The Way Forward for Soil Moisture Monitoring in Canada

A Proposal for Advancing Observational Data Collection, Modeling and Data Accessibility for Monitoring Soil Moisture in Canada

Report for the Canadian Group on Earth Observation

Prepared by A. Howard
and the CGEO Soil Moisture Working Committee
September, 2007.

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Table of Contents

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Report for the Canadian Group on Earth Observation:

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Report Summary:
This report is prepared for the Canadian Group on Earth Observation (CGEO) who requested identification of a way forward for monitoring soil moisture in Canada as part of an overall approach to improved understanding of the water cycle. The process to obtain and analyze the information was undertaken by the Soil Moisture Working Committee, a committee of experts from 3 federal departments and a government agency-university research network. The report is based primarily on information obtained from a national workshop to identify a way forward for soil moisture monitoring, and also on additional reports and expert opinion from the committee members. Due to the broad scope of the issue, the committee focused on agricultural and related landscapes, with the expectation that the planning relevant to other landscapes can be incorporated as a national vision is developed. The workshop identified several short, medium and long range goals pertaining to monitoring in agricultural landscapes. To prepare and enable a way forward a set of overarching recommendations was prepared by the committee.

The following overarching recommendations are put forward to initiate an improved soil moisture monitoring system for Canada:

- As soon as possible, CGEO should identify a champion, as an interdepartmental steering committee, that will develop a national vision of a Canadian soil moisture monitoring system that would include measurements (*in-situ* and remote-sensing) as well as the assimilation of measurements into a Canadian Land Data Assimilation System (LDAS). The champion will also lead and coordinate the way forward.
- By the year 2010, a proposal should be ready for submission to the Treasury Board to request support to implement the monitoring system. This report and the supporting documents can be foundational information for the proposal.
- As soon as possible, a communication network be established for information updates, dialogue and coordination of future meetings and workshops. CGEO could provide support for establishment of a website to help meet this need.
- By 2008, involve industry but at the proposal review level. Their needs, roles and level of involvement in the process can be identified at that time.
- By 2008 the steering committee will manage four subcommittees each representing a theme area including *In-situ* Monitoring, Remote Sensing, Modeling and Data Assimilation and User Services and Applications. The subcommittees will address issues and tasks specific to their theme area for preparation of the proposal and should also identify research priorities and funding avenues for their theme areas. A preliminary list of specific issues and tasks has been identified in Tables 1-3.
- As soon as possible, provide a total budget of $25K per year, split at the CGEO representatives' discretion, to support the operation of the steering committee, its subcommittees and the workshops and meetings required to prepare the proposal.

The Departments would provide appropriate time for staff to participate on the committees.

- By 2008, develop a communication plan to build awareness of the soil moisture plan and a comprehensive user needs plan to identify key requirements in all sectors.

To address these recommendations, the following roles for the CGEO- related agencies and committees are recommended:

The interdepartmental steering committee to address soil moisture monitoring:

- Define soil moisture community
- Develop a vision for effective soil moisture monitoring in Canada
- Manage a study to identify key user requirements at the national, regional and local scales in all sectors of Canada
- Assign staff and manage sub-committees to address the four theme areas identified in the June 19-20 workshop: *In-situ* Monitoring, Remote Sensing, Modeling and Data Assimilation and User Services and Applications.
- Manage the preparation of the proposal to Treasury Board
- Maintain a website that will function as a centre for communication of soil moisture information. This will include coordination of the sub committee theme based web pages, providing information updates, dialogue and coordination of future meeting and workshops.
- Maintain linkages to key research initiatives, such as the Drought Research Initiative, and enhance relations between GEO and the Universities for the purpose of sharing research information and user needs and promoting priority areas for research
- Develop a communication plan to build awareness of the proposed system, as well as a technology transfer plan to educate and assist regional and local agencies in utilizing soil moisture and in the development of local monitoring networks that can be integrated into a national system.
- Develop a plan, with the theme sub-committees for delivery of soil moisture monitoring information through a singe web portal.

