7.27 DEVELOPMENT AND USE OF A PROTOTYPE NOWCASTING SYSTEM FOCUSED ON OPTIMIZATION OF THE HUMAN-MACHINE MIX

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1. INTRODUCTION

Canada is the second largest country in the world by area. Nowcasting** in Canada is particularly challenging due to the wide variety and frequency of severe weather that affects the country as well as the scarcity of observational data, especially in remote regions. Environment Canada (EC) has six regional forecast centres spread from coast to coast. At each centre, staffing is modest and the area of responsibility is immense - more than 1 million km^2. EC severe weather forecasters must monitor data from a large number of sources, including 10 or more radars, to maintain situational awareness. To further complicate the problem, storm development in many regions is greatly influenced by mesoscale processes (e.g. thunderstorm initiation at drylines / lake breeze fronts / gust fronts, lake effect snow, etc.).

Currently, EC employs a variety of sophisticated analysis and diagnosis tools using data from various observational platforms such as radar, satellite, surface and upper-air stations, etc. Some extrapolation-based tools are also available for the nowcasting of storms. However, the majority of prognosis guidance used by the severe weather forecaster comes from operational numerical weather prediction (NWP) models such as the Global Environmental Multiscale (GEM) model (Côté et al. 1998). In its current state, such guidance is not well suited to nowcasting time and space scales.

For reasons discussed below, we assume that human forecasters will be very much a part of the nowcasting process in the future. Therefore, a nowcasting system combining sophisticated representation of observational data, NWP, and artificial intelligence (AI) techniques is needed to help the forecaster cope with the prediction of severe weather in the Canadian context. It is recognized, however, that such a system needs to be carefully designed so that it does not erode forecaster expertise. Thus, the human-machine mix must be optimized to make the best use of both human and machine strengths.

In this paper, we will further discuss these issues and describe the Aurora nowcasting prototype platform that is being used to demonstrate these concepts in a real-time, operational setting. Since the lead author's interest is mainly summer severe weather, the paper will be focused on nowcasting in that context.

2. OPTIMIZING THE HUMAN-MACHINE MIX

Though NWP and AI techniques have come a long way over the last several decades, human forecasters are still able to consistently add value, especially in the short range. For instance, a study of the performance of various nowcasting systems during the Sydney 2000 forecast demonstration project revealed that only the NCAR Auto-Nowcast System, which incorporated human-entered boundary-layer convergence lines for nowcasting convective initiation, resulted in nowcasting skill greater than extrapolation (Wilson et al. 2004). Also, the Project Phoenix experiments conducted at the EC regional office in Winnipeg, Manitoba, have consistently demonstrated that short-term forecasts made using analysis, diagnosis and prognosis techniques without the aid of NWP are more accurate than those made with the aid of NWP (see Purcell 2001). There are numerous other examples in the literature (see discussion in Roebber et al. 2004).

** Nowcasting is defined here to mean analysis / diagnosis at T0 and prognosis out to 12 hours.

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Clearly, there are areas where the ability of the human forecaster remains superior and will be so for some time. We suggest that these include:

- pattern recognition,
- use of conceptual models,
- judgment / decision-making, and
- adaptive strategies.

Conversely, machine strengths currently include:

- dealing with large volumes of data,
- integrating numerous datasets,
- rapid handling of complex calculations and complicated parameter interactions, and
- performing tedious tasks.

To facilitate the machine strengths, a nowcasting system should have a robust architecture capable of ingesting and managing very large amounts of data and rapidly performing calculations using these data. The system may also be able to free the forecaster from tedious production tasks with the ability to generate any number of pre-defined products from a forecaster-modified database.

To facilitate the human strengths, a nowcasting system should have a sophisticated graphical user interface that allows the forecaster to intuitively use conceptual models and pattern recognition, and easily modify objects and selected gridded fields in a timely fashion. Data representation is therefore a critical issue, as is the way in which the database may be modified. In addition, the nowcasting system should be designed in such a way that forecaster experience and expertise are enhanced, not atrophied, with regular use.

