will operate (or pay to operate) the given infrastructure. But an academic partnership can provide the impetus to support the facility development, and/or provide funds for operation, especially during the lifetime of key projects. In many cases, it may be that one partner provides in-kind contributions while the other provides actual cash, and/or personnel. Examples of successful partnerships of this nature include several of the CCAR programs such as CANDAC/PAHA, NETCARE, GEOTRACES, VITALS, CNRCWP, CanSISE, etc. Coordinating with the academic community greatly increases the value of the original infrastructure investment.

Generally speaking, broad community use of infrastructure, ranging from satellite data streams to computing resources, models, etc., is the increasing norm today. This is especially the case in open-source modeling, cloud computing and open access data archives. Indeed, federal implementation of Open Science/Open Data practices is now being mandated, and this provides an excellent opportunity to facilitate academic access to federal data holdings. This has the advantage of a large community working to access infrastructure, analyze data, and develop codes. This trend opens the door to partnerships in which the academic community works on testing and exploring new approaches that can be used in operational settings. It also facilitates training and the ability for ARR HQP to transition between academia and government. Finally, it ensures that the broadest possible group within and outside Canada can exploit new resources. Supporting a large community provides a real challenge to government researchers but is an area where academic partners can assist in a liaison and support role. Such a role aligns well with the universities' mandate in education and training (see below).

As research priorities for academic-government partnership are developed, we hope to identify major infrastructure priorities for the ARR community that can feed into strategic planning, programs and facility requests to federal departments and agencies such as the Canadian Foundation for Innovation (CFI).

Key recommendations in the area of partnership in research infrastructure:

- To ensure that ongoing strategic planning for infrastructure supporting government-led ARR involves input from the academic community. This will ensure good alignment from the outset in such programs.

- To facilitate the use of government operated facilities and field programs by the academic community, in collaboration with government scientists, to ensure the best outcome for the publicly funded investment.
- To facilitate the use of shared community models, visualization and analysis suites and databases, between the academic community and the government, to ensure sharing of knowledge to drive improved research outcomes, as well as technology transfer back to operational groups within the government.
- To ensure that federal implementation of Open Science/Open Data practices facilitates academic access to federal data holdings.

International Connections

Extending the value federal departments and academia obtain through effective academic–government collaborations within Canada, there are opportunities for us to better coordinate our research at an international level. Canada brings scientific and technical strengths to several areas (modeling, prediction, Arctic and cold regions, cryosphere, aquatic environments, etc.) that have connections to global atmosphere-related processes. Weather, climate, and air quality are global phenomena, so to effectively advance atmospheric science requires access and contributions to global observing networks and satellite infrastructure. Canada also contributes significant global data to the international ARR community. For example, the Canadian space-based instruments ACE-FTS, OSIRIS and MOPITT generate important atmospheric composition data that is used by hundreds of scientists around the world, often in the context of WCRP/SPARC and WMO-UNEP activities. Canada is a participating member of the European Space Agency (ESA) and, through the CSA, makes significant investments in ESA's Earth Observation programs. Similarly, Canada provides surface atmospheric and terrestrial monitoring data to global networks and data centres contributing to, for example, GCOS and WMO GAW. This enables Canadian industry and researchers to participate in numerous competed activities related to the development, validation and use of data from ESA space-based instruments. Canadian scientists often add value to foreign satellite missions to address government (e.g. ECCC and HC) objectives.

Canadian expertise, multi-decadal observational datasets, field campaign coordination and support capacity, and strong experience in model development and evaluation, are contributed to the international community. In return, Canada can leverage the resources of the international community through international engagement and collaboration.

Thus, the value of strong international engagement by Canadian atmospheric scientists is three-fold. 1) Canada can leverage the large international capacity to advance key science of specific interest to Canada. 2) Canada can maintain scientific expertise and infrastructure at the leading edge, by remaining competitive with the highest excellence in ARR globally. This enables us to inform Canadian atmospheric policy, regulations and planning with the highest calibre and state of art knowledge. 3) As no single Canadian institution or community can address the diverse expertise in ARR needed to address federal priorities, we can reach outside of Canada to access globally available expertise to meet these needs.