CGEO Managerial Committee:

- Develop process of reporting through CGEO to senior management
- Provide human resource and financial support for establishment of the website required for communicating soil moisture information.
- Identify where the source of funding will originate for supporting the committees
- Provide review and guidance to the steering committee
- Promote the activities of the way forward in the international community

Soil moisture theme sub-committees

- Revisit, update and keep current the key short, medium and long term activities in Tables 1-3
- Plan follow-up workshops and meetings on specific issues
- Maintain linkages to the expert community for each theme
- Identify key needs and gaps in the science to propose as research priorities to the steering committee.

- Form working groups to address specific issues (e.g. define standards for *in-situ* sensors, site characteristics, scaling, data collection and accessibility, quality control, international collaboration, and user needs)

Federal Departments

- Support staff to move forward the CGEO initiatives in addressing soil moisture monitoring and the water cycle
- Provide staff and NPO resources for the steering and sub-committees to operate effectively
- Provide support and guidance to the development of the proposal to the Treasury Board.

Introduction:

This report is prepared for the Canadian Group on Earth Observation (CGEO) who requested identification of a way forward for monitoring soil moisture in Canada as part of an overall approach to improved understanding of the water cycle. The process to obtain and analyze the information was undertaken by a committee of experts from 3 federal departments. The report is based primarily on information obtained from a national workshop to identify a way forward for soil moisture monitoring, and also on additional reports and expert opinion from the committee members. The workshop identified several short, medium and long range goals for the soil moisture monitoring effort that form the basis of the way forward proposed in this report.

Background

The Group on Earth Observation (GEO), the inter-governmental group to which CGEO reports, was advanced at the first Earth Observation Summit in 2003. In 2005 it was initiated and charged with developing a 10-year implementation plan to use earth observation to improve our ability to understand and address global environmental and economic challenges. The Canadian Federal Government founded the Canadian Group on Earth Observation (CGEO) in September 2005 with a Vision of *A healthy, safe and prosperous Canada through comprehensive, sustained and coordinated Earth Observation.* CGEO immediately initiated a Federal Strategy for Earth Observation. Since GEO uses Ministerial Summits to engage member countries, CGEO is making preparations to report on the Federal Strategy at the next Summit, which is to be held in Cape Town S.A. in November of 2007.

At a CGEO managerial retreat in January 2007, three 3 priority areas were identified as part of the Federal Strategy for Earth Observation: monitoring arctic Canada, analyzing and predicting the water cycle, and enabling through improving infrastructure. Within the water cycle priority area, improved soil moisture monitoring was identified as the most immediate need and therefore the first step in addressing the understanding of the entire water cycle. AAFC and E.C. were asked to develop a way forward for monitoring soil moisture in Canada as a first step in addressing the soil moisture issue. The timeline was to present the report to CGEO in a timely enough manner that it could be used in the report to the Summit in November.

A workshop was held June 19 – 20, 2007 in Saskatoon to identify key issues and requirements by the soil moisture community. The workshop was seen as the key step in the process of addressing the way forward and is foundational for the recommendations in this report.

Key results of Workshop

The workshop "Soil Moisture Monitoring, Analysis, and Prediction in Agricultural Landscapes." was cosponsored by Agriculture and Agri-Food Canada and Environment Canada and was coordinated by a committee representing both Federal Departments, as well as Statistics Canada. It was held in Saskatoon on June 19 and 20, 2007, and attended by 60 people, including representatives from 6 Canadian universities, a dozen federal and provincial agencies, and 2 US federal agencies.

The purpose of the workshop was to get the baseline information required to draft a way forward for soil moisture monitoring in Canada and had the following specific objectives:

- Understand the status of soil moisture information in Canada
- Identify user requirements
- Characterize the information requirements and gaps
- Draft process to address these requirements and gaps
- Identification and commitment to short-term collaboration opportunities

The process of the information exchange at the workshop included three speaker sessions and a breakout session for small group discussion of specific issues and an overall discussion to build consensus on the way forward based on the recommendations from the discussion groups.

Across all sessions, speakers not only spoke about the state of the science and the user requirements, but several speakers made reference to a number of overarching gaps and requirements that need to be addressed to effectively study soil moisture. These include the lack of data available to study soil moisture, the lack of coordination among agencies, the need for consistent resources to sustain monitoring and research, and the need for an individual, agency, or committee to champion the cause.

