ON THE MSC FORECASTERS FORUMS AND THE FUTURE ROLE OF THE HUMAN FORECASTER

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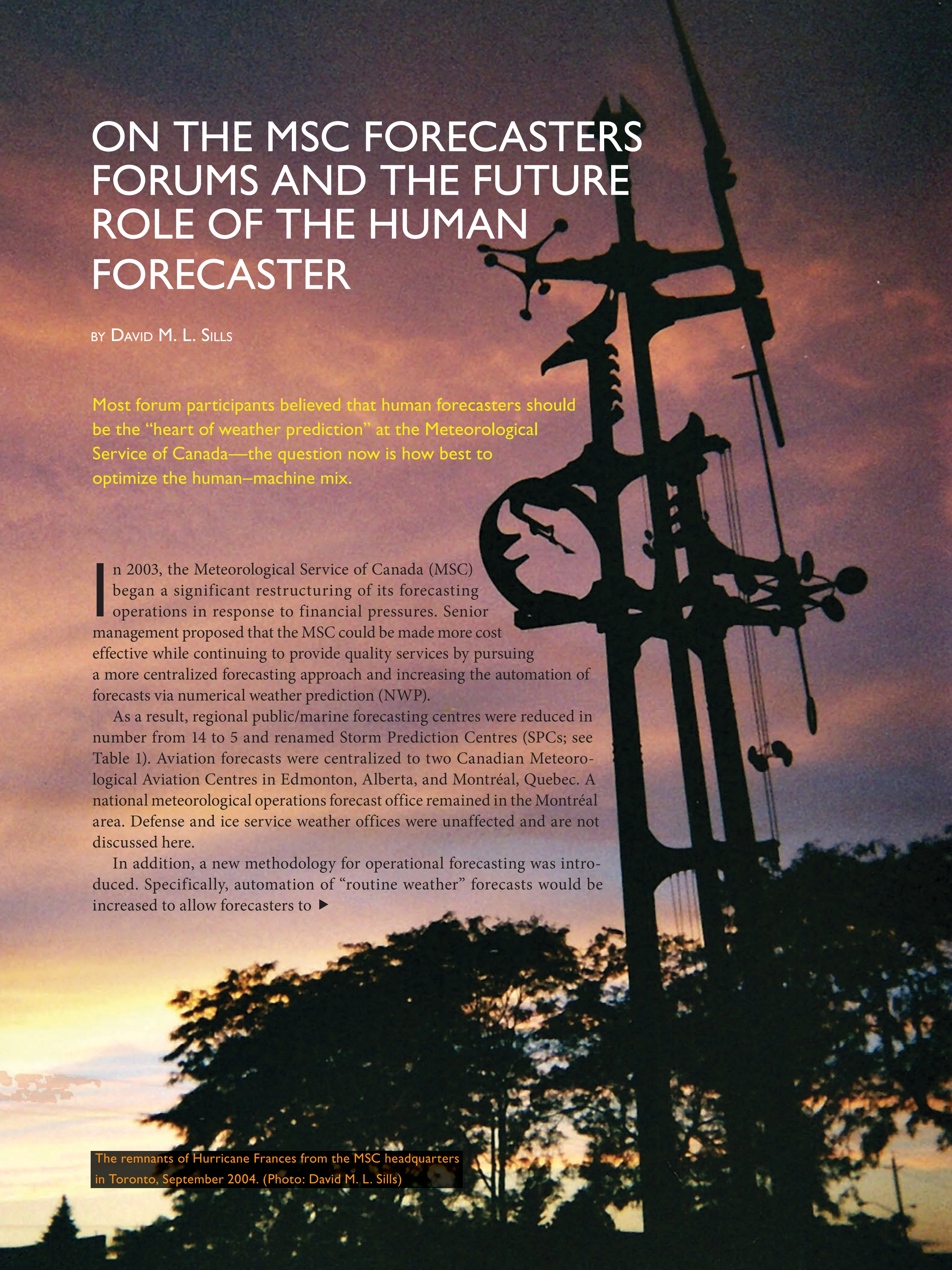
Most forum participants believed that human forecasters should be the "heart of weather prediction" at the Meteorological Service of Canada—the question now is how best to optimize the human–machine mix.

