18.7 THE UNDERSTANDING SEVERE THUNDERSTORMS AND ALBERTA BOUNDARY LAYERS EXPERIMENT (UNSTABLE): OVERVIEW AND PRELIMINARY RESULTS

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1. INTRODUCTION

Severe thunderstorms are a frequent occurrence on the Canadian Prairies with an average of 217 severe weather reports received by Environment Canada each summer (McDonald and Knott 2007). As evidenced in climatological lightning data, the Rocky Mountain foothills in Alberta see more lightning days than anywhere else in the Prairie Provinces (Fig. 1). The foothills are characterized by sloping terrain ranging in elevation from < 1000 m on the western prairies to ~ 1800 m at the base of the Rocky Mountains (Fig. 2.). The foothills have long been recognized by forecasters and the public alike as a favoured area for storm initiation with most storms initiated there moving to the NE or E affecting the Edmonton to Calgary corridor. This corridor has become one of the most densely populated and fastest growing regions in Canada (Statistics Canada 2006 – Fig. 3). The proximity of this active convective initiation (CI) area to growing population has proven to be costly. Since 1981, Public Safety and Emergency Preparedness Canada estimates that severe thunderstorms have been responsible for 40 deaths and over $ 2.5 billion in property damage. Recognition of the potential for future losses has led Environment Canada researchers and scientists from academia to develop a field experiment to investigate atmospheric processes associated with CI in this region. The Understanding Severe Thunderstorms and Alberta Boundary Layers Experiment (UNSTABLE) has been designed to take place over two summers with a pilot experiment conducted during June to August 2008. A full-scale experiment is planned for the summer of 2011. The ultimate goal of UNSTABLE is to gain an increased understanding of the processes associated with CI and to work with forecasters to maximize severe thunderstorm watch / warning lead time and accuracy.

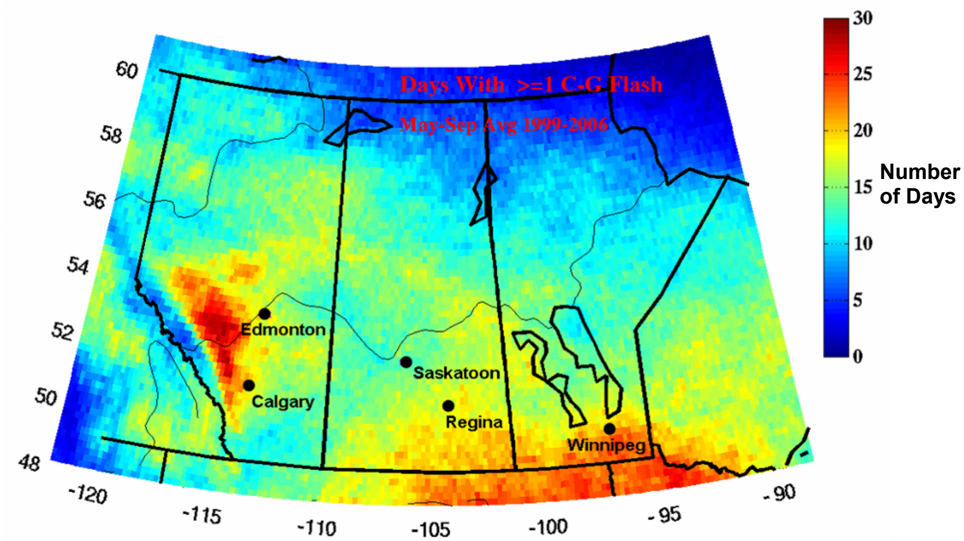

Fig.1: Average number of days with at least one cloud-to-ground lightning strike from 1999 to 2006 over the Canadian Prairies (Burrows 2007, personal communication). The area west of the Edmonton to Calgary corridor is associated with more thunderstorm days than anywhere else in the Canadian Prairie provinces.

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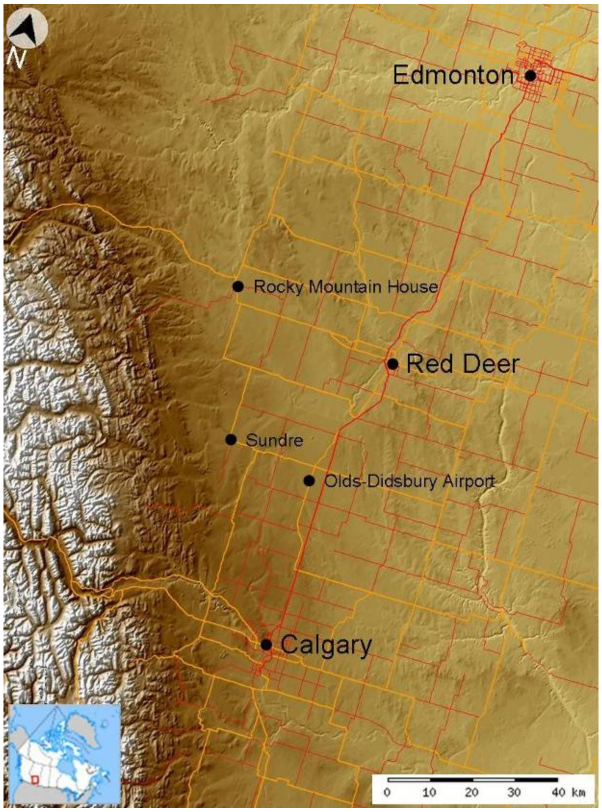

Fig. 2: Shaded relief map showing topography over the transition from the Rocky Mountains to the Plains in southern Alberta. Elevations range from ~ 1000 m in the Red Deer – Calgary corridor to ~ 1800 m at the base of the Rocky Mountains. Image generated from The Atlas of Canada online (Natural Resources Canada).

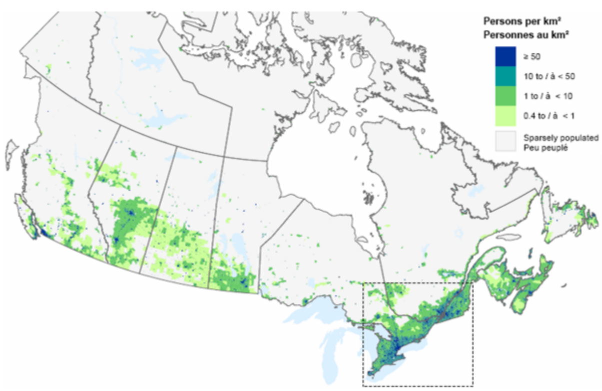

Fig. 3: Canadian population density showing the Edmonton to Calgary corridor as one of the most densely populated regions in Canada (Statistics Canada 2006 Census).

2. ALBERTA FORECAST CHALLENGES

The sensitivity of CI to surface and atmospheric boundary layer (ABL) processes is well-established with particular emphasis having been placed on ABL water vapour (e.g., Mueller et al. 1993, Crook 1996, Weckwerth and Parson 2006) and convergence lines (e.g., Wilson and Schreiber 1986, Wilson and Mueller 1993, Sills et al. 2004, Wilson and Roberts 2006). Results from these and other studies suggest that ABL moisture and convergence processes are intrinsically linked. Further, variability in ABL characteristics that influence the potential for CI have been found to occur on small horizontal scales and are not necessarily limited to near surface effects (see Weckwerth and Parsons 2006 for an excellent review). If forecasts of CI and subsequent severe weather are to improve, our knowledge and understanding of ABL processes must increase.

There is a long history of thunderstorm research in Alberta focusing largely on hail and thunderstorm outbreaks over the foothills (e.g., Longley and Thompson 1965, Chisholm and Renick 1972, Strong 1986, Smith and Yau 1993). These studies focused mainly on upper-air and synoptic environments associated with storm and hail development. Conceptual models developed in these studies depended on observations with fairly low spatial and temporal resolution and the importance of drylines and other mesoscale boundaries were not yet considered.

The surface observation network over the foothills is sparse (Fig. 4). Forecasters often do not have in-situ measurements of surface dewpoint or other parameters and have virtually no observational data on moisture stratification in the vertical within the ABL. As a result, conceptual models developed 15 or more years ago are still (along with recent applicable models developed elsewhere) used by Alberta forecasters. The importance of the dryline for CI in Alberta was first proposed by Knott and Taylor (2000) and in recent years has garnered more attention (e.g., Taylor 2001, 2004, Hill 2006). Until recently, sampling of the dryline had been limited to inferring its position and behaviour using sparse surface observations and remote sensing observations. Results from mobile transect data (temperature, humidity, and pressure) during the A-GAME (Alberta GPS Atmospheric Moisture Evaluation) project (Hill 2006) gave the first indications of the actual moisture gradient across the dryline in Alberta. Given the significance attributed to the dryline in the U.S. and its perceived importance in Alberta, more complete documentation and understanding of this boundary is necessary.

