The Understanding Severe Thunderstorms and Alberta Boundary Layers Experiment (UNSTABLE):

A Report Following the First Science Workshop 18-19 April 2007, Edmonton, Alberta

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Résumé (Traduit par la direction): Les chercheurs d'Environnement Canada et d'autres scientifiques intéressés venant du milieu universitaire et du secteur privé sont à concevoir une expérience sur les contreforts de l'Alberta afin d'examiner les processus de la couche limite atmosphérique associés au déclenchement convectif et à l'origine d'orages violents. Le projet "Comprendre les orages violents et l'expérience albertaine sur la couche limite («UNSTABLE»)", planifiée pour l'été 2008, fera usage d'un réseau à haute résolution d'instruments fixes et mobiles en surface, en altitude et en vol pour échantillonner les processus à la méso-échelle dans la zone de l'origine de ces orages. Des efforts pour rencontrer cet objectif seront faits pour transmettre les résultats aux prévisionnistes d'Environnement Canada dans le but d'accroître le temps d'attente et l'exactitude des avis et des veilles d'orages violents en Alberta et dans le reste du Canada. Faisant suite à des informations générales sur le projet, on présente un sommaire de la première rencontre scientifique d'UNSTABLE.

Introduction

Environment Canada researchers and other interested scientists from academia and the private sector are currently designing a field experiment over the Alberta foothills to investigate Atmospheric Boundary Layer (ABL) processes associated with convective initiation (CI) and severe thunderstorm genesis. The Understanding Severe Thunderstorms and Alberta Boundary Layers Experiment (UNSTABLE), planned for summer 2008 (funding permitting) or possibly 2009 (if funding delayed), will utilize a high-resolution network of fixed and mobile surface, upper air, and airborne instruments to sample mesoscale processes in this thunderstorm genesis zone. Targeted efforts will be made to transfer results to Environment Canada forecasters with the aim of increasing lead time and accuracy of severe thunderstorm watches and warnings in Alberta and the rest of Canada. Following some background information on the project, a summary of the first UNSTABLE science meeting is presented.

Rationale for UNSTABLE

The Canadian prairies are subject to a high frequency of thunderstorms and associated severe weather during the summer months. Based on severe weather reports received by the Prairie and Arctic Storm Prediction Centre (PASPC), the prairies experience an average of 203 severe weather events each summer (McDonald and Dyck 2006). Areas of the prairies experiencing a high frequency of thunderstorms are evident in climatological lightning data from the Canadian Lightning Data Network (CLDN). A map of the mean number of days with at least one cloud-to-ground lightning flash detected between 1999 and 2006 (Burrows 2006, personal communication) shows that the Rocky Mountain foothills region of Alberta experiences, on average, the most days with lightning (Fig. 1). A secondary maximum of lightning activity extends through the far southern portions of Saskatchewan and Manitoba.

Note: In this paper, severe weather refers to the occurrence of tornadoes, hail with diameter **20 mm** or greater , convective wind gusts of **90 km h^{-1}** or greater and/or convective rainfall amounts of **50 mm** or greater in **1 h**.

ABL = Atmospheric Boundary Layer.
CI = Convective Initiation.