In 2003, the Meteorological Service of Canada (MSC) began a significant restructuring of its forecasting operations in response to financial pressures. Senior management proposed that the MSC could be made more cost effective while continuing to provide quality services by pursuing a more centralized forecasting approach and increasing the automation of forecasts via numerical weather prediction (NWP).

As a result, regional public/marine forecasting centres were reduced in number from 14 to 5 and renamed Storm Prediction Centres (SPCs; see Table 1). Aviation forecasts were centralized to two Canadian Meteorological Aviation Centres in Edmonton, Alberta, and Montréal, Quebec. A national meteorological operations forecast office remained in the Montréal area. Defense and ice service weather offices were unaffected and are not discussed here.

In addition, a new methodology for operational forecasting was introduced. Specifically, automation of "routine weather" forecasts would be increased to allow forecasters to ▶



The remnants of Hurricane Frances from the MSC headquarters in Toronto, September 2004. (Photo: David M. L. Sills)

Table 1. MSC SPCs and office locations (both the Atlantic SPC and the Prairie and Arctic SPC have two office locations). Area of responsibility values include marine areas. Population figures are from the 2006 Canadian census. Note that population in Canada is concentrated mainly in and near urban centers. There are large regions with low population densities, especially in the northern parts of each area of responsibility.

Storm Prediction Centre	Forecast office location(s)	Area of responsibility (km^2)	Population
Atlantic (ASPC)	Dartmouth, Nova Scotia Gander, Newfoundland and Labrador	2,742,700	2,284,800
Québec (QSPC)	Montréal, Québec	1,667,900	7,546,100
Ontario (OSPC)	Toronto, Ontario	1,068,600	12,160,300
Prairie and Arctic (PASPC)	Edmonton, Alberta Winnipeg, Manitoba	8,273,600	5,477,800
Pacific (PSPC)	Vancouver, British Columbia	1,888,900	4,143,900

concentrate their efforts on "high-impact weather" ("HIW"). There would also be greater emphasis on science in operations, including improved forecaster knowledge, tools incorporating the latest research, and a more scientific forecasting process [Roebber et al. (2004) provide a good description of "scientific forecasting"]. National laboratories were to be established at each SPC, focusing on enhancing the flow of knowledge and technology between operations and research, and developing new approaches to regional meteorological problems with national applications. Figure 1 is a map showing SPC locations and areas of responsibility after restructuring.

The reduction in the number of weather offices meant that the area of responsibility for each new SPC would be more than 1,000,000 km^2 (see Table 1). By comparison, France is approximately 540,000 km^2 and is served by seven regional forecast offices (S. Sénési 2007, personal communication), while the U.S. state of Texas covers approximately 690,000 km^2 and is served by 13 regional forecast offices (see www.srh.noaa.gov).[1]

Larger areas of responsibility effectively decrease the number of days with routine weather, since on any given day meteorological conditions are rarely quiescent across the entire domain. Despite these new challenges, fewer operational forecasters were assigned to each new SPC than were working in the same region before restructuring. Surplus staff was offered work in outreach and applied research positions at national service offices and national laboratories, respectively.

As the transition to the new MSC commenced, important questions began to emerge: How would the role and responsibilities of the human forecaster change in this restructured organization? How would routine weather be discriminated from HIW on a daily basis? What kind of tools and techniques would allow monitoring of, and forecasting for, such large areas of responsibility?

To help address these questions, three Forecasters Forum meetings were held. The meetings gave numerous participants from within and outside the MSC the opportunity to influence the details of the restructuring and to work toward a common vision for the future via wide-ranging, interactive discussions.