3. UNSTABLE GOALS AND SCIENCE QUESTIONS

The goals of the UNSTABLE project may 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 elsewhere in Canada
- To improve accuracy and lead time for severe thunderstorm watches and warnings

- To assess the utility of the Canadian Meteorological Centre's (CMC) Global Environmental Multiscale (GEM) Limited Area Model (LAM) in resolving physical processes over the Alberta foothills and its ability to provide useful numerical guidance for the forecasting of severe convection
- Through observational, case, and numerical modeling studies refine current existing conceptual models describing CI and the development of severe thunderstorms over Alberta and the western prairies

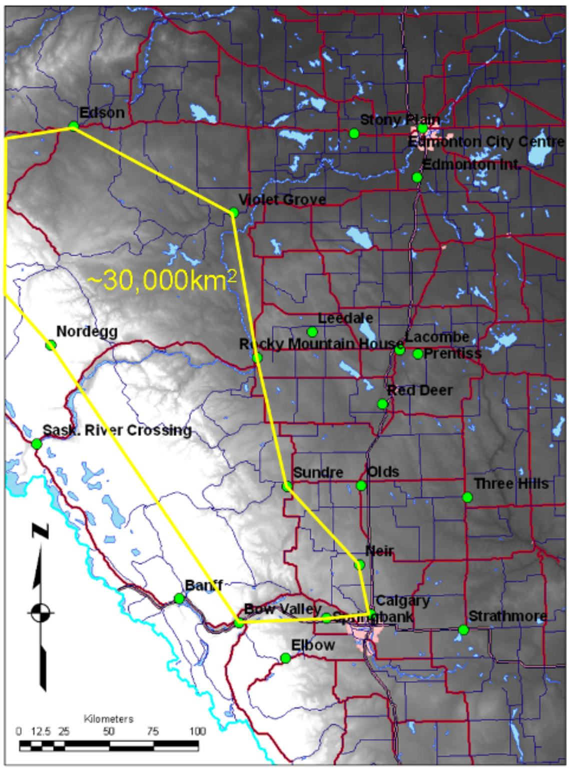

Fig. 4: Map showing the existing real-time surface observation network available to Environment Canada forecasters. The yellow polygon highlights a 30 000 km^2 region in which there are no real-time surface observations. The nearest routine soundings in Alberta are released from Stony Plain (~40 km west of Edmonton) which is 200 km or more away from foothills areas of interest.

In developing plans for UNSTABLE three over-arching science questions were formulated and a science lead or leads designated for each. A number of sub-questions were also identified to further focus efforts, sub questions may be found in the UNSTABLE scientific overview document (Taylor et al. 2007).

Q1. 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?

Question 1 deals with ABL water vapour availability and stratification in the vertical, the role of mesoscale boundaries and circulations in CI in the region, four-dimensional characterization of the dryline, factors inhibiting CI in the region and revision of existing conceptual models for CI.

Q2. 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?

Question 2 seeks primarily to investigate the development and influence on CI of horizontal water vapour gradients and mesoscale circulations in response to contrasting areas of root-zone soil moisture and vegetation type. During the pilot project, observations were limited to meteorological measurements. A more complete investigation of question 2 will have to wait for the inclusion of direct flux measurements in the full-scale UNSTABLE campaign tentatively planned for 2011.

Q3. 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 third science question targets the use of high-resolution numerical weather prediction in forecasts of CI and severe weather. Investigations will include the ability of the CMC GEM LAM at 2.5-km and 1.0-km horizontal grid spacing to simulate ABL and surface processes under consideration in questions one and two, observed storm structures, and microphysical fields. Potential deficiencies in current parameterizations will also be examined.

4. EXPERIMENTAL DESIGN

UNSTABLE project domains (see Fig. 5) were selected based on climatological thunderstorm and severe weather activity, proximity to the cities of Calgary and Red Deer, the opportunity to collaborate with Weather Modification Inc. in terms of a project headquarters, the presence of pre-existing surface stations that could be exploited, and the experiences of forecasters and the principal investigators. The primary domain (inner polygon) was selected to focus on CI and would contain most of the specially-deployed instrumentation. The secondary domain (outer polygon) was selected to allow for documentation of storm evolution, consideration of agricultural areas for question 2, and for targeting CI missions that may fall outside the primary domain.

The pilot UNSTABLE experiment was conducted from mid June to mid August 2008 over the domains outlined in Fig. 5. During this overall study period five fixed ATMOS (Automated Transportable Meteorological Observation System) mesonet stations were installed to record one-minute average measurements of 1.5 m temperature (T) and dewpoint (T_d), 10 m wind speed and direction, barometric pressure (P), liquid precipitation, 9.5 m – 0.5 m delta T, and incoming solar radiation. Locations of these stations are also shown in Fig. 5. Fixed mesonet stations also included three existing Environment Canada stations from the Foothills Orographic Precipitation Experiment (FOPEX, Smith 2007) recording one-minute T, P, relative humidity (RH), 2 m wind speed and direction and liquid precipitation. Additionally, stations from the University of Calgary's Foothills Climate Array were used with a subset of 20 stations converted to recording one-minute average samples of T, RH, and liquid precipitation.

The UNSTABLE Intensive Observation Period (IOP) took place between 9 and 23 July 2008. During this time a suite of fixed and mobile surface and upper-air instrumentation platforms were deployed strategically within the UNSTABLE domains in support of the science questions from section 3. Central to the success of UNSTABLE is the use of targeted mobile surface and upper-air observations. Mobile instrumentation deployed during the IOP consisted of:

- Environment Canada's Automated Mobile Meteorological Observation System (AMMOS) collecting two-second samples of T, T_d, P, and wind speed and direction.
- Two mobile surface teams (T, T_d, P only).
- Two mobile radiosonde teams (one of these was the University of Manitoba's MARS* trailer) each releasing a sounding every two hours beginning at 1600 UTC.
- Instrumented aircraft.

In addition to existing surface stations and other networks (e.g., radar, satellite, lightning, AMDAR, etc.), UNSTABLE utilized two additional fixed radiosonde stations (each releasing two-hourly soundings beginning at 1200 UTC), a network of GPS precipitable water sensors, a tethersonde system, water vapour radiometer, profiling microwave radiometer, and Doppler sodar. Positions of some of these instrumentation platforms are shown in Fig. 5.

To facilitate sampling data in support of the science questions a number of operational missions were designed to be implemented on Intensive Observational Days (IODs). IOD missions utilized pre-defined sampling strategies and planned transects for surface mobile teams and aircraft. In general, missions were designed to obtain soundings on either side of boundaries of interest with surface and aircraft transects across the boundaries. Aircraft flew in ascending / descending spiral, stepped traverse, and racetrack flight patterns depending on the mission. A summary of the missions and their objectives is given in Table 1.

Table 1: Summary of IOD missions designed for UNSTABLE.

Observation Mission	Objectives
CI 1 (ABL Water Vapour)	*Characterize evolution of ABL water vapour within areas favourable for CI in the absence of well-defined mesoscale convergence boundaries.*
CI 2 (Mesoscale Boundary)	*Sample the environment near and within mesoscale boundaries and associated circulations with the potential to trigger CI.*
Dryline	*To resolve and characterize the 4-D dryline environment with and without associated CI and thunderstorm development.*
Water Vapour Gradient 1 (WVG1 - Soil Moisture)	*Sample horizontal water vapour gradients associated with discontinuities in soil moisture from PAM-II* model forecasts and observed areas of recent precipitation.*
Water Vapour Gradient 2 (WVG2 - Vegetation)	*To sample horizontal water vapour gradients associated with contrasting areas of vegetation type, specifically forested vs. cropped areas.*

Daily operations planning would begin the evening prior to a potential IOD with a briefing to determine the likelihood of operations the following day and discuss preliminary mission decisions. The following morning final operational decisions, mission selection, and team positions would be made utilizing the latest available observational and short-range NWP data. Field teams were in transit by 1400 UTC to allow set-up time for a 1600 UTC sounding. Field coordination was conducted from Olds – Didsbury airport with support and workspace from Weather Modification Inc. UNSTABLE soundings and mobile team positions and were provided to the field coordinator in real-time via cell communications. Field observations (including sounding data) were frequently communicated to operational forecasters. Forecast and nowcast expertise was provided by Environment Canada's Prairie and Arctic Storm Prediction Center (PASPC) in Edmonton, AB through a dedicated desk in support of UNSTABLE.

