P4.19 GEM-LAM CONVECTIVE FORECASTS: HOW CAN THEY BE USED IN AN OPERATIONAL FORECAST ENVIRONMENT?

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1. INTRODUCTION

The operational high resolution Limited Area version of the Canadian Global Environmental Multi-scale Model (GEM-LAM) is a one-way nested model with a 2.5-km horizontal resolution (hereafter LAM2.5). The western domain of the LAM2.5 covers southern British Columbia and southern Alberta. See Fig. 1 for the available windows.

During the summers of 2006 and 2007, a systematic evaluation of LAM2.5 utility for forecasting convection over Alberta was performed. Conclusions were that while the timing of convective initiation over the foothills was modelled reasonably well, the subsequent convective development pattern downstream was unreliable. In April 2008, the Milbrandt-Yau (Milbrandt and Yau 2005) condensation scheme replaced the Kong-Yau (Kong and Yau 1997) scheme in the LAM2.5. To determine if the new condensation scheme improved the model's utility, eight convective events within Alberta during the summer of 2009 were evaluated. Section 2 describes the configurations of the models used followed by our objectives and evaluation methods. Results are then presented before the final discussion.

2. MODEL CONFIGURATIONS

The operational Canadian Global Environmental Multi-scale model (hereafter GEM15) is a four-dimensional variational data assimilation model (Gauthier et al. 2007) with a 15-km horizontal resolution (Mailhot et al. 2006). The operational GEM Limited Area Model (LAM) uses a horizontal resolution of 2.5 km. The physics and dynamics used by the LAM2.5 are described in Table 1. The GEM15 uses different physical parameterization schemes than the LAM2.5 so a direct initialization of the LAM2.5 from the GEM15 can lead to spin-up problems (Moffet and Erfani 2007). To circumvent these problems, a 15-km version of the GEM-LAM (hereafter LAM15) is used to initialize the LAM2.5. The LAM15 ingests its boundary conditions from the GEM15 since an independent data assimilation process is not available for the GEM-LAM grids. Currently, the LAM15 is initialized at 0600 UTC from the 6-h GEM15 forecast and run for 30 hours. The western domain of the LAM2.5

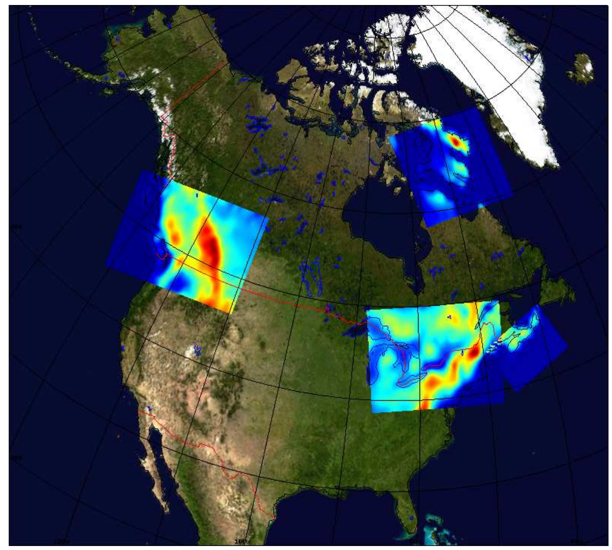

Fig. 1: *Canadian domains of the LAM2.5 for summer 2009.*

Horizontal grid	672x494
Vertical levels	58
Time step	60s
Shallow convection	Precipitating Kuo Transient
Condensation	Single Moment Milbrandt-Yau
Deep convection	None (explicit)
Boundary layer scheme	MoisTKE

Table 1: *LAM2.5 configuration for the western domain. (Belair et al. 2005; Erfani et al. 2005; Milbrandt and Yau 2005; Mailhot et al. 2006; Goodson 2010, personal communication).*

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is initialized at 1200 UTC from the 6-h LAM15 forecast and run for 24 hours.