Similar meetings on the future role of the human forecaster have taken place in other countries. In the United States, these include a session at the First American Meteorological Society (AMS) Conference on Artificial Intelligence in 1998 and the AMS "Future Role of the Human in the Forecast Process" interactive forums in 2004 and 2005 (see Stuart et al. 2006, 2007a,b). A session was also held on the role of the forecaster and production tools at the 2006 European Working Group on Operational Workstations (EGOWS) meeting (see

[1] The populations of Canada, France, and Texas are approximately 31.6, 63.3, and 23.5 million, respectively (Canadian Census and U.S. Census Bureau figures for 2006).

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www.met.hu/pages/egows2006). In addition, many papers during the past several decades have discussed the role of the human forecaster, including Novak et al. (2008), Stuart et al. (2007a,b), Stuart et al. (2006), Baars and Mass (2005), Doswell (2004), Roebber et al. (2004), Bosart (2003), Mass (2003), Andra et al. (2002), Roebber et al. (2002), Roebber and Bosart (1996), Doswell, (1986), and Snellman (1977).

Although a variety of topics related to operational forecasting were discussed at each Forecasters Forum, this article will focus mainly on the future role of the human forecaster, including future forecast tools.[2] Though results specifically pertain to the MSC, they may be of interest to other organizations contemplating the future human role in the forecast process.

THE FORECASTERS FORUMS. The Forecasters Forums took place in Victoria, British Columbia, in 2003 (161 participants), in Toronto, Ontario, in 2004 (129 participants), and in Montréal, Québec, in 2005 (163 participants). Each forum was 3 days in duration and was organized to have themed presentations followed by related "break out" sessions. In addition, each meeting was designed so that approximately 50% of the participants were MSC operational forecasters from all parts of the country. In fact, more than 60% of *all* MSC operational forecasters—including MSC aviation, defense, and ice forecasters—attended at least one of the three forums. Although MSC managers, researchers, and outreach officers made up most of the other participants, forecasters, managers, and researchers from other organizations—such as universities, the U.S. National Oceanic and Atmospheric Administration, and The Weather Network (a Canadian cable television channel)—were also present.

Presentation themes for the three forums included the new MSC structure and forecasting methodology; defining HIW; the future role of the human forecaster at MSC; forecast tools of the future; forecaster training and development; links between operational meteorology and research; the future of NWP; and the communication of uncertainty via probabilistic approaches.

The first forum had break-out session groups with up to 30 participants. For the second and third forums, however, the aim was to have a larger number of groups, each with approximately 15 participants. To gather the desired input from forum participants in an effective and manageable manner, the break-out groups addressed a limited number of questions per session, providing detailed answers and recommendations via consensus. This meant that not all of the forum participants answered all break-out session questions. There were efforts to ensure a cross section of perspectives, and summary sessions were scheduled after each break-out session to discuss recommendations with the larger group. Therefore, it was assumed that the input and recommendations received related to each break-out session question represented the thoughts of the larger group of forum participants.

The presentation and break-out sessions during the three forums revealed a surprising degree of concurrence. The new MSC forecast methodology—that routine weather forecasts would be automated and forecasters would focus on HIW—was well understood and for the most part accepted by those at the forums. There was also agreement that a definition of HIW proposed by MSC's former High-Impact Weather Advisory Committee (HIWAC) could serve as a foundation upon which to build, since it allowed for local and regional variations and implied possible differences between single and cumulative events. Their proposed definition of HIW was "any meteoro-

Fig. 1. Map of Canada showing MSC SPC areas of responsibility (thick lines) and office locations (circles). Canadian Meteorological Aviation Centres are colocated with the SPCs in Edmonton and Montréal. The national meteorological operations forecast office is also located in the Montréal area.