It is recognized that the 'optimum' human-machine mix may be different for various applications. In some cases, an entirely automated forecast product may be good enough, providing useful information 90% of the time. However, for the purposes of nowcasting severe weather, that extra 10% may represent the most significant weather events. In addition, the ability to respond to any type of situation, even those that are rapidly changing or unexpected, is essential. Thus, we suggest that the optimum human-machine mix for a severe weather nowcasting system will be achieved when both the human and machine strengths listed above are fully exploited in a complementary manner.

3. DATA REPRESENTATION

Each shift, the forecaster is bombarded with great quantities of data from a variety of different sources. Managing such data, either manually or by some automated process, is required to make sense of the information, formulate mental models of how atmospheric conditions are evolving, and establish and maintain situational awareness. Once a mental model is formulated, it needs to be shared with other forecasters in the office and beyond. Generating a graphical depiction of this mental model is an efficient way of doing this.

3.1 *Simplification*

One approach to managing data for visualization purposes is simplification. As an example, consider a subway system. There are very detailed maps that are used by engineers and technicians to find specific locations for maintenance, emergencies, etc. However, most of the maps in subway cars around the world consist of greatly simplified 'circuit'-style diagrams that are typically not even to scale. For the subway rider, much of the detail is extraneous and its inclusion would hinder the communication of the most pertinent information.

Nowcasting is concerned with parameters and features that need forecasting, and not all of them can or should be represented by very detailed grid point data. For example, a line object can be used to represent a mesoscale boundary. A cluster of severe thunderstorms can be represented by an area object.

Also, in most instances, it is sufficient to work with a 'composite view' that shows features from various heights on a single plane. For instance, a severe weather prognosis chart might consist of the forecast positions of upper and lower jets, synoptic-scale fronts, mesoscale boundaries, and areas of current thunderstorm activity. Some of these features might also include a time history and/or extrapolation into the future. It is much simpler to interpret such a composite chart than to try to find these features within a four-dimensional, gridded data set.

3.2 *Fusion*

Visualizing data requires picking 'real' patterns out of a number of 'possible' patterns that might be manually or automatically identified, especially

Table 1. Percentage of days in the period June-August 2001 where a lake breeze front from Lake Huron and/or Lake Erie was identified using a variety of detection methods.

% of days	**Surface Stations**	**C-band Radar**	**Visible Satellite**	**Integrated**
Lake Erie	37	41	61	62
Lake Huron	32	42	40	59
Either	51	59	71	73
Both	10	29	41	49

when patterns are diffuse or incomplete, or when data are conflicting. As well, there is a requirement to recognize patterns that extend into regions with no data. The forecaster can do this simply by using conceptual models of atmospheric processes.

An example that illustrates this well is the detection and monitoring of lake breeze fronts. In the Great Lakes region of North America, these boundary-layer convergence lines develop frequently in summer, can act as the triggering mechanism for convective initiation, and have been shown to have a significant impact on tornado climatology (see Sills et al. 2002, King et al. 2003).

Three observational platforms are commonly used to identify lake breeze fronts: surface stations, radar and satellite. However, each platform has its limitations. Surface stations are not available in many locations near the shore, and wind shifts and thermal / moisture gradients at lake breeze fronts can be very subtle in moderate gradient wind regimes. Radar can detect lake breeze fronts as clear air echo 'fine lines' in many (but not all) cases, but only within a limited area around the radar. Lake breeze fronts cannot be identified using visible satellite imagery if cumulus clouds are obscured by a thin layer of cirrus, or if the lifting condensation level is too high for them to develop. If data from each of these platforms, plus the conceptual model of a lake breeze front, are together used for identification, a greater proportion of lake breeze fronts should be identified.

This hypothesis was supported in a study by Sills and Hill (2003). Table 1 shows the detected occurrence frequency of lake breeze fronts from Lake Huron and Lake Erie for the period June-August 2001. When data from the three different platforms are integrated, a greater number of detections can be made. This concept can, of course, be extended to the identification of various mesoscale and synoptic-scale features, including fronts and thunderstorm features.