There is a wide range of international ARR programs and sponsors, many of which now are strongly linked and coordinated, and present opportunities for Canadian scientists. An illustrative but not complete list includes:

- The multi-lateral UN based collaborative research programs coordinated by WMO, UNEP, WHO, and UNESCO which include WWRP, GAW…
- The ICSU Future Earth program, and the international Commission on Atmospheric Chemistry and Global Pollution (iCACGP). IGAC jointly sponsored by both.
- The WCRP sponsored by WMO, UNESCO, IOC and ICSU. Canadian space-based atmospheric composition data is of particular importance for Stratosphere-troposphere Processes And their Role in Climate (SPARC).
- Collaborative research programs inviting international participants, particularly in Earth observations (ESA Earth Explorer satellites, NASA AboVE).
- iLEAPS — Integrated Land Ecosystem-Atmosphere Processes Study and SOLAS — Surface Ocean–Lower Atmosphere Study, which are Global Research Projects of Future Earth
- The national government sponsored collaborative research opportunities: EU Horizon 2020, NA IAI, etc.
- The science assessment programs of UNEP, WMO, WHO, Arctic Council, Global Burden of Disease, and IPCC.

Challenges in accessing these opportunities lie in simply being aware of them, in understanding the complexity of international relationships and structures in which the projects operate, in obtaining base funding to enable participation or join as a partner, and in demonstrating the value back to GoC departments or granting councils who would be asked to support and/or facilitate Canadian engagement.

Attention to and coordination of Canadian engagement in the context of academic-government partnerships will contribute to federal government development of knowledge and tools to inform weather, climate and air quality policy, regulations and services. This includes enhanced opportunities:

- for field campaigns or intensive studies, located in Canada with increased Canadian participation in internationally coordinated programs. This would also further exploit and utilize existing Canadian observational networks and infrastructure.
- to advance atmospheric processes understanding, parameterization and modeling.
- to integrate Canadian observational activities within international programs, giving Canada access to global surface and satellite data, and ensuring optimal use of observations made with Canadian infrastructure.
- to apply and evaluate Canadian models over Canadian and global domains, and

- to facilitate financial support for both government and academic participants, including uptake of new knowledge in federal programs.

Thus, we have identified the need for mechanisms to improve communication of opportunities, coordination and funding of ARR in Canada to more effectively leverage Canadian participation in the international context. Federal science based departments, the granting councils and National Research Council all have a role to play which would be facilitated by the proposed PARRC. For example, a basic practical issue is providing travel support for both government and academic research scientists to attend international meetings. The PARRC could be used to identify potential experts to represent Canada at an international level and potential funding mechanisms to support their travel. Enhanced coordination of Canada's contributions to international programs in ARR is urgently needed.

Key recommendations in the area of international connections:

- Review the potential for and enhance existing Canadian National Committee structures to improve communication regarding international programs to the ARR community (e.g.: CNC SCOR, CNC WCRP, etc.).
- Profile international programs and initiatives through targeted Canadian ARR conference sessions, or information sessions at conferences.
- Encourage government focal points to establish broader reach to Canadian ARR community in seeking expert nominations to international programs and assessments.
- Encourage granting councils to initiate Canadian programs complementary to and in parallel to international programs, to facilitate and support Canadian engagement.

Education and Training

Universities have the unique mandate of being responsible for academic education and thus contributing to the development of trained and skilled professionals needed by governmental departments. In one sense this can be viewed as a feeder system, with students getting their foundational learning in K-12 schools, and then going onto university and/or college that will provide the people to populate government operations, industry and research. Given the importance of this system in providing the skilled people needed to satisfy governmental needs, strategic planning is needed to identify strengths, gaps and needed coordination. Because this aspect of planning also requires input from industry, and extends well beyond issues directly related to government partnerships, we will develop a separate focus paper on this topic. But we make several points related to academic-government partnership issues here.