Typically, numerical weather prediction (NWP) models cannot accurately simulate a feature that is smaller than seven to ten times the horizontal grid spacing (Milbrandt 2010, personal communication) therefore the LAM at 2.5 km cannot fully resolve a convective storm, even given perfect initial conditions. Studies, such as Bryan et al. (2003), have shown that a resolution of less than 1 km is needed to properly simulate circulations in and around a convective storm. However, at 1 km basic convective structure can be resolved. Some simulations with the 1-km experimental version of the GEM-LAM have successfully produced more realistic convective mode than 2.5-km solutions (Taylor et al. 2010).

3. OBJECTIVES

Output from the LAM2.5 has been available in forecast operations for southern Alberta since 2006, when the western domain was expanded eastward from British Columbia. Systematic evaluations of LAM2.5 convective forecasts over Alberta were performed during the summers of 2006 and 2007. Results by Moffet and Erfani (2007) showed that finer details and more realistic mesoscale processes, such as drylines, were evident in the LAM2.5 output as compared to the GEM15. However, they reported that convection modelled by the LAM2.5 was unreliable over Alberta. Precipitation amounts were exaggerated and precipitation rates in convective situations seemed to be too strong leading to strong downdrafts and outflows that generated spurious cells.

In April 2008, the single moment Milbrandt-Yau (Milbrandt and Yau 2005) condensation scheme replaced the Kong-Yau (Kong and Yau 1997) scheme in the GEM-LAM. The Milbrandt-Yau scheme was expected to improve precipitation quantities, rates, and typing and produce more realistic outflows and boundary interactions (new cell development).

In the fall of 2009 a team of forecasters was assembled to determine if the new condensation scheme had improved the convective output of the LAM2.5 over Alberta and whether this model output could aid in forecasting convection. Could the LAM help forecast convective mode and evolution? Would use of the model help or hinder the forecast team? The detailed and realistic appearance of the LAM2.5 simulated reflectivity is seductive. Would decisions be modified if the LAM showed a solution different from what was initially expected?

4. EVALUATION METHODOLOGY

A subjective assessment of the LAM2.5 performance over Alberta was conducted for seven severe weather days during the summer of 2009. A severe weather day was simply defined as a day in which the Meteorological Service of Canada received at least one report of a tornado, hail having a diameter of at least 20 mm, wind gusts of at least 90 km h^{-1} and/or at least 50 mm of rainfall in one hour or less. As well, one null case was chosen as a day when severe thunderstorm watches were issued but no severe weather reports were received. A list of the reviewed cases can be found in Table 2.

Date	Event Type
4 July	Weak tornado
7 July	Weak tornado
18 July	Damaging winds
1 August	Damaging winds
2 August	Damaging winds/hail
14 August	Null case
21 August	Hail/possible tornado
26 August	Heavy rainfall

Table 2: *List of 2009 cases evaluated. All events occurred within the province of Alberta*.

Due to resource constraints, cases were not evaluated in real time. A single case was assigned to each evaluation participant. Individuals developed a convective prognosis using tools available on an operational shift. This was done to simulate a “normal” day on the forecast desk. A sense of the level of forecast confidence for each case was arrived at based on archived significant weather discussions and forecasts.

The LAM2.5 1-hourly output was compared to surface observations, radar, satellite, and upper air soundings. Representation of the pre-storm environment by the LAM2.5 was assessed through moisture distribution and advection, placement and strength of convergence zones (and other possible convective triggers), instability, and shear. Convective evolution, including initiation, mode and motion, within the LAM2.5 was assessed using simulated reflectivity and 1-h quantitative precipitation forecasts (QPF). Simulated reflectivity in the LAM2.5 is approximately equivalent to a 1.5-km above ground level (AGL) Constant Altitude Plan Position Indicator (CAPPI) radar reflectivity. These fields were then compared to the observed CAPPI 1.5 km or lowest elevation angle radar reflectivity. The LAM2.5 output was also compared with the governing 0000 UTC GEM15 output, and the later 1200 UTC GEM15 solution.

Characteristics of mesoscale features, such as meso-lows and drylines, depicted at the finer level of detail provided by the LAM2.5 were also identified. Even if timing and location are wrong, such detail can help forecasters fill in gaps in conceptual models of thunderstorm environments. As well, this detail may assist in identifying important signals for thunderstorm development from the LAM2.5 in the future.