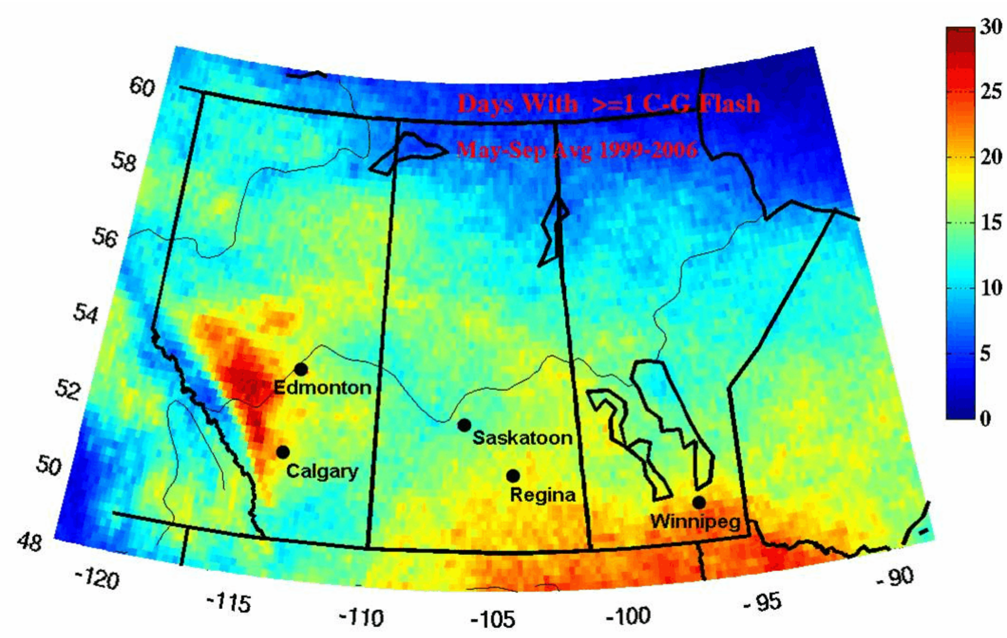

Figure 1: Climatological lightning activity over the Canadian Prairies showing the average number of days with at least one cloud to ground flash from 1999 to 2006 (Burrows 2006, personal communication).

Alberta has proven to be particularly susceptible to costly summer severe weather events. The most devastating event in the last half century is the Edmonton F4 tornado and hailstorm of 31 July 1987 resulting in 27 lives lost and damage estimates in the range of $660 M[1]. Public Safety and Emergency Preparedness Canada estimates that since 1980 more than 40 lives and $2 B have been lost in association with severe thunderstorms. Nearly all of these events occurred within the Edmonton to Calgary corridor which lies just east of the Alberta foothills. Thunderstorms developing on the foothills tend to move eastward with prevailing westerly winds aloft. Alberta contains 2 of Canada's 10 busiest airports (Calgary International 3rd and Edmonton International 6th, Transport Canada 2006) and the Edmonton to Calgary corridor is one of the most densely populated and fastest growing regions in Canada (Statistics Canada 2006, see Fig. 2). Given the above, the potential for further risk to life and property in southern Alberta due to summer severe weather events is clear. Improved understanding of processes associated with the development of severe thunderstorms in the Alberta foothills and application of that knowledge to operational forecast techniques will allow forecasters to maximize their ability to issue accurate and timely severe weather warnings and forecasts.

Meteorologists face numerous challenges with respect to forecasting severe thunderstorms. These include, though may not be limited to:

- Limited knowledge of the ABL structure and evolution, especially with respect to the stratification of water vapour in the vertical;

- Inadequate conceptual models to describe processes leading to CI and the development of severe thunderstorms;

- Difficulty in detecting mesoscale boundaries and circulations in regions of interest and their behaviour in association with CI. In the absence of sufficient observations, appropriate techniques are needed to infer important atmospheric characteristics and their evolution, given available observations.

- An incomplete understanding of important land-surface interactions with the convective ABL in the region of interest and their role in CI

- Inconsistent performance of numerical models with respect to the above (e.g., strengths, weaknesses, systematic biases)

The foothills region of Alberta suffers from an inadequate observational network with respect to surface and upper-air measurements. The one radiosonde location in Alberta (Stony Plain, 53.52˚N 114.09˚W, 766m) is ~200 km from favoured CI regions in the foothills and is often not representative of the ABL in the pre-storm environment over the foothills region. Surface observations over the foothills region are sparse. During the summer of 2006 there was an area of ~30,000 km^2 without any real-time surface observations over the foothills west of the Edmonton – Calgary corridor (Fig. 3).

[1] Events prior to 2001 are adjusted to 1999 dollars.