* Mobile Atmospheric Research System including Atmospheric Emitted Radiance Interferometer (AERI), Atmospheric Microwave Radiometer, Infared pyrometer and surface weather station.

* Prairie Agrometeorological Model – II (Raddatz et al. 1996)

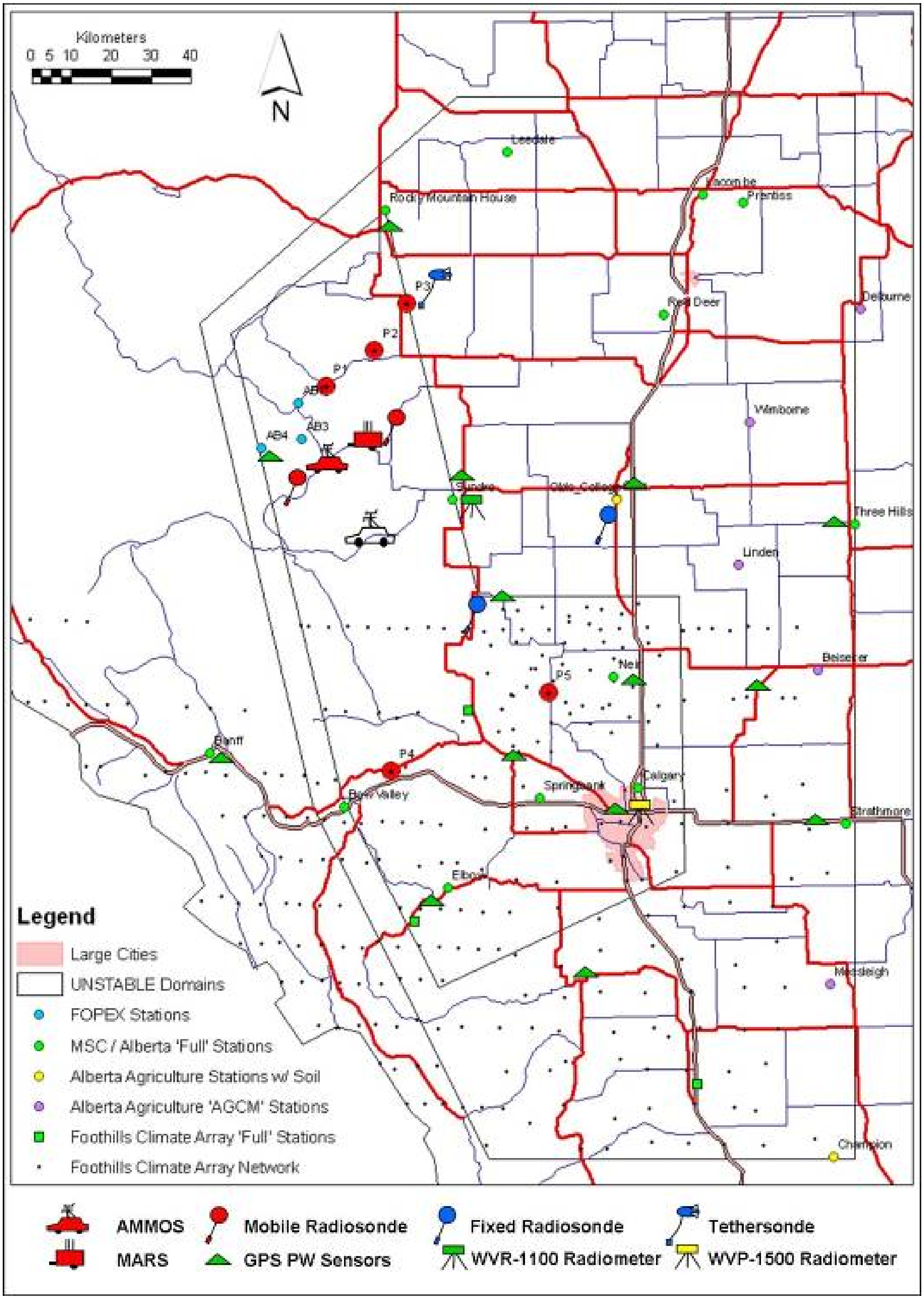

Fig. 5: UNSTABLE study domains are outlined. ATMOS stations are red circles labeled P1 through P5, other surface stations and instrumentation platforms are as indicated.

5. OPERATIONS HIGHLIGHTS

Full UNSTABLE operations were conducted on 8 IODs with partial operations conducted on an additional day (2 mobile surface teams and MARS team only). Some highlights from the field campaign include:

- Conditions suitable for conducting all five IOD missions during the IOP
- Severe weather reports were received by Environment Canada on 6 days in the UNSTABLE domains during the 15-day IOP.
- Finescale surface transects of multiple drylines with spatial and temporal resolution never before obtained in Canada.
- Simultaneous soundings on both sides of drylines and other boundaries coordinated with aircraft, surface, and other observations.
- Aircraft traverses through the dryline and other boundaries in coordination with surface and upper-air measurements.
- A post-storm damage survey within hours of an F1 tornado. The storm was initiated within the secondary UNSTABLE domain.
- Preliminary indications of contrasting surface energy partitioning into sensible and latent heat over forested and cropped areas.

The pilot UNSTABLE campaign has already been considered a success in that we were able to test the placement of fixed and mobile instrumentation as well as measurement strategies required to answer the science questions.

6. A FEW PRELIMINARY RESULTS

UNSTABLE dataset collation and quality control is ongoing at the time of this manuscript but early analysis of some data show promising results. The following are some preliminary results associated with each science question from section 3.

6a. *Science Question 1*

On 13 July 2008 a dryline was forecast to develop by 1800 UTC running through the primary UNSTABLE domain from north to south approximately parallel to the AB-BC provincial boundary. It was decided to attempt a dryline mission with mobile sounding teams placed on the dry and moist sides of the boundary. Surface transects were conducted along three approximately parallel roads normal to the forecast axis of the dryline. The aircraft conducted stepped traverses across the boundary during the early stages of its development. Storms were forecast to initiate along northern portions of the boundary. Placement of the mobile teams and aircraft flight track are shown in Fig. 6.

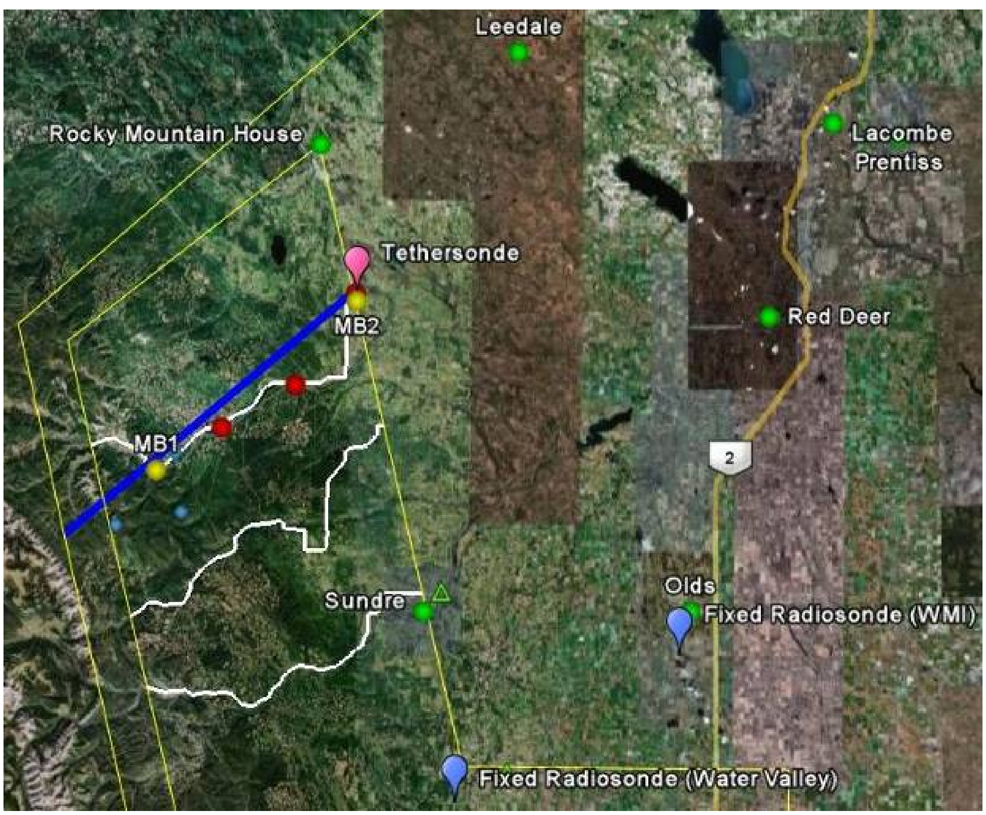

Fig. 6: Google Earth image showing placement of the mobile sounding teams (yellow circles - MB1 and MB2), aircraft flight track (blue line), and surface mobile transects (white lines). Red circles are ATMOS stations, blue circles are FOPEX stations.