[2] The forums and their outcomes are discussed in greater detail by Sills (2008) and Bensimon et al. (2005).

logically related event, or combination of events, that occurs within a time period less than seasonal that can result in significant impacts (real or perceived) on safety, health, environment or economy."

Most participants thought that the human forecaster should be the "heart of weather prediction," meaning the forecast process would be driven by the forecaster rather than automated NWP systems. Furthermore, it was thought that to do an adequate job of predicting HIW, the forecaster must—on a daily basis—go through the analysis/diagnosis/prognosis process (i.e., "hands on" meteorology) to have the opportunity to recognize potential HIW events, maintain skills, and develop expertise. NWP was considered to be a tool offering important guidance, and it was agreed that forecasters should have a greater variety of models to interrogate (including long- and short-range ensemble and "rapid update cycle" systems) as well as sophisticated methods of viewing NWP guidance and comparing it with observational data. Participants also thought that future statistical NWP and decision support tools should not be "black boxes," but should make the forecaster aware of underlying decision processes.

Most participants thought that output from ensemble forecast systems should be used by the forecaster to make deterministic products better, and that additional forecaster training is needed to reach a greater level of comfort with ensemble concepts. However, most participants also thought that more probability information should be included in public forecasts, especially in the longer range. Free-form text was identified as the best way for forecasters to express uncertainty to the public, especially when combined with graphical representations (e.g., the "cone of uncertainty" commonly used by the U.S. National Hurricane Center).

There was agreement, even among managers in attendance, that additional forecasters are needed to achieve a "critical mass" at each of the new SPCs. As was discussed at the forum, such a critical mass is not only needed to enable forecasters to cover the larger areas of responsibility but also to allow for scheduling flexibility, so that forecasters get the off-shift development time that they need. Changes to the composition of the forecast team were also suggested, including the addition of mesoscale analysts, forecasters responsible for maintaining situational awareness, and meteorologists responsible for interpretation and communication.

Three forecast production system paradigms were presented and compared via a panel discussion: a point-based matrix-editing approach (e.g., SCRIBE[3]), an area-based grid-editing approach [e.g., Interactive Forecast Preparation System (IFPS)[4]], and an area-based object-editing approach [e.g., Forecast Production Assistant (FPA)/Aurora[5]]. All three approaches employ an underlying digital weather database. However, most participants thought that an area-based approach would be more intuitive for the forecaster than a point-based approach. They also believed that such an approach would be better suited to forecasting for large areas and would make it easier to both incorporate local effects and provide graphical and gridded output for internal and external users. In addition, most believed that an approach that incorporates modifiable line, area, and gridded field objects, such as that used with FPA/Aurora, would allow the forecaster to do more hands-on analysis, diagnosis, and prognosis. This is supported by Ruth (2000), who reviewed methods for interactive forecast preparation and suggested that area-based, object-oriented editing "[fits] well with the conceptual approach of most forecasters."

At the time of the forums, the MSC had committed to developing a new national forecaster workstation to replace a plethora of disparate and increasingly obsolete software tools, and joined with a European consortium to develop a workstation called NinJo (see Koppert et al. 2004). Thus, it was even more important to determine the future role of the human forecaster, since that would help to establish the forecast system paradigm to be implemented. When asked for input on a new workstation, participants envisioned software that is fast and robust; flexible and configurable; offers sophisticated visualization; allows case replay and simulations; includes real-time NWP verification against observations; and works in a way that is intuitive to the forecaster. It also has to continuously evolve, and be supported by adequate training. Participants also underlined the importance of having NinJo developers work closely with forecasters when designing the workstation.

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[3] SCRIBE is a forecast production tool developed and used operationally by MSC (see Verret et al. 1995).

[4] IFPS is a forecast production tool developed and used operationally by the U.S. National Weather Service (see Ruth 2002).

[5] The FPA is a forecast production tool developed by MSC and used operationally at many commercial and government forecasting offices (see Paterson et al. 1993). Aurora is a prototype nowcasting research platform based on the FPA (see Greaves et al. 2001).