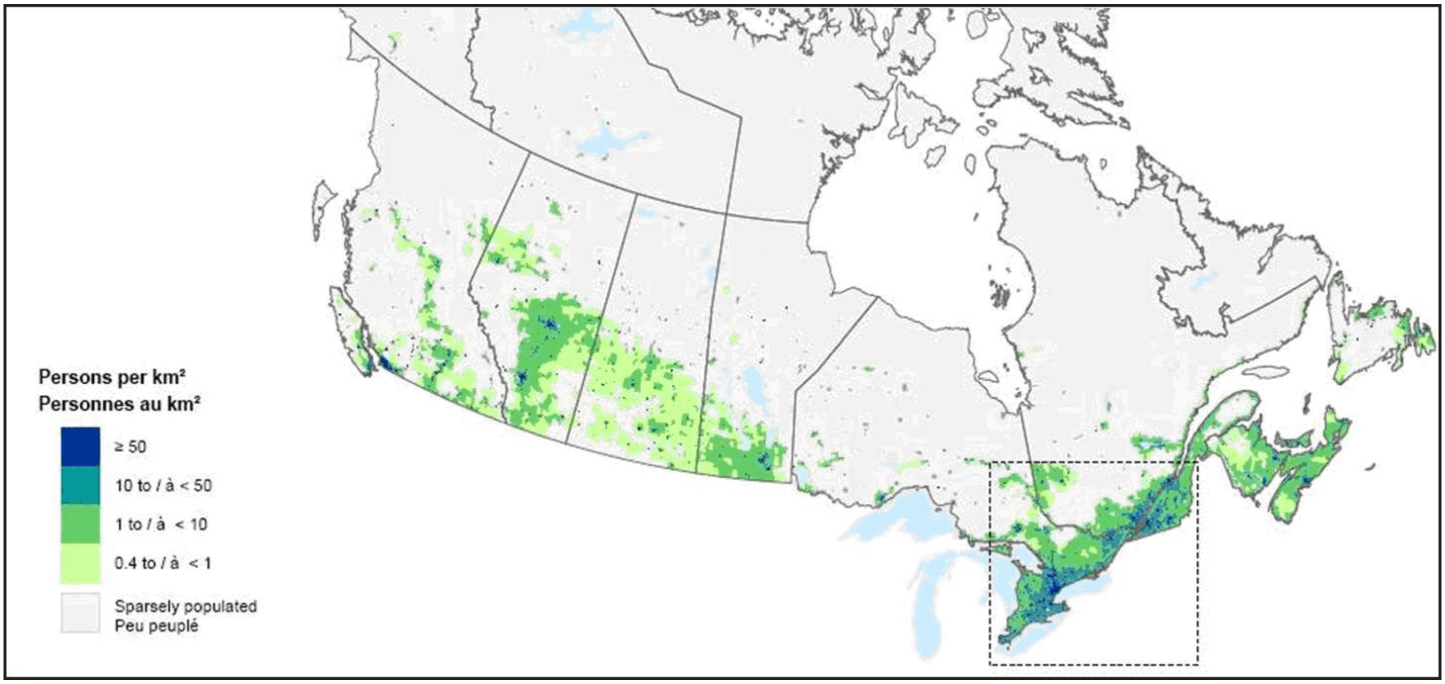

Figure 2a

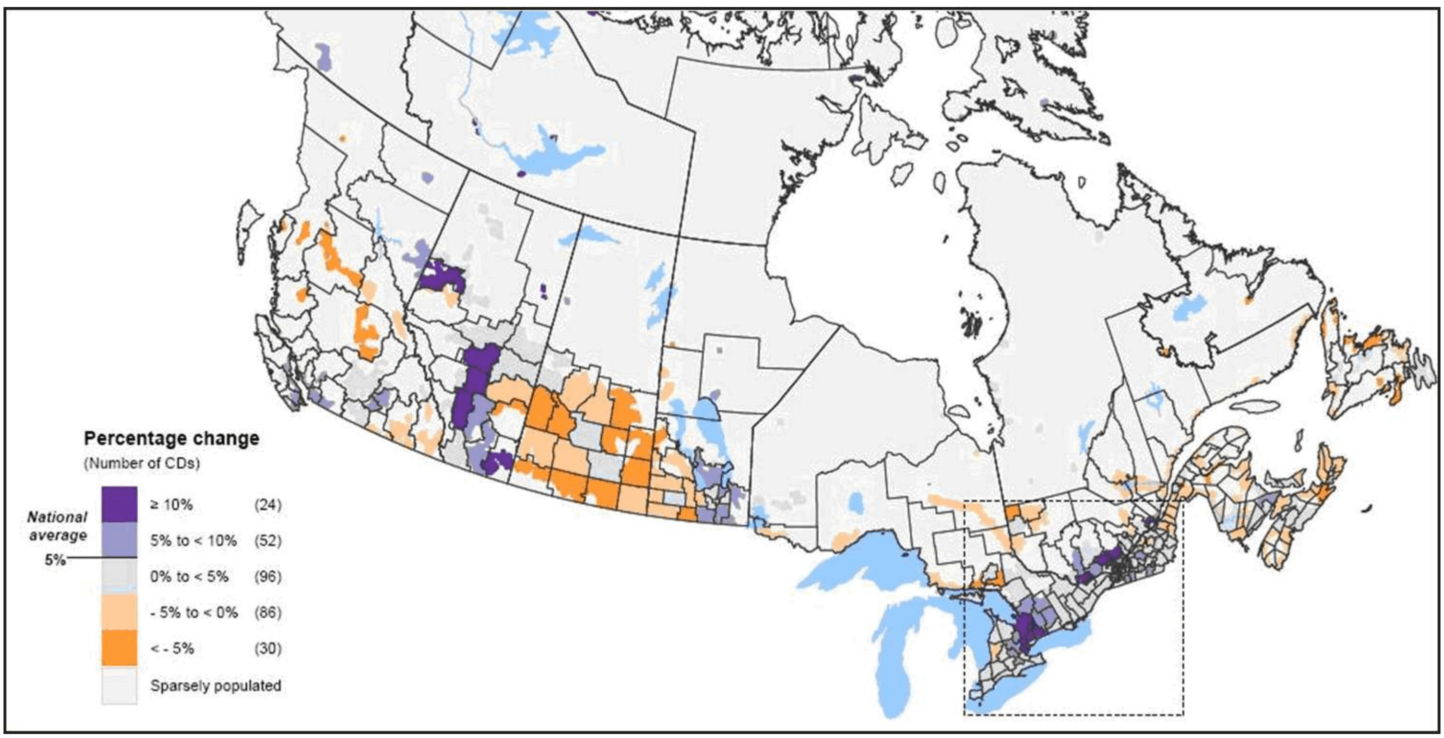

Figure 2b

Figure 2: (a) Population density and (b), change in population from 2001 to 2006 over southern Canada from the Statistics Canada 2006 Census. The Edmonton – Calgary corridor is among the most densely populated and fastest growing regions in Canada.

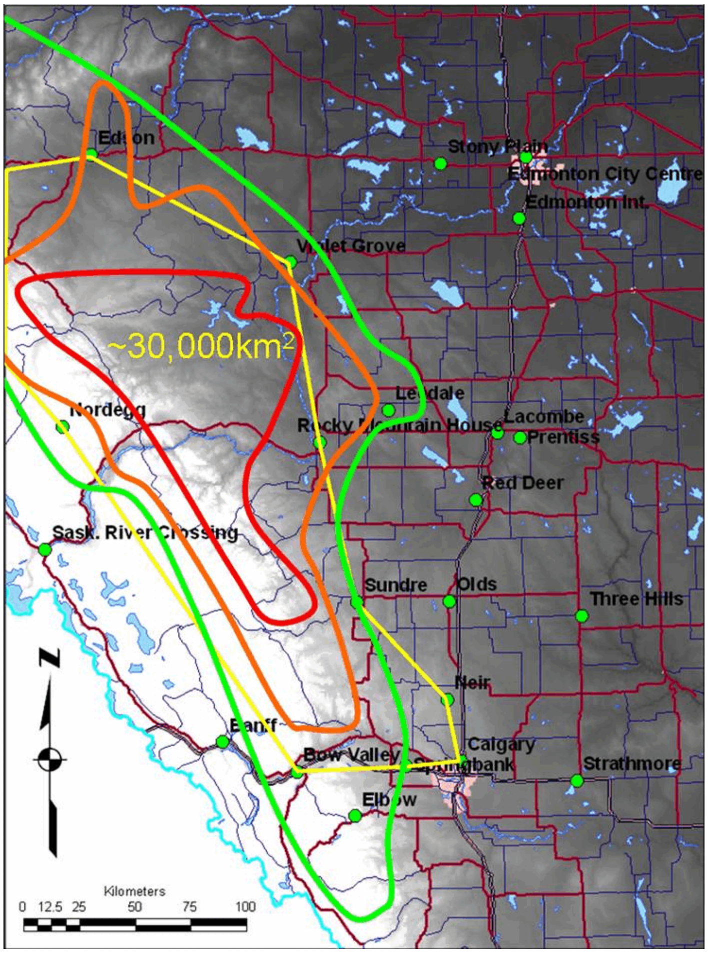

Figure 3: Hourly surface observation sites available to forecasters over the foothills region of Alberta. The yellow polygon denotes an area of just over 30,000 km^2 within which there are no real-time surface observations. Approximate contours of days with at least 1 cloud-ground lightning strike as in Fig. 1 are contoured at 22-26 (green), 27-32 (orange), and > 32 (red). We see that the area with the greatest number of lightning days corresponds to a void in surface observations within the current operational network.

A significant amount of severe thunderstorm research has occurred in Alberta dating back to the Alberta Hail Studies (ALHAS) and Alberta Hail Project (AHP) between 1957 and 1985. Later field experiments include the Limestone Mountain Experiments (LIMEX, Strong 1986, 1989) and the Alberta GPS Atmospheric Moisture Evaluation (A-GAME, Hill 2006). Research from these projects focussed mainly on hail and upper-air processes. More recent research in Canada and the U.S. has focussed on ABL moisture, convergence boundaries, and mesoscale circulations associated with CI and severe storms (e.g., Sills et al. 2002, Sills et al. 2004, Weckwerth et al. 2004, Weckwerth and Parsons 2006, Hill 2006). These findings indicate that more work is required both regionally and abroad to better understand the significance and influence of ABL processes on CI and the development of severe thunderstorms.