While a number of specific recommendations were made in the speaker presentations, the purpose of the discussion groups was to identify short (<2 years), medium (2-4 years), and long (>4 years) term goals that were required to enable Canada to have an effective system for monitoring soil moisture. The four breakout session themes were *In Situ* Monitoring, Remote Sensing, Modelling and Data Assimilation, and User Services and Applications. The overall discussion developed a matrix of recommended short, medium and long term actions by theme (Tables 1-3) as well as some additional recommendations and collaboration opportunities (Table 4).

Table 1. List of short term (<2 year) goals for soil moisture monitoring in Canada, from the June 19-20, 2007 workshop.

Short Term Goals:

***In-Situ* Monitoring:**

1. Form working group(s) for sensor selection/defining standards, for quality control and calibration, for network design, and for data assimilation
2. Network design manual of procedures
3. Write operating procedures
4. Define data standards
5. Determine locations for test bed facilities
6. Ensure sustainability of existing networks (Quebec has funds ending soon)
7. Plan workshop for quality control of data and assimilation of existing data
8. Identify partners and user requirements

Remote Sensing

1. Generate inventory of existing data
2. Execute formal partnership agreements
3. Obtain access to existing L band SAR data (ALOS PALSAR)
4. Find resources to work with SMOS data, initially for calibration and validation
5. Form partnerships in SMAP mission
6. Improve understanding of relationship between point observations and pixel scale observations

Modeling and Data Assimilation

1. Execute agreements to access near-real time data on soil moisture and precipitation
2. Gain access to existing land cover and soil texture data sets
3. Write model documentation
4. Improve assimilation of existing remotely-sensed data
5. Participate in new satellite planning
6. Research on the inclusion of remote-sensing data in a Canadian LDAS

User Services and Applications

1. Plan follow-up workshop(s) for users – include more provincial representatives
2. Identify users and their needs/applications
3. Identify and manage data standards
4. Establish formal linkages to GEO tasks and committees

Table 2. List of medium term (2-4 year) goals for soil moisture monitoring in Canada, from the June 19-20, 2007 workshop.

Medium Term Goals:

***In-Situ* Monitoring**

1. Create web portal for soil moisture data and community – need champion
2. Develop data QA/QC process
3. Execute land and data sharing agreements for monitoring network locations
4. Implement test beds

Remote Sensing

1. Find resources to better characterize land surface parameters
2. Form working group on data validation
3. Improve transfer (or observation) models used in LDAS for the assimilation of remote-sensing data

Modeling and Data Assimilation

1. Improve existing in situ and remote sensing networks/datasets
2. Implement near real time vegetation analysis
3. Implement remote sensing data in LDAS
4. Execute operational access agreements to near real time data soil moisture and precipitation
5. Speed up movement from research to operation

User Services and Applications

1. Develop algorithms and tools to generate useful information through a client committee (user researcher interface)
2. Form community of practice

Table 3. List of long term (>4 year) goals for soil moisture monitoring in Canada, from the June 19-20, 2007 workshop.

Long Term Goals

***In-Situ* Monitoring**

1. Oversee network implementation
2. Review/re-evaluate sensors and test beds
3. Maintain equipment (life cycle management)
4. Update standards
5. Perform site maintenance
6. Perform ISO audits
7. Manage metadata
8. Install new key monitoring networks

Remote Sensing

1. Better understand plant-soil interactions
2. Create experimental watersheds (calibrated basins or super sites) for validation and calibration of sensors
3. Establish procedures for extending surface data (from satellites) to soil profile/depth information from sensors/modeling

Modeling and Data Assimilation

1. Improve models through collaboration with Universities and researchers
2. Improve topographic input, using LiDAR Digital Elevation Model (DEM)
3. Ensure coverage / representative-ness of data is appropriate
4. Soil moisture modelling and assimilation at smaller scales (towards field scale)
5. Probabilistic soil moisture products using ensemble techniques

User Services and Applications

1. Develop capability to deliver daily profiles of soil moisture at high spatial resolution (~km)

Table 4. List of recommendations and collaborative opportunities raised during the way forward open discussion session at the June 19-20, 2007 workshop.