The dryline was developing by 1800 UTC. By 2000 UTC the westernmost fixed stations in the UNSTABLE domains were in dry air with a westerly component to the wind (Fig. 7). At this time the dewpoint difference between the nearest fixed mesonet stations was 8.4 °C over 10.3 km corresponding to an estimated gradient of 0.8 °C km^{-1}.

By 2000 UTC all three mobile surface teams had sampled the dry air thereby allowing further refinement of dryline position and strength of the associated moisture gradient (Fig. 8). The AMMOS was able to sample an overall dewpoint difference across the dryline mixing zone of 8.7 °C over 518 m corresponding to moisture gradients of 16.8 °C km^{-1} or 7.2 g kg^{-1} km^{-1}.

Closer examination of the moisture gradient across the dryline as sampled by the AMMOS reveals additional finescale structure (Fig. 9). Within the transition from dry to moist air there is an embedded stronger moisture gradient with a change in dewpoint of 4.8 °C over a distance of only 179 m. This corresponds to a moisture gradient of 26.9 °C km^{-1} or 11.0 g kg^{-1} km^{-1}.

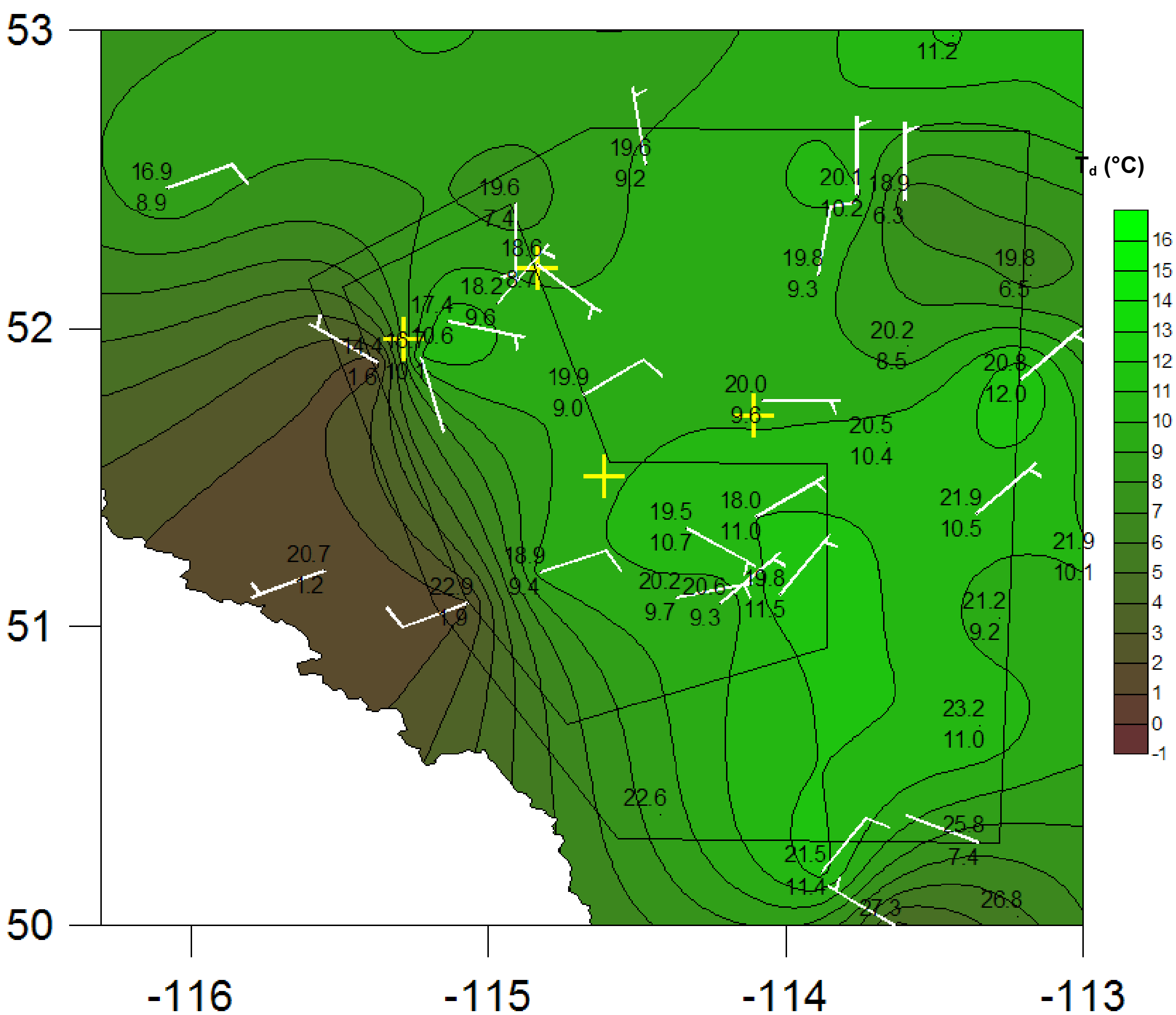

Fig. 7: Surface isodrosotherms at 2000 UTC using only fixed station measurements. The standard surface observation model is used showing temperature and dewpoint (°C) and winds (half barb, 2.5 ms^{-1}; full barb, 5 ms^{-1}, etc.). Locations of soundings are indicated with yellow crosses.