We believe that it is important to increase exposure to atmosphere-related science (including the physics, chemistry, and biogeochemistry of the Earth system and its components) in the present-day school curriculum. This exposure will encourage students to consider further education and career in our fields, in a way that will allow them to productively develop their math, science, and computer programming abilities through creative hands-on research. Such exposure can happen if ARRCU raises awareness in school boards of the professional possibilities that a strong training in ARR can provide students in the work force in academia, government, and industry.

We see a need to bring better information to undergraduate education programs about the needs and opportunities in government-based research. This will necessarily take place on a longer planning horizon, since educational programs at Universities evolve on a longer timescale than research priorities. Nevertheless, universities need to keep current on what is needed by working atmospheric and related science professionals within government so that students graduate with the skills qualifying them for work within government agencies. We also see an opportunity for academics and government researchers to communicate their views on the trends in training requirements. This effort will be addressed in our separate planning activities related to education, training, and outreach in ARR.

Regarding training at the postgraduate and post-doctoral level, as we distil our priorities it will be more straightforward for university faculty members to share and teach towards these areas of need within government. For students interested in the scientific research carried out in federal departments, this will ensure that their research is relevant to current and medium-term needs. For students with an interest in more fundamental research, this awareness will allow them to efficiently plan their future professional work as necessary. We recommend enhancing the scope and opportunities for HQP training using various grants and contributions mechanisms in government laboratories. Additional ways to provide and facilitate internships and extended research stays in governmental labs would be beneficial. Such visits by university-based HQP would give them an understanding of the governmental work environment as well as facilitating direct interactions and building networks. We also see a need to make sure that organizations like MITACS, which provide government matching support for internships with industry, also ensure that internships with federal (and provincial) government departments qualify for internship funding. Finally, we recommend facilitating HQP training through providing government scientists enhanced opportunities to serve as visiting scientists at academic institutions, thus allowing significant exchange of ideas and expertise.

Along similar lines in the area of communication, many HQP could be made much more aware of available research and job opportunities within government departments, by the development of a common job market posting resource and by regularly holding jobs fairs and career interview sessions at CMOS, CSC, and CAP meetings. Developing job market knowledge while they are still in training would help guide students in decisions about obtaining training relevant to available positions over the long-term. Seeing the range of opportunities will be helpful for those in degree programs in professional areas like meteorology or for potential recruits to our field; it would, for example, provide alternative paths for employment in ARR, beyond ECCC's regular recruitment of forecasters. ARRCU has started an "opportunities" email list to publicize programs of study and research opportunities, and with moderate support this could be broadened into a more systematic postgraduate career program in ARR that would serve the needs of academics and government.

The key area for progress, therefore, is in the area of communication and coordination between university and government departments (which could include scope for partnerships between government, industry, and academia) for long-range planning in education and training in ARR. We are aware of international examples (for example, the US University Corporation for Atmospheric Research's educational programs) that shows what can be gained by investing in reviewing the feeder system and its effectiveness. Regular meetings to communicate needs, trends and strengths/weaknesses of the present training system would encourage greater collaboration between different academic groups at different universities. This could, over the long term, help fill gaps in graduate and undergraduate programs for university departments that include relatively few courses and instructors.

Key recommendations in the area of education and training:

- Enhanced coordination between government and academic partners is urgently needed in the areas of education and training. This includes regular meetings to assess and undertake year-to-year planning to improve education and training programs in ARR across Canada. This could also encourage greater collaboration between different academic groups at different universities (e.g. many smaller groups/universities have difficulty running full undergraduate programs).
- We recommend exploring more ways and mechanisms for student and postdoctoral funding to engage in partnership research. The scope could be flexible and include industry, government at all levels, and non-governmental organizations.