Once conclusions were drawn for the individual cases, the evaluation team met to discuss their observations. This helped in part to address potential biases inherent with subjective evaluations (Kain et al. 2006). Common themes surfaced between the cases and individual items of interest were reviewed. A subjective determination was made on whether the LAM2.5 would have added value to the convective prognosis.

5. RESULTS

a. Pre-storm Environment

Initial conditions, such as surface moisture distribution and wind fields, were generally modelled well by the LAM2.5 provided conditions were reasonably well forecast at 1200 UTC by the GEM15. The LAM2.5 cannot correct poor initial conditions nor be expected to improve a forecast from the governing 15-km models. Rather, it will be prone to amplify any deficiencies in initial conditions. A significant example of this occurred on 4 July 2009. The LAM2.5 developed a surface trough approximately 135 km further north than the observed position, though orientation was similar (Fig. 2). This was due to poor positioning of this feature in the driving model. Error in placement of the modelled surface trough caused the LAM2.5 to generate convection further north than what was observed. Although there were errors in the modelled position of the surface trough, a forecaster could use the convective trigger to shift the simulated convective cells to where the observed trough was analyzed.

Surface dewpoint temperatures over southern Alberta were forecast higher than observed in two cases. It is suspected that the spurious convection initiated by the LAM2.5 on these days was attributable to model enhanced surface moisture. During the 2006 evaluations this issue was identified as a soil type mismatch and was resolved. However, if the same result occurs in future evaluations then the issue will need to be revisited.

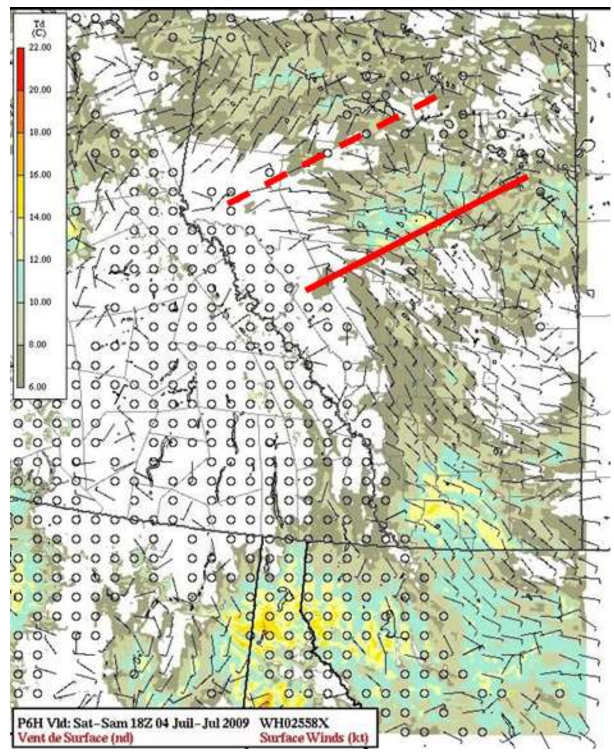

Fig. 2: *6-h forecast of LAM2.5 winds and dewpoint temperatures valid at 1800 UTC 4 July 2009. The solid red line corresponds to the observed surface trough. The dashed red line represents the LAM2.5 surface trough position.*

b. Convective Evolution

Timing and placement of convective initiation was generally well forecast by the LAM2.5. This was also true of the governing GEM15, though in less detail. While initiation of convection was well handled by the LAM2.5, decay of modelled convection occurred too soon in many cases. As expected, the LAM2.5 produced convective structures with finer detail which allowed for better identification of storm mode and evolution than the coarse GEM15 output.