UNSTABLE Goals and Science Questions

UNSTABLE seeks to fill in some knowledge gaps with respect to ABL processes and severe thunderstorms. The overall goals of the UNSTABLE project can be summarized as:

- To better understand atmospheric processes leading to thunderstorm development over the Alberta foothills (both prior to and during CI) with an aim to extend results to the rest of Canada;

- To improve the accuracy and lead time for severe thunderstorm watches and warnings;

- To assess the utility of the GEM-LAM model in resolving physical processes over the Alberta foothills and its ability to provide useful numerical guidance for the forecasting of severe convection;

- To refine current existing conceptual models describing CI and the development of severe thunderstorms over Alberta and the western prairies through observational and numerical modeling studies.

A primary goal of UNSTABLE is to improve accuracy and lead time for severe thunderstorm watches and warnings. For this to be achieved, appropriate mechanisms must be in place to ensure knowledge gained from UNSTABLE is transferred to operational forecasters. Collaboration between the National Labs and Storm Prediction Centres within Environment Canada is increasing. Already, laboratory staff are involved in training workshops and seminars and have implemented Research Support Desks (RSDs, Sills 2005, Taylor 2006) directly in forecast operations within two of Canada's Storm Prediction Centres. The PASPC is anticipated to be involved in UNSTABLE during the field campaign and is involved to a lesser extent in the planning of the project. Following a period of data analysis, laboratory staff will work with the PASPC (and other Storm Prediction Centres) to incorporate results into operational conceptual models and forecast techniques. This will be accomplished through traditional means such as those listed above but also through the RSD where researchers can work with forecasters in real-time to apply UNSTABLE results to convective forecast and warning decisions.

To achieve the goals of the project, and for experiment planning purposes, three primary science questions have been formulated to investigate specific areas related to CI and severe thunderstorms. These involve ABL processes, land surface interactions, and numerical weather prediction. Scientific leads have been identified for each question to oversee their respective component of UNSTABLE including instrumentation / measurement strategies and data analysis. Each science question and a brief summary are included below.

1) What are the contributions of ABL processes to the initiation of deep moist convection and the development of severe thunderstorms in the Alberta Foothills region?

This first question deals with processes associated with ABL water vapour and convergence lines as they relate to CI and severe storm development. More specifically, we are interested in characterizing ABL diurnal evolution, water vapour stratification, and the role that mesoscale convergence boundaries and circulations play in CI. The influence of highly varied terrain and mesoscale circulations and boundaries on storm evolution will also be investigated. In recent years the dryline has been identified as an important feature for CI in the region. Four-dimensional characterization of the dryline prior to and during storm development will be a priority of the field campaign. UNSTABLE will result in a dataset of high-resolution observations that will be used to evaluate the utility of current observational networks and to modify existing conceptual models for CI and severe weather outbreaks in southern and central Alberta.

2) What are the contributions of surface processes to the initiation of deep moist convection and the development of severe thunderstorms in the Alberta Foothills region?

This question deals mainly with the effects of latent and sensible heat fluxes associated with varying soil moisture and evapotranspiration. We are interested in investigating effects of adjacent wet and dry soils (as defined by an agrometeorological model) on storm initiation and evolution. Attempts will be made to sample the development and evolution of moisture gradients and mesoscale circulations associated with surface discontinuities (e.g., land-land breezes). Targeted, high-resolution field observations will be compared with existing observations to evaluate the degree to which the current observational network can be used to detect these circulations sometimes associated with thunderstorm development.

3) To what extent can high-resolution numerical weather prediction models contribute to forecasting the initiation and development of severe convective storms that originate in the Alberta foothills?

The last science question relates to the use of high-resolution numerical modeling to forecast CI and severe thunderstorm development in the Alberta foothills. Specific questions address the ability of the Canadian Meteorological Centre's Global Environmental Multi-scale (GEM) Limited Area Model (LAM) at 2.5 km resolution to simulate ABL and surface processes investigated in questions one and two, observed storm structures, and microphysical fields. Also of interest are identifying any deficiencies in current physical parameterizations and the effects of performing nested model runs on higher-resolution grids (e.g., 1 km). Other areas to be investigated using the observational dataset from UNSTABLE include high-resolution ensemble forecasts of CI and the use of a high-resolution analysis to improve prediction of CI and subsequent storm development.