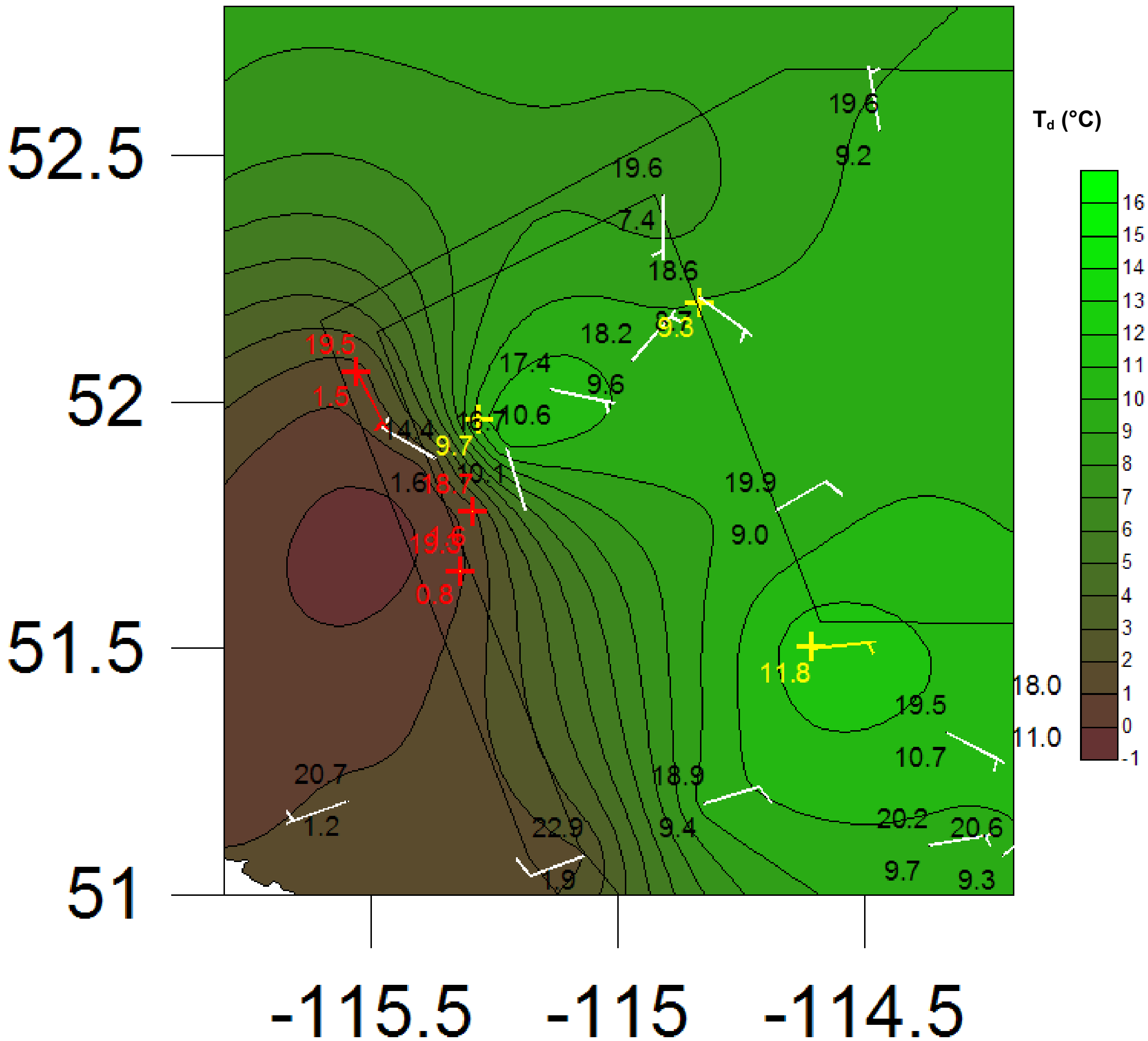

Fig. 8: Surface isodrosotherms at 2000 UTC. Positions of mobile teams at this time are plotted with red crosses.

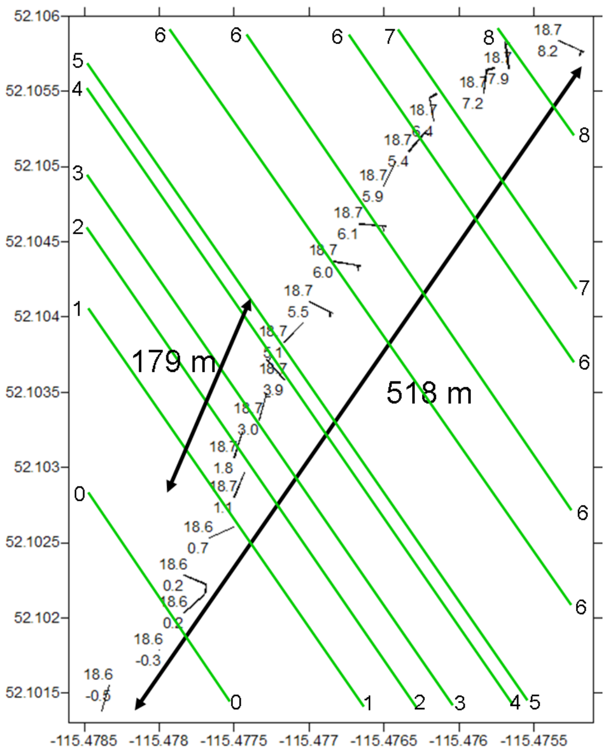

Fig. 9: AMMOS transect of the dryline from 20:48:02 UTC to 20:48:38 UTC. Surface data are two-second samples. Subjective isodrosotherms are green lines. The overall dryline mixing zone is estimated to be 518 m wide with the strongest gradient found over a 179 m distance. The 179 m distance spans surface observation points and in the figure extends beyond the tightest gradient as indicated by the isodrosotherms.

By 0000 UTC the dryline had advected eastward far enough that the westernmost mobile radiosonde team (MB1) was positioned in the dry air (observed surface dewpoint -0.6 °C). This allowed for simultaneous soundings on either side of the dryline near 0000 UTC. Positions of the sounding teams and surface isodrosotherms are shown in Fig. 10. Comparison of the MB1 and MB2 soundings (Fig. 11) shows features consistent with accepted conceptual models for the dryline as observed in the U.S. (e.g., Ziegler and Rasmussen 1998). The MB1 sounding shows a deeply mixed, dry (surface mixing ratio 4.6 g kg^{-1}) and warm ABL extending to ~ 3700 m AGL. With the exception of the surface wind observation, winds throughout the ABL are generally westerly with speeds up to 10 ms^{-1}. Lifting a parcel using the lowest 50 mb mixed layer yields MLCAPE of 140 J kg^{-1} with an LCL height of 2807 m AGL. At 0000 UTC Cu and TCu clouds were evident on visible satellite imagery (not shown) near the position of MB1 and were observed by the sounding team. The MB2 sounding is characterized by a much shallower (~ 1400 m AGL) ABL, with higher mixing ratio (surface mixing ratio 8.9 g kg^{-1}) and cooler temperatures. A nose of warm air near 700 mb caps the ABL to surface-based convection with 50 mb MLCAPE (MLCIN) values of 68 (76) J kg^{-1}. The mid-level temperatures on the MB2 sounding are higher than on the MB1 sounding as the latter sounding was closer to an upper-level shortwave trough approaching from the west. A comparison of potential temperature (θ) between 600 and 700 mb suggests that air from the deep ABL to the west of the dryline is advected over the capped ABL to the east with θ values from both soundings in this layer within ~ 1 K throughout. This is consistent with the elevated residual layer in the conceptual model of Ziegler and Rasmussen (1998). The larger difference at the bottom of this layer (also difference in T_d / mixing ratio) suggests the presence of a shallow mixing layer between the top of the moist ABL and the elevated residual layer.

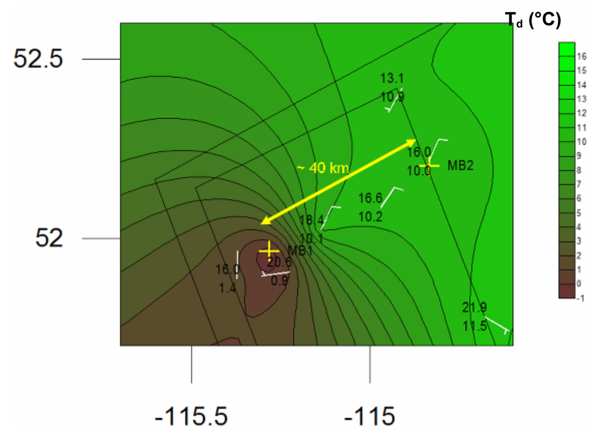

Fig. 10: Surface isodrosotherms at 0000 UTC 14 July 2008. Positions of mobile sounding teams MB1 and MB2 are indicated as yellow crosses. The distance between the teams is ~ 40 km.