Facilitating Academic-Government Consultation: The Panel for ARR in Canada

Across the areas of research partnership, infrastructure partnership, and education/training, we have identified the urgent need for the Canadian ARR community to enhance communication and coordination for academic and federal government participants in ARR. We propose to establish the *Panel for ARR in Canada* (PARRC), whose purpose would be to ensure that we meet our overarching objective of configuring this academic-government partnership in ARR to most benefit Canada. We see the PARRC as a mechanism whereby, in areas of common interest to the Canadian ARR community, Canada sustains and strengthens its international leadership in atmospheric-related science, and hence in the ARRCU priority areas for partnership. The PARRC interests include also research infrastructure, education and training.

The specific objectives of the PARRC would be:

1. A *strategic planning objective* for research partnerships and priorities, to propose new research priorities to address atmospheric-related national issues and to be involved in pushing forward and coordinating those new initiatives in collaboration with NSERC, CFI and other funding agencies. This would satisfy the need identified above of increased engagement of both academic and federal government researchers in the design and delivery of strategic partnership programs.
2. An *operational objective* of enabling ongoing smooth collaboration between the academic and government ARR communities by working to coordinate research activities in collaboration with the NSERC, CFI and other funding agencies, and to ensure effective participation in relevant new national and international research programs.
3. An *international competitiveness objective* to ensure that the Canadian ARR community has access to internationally competitive tools and infrastructure for maintaining an appropriate national capability in observing, understanding, modelling and predicting the atmosphere.
4. An *education/training* objective to promote the more effective pull through of research to improve government services and training of relevant HQP.

The PARRC will allow the Canadian ARR community to speak with one voice on issues around major joint research programs and infrastructure investments and will permit a more unified approach to innovations arising from ARR. The PARRC should be composed of federal government senior scientists (director, chiefs and scientists), university atmospheric department professors, possibly research or high level administrative officers from one or two universities, and representatives from other sectors such as NGOs, industry, or other expert domains. The PARRC should aim at a balance between academia and federal government membership. Scientists will be invited for specific discussions, especially for program presentations or new initiative proposals within a recurring strategic planning horizon. The PARRC co-chairs should be one federal government and one academic representative. Members should have a mandate of three years (with possibility of one renewal). NSERC or other funding agencies representatives should be part of the membership. PARRC should meet at least twice a year (with one face-to-face). Further details of the mandate and draft terms of reference regarding the PARRC are provided in Appendix A.

Key recommendation in facilitating government-academic consultation:

- The Panel on Atmosphere Related Research in Canada (PARRC) should be formed as soon as possible to implement our strategic planning ideas in research partnership, in infrastructure planning, and in education and training.

Conclusion

The time has long passed in which Canadian academic and federal laboratory scientists in ARR could productively conduct their research in separate silos, meet at conferences to share their accomplishments, and then return to their respective institutions to further pursue their work in isolation. ARR has become far more competitive, connected, collaborative, and practical as it has grown into a modern operational and research enterprise. Several trends underscore the need for greater coordination and advocacy in this vital domain, including the widening routine use of the applications of ARR, its increasingly interdisciplinary character, its associated diffusion into a wide range of academic disciplines and departments, and the stagnation of public funding to support it.

The key idea we promote is that effective partnership between academic and government researchers will accelerate the benefits that ARR brings to all Canadians. This idea is based on the premise that fundamental advances in ARR create important practical benefits to the advantage of Canada's society and economy (e.g. Bauer et al. 2015[6]). ARR relies on investments in national-government based infrastructure and research, to an extent that we believe is quite unique to our science. Thus, effective partnership between the academic and the public sectors requires at its core a strong strategic plan between university and federal government researchers.