4. THE AURORA PROTOTYPE NOWCASTING SYSTEM

A prototype system named Aurora is being developed in an effort to optimize the human-machine mix in the nowcasting context (see Greaves et al. 2001). Aurora is based on a commercially available workstation application developed at Environment Canada called the Forecast Production Assistant (FPA, see http://www.msc.ec.gc.ca/fpa). FPA was designed for short- to long-range forecasting purposes and is focused mainly on automated product generation from a forecaster-modified gridded and object database derived from NWP fields.

Aurora has all of the features of FPA plus the ability to work with nowcasting-related observational data. Various data sets are ingested including satellite, radar, lightning, and surface observations, as well as NWP fields from both operational models and high-resolution experimental models. However, any geo-referenced data set can be ingested and displayed using a common projection. Aurora is also fully configurable so that many aspects of the system's processing and display can be changed to suit user needs.

4.1 *Addressing Human Strengths*

To date, the main effort with Aurora has been developing a graphical user interface that optimizes the representation of nowcasting-related data and the interaction of the forecaster with the database when editing/modifying gridded and object fields. Work is done by the forecaster mainly in time-linked depictions of weather features from various elevations on a single plane. The use of objects to represent weather features greatly simplifies the graphical display.

Radar and satellite can be blended using the blending ratio selected by the user. Also, any combination of data can be superimposed and toggled on/off. As discussed earlier, the ability to overlay multiple types of data in one display helps greatly with building a mental model of the evolving atmosphere. Toggling fields on and off allows the user to make use of the data when needed yet keeps the main display uncluttered. It is important to note that data, not images, are displayed. Therefore, the resolution of the original data can be accessed as one zooms in, field values can be sampled directly, and calculations can be made between different fields using the original data values. Animation is also important for feature detection and there is the capability within Aurora to animate fields either simultaneously or independently.

Figure 1 is a screen capture showing Aurora being used to generate a mesoscale analysis at 19 UTC on 8 June 2005. Visible satellite, radar echo tops, surface observations, and the corresponding GEM model gridded field for surface winds are all displayed. Objects representing synoptic-scale fronts and lake breeze fronts have been introduced and edited via the forecaster interface.

4.2 *Addressing Machine Strengths*

Many severe weather nowcasting systems have been focused on the goal of addressing machine strengths via NWP or AI techniques. With some systems, such as the NCAR Auto-Nowcast System (Mueller et al. 2003), efforts are now underway to better facilitate human strengths. Still others will likely remain fully automated, such as MAPLE (Turner et al. 2004) and the RUC model (Benjamin et al. 2004).

With Aurora, we have approached the severe weather nowcasting problem from a unique direction. We have developed a sophisticated gridded and object database and many of the human strengths are being addressed in the philosophy behind the system and the design of the graphical interface. It is encouraging to see that groups currently developing new severe weather nowcasting systems, such as SIGOONS (Sénési et al. 2004) and NinJo (Joe et al. 2005), have similar goals.

The challenge for Aurora now will be to address the machine strengths to a greater extent. Currently, Aurora exploits machine strengths in a limited number of ways. Graphical and text products can be automatically generated from the forecaster-modified database, allowing time previously used for product generation to be spent working on the meteorology. In addition, Aurora allows interpolation and extrapolation using database information from depictions at regular intervals. For example, the forecaster can create depictions every 6 hours and then interpolate between these depictions to obtain gridded data values at times in between.

There are also a number of sophisticated modification tools for editing both gridded fields and objects. The graphical interface makes this easy for the forecaster though a large amount of processing is required in the background. Lastly, Aurora can make use of processing done outside of the system. For example, radar processing is handled by EC's Unified Radar Processor (URP, see Joe et al. 2003).

5. USE OF AURORA ON A RESEARCH SUPPORT DESK

Aurora is currently being used in a real-time, operational setting via a research support desk at the Ontario Storm Prediction Centre in Toronto. The focus is currently on detailed mesoscale analyses but experimentation with nowcasting techniques and products is also underway.