Figure 4: Environment Canada's Automated Transportable Meteorological Observing System (ATMOS).

Experimental Design

UNSTABLE will take place from 1 June to 31 August 2008 with a three-week Intensive Observation Period (IOP) planned from 9 July to 31 July. Fixed mesonet stations will be deployed prior to 1 June with all other supplementary instrumentation deployed during the IOP. The field campaign will utilize targeted, high-resolution fixed and mobile measurements from a variety of observation platforms. Central to the success of the project is a mesonet of surface weather stations, mobile surface observing platforms, multiple profilers, and an upper-air campaign utilizing multiple radiosondes, a tethersonde and, if sufficiently funded, a research aircraft. The surface mesonet is designed using both grid (~ 25 km spacing) and linear (~ 10 km spacing) configurations to resolve surface characteristics spatially and their evolution in time. The mesonet will consist of existing weather stations in cooperation with the Government of Alberta and Canadian universities and 10-15 Automated

Transportable Meteorological Observing Systems (ATMOS, see Fig. 4). Mobile surface measurements will be used to resolve surface convergence and other boundaries in space and time. To do this we will deploy one or more Automated Mobile Meteorological Observing Systems (AMMOS, see Fig. 5) capable of atmospheric state variable measurements (including wind speed and direction) while stationary or in motion.

Figure 5: Environment Canada's Automated Mobile Meteorological Observation System (AMMOS), photo by David Sills.

Upper-air measurements during UNSTABLE will be conducted using up to 5 radiosonde systems (3 mobile and 2 fixed), a recently-purchased Vaisala tethersonde, and a number of profiling and total column water vapour instruments (radiometers and GPS precipitable water measurements) contributed by the University of Manitoba and the University of Calgary. The majority of these instruments will be deployed in fixed locations but the University of Manitoba Centre for Earth Observation Science will be participating with their Mobile Atmospheric Research System (MARS) trailer. The MARS contains a profiling radiometer, Atmospheric Emitted Radiance Interferometer (AERI) and Doppler sodar along with a surface weather station. The MARS will be deployed in conjunction with other mobile surface observations in the vicinity of mesoscale boundaries and favoured areas for CI.

The UNSTABLE study area is designed to take advantage of other existing observing networks. These include existing surface stations, the Stony Plain radiosonde station, the CLDN, Environment Canada radars at Carvel (53.56˚N, 114.14˚W) and Strathmore (51.21˚N, 113.40˚ W), and satellite imagery received by Environment Canada. Additional radar information is anticipated from the Weather Modification Inc. radar at the Olds-Didsbury airport (51.71˚N, 114.11˚W). The study area consists of a primary and a secondary domain. Most of the instrumentation described above will be deployed in the primary domain as indicated in Fig. 6. The secondary domain will allow for mobile measurements to be obtained when features of interest develop away from the foothills but in locations where storms could still impact densely populated areas. Final locations of instrumentation in Fig. 6 are still unconfirmed as mesonet and other equipment siting is under way.