Actions and collaborations raised in the way forward open discussion session

Immediate needs/opportunities

1. Identify "soil moisture champion" (CGEO to decide who)
2. Define soil moisture community
3. Form working groups to address specific issues
4. Develop process of reporting through CGEO to senior management
5. Create "virtual" inventory of existing data
6. Plan follow-up workshops on specific issues – work plans may be realigned/reorganized through communication
7. Enhance Federal University relations: Find a mechanism, establish programs
8. Establish user education programs on products (including university courses)
9. Improve collaboration/user researcher interface
10. Create virtual Soil Moisture Centre of Excellence

Short term collaborative opportunities

1. Agriculture and AgriFood Canada (AAFC) (Allan Howard), Environment Canada (EC) (Yves Durocher), Alberta Agriculture (Daniel Itenfisu), and NOAA/NCDC (Bruce Baker) workshop for in situ sensor placement
2. Eastern Cereal and Oilseed Research Centre (AAFC) (Heather McNairn), University of Guelph (Aaron Berg), AAFC (Allan Howard), and Province of Saskatchewan (Magfur Rahman) combining active and passive microwave satellite sensors for soil moisture analysis
3. EC (Craig Smith/Vincent Fortin) and Manitoba Agriculture (Andy Nadler) on precipitation analysis
4. AAFC (Scott Smith) and EC (Stephane Belair) to update land surface database for modelling assimilation
5. Canada Centre for Remote Sensing (CCRS) (Brian Brisco) and EC (Al Pietroniro/Stephane Belair) algorithm development for assimilating active and passive radar data into Numerical Weather Prediction (NWP)
6. CCRS, EC, and Statistics Canada (Gordon Reichert) to coordinate using ten-day composite MODIS NDVI product (perhaps also DRI project (Rob Armstrong))
7. StatCan (Gordon Reichert), NLWIS (A. Davidson), Universities to coordinate using NOAA NDVI data (AVHRR)
8. Upcoming MODIS NDVI workshop with National Land and Water Information Service (NLWIS): open to other users
9. Health Canada (Bliss Tracy) and AAFC (Scott Smith) to coordinate on soil texture data for Radon map

Other recommendations

1. Government Related Initiatives Program (GRIP) call for proposals (CSA Earth Observation program) may be appropriate for this group (or subsets) – due sometime early Fall

Published Information

Soil moisture monitoring requires careful attention to several complex issues. These include a lack of data, need for data over a wide range of scales from national to local, rapidly emerging technical developments in remote sensing, *in-situ* sensors modeling and data accessibility, multiple stakeholders and observation networks, and a wide range of users with varying needs. For this reason additional information from two published reports was included to support the information presented at the workshop.

US NIDIS Program

In the United States, a National Integrated Drought Information System (NIDIS) is in development. It will utilize national, state and local resources to provide drought monitoring resources from the national to the local levels and serve as the nation's early warning system for 21st century droughts. While NIDIS is intended for drought, it is useful to this report because many of the complexities it recognizes are applicable to soil moisture monitoring as well. In addition the deficiencies in soil moisture observation data identified in the NIDIS development plan provide an opportunity to work with the United States GEO agencies in development of the way forward for Canada.

Developing NIDIS will require integration of a several complex issues and systems including

- a wide array of observing and modeling systems, many with complementary and sometimes overlapping capabilities,
- quantifying and communicating information on drought impacts to socioeconomic sectors of the nation,
- the need for national and state agencies to work closely together in creating a backbone of information from which linkages can be created in the form of tools that users can exploit to obtain the drought information needed to mitigate the effects of drought.
- a vision of the information delivered through a single web-based portal that heavily leverages Geographic Information Systems (GIS) products and methods
- careful selection and design of essential decision support tools to ensure that the information applies at not only a national scale but is useful for decision support at the local scale as well. Users must be engaged early in the development process.
- user education through creation of an educational component connecting users to readily available decision support information will enable decision-makers to plan more wisely even before NIDIS is fully developed and implemented.