An EC research meteorologist operates the support desk alongside the operational forecasters when active weather is expected. The goal is to use Aurora's graphical representation capabilities to produce hourly mesoscale analyses that can include positions of features such as synoptic-scale fronts, lake breeze boundaries, outflow boundaries, and positions of upper-level and low-level jets. An example is shown in Figure 2 from 21 UTC on 10 June 2005. Visible satellite, low-level reflectivity and surface station data are displayed. Thunderstorms have formed at lake breeze fronts and have produced outflow boundaries. These outflow boundaries are interacting with the lake breeze fronts leading to additional convective initiation. Such products can be used by operational forecasters to improve the accuracy of watches and warnings.

An 18 UTC mesoscale prognosis product is also being tested. The prognosis typically includes many of the same features depicted in the mesoscale analysis. However, NWP and lake breeze front locater charts (historical analyses of lake breeze front locations under different wind regimes) are used to forecast the positions of these features. An 18 UTC prognosis time was chosen since at that time, pre-storm features are usually detectable but typically thunderstorms have not yet been initiated. Therefore, the positions of lake breeze boundaries are usually not yet affected by thunderstorm outflows whose locations are much more difficult to anticipate. The product is aimed at helping operational forecasters as they do their morning work-ups for the public and severe weather forecasts. An example is shown in Figure 3.

6. FUTURE WORK

A five year plan has been assembled to direct the development of Aurora as part of the EC National Laboratory for Nowcasting and Remote Sensing Meteorology in Toronto. The first stage of the plan is to complete the work on the mesoscale analysis capabilities of the system, which may include some AI as part of a data management strategy. Improving Aurora's capacity for visual representation of the forecaster's mental model and the ability to share it with others is an important part of this work.

As discussed earlier, the next stage will be to begin to take greater advantage of machine strengths involving NWP and AI. Work will begin on including cell-tracking and extrapolation based on radar, satellite and lightning algorithms. Historical information on individual cells provides important indications about storm type through cell longevity. Intensity trends are also essential for assessing the severe weather potential of storms.

Further into the future, we envision developing an expert system for determining positive and negative convective environments similar to that used with the NCAR Auto-Nowcast System (see Mueller et al. 2003). Such an expert system would make use of forecaster-modified database information (e.g. positions of boundaries), observations, and NWP to generate convective guidance fields. Again, care would be taken to ensure that such an expert system is designed to enhance forecaster expertise rather than erode it. We also plan to investigate graphical probabilistic representations and products for use with severe weather nowcasting.

It is anticipated that successful components of the prototype system will be transferred to the NinJo national forecaster workstation presently under development (see Joe et al. 2005).

7. SUMMARY

Environment Canada meteorologists are responsible for forecasts over a very large land mass with a wide variety of severe weather. They need sophisticated nowcasting tools to help them perform their duties. The Aurora prototype nowcasting system is being developed at Environment Canada with a focus on optimization of the human-machine mix. Data simplification and fusion are two ways in which the Aurora system facilitates human interpretation and evaluation strengths in the nowcasting process. Aurora can generate products automatically from its database and will address more machine strengths in the near future. However, any automation will be done in a way that does not erode forecaster expertise.

The Aurora system is being tested in a real-time operational setting at the Ontario Storm Prediction Centre in Toronto. Development of this system will continue over the next several years with the goal that the technology will be transferred to the NinJo national workstation when it becomes available.

ACKNOWLEDGMENTS

Thanks to Janti Reid and Delroy Barrett for assistance with Aurora and to Stewart Cober, Patrick King, and Ontario Storm Prediction Centre forecasters for feedback and encouragement.