This focus paper has identified several areas for improved coordination and planning. We have articulated key research priorities for academic-government partnership based on priorities current as of spring 2017, have identified target areas for infrastructure planning, and have pointed out the need for better coordination of education and training. The key recommendations we make in AGP are summarized in Table 2. Among these recommendations, perhaps the most important is the need for the PARRC, which will begin to implement improved research coordination in Canada and help promote Canadian ARR at an international level.

The final recommendation in the Table relates to an issue not yet discussed. An assessment of the capacity in infrastructure, personnel, and funding of university-based ARR has not, to our knowledge, been even partially quantified in at least 10 years. Compared to our federal government counterparts, university-based researchers have very limited information about the amount of funding and infrastructure employed by this community. Gathering such information will require us to survey our community, which in turn requires investment by universities in administrative resources to undertake this. This is a current topic of discussion on the ARRCU working group, and will be addressed as we further progress in our strategic planning process.

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[6] Bauer, P., A. Thorpe and G. Brunet, 2015: The quiet revolution of numerical weather prediction. *Nature*, **525**, 47-55, doi:10.1038/nature14956.

Table 2: Summary of key strategic planning recommendations

Planning Area	Recommendations
Facilitating government-academic coordination	• Expedite formation of Panel on Atmosphere Related Research in Canada (PARRC) to implement these strategic planning ideas.
Academic-Government Partnership Research and Priorities	• Continue refinement and seek community input on priorities outlined in Figure 1. • Increase collaboration between academic and government partners to enable effective engagement in national and international research priorities. • Review impact of tri-council regulations on partnership research.
Research infrastructure	• Increase academic community input on government-led infrastructure supporting ARR. • Enhance use of government operated facilities, field programs, models, data by the academic community, in collaboration with government researchers, consistent with best Open Science / Open Data practices.
International connections	• Enhance academic involvement in international programs to the ARR community through Canadian National Committees, targeted conferences, outreach by government focal points. • Encourage granting councils to initiate Canadian programs reflecting international programs.
Education/training	• Enhanced coordination between government and academic partners is urgently needed in the areas of education and training. • New mechanisms for supporting HQP in partnership research, for academia/industry/government/NGOs.
Assessing University community capacity	• Engage in a systematic survey across academia, government and industry of Canada's capacity in weather, climate, and air quality research.

Appendix A: Terms of Reference for the Panel for ARR in Canada (PARRC)

1. Introduction

The Panel for ARR in Canada (PARRC) is a committee to enhance communication and coordination of academic and federal government ARR community activities. The overarching goals are:

- to ensure that academic-federal government partnership in ARR is configured to most benefit Canada; and

- to sustain and strengthen international leadership, research infrastructure, education and training in Canadian ARR.

2. Mandate

The PARCC provides advice for strategic planning for new research partnerships and priorities:

- to address emerging national issues;
- to push forward and coordinating new initiatives in collaboration with NSERC, CFI and other funding agencies; and
- to ensure effective participation in relevant new national and international research programs.

The PARCC enables ongoing smooth collaboration between the academic and federal government ARR communities by working to coordinate research activities in collaboration with NSERC, CFI, CSA and other agencies.

The PARCC ensures that the Canadian ARR community has access to internationally competitive tools and infrastructure for maintaining an appropriate national capability in observing, understanding, modelling and predicting the atmosphere and earth systems connected to it.

The PARCC promotes the more effective pull through of research to improve government services and education/training of HQP.

The PARCC allows the Canadian ARR community to speak with one voice on issues around major joint research programs and infrastructure investments (such as, for example, promoting ARR HPC requirements to CFI and to Compute Canada).

3. Membership

3.1 Composition

The committee is formulated to obtain broad representation from the Canadian ARR community and stakeholders. The PARRC should aim at a balance between academia and federal government membership. PARRC core and additional members are eligible to vote while Ex Officio members are not eligible to vote.