It will also require addressing several technical challenges, the greatest being overcoming observational and modeling deficiencies. Observational deficiencies are due primarily to inadequate spatial and temporal measurement of both precipitation and soil moisture. Soil moisture measurements are made in a few local or state mesonet systems, but widespread soil moisture monitoring networks are absent in most areas of the country. Knowledge of soil moisture conditions is an essential aspect in assessing drought severity as well as forecasting related factors such as runoff, streamflow and reservoir levels.

Given the overall objectives and technical challenges, implementation strategies were identified for 2-year, 6-year and 10-year timeframes. The 2-year strategy focused on acquiring user requirements and feedback, development of an outreach capability to focus on education tools, and addressing areas where national objectives could be quickly gained such as operationalizing a national monitoring system for drought - North American Drought Monitor, and extension of local and regional based prediction tools to nationwide. Addressing the major technical challenges of observational and model deficiencies is the primary focus of the 6- to 10-year strategy.

Canada Space Agency study of user needs for SMOS

The Canadian Space Agency (CSA) conducted a survey to identify the needs of the user community for the SMOS (Soil Moisture and Ocean Salinity) satellite scheduled for launch in 2008. The two primary goals of SMOS are to observe and document the two crucial variables of Soil Moisture over land masses, and Ocean Salinity of the world's oceans. As a secondary objective, a significant amount of information will be collected on the Earth's cryosphere. The SMOS concept may also pave the way for more ambitious remote sensing platforms capable of providing higher multi-spectral resolutions.

The CSA contracted Array Systems Computing Inc. to conduct a user needs survey to understand the potential users and their needs for SMOS data. The two main goals of the survey were to:

- understand the requirements of potential SMOS users and determine the relevance of the SMOS data to them, when it becomes available, and
- to determine the intended use of the SMOS data and its corresponding requirements.

The majority of respondents were from research based organizations in the university and government sectors and 70% said they were interested in soil moisture data and 85% of respondents could use the data as soon as it becomes available in 2008. Despite the coarse resolution of the SMOS data (about 35km – 40 km), a majority of respondents who require 1 – 10 km resolution would use coarser SMOS data to validate or support their finer resolution data (Array Systems Computing Inc., 2007).

The study was valuable to this report in demonstrating that passive radiometric data could be used immediately by the majority of research and government agencies in Canada for soil moisture monitoring, in spite of its relatively coarse resolution. This underscores the need to support immediate development of a way forward for soil moisture monitoring.

Industry Consultation

The need to involve industry was discussed extensively by the Soil Moisture Working Committee however there was no clear information as to who the key industry players were, and a concern that including some but not all would result in a negative reaction by those who were not consulted. It was decided therefore that there would be good opportunity to participate in the process once the initial draft of the Treasury Board proposal was in place. It could be made publicly available on a website and those who had interest could respond to it with a reduced risk of leaving interested parties out.

One company approached CGEO with an interest in attending the workshop, however the attendance list was finalized at that time. The company was given the workshop report and invited participate in future activities**.**

The Way Forward Recommendations

The following overarching recommendations are put forward to initiate an improved soil moisture monitoring system for Canada:

- As soon as possible, CGEO should identify a champion, as an interdepartmental steering committee, that will develop a national vision of a Canadian soil moisture monitoring system that would include measurements (*in-situ* and remote-sensing) as well as the assimilation of measurements into a Canadian Land Data Assimilation System (LDAS). The champion will also lead and coordinate the way forward.
- By the year 2010, a proposal should be ready for submission to the Treasury Board to request support to implement the monitoring system. This report and the supporting documents can be foundational information for the proposal.
- As soon as possible, a communication network be established for information updates, dialogue and coordination of future meetings and workshops. CGEO could provide support for establishment of a website to help meet this need.
- By 2008, involve industry but at the proposal review level. Their needs, roles and level of involvement in the process can be identified at that time.
- By 2008 the steering committee will manage four subcommittees each representing a theme area including *In-situ* Monitoring, Remote Sensing, Modeling and Data Assimilation and User Services and Applications. The subcommittees will address issues and tasks specific to their theme area for preparation of the proposal and should also identify research priorities and funding avenues for their theme areas. A preliminary list of specific issues and tasks has been identified in Tables 1-3.
- As soon as possible, provide a total budget of $25K per year, split at the CGEO representatives' discretion, to support the operation of the steering committee, its subcommittees and the workshops and meetings required to prepare the proposal. The Departments would provide appropriate time for staff to participate on the committees.
- By 2008, develop a communication plan to build awareness of the soil moisture plan and a comprehensive user needs plan to identify key requirements in all sectors.