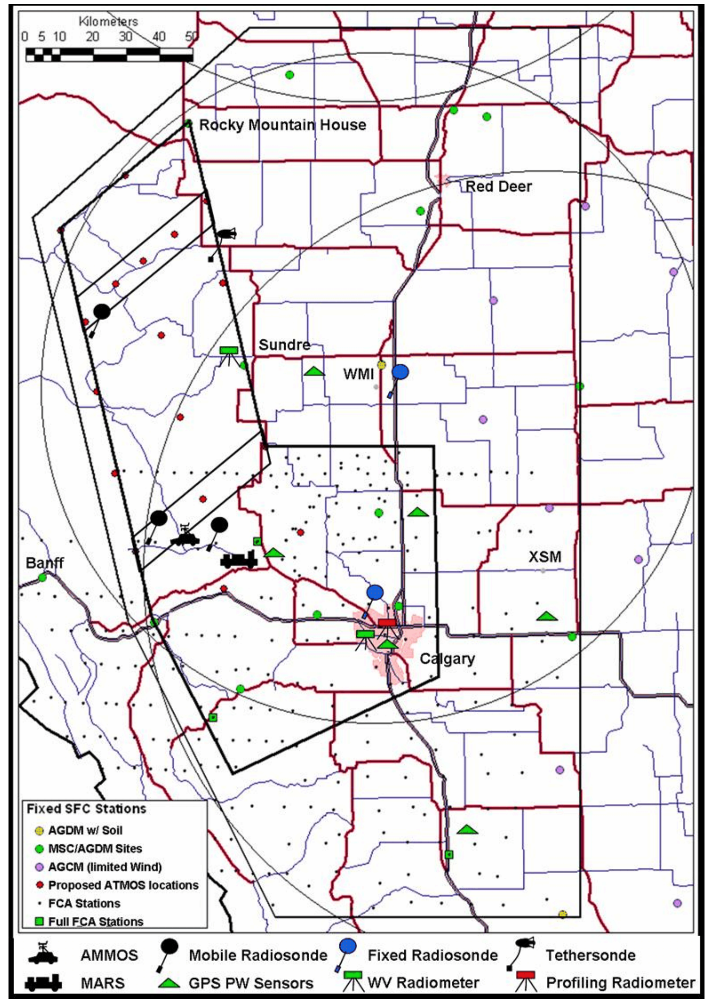

Figure 6: Map showing possible instrumentation locations within the UNSTABLE domain(s). Black circles are 120 km range rings for WHK and XSM radars and the 100 km range ring for the WMI radar. The heavy black line is the primary UNSTABLE domain enclosing the mesonet, the lighter black line is the secondary study domain. Black polygons within the primary domain are proposed locations for higher resolution lines of mesonet stations (the southern one will depend on station availability). Fixed surface mesonet and other stations are as indicated as is other instrumentation to be deployed. Final locations of fixed profiling / other platforms are to be determined. Mobile instrumentation will be deployed on Intensive Observation Days (IODs) within a specified target area. Aircraft (not shown) will be deployed on IODs when mesoscale circulations are expected to develop. Circuits and stepped traverses will be employed to sample the circulation spatially and in the vertical.

The Canadian Meteorological Centre will continue to run the GEM-LAM model in quasi-experimental forecast mode over the western 2.5 km grid during the summer of 2008. In support of UNSTABLE, the eastern boundary of this grid will likely be extended to approximately the Alberta-

Saskatchewan boarder. The full western grid (with the extended boundary) with model terrain is shown in Fig. 7. The real-time runs performed on this grid will be examined in detail during the experiment with close comparisons made to the measurements taken during the IOP period. Case study simulations and sensitivity experiments will be performed in hind-cast mode on this grid as well as finer resolution subdomains.

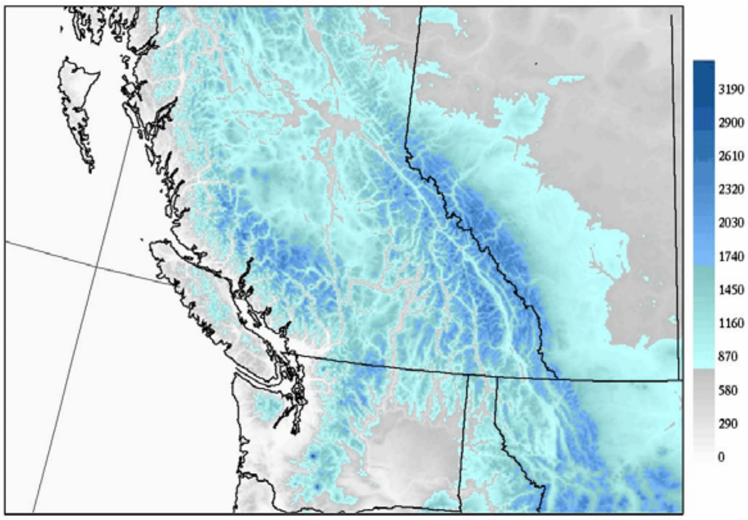

Figure 7: Western 2.5 km grid for the GEM-LAM to be used for the real-time NWP forecasting during the summer of 2008. Shading indicates model terrain elevation (m).

The First UNSTABLE Science Workshop, 18-19 April 2007

The first UNSTABLE science workshop was held in Edmonton, Alberta on 18-19 April 2007. The meeting brought together over thirty Canadian scientists from across the country representing various divisions of federal and provincial government agencies and Canadian universities. This workshop was an opportunity for interested participants in the experiment to share their interests and contributions to the project and to discuss the draft science questions along with strategies for answering them. The meeting allowed the principal investigators to confirm the level of contribution of participants and their involvement in the field campaign. Results of discussions from the meeting are being used to refine both the science questions and the UNSTABLE science plan. Organizations that were represented at the meeting are listed in the table shown below.