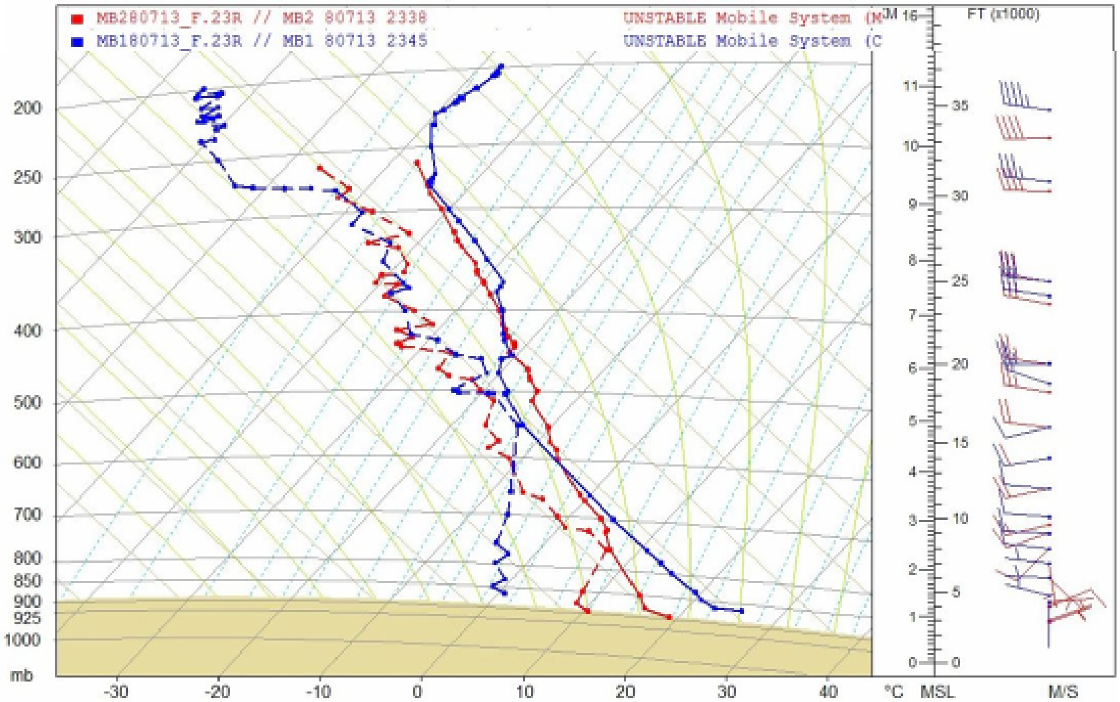

Fig. 11: Soundings released on either side of the dryline just prior to 0000 UTC (release times indicated at top) with the MB1 sounding in blue and the MB2 sounding in red. Wind barbs are in ms^{-1}.

Advancing upper-level cooling (MB1 soundings cooled by 2 - 4 °C at mid to upper levels through the day) appears to have destabilized the environment above and near the dryline late in the day leading to convective initiation of a number of thunderstorms both within and to the north of the UNSTABLE study domains. Reports of hail (up to golf ball sized) and funnel clouds were received by the PASPC from within the UNSTABLE domain. Further data analysis is required to determine with certainty whether or not the initiation of these storms was directly associated with the dryline.

6b. ***Science Question 2***

The Water Vapour Gradient 2 mission was designed to investigate ABL evolution across varying vegetation cover under quiescent surface and upper-air wind conditions and relatively clear skies. This mission was attempted on 20 July 2008 with the placement of the mobile teams shown in Fig. 12. The aircraft flew a modified racetrack pattern to maximize the flight time spent over each of the forested and cropped areas.

Soundings at 1600 UTC from MB1 and MB2 show differences in the ABL between the two vegetation types (Fig. 13). The sounding over the forested area is already well mixed near the surface by 1600 UTC and is relatively dry (surface mixing ratio of 5.6 g kg^{-1}). Over the cropped area there is a shallow ABL that is both cooler and moister (surface mixing ratio 9.7 g kg^{-1}). 1600 UTC is 1000 LT so that evapotranspiration from vegetation is well underway over both regions. These soundings illustrate the influence that vegetation type has on the partitioning of incoming solar radiation into sensible and latent heat. Specifically, over the forested area the ABL is deeply mixed and warm suggesting energy is transferred from the surface to the ABL mainly in the form of sensible heat. Over the cropped area, the cooler and moister ABL (not yet deeply mixed) is indicative of portioning of radiation into latent heat.

Aircraft data from the lowest path (approximately 300 m AGL) along the north side of the flight pattern (Fig. 12) is shown in Fig. 14. There is a marked increase in mixing ratio of ~ 1.2 g kg^{-1} over the cropped area as compared to the forested area. The potential temperature decreases from west to east reaching its lowest value over the cropped area. These results are consistent with the earlier sounding data suggesting a preferred partitioning of energy into sensible heat over the forested area and into latent heat over the cropped area.

The ratio of sensible to latent heat flux is defined as the Bowen ratio (Pielke 2001). Lower Bowen ratios have been associated with an increased potential for, and intensity of, deep moist convection (e.g., Segal et al. 1995). Adjacent areas of contrasting soil moisture or vegetation types, e.g., the forest vs. crop areas considered here, could be linked with preferred regions for CI and development of horizontal water vapour gradients or local mesoscale circulations influencing the timing and location of CI, similar to, for example Hanesiak et al. (2004). Further investigation into data from 20 July 2008 and other days during UNSTABLE will hopefully clarify the influence of these factors in local CI and severe weather occurrence.

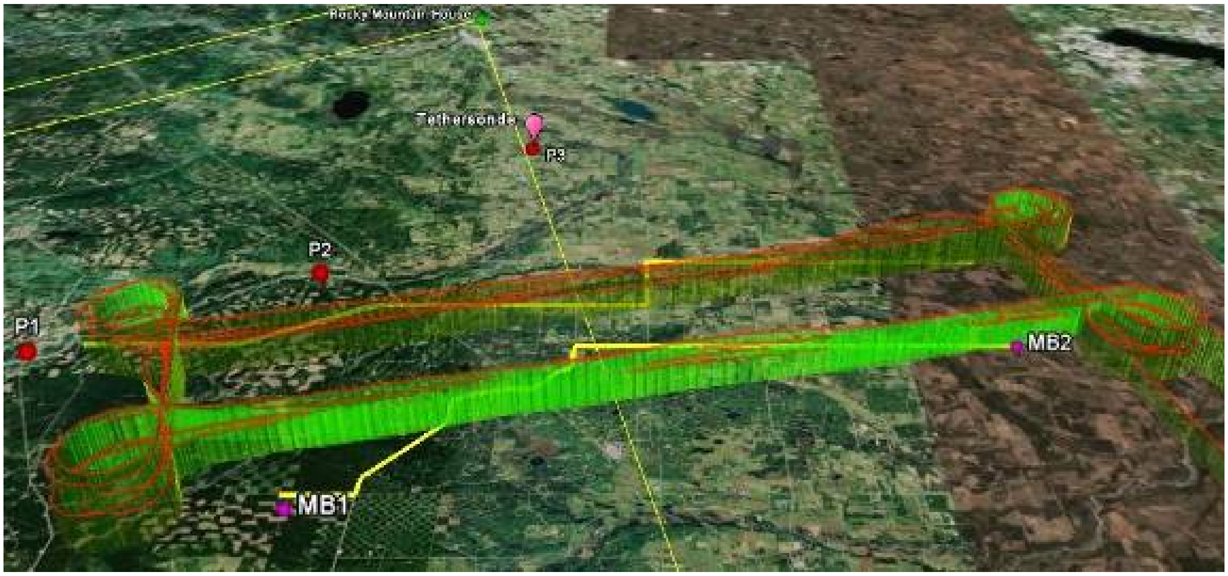

Fig. 12: Google Earth image showing team placements for 20 July 2008. MB1 and MB2 are the locations of the mobile radiosonde teams, P1-P3 represent ATMOS mesonet stations, The tethersonde was co-located with P3. The research flight path across the forested to cropped areas (from left to right) is also indicated (red lines with green shading indicating altitude). Yellow tracks from west to east indicate transects for mobile surface teams.