To address these recommendations, the following roles for the CGEO- related agencies and committees are recommended:

The interdepartmental steering committee to address soil moisture monitoring:

- Define soil moisture community
- Develop a vision for effective soil moisture monitoring in Canada
- Manage a study to identify key user requirements at the national, regional and local scales in all sectors of Canada
- Assign staff and manage sub-committees to address the four theme areas identified in the June 19-20 workshop: *In-situ* Monitoring, Remote Sensing, Modeling and Data Assimilation and User Services and Applications.
- Manage the preparation of the proposal to Treasury Board
- Maintain a website that will function as a centre for communication of soil moisture information. This will include coordination of the sub committee theme

based web pages, providing information updates, dialogue and coordination of future meeting and workshops.

- Maintain linkages to key research initiatives, such as the Drought Research Initiative, and enhance relations between GEO and the Universities for the purpose of sharing research information and user needs and promoting priority areas for research
- Develop a communication plan to build awareness of the proposed system, as well as a technology transfer plan to educate and assist regional and local agencies in utilizing soil moisture and in the development of local monitoring networks that can be integrated into a national system.
- Develop a plan, with the theme sub-committees for delivery of soil moisture monitoring information through a singe web portal.

CGEO Managerial Committee:

- Develop process of reporting through CGEO to senior management
- Provide human resource and financial support for establishment of the website required for communicating soil moisture information.
- Identify where the source of funding will originate for supporting the committees
- Provide review and guidance to the steering committee
- Promote the activities of the way forward in the international community

Soil moisture theme sub-committees

- Revisit, update and keep current the key short, medium and long term activities in Tables 1-3
- Plan follow-up workshops and meetings on specific issues
- Maintain linkages to the expert community for each theme
- Identify key needs and gaps in the science to propose as research priorities to the steering committee.
- Form working groups to address specific issues (e.g. define standards for *in-situ* sensors, site characteristics, scaling, data collection and accessibility, quality control, international collaboration, and user needs)

Federal Departments

- Support staff to move forward the CGEO initiatives in addressing soil moisture monitoring and the water cycle
- Provide staff and NPO resources for the steering and sub-committees to operate effectively
- Provide support and guidance to the development of the proposal to the Treasury Board.

Supporting Documentation.

The following report is a summary of the workshop to address Soil Moisture Monitoring, Analysis, and Prediction in Agricultural Landscapes. A more detailed report and notes from the discussion groups is available from the CGEO Soil Moisture Working Committee.

Soil Moisture Workshop, 19-20 June 2007, Saskatoon, Saskatchewan

Summary report
Julie Friddell, Workshop Facilitator

This workshop, hosted by Agriculture and Agri-Food Canada and Environment Canada and attended by representatives from 6 Canadian universities, a dozen federal and provincial agencies, and 2 US federal agencies, was held to draft a path forward to address "Soil Moisture Monitoring, Analysis, and Prediction in Agricultural Landscapes." This gathering of 60 people resulted from the work of the Canadian Group on Earth Observations (CGEO), Canada's contribution to an international initiative formed to develop a comprehensive, coordinated, and sustainable earth observation system among governments and the international community. The Group on Earth Observations (GEO), the inter-governmental group to which CGEO reports, was formed at the first Earth Observation Summit in 2003 and is charged with developing a 10-year implementation plan to use earth observation to improve our ability to understand and address global environmental and economic challenges. During a meeting in January 2007 in Merrickville, Ontario, CGEO determined that there were 3 priority areas for accomplishing this goal: monitoring arctic Canada, analysis and prediction of the water cycle, and enabling through improving infrastructure. The soil moisture workshop is CGEO's first step in addressing the water cycle priority area, and this brief document is the first of two that will report on the workshop and the recommended path forward.