FUTURE ROLE OF THE HUMAN FORECASTER.

Since the final forum in 2005, the MSC has completed the implementation of its restructuring strategy, and senior management has worked toward addressing many of the various Forecasters Forum recommendations. The first operational version of the evolving NinJo workstation will be implemented across the MSC in 2009, and there is a long-term commitment to workstation development. However, some important recommendations made at the forums have yet to be acted upon, including committing to area-based, object-oriented forecast production, and studying alternative team coordination approaches and the staffing levels needed for critical mass at SPCs. In addition, considerable uncertainty persists regarding the future role of the human forecaster.

To address this lingering uncertainty, the results collected during the course of the three Forecasters Forums will be used below to make detailed recommendations regarding the future role of human forecasters at the MSC and the tools they should use.

A working definition of HIW is required to determine the scope of the future work of the human forecaster. For the purpose of this discussion, a somewhat simpler and narrower version of the HIWAC definition of HIW discussed at the forums is used: "HIW is weather that can result in significant impacts on safety, property and/or socioeconomic activity." This definition facilitates an emphasis on storm prediction, as the new MSC forecast office monikers suggest. It is also recognized that weather can present a spectrum of effects from low to extreme (depending on the type, intensity, timing, location, and duration of the weather event as well as antecedent conditions), and that the alerting tools available to the forecaster should reflect this spectrum (see McCarthy 2007). For example, a new tier of bulletins might be introduced for climatologically extreme weather, or events where extreme effects are expected.

At every forum, it was heard that human forecasters should be the "heart of weather prediction," and that there needs to be a return to hands-on meteorology, even if focused mainly on HIW. The tenet that forecaster skills atrophy as more of the forecast process is automated (Bosart 2003; Pliske et al. 1997; Roebber and Bosart 1996; Doswell 1986; Snellman 1977) was discussed on numerous occasions. The forecasters of the future would not be able to maintain their analysis, diagnosis, and prognosis skills if their only role is occasional intervention when automated forecast processes go awry (although, it is recognized that there would be skill in knowing *when* to intervene). In addition, the further forecasters get from working with unprocessed meteorological data, the less likely they will be able to recognize the cues and patterns that match conceptual models and lead to appropriate and effective actions—a process described by Klein (1998) as "recognition-primed decision making."

Instead of the popular analogy of the forecaster as a fire fighter (responding only as a critical situation arises) or as an airline pilot [intervening only at critical times, such as takeoff, landing, or during computer failure, as discussed in Stuart et al. (2006)], an alternative analogy of the forecaster as a professional athlete (a hockey player was specifically mentioned) emerged at the forums. The firefighter, the airline pilot, and the hockey player each work as part of a team and require frequent training and practice. However, the hockey player uses skills throughout the game, not just when the team gets behind, and develops expertise on a continuous basis. Like the hockey player, the forecaster needs to use skills continuously, so that they are not eroded and in doing so, develops expertise, gains experience with recognizing HIW, and maintains the situational awareness necessary for rapid and effective response in critical situations.

It is often stated that it is becoming increasingly difficult for human forecasters to add value to NWP forecasts, especially beyond the first 12 h or so, since only occasionally is NWP guidance seriously in error (e.g., Stuart et al. 2006; Baars and Mass 2005; Mass 2003; Brooks et al. 1996; Roebber and Bosart 1996). However, it is at precisely those times when NWP does poorly that the weather is typically of critical importance to the public—that is, in significant HIW situations. Under these circumstances, expert forecasters can increase forecast skill considerably (see Roebber et al. 2004). Therefore, until NWP can better handle these critical situations, the human forecaster will have a crucial role in producing the best possible forecast for HIW. This role should be recognized and resources devoted to better facilitating it.