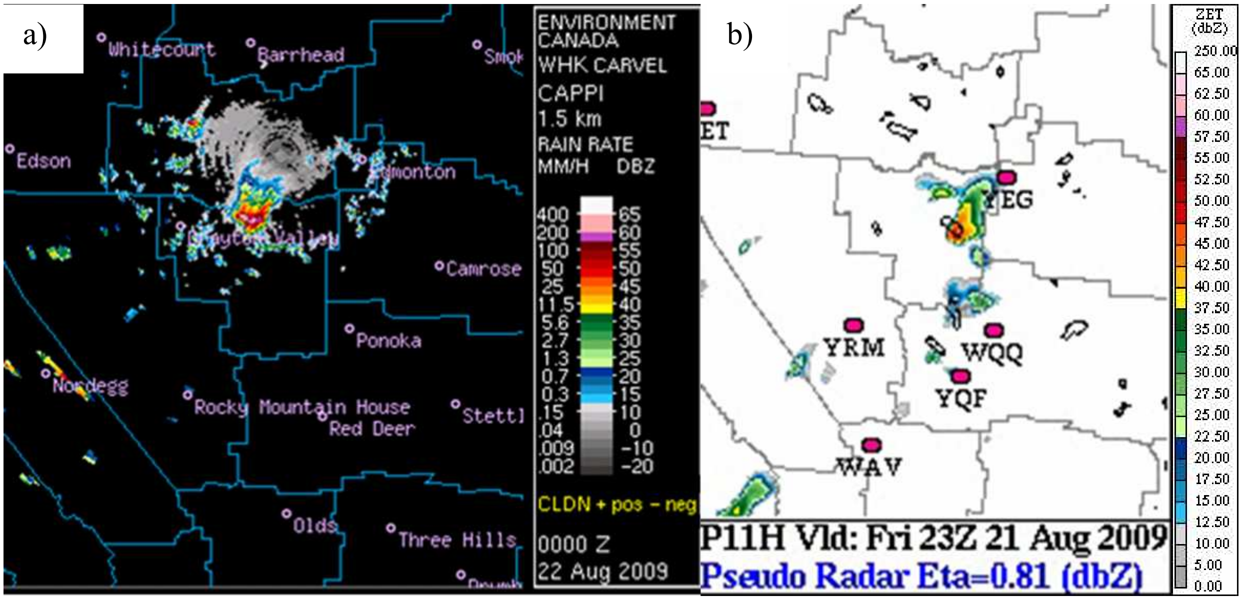

Fig. 3: *a) Observed CAPPI 1.5 km radar reflectivity at 00Z August 22 2009 shows a maximum reflectivity of 60dbZ in thunderstorm cell south west of Edmonton where b) the LAM2.5 simulated 1.5 km AGL reflectivity at 23Z August 21 2009 indicates a lower maximum of 45dbZ in the modelled thunderstorm cell south-southwest of Edmonton.*

One case in which the LAM2.5 produced a superior forecast occurred on 21 August 2009. The higher resolution model produced a realistic simulated convective cell southwest of Edmonton. Fig. 3 shows a comparison of the observed 1.5-km CAPPI radar reflectivity to the LAM2.5 simulated reflectivity output. A case in which the GEM15 produced a more valuable forecast than the LAM2.5 occurred on 1 August 2009. The LAM2.5 failed to produce the linear structure that was observed on radar (Fig. 4). However, the intensity of the precipitation from the LAM2.5 solution was more analogous to what was observed than the GEM15 solution.

c. Microphysics Schemes

Evaluations from 2007, when the LAM2.5 was still using the Kong-Yau scheme, showed that the QPF was generally overdone and convective lines were developed too readily. In all evaluated cases from 2009, cumulative precipitation and simulated reflectivity seemed to be underforecast by the LAM2.5. It is possible that with weaker cells under the Milbrandt-Yau scheme, subsequent cell development along outflow boundaries is diminished because the initial cells themselves are weaker and therefore produce weaker outflows. An example of the LAM2.5 not generating new cells along a model outflow boundary was observed on 18 July 2009 (Fig. 5d).