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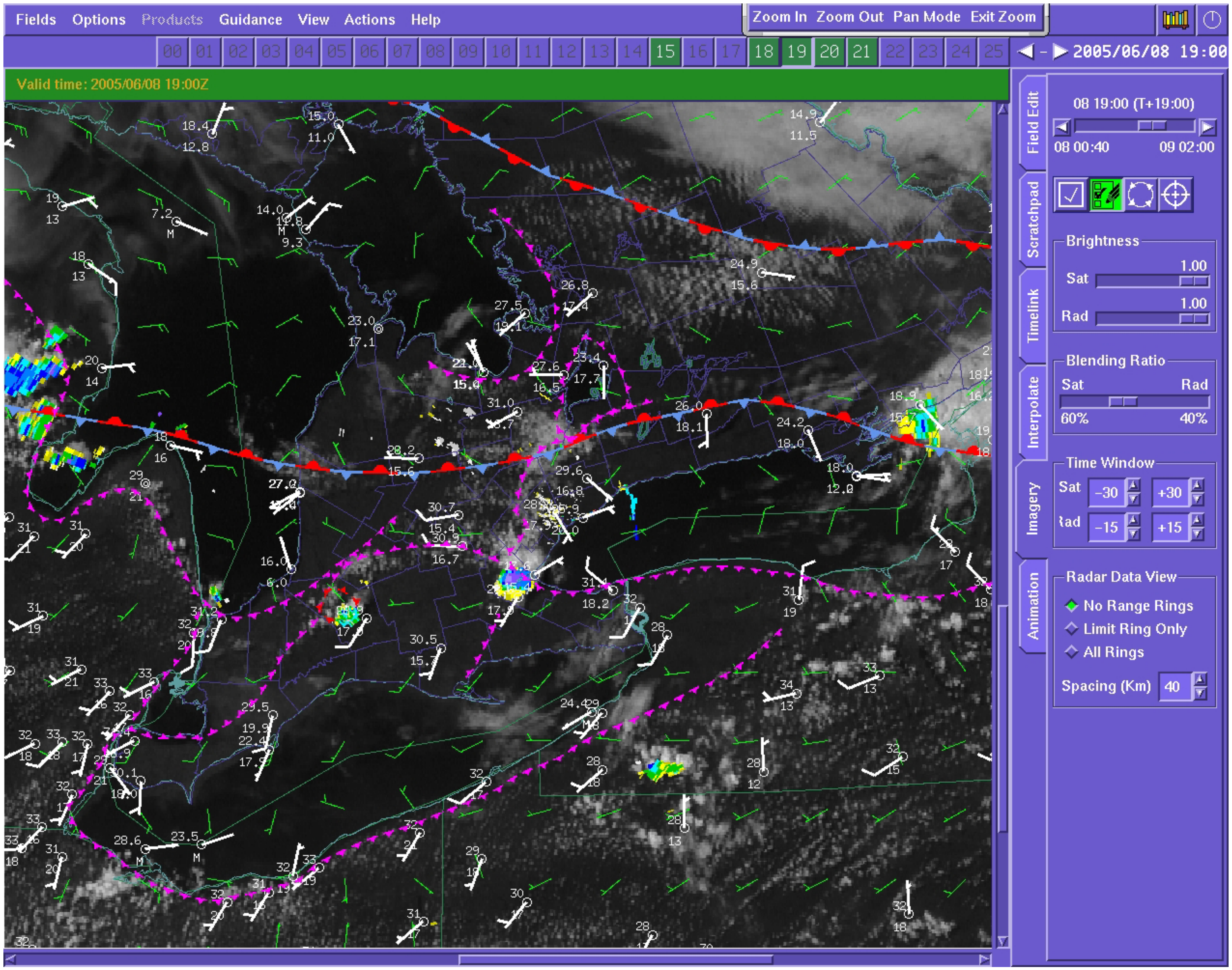

Figure 1. Screen capture showing the Aurora user interface and a mesoscale analysis for southern Ontario at 19 UTC on 8 June 2005. Broken magenta lines indicate the positions of lake breeze fronts. Green wind barbs are model surface winds in knots. Visible satellite data, radar data, surface observations, and synoptic-scale fronts are also present.