To open the meeting, the workshop organizers briefly summarized the history of GEO and CGEO and introduced the purposes of the workshop: Most importantly, the participants were gathered to draft a path forward to address information and implementation gaps in using soil moisture in agricultural landscapes, but it was also important to determine whether the participants were in agreement on such a path forward and if there were other individuals or groups that should be included in future discussions on this topic. By the end of the workshop, it was apparent that the participants were indeed in general agreement on several overarching needs, details of which will be discussed at the end of this document and in a more comprehensive report to CGEO.

The first session of the workshop was composed of four plenary presentations on the "State of the Science" with respect to soil moisture and the water cycle. The first talk focused on the fundamentals of the water cycle and feedbacks within the climate system such as the amplification of extremes, i.e., additional heating leads to soil drying, which leads to less soil moisture for evaporation and attendant cooling, so the initial heating is reinforced, leading to further drying and possibly drought. It was also pointed out that, although physics dictates that rising global temperatures should enhance the hydrological cycle and increase water vapour in the atmosphere, we do not even yet have enough

precipitation data to state definitively whether such hydrological alteration is occurring. This reference to a lack of data was the first expression of a theme that continued to occur and grow throughout the workshop, in relation to both *in situ* and remote sensing observations and the integration of data with models. The other three talks of the morning covered current technologies used for *in situ* monitoring of soil water content, current and needed capabilities of remote sensing of soil moisture, and Canada's capabilities in modelling and predicting soil moisture. Major points raised during these presentations included the need to integrate active and passive microwave radar methods and the need to develop a well-informed soil moisture prediction system that assimilates available monitoring information with physics knowledge and includes realistic error estimates. Another interesting discussion centered on the soil water reservoir: Although water in soils is only 0.005% of the total surface water reservoir, this is still five times larger than the atmospheric water reservoir which is so intensively studied by atmospheric scientists. The point was made that rather than being solely interested in the reservoirs of water themselves, the purpose of the CGEO soil moisture initiative is to understand and predict the processes that control the exchange of water between the various reservoirs so that we will know when soil moisture is adequate for our needs and when it is not.

The second session of the workshop focused on "users," groups which either currently use or seek to incorporate soil moisture information in their operational products. Topics included climate and weather prediction; hydrological forecasting; estimating agricultural production, crop health, and drought risk; irrigation scheduling; and estimating radon movement in soils. The climate, weather, and hydrological presentations each identified issues that are known to be problematic and are the subject of current work, such as the effect of soil moisture on land-atmosphere interactions and feedbacks, the lack of accurate high-resolution land cover classification data, and the uncertainty on whether incorporation of soil moisture information actually improves or hinders streamflow forecasting. During the four agricultural talks, it was apparent that soil moisture information is currently being widely used in Canada to provide products that help maintain the modern farm industry, from reducing water wasted by unnecessary irrigation to modelling soil moisture (thus the amount of forage) in pasture land to seeking new markets for selling grain from the next harvest. The final talk, on using soil moisture and soil texture data to estimate radon diffusion rates and thus danger to humans from the radioactive gas, invited suggestions on how to determine the relationship between soil type and radon gas potentials across Canada. Emergent themes included the need to find and make available applicable data and the need to reconcile mismatches between the depths of *in situ* soil observations (often down to 1 m), remotely sensed observations (usually limited to the top few cm of the ground surface), and models (first layer can be as thick as 30 cm).

During the third session, seven speakers provided information on current and future research involving soil moisture. The first topic covered was a new Canadian system of coupled atmospheric-hydrological modelling that makes use of advanced data assimilation techniques and the latest land surface models. In this talk as well as several others, the issue of validation kept surfacing: Not only is it critical to validate and check models with data, but it is also essential to validate remotely sensed data with *in situ* data. Presenting plans that will help address the validation issue, three talks focused on