Organizations represented at the Science Workshop held in Edmonton, Alberta, 18-19 April, 2007

Hydrometeorology and Arctic Laboratory, Environment Canada
Cloud Physics and Severe Weather Research Section, Environment Canada
Prairie and Arctic Storm Prediction Centre (Edmonton and Winnipeg), Environment Canada
Climate Research Division, Environment Canada
Recherche en Prévision Numérique, Environment Canada
University of Manitoba
University of Alberta
University of Calgary
McGill University
Canadian Forest Service
Alberta Agriculture and Food
Alberta Environment

The workshop began with presentations on UNSTABLE observations. These included descriptions of the Foothills Orographic Precipitation Experiment (FOPEX, Smith 2005, 2007), The Alberta GPS Atmospheric Moisture Evaluation (Hill 2006), The Foothills Climate Array mesonet (M. Adams, University of Calgary), GPS measurements of precipitable water (S. Skone, University of Calgary), and the Province of Alberta surface weather stations. The second session of the meeting included presentations from UNSTABLE collaborators and included representatives from the University of Manitoba, University of Alberta, the Prairie and Arctic Storm Prediction Centre, and McGill University detailing their interest and contributions to the project.

Following the formal presentations, science leads summarized their respective science questions and strategies for answering them. Science leads are (1) Neil Taylor and David Sills (Environment Canada), (2) John Hanesiak (University of Manitoba), and (3) Jason Milbrandt (Environment Canada). These presentations served as an introduction to guided break-out sessions. Participants were asked to select one of the science questions and contribute to discussions on such things as:

- Refinement of specific science questions as presented in the draft science plan;

- Who plans to be directly involved in the field campaign and how?

- Funding strategies and opportunities for in-kind support;

■ Data requirements, instrumentation and deployment strategies necessary to answer the science questions;

■ ‘Champions’ for data analysis and quality control.

Break-out discussion results were presented to the group as a whole on the morning of 19 April followed by open discussion by participants.

The workshop achieved its goals and allowed potential UNSTABLE participants to discuss details of the project for an extended period of time. This workshop was invaluable to help refine the direction of the project with respect both to the science objectives and strategies to fulfill them. It also provided an opportunity for UNSTABLE participants to formalize their involvement and contributions to the project. Results from the discussions included identification of a lead for the upper-air campaign, clarification of instrumentation available from Canadian universities, preliminary agreements with respect to data sharing, and support from the PASPC.

Next Steps

Planning for UNSTABLE continues with many issues remaining to be addressed. The science plan is now being revised for submission to Environment Canada management for funding. Specifically, the science questions themselves will be finalized along with instrument requirements and measurement strategies. Beginning in fall 2007 the UNSTABLE field operations plan will be finalized including a data management strategy. This document will detail all logistics issues to be considered during the field campaign (e.g., people in the field, communications, instrumentation, training, occupational health and safety, etc.). Following the production of a draft operations plan, a small and focussed workshop will take place to refine the details. In early spring 2008 instrumentation land-use agreements for mesonet sites will be finalized leading up to deployment and testing in May 2008. Testing of mobile instrumentation and communications will occur in June prior to the intensive observation period scheduled to begin on 9 July 2008.

Summary

UNSTABLE is a collaborative project bringing together scientists from Environment Canada, Canadian universities, other federal and provincial government agencies, and the private sector to investigate severe thunderstorm development in Alberta. The focus on atmospheric boundary-layer phenomena reflects current knowledge gaps within the meteorological community in understanding how thunderstorms form. With a focussed transfer of results into Environment Canada forecast operations, there is an opportunity to enhance lead time and accuracy of severe weather watches and warnings, both in Alberta and across the country.

The first science meeting of the UNSTABLE project was an important step in developing the project. By bringing together the collective knowledge and experience of scientists working in related areas across the country, we can refine the scientific objectives of UNSTABLE and leverage their contributions to ensure its success.

Figure 8a

Figure 8b

Figure 8: Photos from the First UNSTABLE Science Workshop, (a) Hydrometeorology and Arctic Laboratory manager Gary Burke welcoming participants to the workshop, and (b) participants during one of the coffee breaks. Photos courtesy Jingang Wu.

Acknowledgements

Thanks to CMOS for providing hospitality for the first UNSTABLE science workshop, and for the opportunity to publish this article in the *CMOS Bulletin SCMO*. We would also like to thank all the participants in the UNSTABLE science workshop for helping to refine the science plan and for ongoing discussions and contributions to the project. Special thanks go to Stewart Cober, Gary Burke, and others in Environment Canada for supporting the project and ensuring that UNSTABLE will go ahead.

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