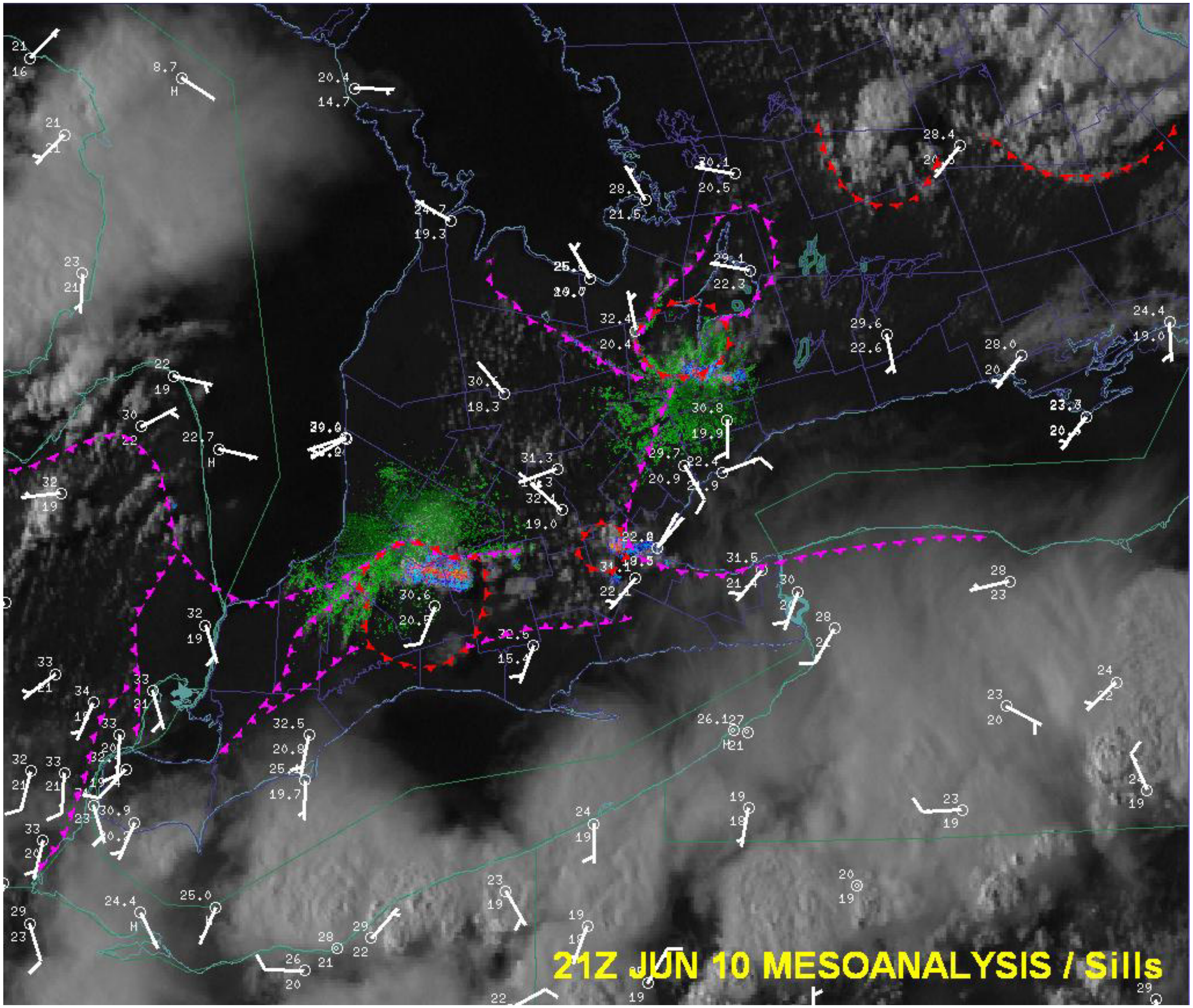

Figure 2. A mesoscale analysis product for southern Ontario generated using Aurora. Broken magenta lines indicate the positions of lake breeze fronts while broken red lines indicate the positions of thunderstorm outflow boundaries. Low-level radar reflectivity data show ‘fine lines‘ in clear air echoes near the radar as well as thunderstorms. Visible satellite data and surface observations are also shown.