PARRC Core members:

Subsequent to initial establishment of the committee by the ARRCU Working Group committee and the ARRCU Academic-Government Partnerships Committee, PARCC core members will be nominated by the committee and appointed by the PARRC on the basis of their expertise, experience, and interest.

The PARRC core membership should be composed of:

- Four (4) federal government senior scientists (director, chiefs and scientists);
- Four (4) university professors active in ARR, who could be focused on research or in high level administrative positions within their universities;
- One (1) representative from the NGO and industry sectors.

PARRC additional members:

The additional PARRC members are appointed by the PARRC to provide additional expertise and experience not otherwise available to the committee. There will be no more than two (2) PARRC Additional members.

Ex Officio members:

Ex Officio members will be appointed when needed by the PARRC to provide representation of stakeholder programs, committees, NGO and working groups. NSERC or other funding agencies willing to send representatives can nominate Ex Officio members.

Invited participants:

Scientists will be invited by the PARCC for specific discussions, especially for program presentations or new initiative proposals within a recurring strategic planning horizon.

3.2 Appointment

Subsequent to initial establishment of the committee by the ARRCU leadership active in 2017-2018, PARRC members will be appointed by the PARRC on the basis of their expertise, experience, and interest in relation to the mandate of the committee. Subject to the foregoing, the membership is selected to reflect a wide geographic distribution across Canada, to represent the diversity of the community and to represent as many of the sub-disciplines within the ARR as is feasible.

3.3 Tenure

PARRC core members serve for a three (3) year term. Membership may be renewed; however, renewal for more than two consecutive terms is discouraged. An appropriate number of members are appointed, renewed, or rotated annually to maintain a representative composition of the committee while minimizing loss of experience and continuity.

PARRC additional members may serve for as long as the PARRC requires their specific expertise and experience to be available to the committee.

PARRC Ex Officio members may serve for as long as the committee requires their specific expertise and experience.

3.4 Executive

The committee executive consists of two co-Chairs and an Executive Secretary:

3.5 PARRC co-Chairs:

The PARRC co-Chairs are appointed by the committee from the PARRC core members. The co-Chairs nominally serve a two (2) year term. The PARRC co-Chairs develop meeting agendas and are responsible for the logistical arrangement of meetings. The PARRC co-Chairs may be asked to represent the committee on advisory committees that address the broader ARR community.

3.6 Executive Secretary:

The executive secretary is appointed by the co-Chairs. The executive secretary records meeting attendance, prepares the minutes of the meetings, and maintains permanent records of the committee's activities. The executive secretary will assist in disseminating communications from the PARRC to the broader ARR community, typically through the ARRCU mailing lists.

4. Meetings

Meetings of the PARRC normally take place two (2) times per year. If the need arises, additional meetings may be organized.

Communications are carried out by email, teleconferences, and video conference. Face-to-face meetings with teleconference/videoconference support may be scheduled if required. The co-Chairs are responsible for the logistical arrangements.

The meeting agendas are developed jointly by the co-Chairs. The draft agenda is made publicly available no later than twenty (20) business days prior to the meeting. Members of the ARR community are invited to suggest items to be added to the agenda.

The minutes of the meetings are prepared by the Executive Secretary. The minutes are made available to committee members no later than ten (10) business days after the meeting.

5. Compensation

No compensation is provided for the committee's work. PARRC core, additional and Ex Officio members cannot request travel support for face-to-face meetings.

6. Reporting and Communications

Results of the meetings will include:

1. the final agenda, attendance list, and minutes of the meeting; and
2. a record of actions for selected PARCC members that should be tracked and reviewed by the co-Chairs at each meeting, as required;

No one, other than the co-Chairs, may represent or speak on behalf of the committee unless requested to do so by the co-Chairs.

Reports from the committee should not be publically shared without mutual consent of the PARCC.

It is understood that the PARRC will be responsible for communicating with the broader ARR community on its activities and outcomes. This reporting will take place following meetings of the PARRC.