collecting soil moisture data directly, using satellite-based Synthetic Aperture Radar (RADARSAT), during the upcoming SMOS mission (Soil Moisture and Ocean Salinity, due for launch by the European Space Agency in 2008), and with Canadian and US networks of *in situ* ground sensors. The Canadian *in situ* network is being designed to validate the SMOS satellite, and the US network is currently being expanded to measure soil moisture and soil temperature at over 100 locations. The growing field of precision farming was introduced as the future of agriculture, and the relationship between soil moisture and nutrient availability in soils, particularly nitrogen, is being studied as a critical component in determining how much fertilizer is required to optimize productivity without creating pollution. The final two presentations focused on drought, or the *lack* of soil moisture, and methods to understand, predict, monitor, and deal with the impacts and aftermath of drought. Many of the projects discussed during this session involve extensive data holdings which should be useful in agricultural and other applications in Canada as well as across North America.

To address the stated goal of the workshop, the remainder of the meeting was spent in breakout sessions and a group exercise to compose a path forward for soil moisture work in Canada. There were four breakout sessions on the four topics *In Situ* Monitoring, Remote Sensing, Modelling and Data Assimilation, and User Services and Applications. In each breakout group, a leader, a student note taker, and a reporter were assigned or chosen from the approximately 10 members. The groups were instructed to use a brainstorming process to identify the issues that are restricting work in the group's topic area, rate the identified issues as high, medium, or low priority, and then determine the steps necessary to address the prioritized issues. The actions were to be sub-divided into short-term, medium-term, and long-term solutions based on the length of time required for implementation (<2 years, 2-4 years, or >4 years) and whether information or systems are already in existence, are funded and being developed, or have yet to be funded or developed. The groups worked for close to 2 hours on this process, filling in the blanks on pre-printed charts and compiling long lists of actions needed to move understanding and prediction of soil moisture forward.

Once the groups finished their work, the completed charts were hung on the wall in the main meeting room for the full assembly to view. The four reporters gave short summaries of their group's conclusions, and then the meeting facilitator presented a “way forward matrix” into which the results of the morning's work were to be summarized. The matrix was composed of the same elements as the breakout groups: short, medium, and long term solutions/actions for each of the four topic areas. The goal of using the matrix was to take the most important items from the breakout groups' reports and incorporate the feedback of the full group for the most inclusive path forward. In addition to specific items for each topic area too numerous to list in this summary report, a consensus on the overall path forward emerged quite easily and rapidly from the exercise. The most immediately necessary plans, according to the group, include identifying a “soil moisture champion” to organize the community and its work, identifying additional soil moisture researchers and users and including them in future meetings and discussions, forming working groups and planning workshops to address specific issues, locating existing data and creating an easily-accessible and comprehensive inventory, and enhancing inter-institutional (federal, provincial, academic, etc.) relations, partly through execution of formal sharing, partnership, and

access agreements. From the I*n Situ* and Remote Sensing groups, there was strong emphasis on ensuring the sustainability of existing observational networks and involvement in the careful and appropriate planning and implementation of future networks and satellites. A major focus of the Modelling group was on improving assimilation of existing and future data into model frameworks and land classification schemes, while the User group emphasized communicating and linking to others through a "soil moisture community of practice" and identifying specific user needs and applications. The final exercise of the workshop was to identify opportunities for short-term collaboration, nine of which were suggested in rapid succession. Actions included planning a workshop for *in situ* soil moisture sensor placement, combining expertise and data on active and passive microwave satellite sensors, and several specific plans to coordinate on updating and improving data assimilation in models. The ease with which these collaborations were offered testified to the effectiveness of the workshop's plan of bringing together experts from different fields to begin solving the soil moisture problem.

To conclude the workshop, the organizers thanked everyone for their hard work and for making this first step in improving the understanding of soil moisture in Canada a success. It was deemed that the path forward, as described above and in more detail in a forthcoming longer report, is a consensus plan sanctioned by the participants. The next steps include reaching out to additional partners who were unable to attend the workshop, clarifying some of the specific items in the path forward, and reporting the outcomes of the meeting to CGEO this fall and to the international GEO at a ministerial summit in South Africa later this year. As a final word, the workshop organizers intend to create a soil moisture web portal for hosting the data inventory, for posting updates on the actions and plans of this group, and for providing a central location for communication to maintain the momentum of this gathering.

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