It appears that observed differences in the model convective forecasts from 2007 to 2009 are due to the change in the microphysics scheme, though it is difficult to know for sure without re-running the LAM2.5 with the Kong-Yau scheme. Different microphysics schemes might give different precipitation rates, however the differences in storm development are likely due to the driving model (Milbrandt 2010, personal communication). A comparison of the 2.5-km LAM output with that of the 1-km LAM, which uses a double moment version of the Milbrandt-Yau scheme (Milbrandt and Yau 2005), will be performed to check this theory.

d. Mesoscale Features

Three of the case studies examined were damaging wind events. The LAM2.5 failed to depict the observed linear convection in all three cases despite a seemingly representative storm environment. However, it was encouraging to see that even though the model simulated reflectivity did not forecast convective cells, the LAM2.5 did generate significant winds in two of the three cases (Fig. 5). The GEM15 did not generate severe winds in any of the cases. The 700 mb vertical velocity field appeared to be a potentially useful predictor, indicating lift along the leading edge of modelled outflow boundaries. Motion, evolution and longevity of resolved boundaries in the LAM2.5 could give clues in forecasting

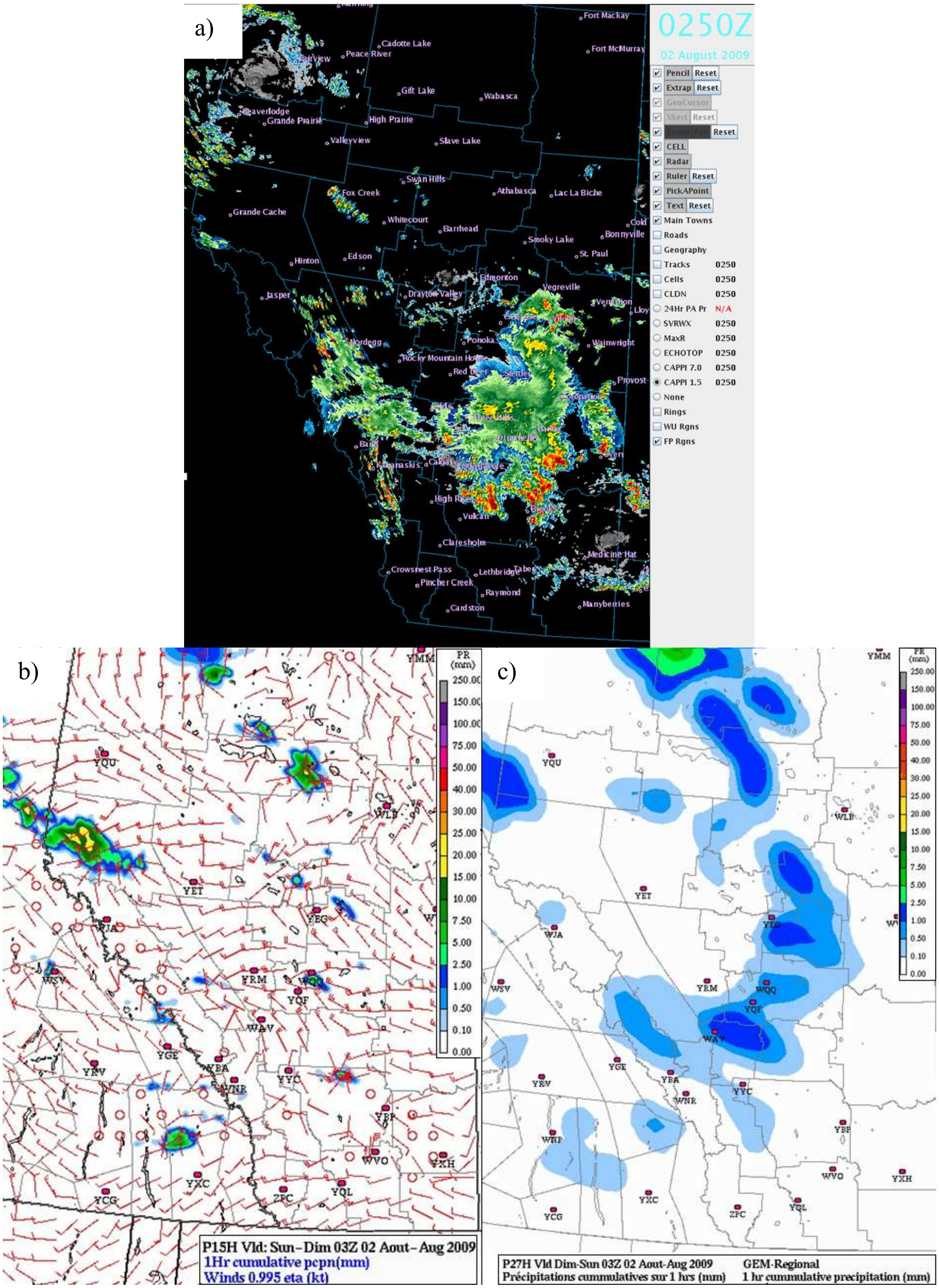

Fig. 4: *a) Observed CAPPI 1.5 km radar reflectivity valid at 0250Z August 2 2009, b) LAM2.5 1-h QPF valid at 03Z August 2 2009 and c) GEM15 1-h QPF valid at 03Z August 2 2009. The linear structure observed in a) is represented best by c). Simulated reflectivity is not available from the GEM15.*