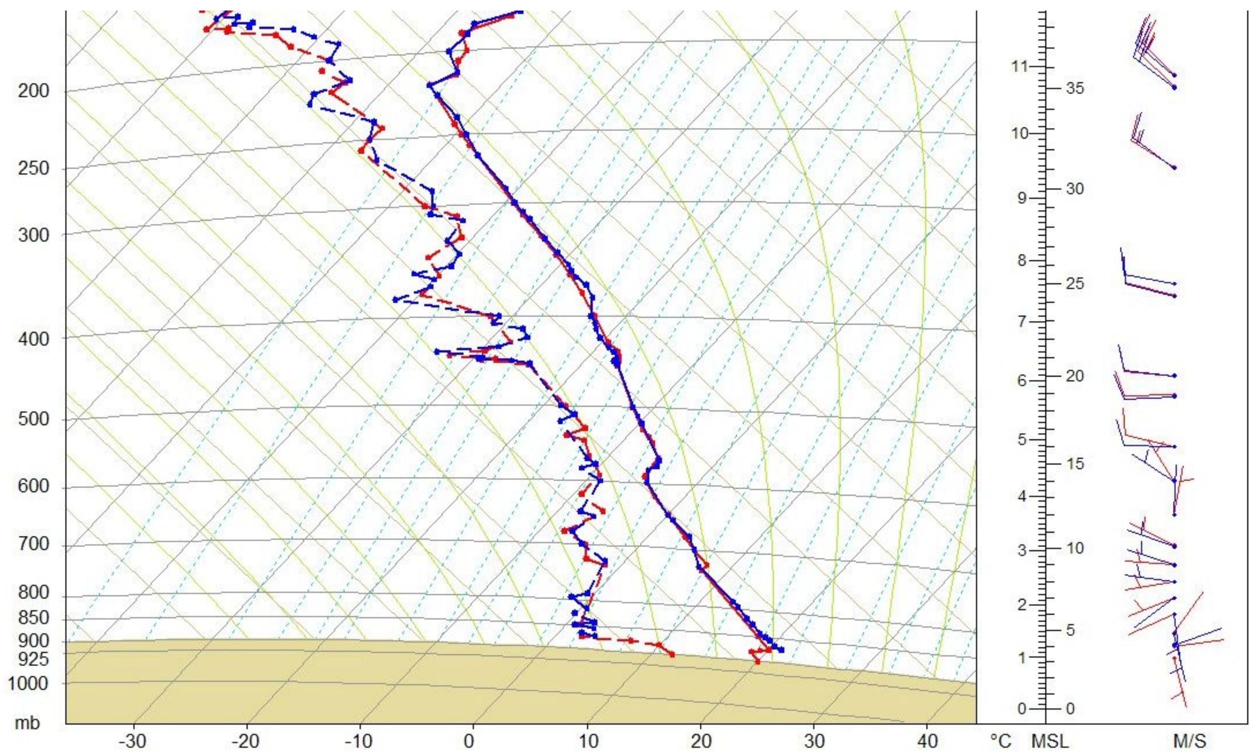

Fig. 13: 1600 UTC soundings from MB1 over a forested region (blue) and MB2 over a cropped region (red). Note the sounding from MB1 was released over higher elevation accounting for the apparent difference in level for surface data.

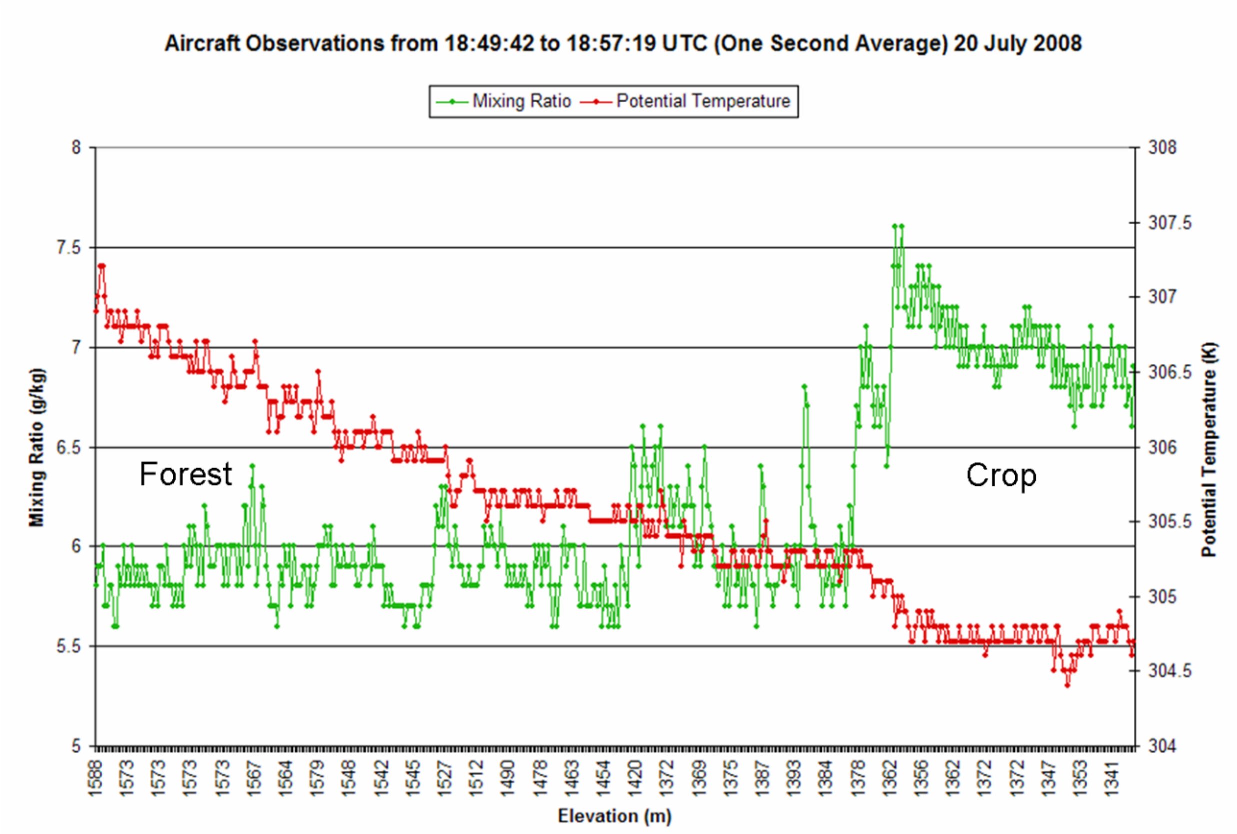

Fig. 14: Aircraft measured mixing ratio (g kg^{-1}) and potential temperature (K) from the northern path of the racetrack pattern in Fig. 13 (i.e., between the NW and NE corner). Values are plotted for elevation ranging from nearly 1600 m ASL over the forested area to ~ 1300 m ASL over the cropped area. Height AGL is approximately 300 m throughout.

6c. *Science Question 3*

Environment Canada runs daily the Global Environmental Multiscale (GEM) forecast model (Côté et al, 1998) in quasi-operational mode over several high-resolution (2.5-km horizontal grid-spacing) limited-area grids, including one which covers most of central and southern Alberta. In addition, a special 1-km grid over the UNSTABLE domain was run daily, nested from the 2.5-km model run, during the entire study period (1 June – 31 August, 2008). Special output imagery were produced and made available to the UNSTABLE field coordinator and PASPC forecasters via an internet interface. In addition to standard model fields produced for forecast operations, a number of experimental fields, development within Environment Canada's Hydrometeorological and Arctic Lab for forecasting CI, were also produced (see example in Fig. 15). Output from the high-resolution model runs were available hourly, from 1500-0300 UTC. All model output and images have been archived for future analysis, comparison with the observed data from the field campaign, and research pertaining to ability of the high-resolution model to serve as an operational tool for forecasting CI and weather associated with severe convection.