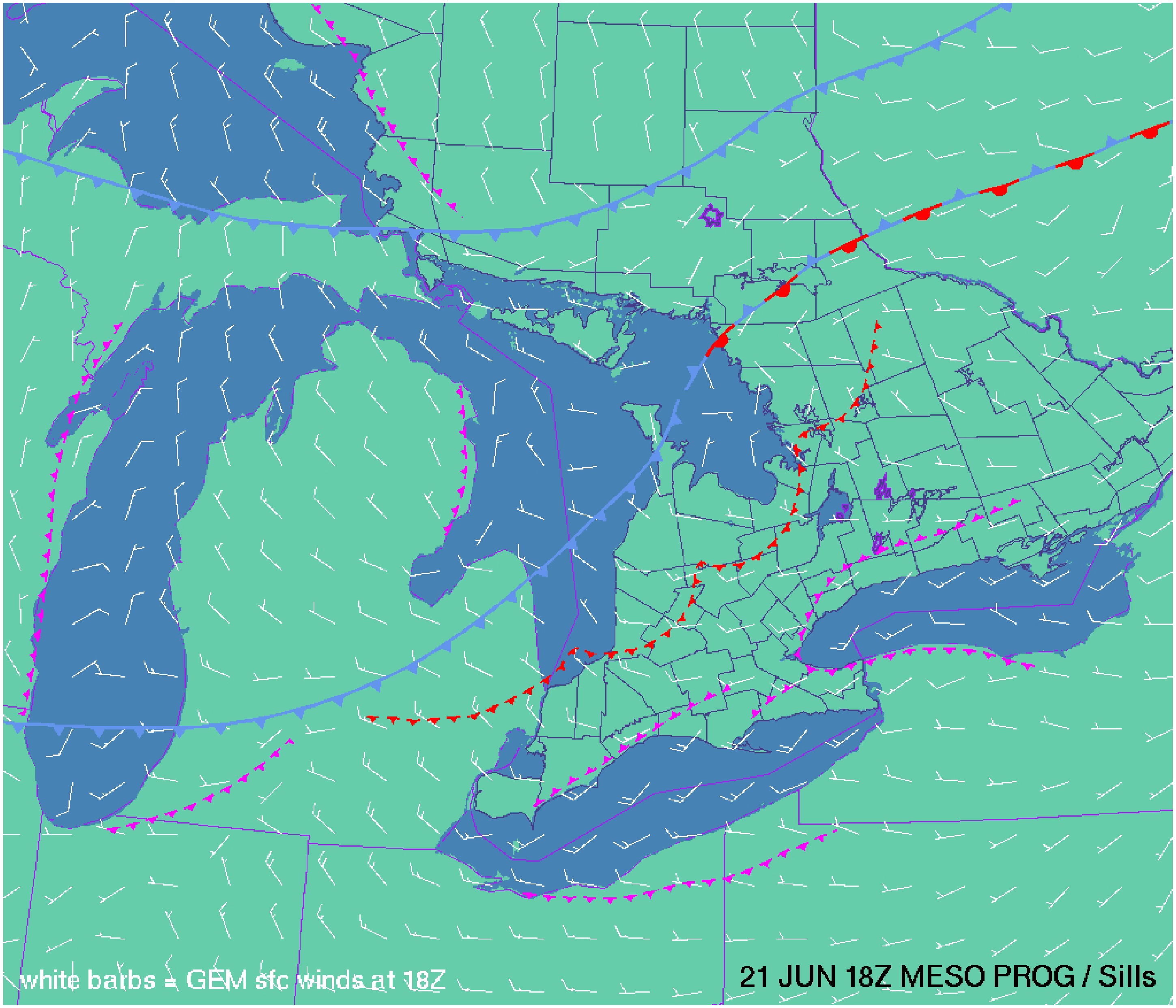

Figure 3. A mesoscale prognosis product generated for southern Ontario using Aurora. Broken magenta lines indicate the positions of lake breeze fronts while broken red lines indicate the positions of thunderstorm outflow boundaries. The positions of synoptic-scale fronts and model surface winds in knots are also shown.