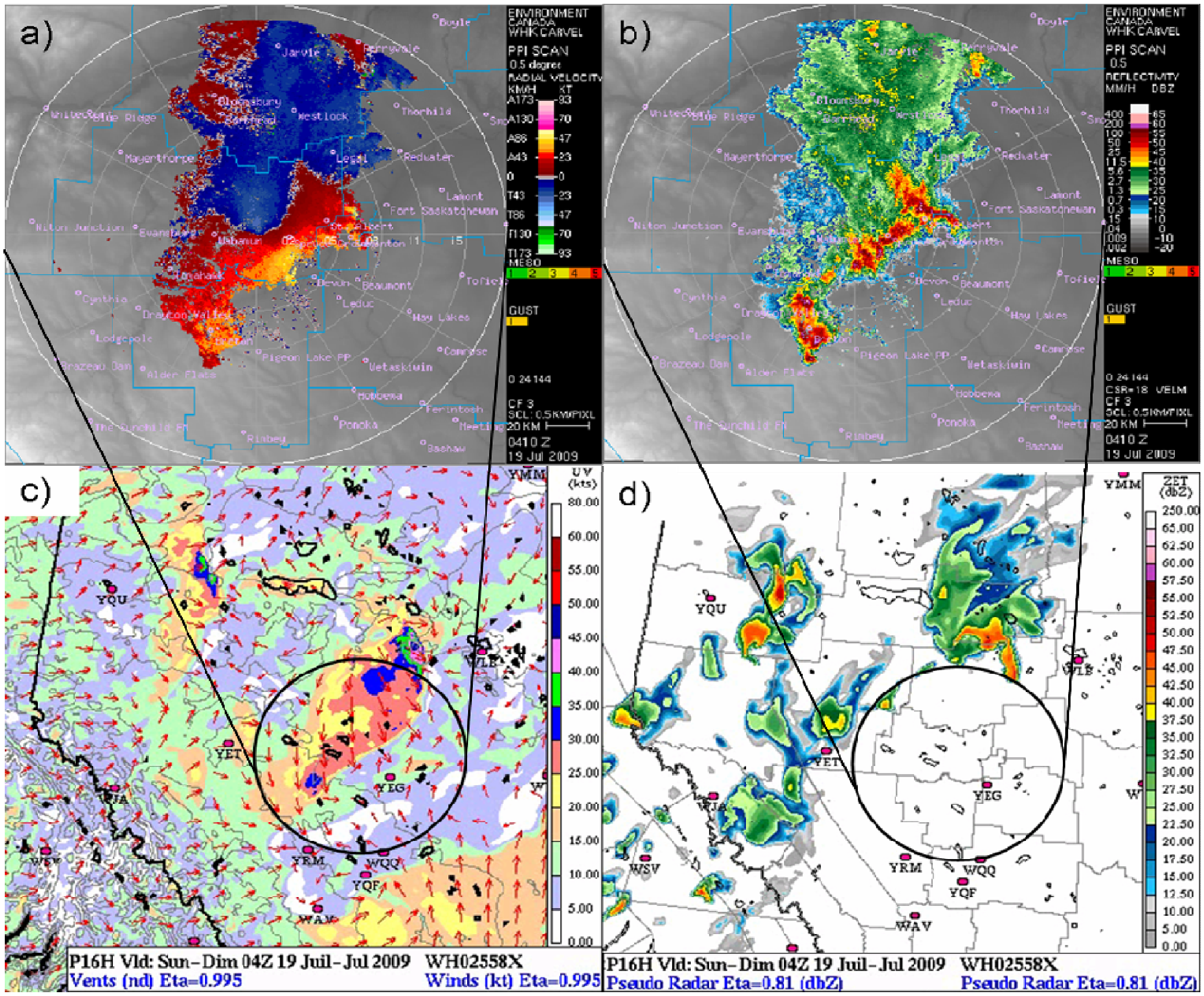

Fig. 5: *a) Observed lowest level velocity valid at 0410 UTC 19 July 2009 and c) LAM2.5 0.995 eta level wind valid at 0400 UTC 19 July 2009, which indicate a wind maximum of 40 to 45 knots north of Edmonton. The strongest winds reported this day occurred at the Edmonton City Centre station with a value of 31G57 knots. The GEM15 produced maximum winds of only 15 knots. b) Observed lowest level reflectivity valid at 0410 UTC 19 July 2009 and d) LAM2.5 simulated reflectivity valid at 0400 UTC 19 July 2009. The same color scale for reflectivity is used in b) and d). The black circles in c) and d) indicate the outer most radar ring as seen in a) and b).*

damaging wind events but simulated wind fields should still be used with caution. Model generated convective outflow winds produce further interactions within the model which can lead to greater deviation from reality with each time step.

An example of the LAM2.5 being unable to correctly generate convective boundaries occurred on 26 August 2009. On that day a deluge during the AC/DC concert at the outdoor Commonwealth Stadium in Edmonton, Alberta left thousands of fans soaked. Using Doppler radar, interaction of several small scale boundaries was seen to the northwest of the city. These lines converged and initiated a cluster of thunderstorms which then tracked through the city. This event occurred on such a small scale that both the LAM2.5 and the GEM15 failed to capture it. This demonstrates that even on a finer grid, some storms still cannot be resolved by NWP models and thus highlights the importance of continual analysis of observed data.

6. SUMMARY AND DISCUSSION

A subjective review of the LAM2.5 convective performance over Alberta was conducted for eight significant weather days during the summer of 2009. The pre-storm environment and convective initiation were reasonably well forecast by the LAM2.5. The high resolution version of the GEM model allowed for identification of convective mode, which was not possible with the coarser resolution of the GEM15.