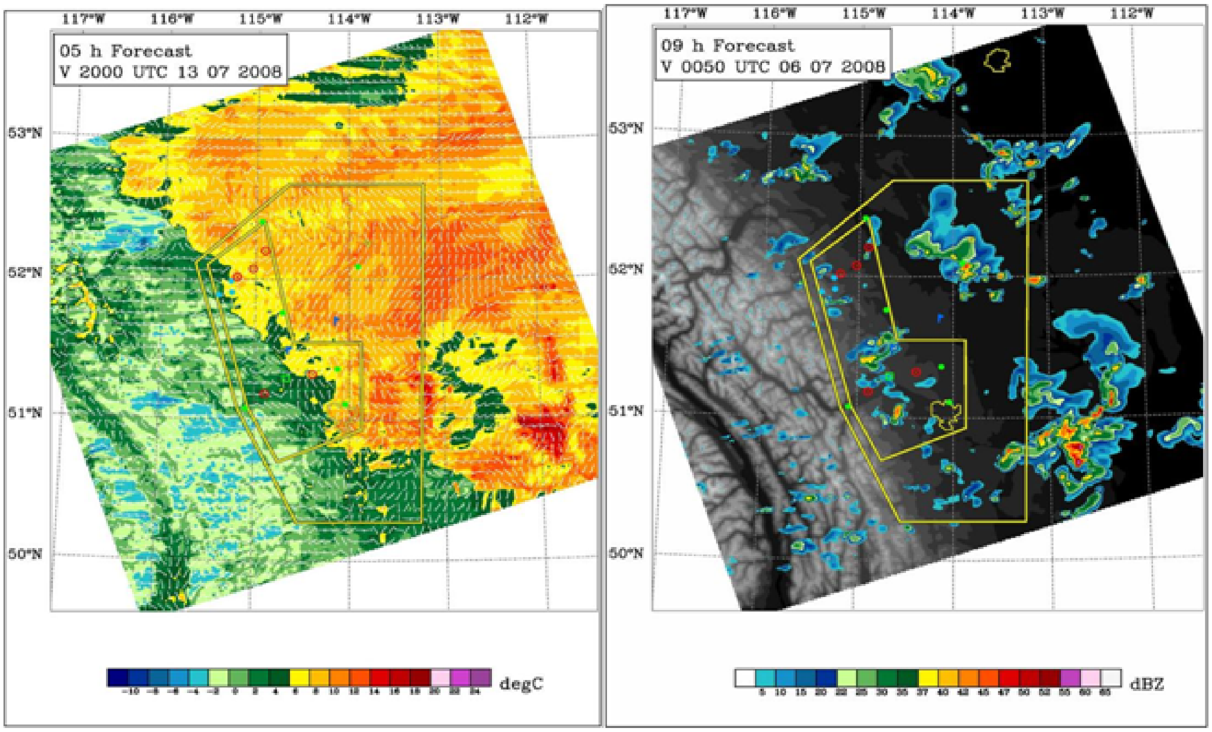

Fig. 15: Sample output from the GEM LAM 1.0 km model run daily for UNSTABLE operations. **Left**: Average T_d over the lowest 50 mb in the model and surface winds (kt) valid 2000 UTC 13 July 2008. **Right**: Synthetic Reflectivity (output every ten minutes) valid 0050 UTC 6 July 2008.

7. SUMMARY AND NEXT STEPS

In response to the increased potential for severe thunderstorms to cause human and economic loss in Alberta, Environment Canada is leading a study to investigate CI and severe storm initiation over the Alberta Foothills. A pilot UNSTABLE field campaign was conducted during the summer of 2008 with a variety of fixed and mobile instrumentation platforms used to obtain surface, ABL, and upper-air measurements of processes associated with CI. Sounding data and other field observations were available to a field coordinator in real-time and were communicated to operational forecasters at the PASPC who provided forecast expertise to the project. Experimental high-resolution model runs were incorporated into operational decisions and will be used for further research into the use of NWP in this region. Field teams were able to collect data with spatial and temporal resolution never before seen in this area including high resolution observations of numerous boundaries. Preliminary indications are that observed moisture gradients across the dryline are comparable to those measured in the U.S. and sounding data show features consistent with accepted dryline conceptual models. Sounding and aircraft data across a forested vs. cropped region show indications of contrasting energy partitioning into sensible and latent heat fluxes that may be important for influencing timing and location of CI in the region of interest.

Collation and quality control of UNSTABLE datasets are underway and results shown here should be considered preliminary. Analysis will continue into the characterization of the dryline and observations of other features and processes of interest. UNSTABLE investigators will be planning regular science workshops to discuss plans and collaboration on future research for formal publication and presentation. Results from the pilot UNSTABLE field campaign will be used to refine measurement strategies for a more complete field experiment tentatively planned for summer 2011.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

Chisholm, A. J. and J. H. Renick, 1972: The kinematics of multi-cell and supercell Alberta hailstorms. *Alberta Hail Studies 1972.* Alberta Research Council, Edmonton, Alberta, Hail Studies Report 72-2, 24-31.

Côté, J., S. Gravel, A. Methot, A. Patoine, M. Roach, A. Staniforth, 1998: The operational CMC-MRB Global Environmental Multiscale (GEM) model: Part I - Design considerations and formulation. *Mon. Wea. Rev.* **126**, 1373-1395.

Crook, N. A., 1996: Sensitivity of moist convection forced by boundary layer processes to low-level thermodynamic fields. *Mon. Wea. Rev.*, **124**, 1767-1785.

Hanesiak, J.M., R.L. Raddatz and S. Lobban, 2004: Local initiation of deep convection on the Canadian Prairie Provinces. *Boundary Layer Meteorol*., 110, 455–470.

Hill, L. M., 2006: Drylines observed in Alberta during A-GAME. M.Sc. Thesis, Department of Earth and Atmospheric Sciences, University of Alberta, 111pp.

Knott, S. R. J. and N. M. Taylor, 2000: Operational Aspects of the Alberta severe weather outbreak of 29 July 1993. *Nat. Wea. Digest*, **24**, 11-23.

Longley, R. W. and C. E. Thompson, 1965: A study of the causes of hail. *J. Appl. Meteor*., **4**, 69-82.

McDonald, M. and S. R. J. Knott 2007: 2007 Prairie Summer Severe Weather event Climatology and Verification Results Report. *Meteorological Services of Canada Internal Repor*t, 36 pp.

Mueller, C. K., J. W. Wilson, and N. A. Crook, 1993: The utility of sounding and mesonet data to nowcast thunderstorm initiation. *Wea. Forecasting*, **8**, 132-146.

Pielke, R.A., Sr. 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys*., **39**, 151-177.

Raddatz, R. L., G. H. B. Ash, C. F. Shaykewich, K. A. Roberge, and J. L. Graham, 1996: First- and second-generation agrometeorological models for the prairies and simulated water-demand for potatoes. *Can. J. Soil Sci*., **76**, 297-305.

Segal, M., R.W. Arritt, C. Clark, R. Rabin, and J. Brown, 1995: Scaling evaluation of the effect of surface characteristics on potential for deep convection over uniform terrain. *Mon. Wea. Rev.*, **123**, 383-400.

Sills, D. M. L., Wilson, J. W., Joe, P. I., Burgess, D. W., Webb, R. M., and N. I. Fox, 2004: The 3 November tornadic event during Sydney 2000: Storm evolution and the role of low-level boundaries. *Wea. Forecasting*, 19, 22-42.

Smith, C. D., 2007: The relationship between monthly precipitation and elevation in the Alberta foothills during the Foothills Orographic Precipitation Experiment. *Atmospheric Dynamics of a Cold Region: the Mackenzie GEWEX Study Experience*, M. K. Woo, ed. Springer, New York.

Smith, S. B. and M.K. Yau, 1993: The causes of severe convective outbreaks in Alberta. Part I: A comparison of a severe outbreak with two non-severe events. *Mon. Wea. Rev.*, **109**, 1099-1125.

Strong, G. S., 1986: Synoptic to mesoscale dynamics of severe thunderstorm environments: A diagnostic study with forecasting implications. Ph.D. Thesis, Department of Geography, University of Alberta, 345 pp.

Taylor, N. M., 2001: Genesis and Morphology of the Alberta Dryline. Presented at the *35th Annual CMOS Congress*, Winnipeg, Manitoba.

Taylor, N. M., 2004: The dryline as a mechanism for severe thunderstorm initiation on the Canadian Prairies. Presented at the *38th Annual CMOS Congress*, Edmonton, Alberta.

Taylor, N., D. Sills, J. Hanesiak, J. Milbrandt, C. Smith, P. McCarthy, and G. Strong, 2007: The UNdestanding Severe Thunderstorms and Alberta Boundary Layers Experiment: UNSTABLE. Scientific Overview. Available at:http://www.umanitoba.ca/faculties/environment/envirogeog/weather/unstable/UNSTABLE_Science_Final.pdf

Weckwerth, T.M., J.W. Wilson, and R.M. Wakimoto, 1996: Thermodynamic Variability within the Convective Boundary Layer Due to Horizontal Convective Rolls. *Mon. Wea. Rev.*, 124, 769–784.

Weckwerth, T.M., 2000: The Effect of Small-Scale Moisture Variability on Thunderstorm Initiation. *Mon. Wea. Rev.*, 128, 4017–4030.

Weckwerth, T.M., and D.B. Parsons, 2006: A Review of Convection Initiation and Motivation for IHOP_2002. *Mon. Wea. Rev.*, 134, 5–22.

Wilson, J. W., and W. E. Schreiber, 1986: Initiation of convective storms at radar-observed ABL convergence lines. *Mon. Wea. Rev.*, **114**, 2516-2536.

Wilson, J.W., and C.K. Mueller, 1993: Nowcasts of Thunderstorm Initiation and Evolution. *Wea. Forecasting*, 8, 113–131.

Wilson, J. W., and R. D. Roberts, 2006: Summary of convective storm initiation and evolution during IHOP: Observational and modeling perspective. *Mon. Wea. Rev.*, **134**, 23-47.

Ziegler, C. L. and E. N. Rasmussen, 1998: The initiation of moist convection at the dryline: Forecasting issues from a case study perspective. *Wea. Forecasting*, **13**, 1106–1131.