8. Records

In addition to the minutes of meetings, the Executive Secretary generates and maintains permanent records documenting the activities of the committee, including copies of presentations, reports produced for or by the committee and records of the membership.

Appendix B: List of acronyms

AboVE	Arctic Boreal Vulnerability Experiment
ACE-FTS	Atmospheric Chemistry Experiment - Fourier transform infrared spectrometer
ADM-Aeolus	Atmospheric Dynamics Mission Aeolus
AgCan	Agriculture Canada
AGP	Academic-Government Partnerships
ARR	Atmosphere-Related Research
ARRCU	Atmosphere-Related Research in Canadian Universities
CANDAC	Canadian Network for the Detection of Atmospheric Change
CanSISE	Canadian Sea Ice and Snow Evolution Network
CAP	Canadian Association of Physicists
CAPMoN	Canadian Air and Precipitation Monitoring Network
CCAR	Climate Change and Atmospheric Research Program
CCRN	Changing Cold Regions Network
CEPA	Canadian Environmental Protection Agency
CFI	Canada Foundation for Innovation
CHARS	Canadian High Arctic Research Station
CMOS	Canadian Meteorological and Oceanographic Society
CNC	Canadian National Committee
CNRCWP	Canadian Network for Regional Climate and Weather Processes
CSA	Canadian Space Agency
CNES	Centre nationale d'études spatiales (France)
CSC	Canadian Society for Chemistry
DFO	Department of Fisheries and Oceans
DoD	Department of Defense
ECCC	Environment and Climate Change Canada
ESA	European Space Agency
EU Horizon 2020	European Union Framework Programme for Research and Innovation
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GEOTRACES	Biogeochemical and Tracer Study of a Rapidly Changing Arctic Ocean
GHG	Green House Gases
GoC	Government of Canada
HC	Health Canada
HPC	High Performance Computing
HQP	Highly Qualified Personnel

iCACGP	international Commission on Atmospheric Chemistry and Global Pollution
ICSU	International Council for Science
IGAC	International Global Atmospheric Chemistry
iLEAPS	Integrated Land Ecosystem-Atmosphere Processes Study
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
MEOPAR	Marine Environmental, Observation, Prediction and Response
MITACS	Mathematics of Information Technology and Complex Systems[7]
MOPITT	Earth Observation Satellite Measuring of Pollution in the Troposphere
MSC	Meteorological Service of Canada
NA IAI	EU New Alert on Israel Aerospace Industry
NAPS	National Air Pollution Surveillance
NASA	National Aeronautics and Space Administration
NETCARE	Network on Climate and Aerosols
NRC	National Research Council
NRCan	Natural Resources Canada
NSERC	Natural Sciences and Engineering Research Council
NWP	Numerical weather prediction
OSIRIS	Earth Observation Satellite
PAHA	Probing the Atmosphere of the High Arctic
PARRC	The Panel on Atmosphere Related Research in Canada
PCIC	Pacific Climate Impacts Consortium
PEARL	Polar Environment Atmospheric Research Laboratory
SCISAT	Canadian Earth Observation satellite
SCOR	Scientific Committee on Oceanic Research
SHARCNET	Shared Hierarchical Academic Research Computing Network
SMAP	Soil Moisture Active Passive
SOLAS	Surface Ocean-Lower Atmosphere Study
SPARC	Stratosphere-troposphere Processes And their Role in Climate
SPARTAN	Global Particulate Matter Network
SWOT	Surface Water Ocean Topography
UN ECE LRTAP	United Nations Economic Commission for Europe - Convention of Long-Range Transboundary Air Pollution
UNEP	United Nation Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change

[7] Acronym no longer used.

VITALS	Ventilation, Interactions and Transports Across the Labrador Sea
WCRP	World Climate Research Program
WestGrid	Western Canada research Grid
WHO	World Health Organization
WMO	World Meteorological Organization
WWRP	World Weather Research Programme