Evaluations of the LAM2.5 under the previous Kong-Yau condensation scheme showed that amount and/or intensity of convection was generally overforecast. In evaluated cases with the newer Milbrandt-Yau scheme, convection appeared to be underforecast. However, without proper sensitivity testing there is no definitive evidence that this was entirely due to the microphysics scheme.

Is the LAM2.5 a reliable tool for forecasting convection? Not yet. However, it was found that while the LAM2.5 did not consistently add direct forecast value over the GEM15, additional mesoscale features are evident in the high resolution version of the GEM. These features may provide value in forecasting convection. It is strongly recommended that a full analysis and diagnosis of a convective threat area be completed using observational data before consulting any model.

Some upcoming improvements for the LAM2.5 in 2010 include implementation of a double-moment microphysics scheme (Milbrandt and Yau 2005), a new radiation scheme and an improved dynamics package. The upgrades are based on the configuration that was successfully run on experimental grids (2.5-km and 1-km) over the Vancouver-Whistler region for Environment Canada's forecast support during the 2010 Vancouver Olympics (Milbrandt 2010, personal communication; Mailhot et al. 2010).

Other future possibilities include the development of a mesoscale ensemble system using the GEM-LAM. Implementation of an independent data assimilation cycle would also improve issues with model sensitivity to initial conditions (Milbrandt 2010, personal communication). The GEM-LAM could be more useful if it ingested its own boundary conditions thereby offering a unique opinion from the GEM15.

Another evaluation on the horizon for 2011/12 will help determine whether or not the upgrades to the GEM-LAM will improve the performance of the model in convective situations. Rigorous real-time daily evaluations of the GEM-LAM are needed to properly identify whether the model enhances or degrades forecast quality. However, limited resources have prevented this from happening in the past.

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