Computers are still a long way from doing what humans do best. During the Sydney 2000 nowcasting demonstration project, the relative success of the National Center for Atmospheric Research (NCAR) Auto-Nowcaster system at nowcasting deep, moist convection compared to other nowcasting systems was based on the ability of the human forecaster to correctly analyze and diagnose low-level convergence boundaries and enter boundary information into the system (Wilson et al. 2004). Also, Project Phoenix, an ongoing initiative at the Prairie and Arctic SPC, has consistently shown that forecasters generate considerably better short-range predictions when NWP is withheld, and forecasters are forced to spend more time on analyses and diagnoses, and creating their own prognoses (McCarthy et al. 2007).

Taking all of the above into account, it is suggested here that the primary role of the human forecaster should be to develop and maintain a shared weather-object database that uses a sequence of plan-view composite depictions that evolve through time to best represent the current and future states of the atmosphere.[6] This would be accomplished using an area-based, object-oriented analysis/forecast system with an intuitive user interface, plus a toolbox of NWP guidance and carefully designed artificial intelligence (AI) assistants. The emphasis would be on sensible weather near the surface, since that region of the atmosphere has the greatest influence on the activities of the public.

This proposed role is illustrated in Fig. 2. As shown in the flowchart, the interaction between the human forecaster and the analysis/forecast system would be central to the forecast process, though the forecaster could also influence quality control, observations (e.g., targeted or special observations), and NWP (to be discussed later).

In this forecast process, the forecaster would begin with analysis and diagnosis using past and current observational data to develop a mental model, or working hypothesis, for the current weather situation. Once a robust understanding of the current weather has been achieved (a critical step for accurate prediction), the forecaster would decide which NWP solution to use as a basis for prognoses. The NWP solution could be output from a deterministic model or an ensemble prediction system. For instance, the forecaster could choose whether to use the ensemble mean or the solution from a superior member (as suggested by Mass 2003), or run a high-resolution model using initial and lateral boundary conditions from a selected low-resolution ensemble member (as suggested by Roebber et al. 2004). Using the analysis/forecast system, any combination of observational and NWP data layers could be superimposed by the forecaster to assist with this selection.

Once the analysis/forecast system database has been populated with the selected NWP data, the forecaster would use the NWP guidance, conceptual models, and the forecast data from the previous shift to develop plan-view composite depictions at future times. The depictions would be deterministic in nature, representing the forecaster's best estimate of the evolution of weather features over time. The temporal and spatial resolution of the depictions would be range dependent (e.g., every 3 h at 15 km for short-range forecasting and every 6 h at 30 km for medium-range forecasting). Line and area objects would be used to represent conceptual weather features, such as fronts and jets, and precipitation and cloud areas. Gridded field objects—including surface pressure, temperature, relative humidity, and wind—would be modified as needed at each time interval to match the placement of the line and area objects. For routine weather, only minor adjustments to the depictions developed by the previous shift might be needed. Note that while both observations and NWP output could be *viewed* in three spatial dimensions, any object *editing* would be done in the much simpler two spatial dimensions (i.e., plan view).

Through the above analysis/diagnosis/prognosis process, the forecaster would identify any potential, imminent, or occurring HIW and focus further efforts there. In particular, the forecaster would investigate uncertainty in the timing, location, and intensity of the HIW, as well as related influences. For example, the forecaster could identify key parameters for the period in question and control the generation of perturbations for additional ensemble runs (as described by Homar et al. 2006) to refine the HIW prognosis. Allowing the forecaster to guide the generation of ensemble solutions improves probabilistic information and enhances conceptual understanding (see Novak et al. 2008). Most modifications to the weather-object database would likely occur during this part of the forecast process.

Once all the depictions have been finalized, the forecaster would initiate interpolation between time intervals to create depictions at higher temporal and spatial resolution (e.g., every hour at 5 km for nowcasting and short-range forecasting and every 3 h at 15 km for medium-range forecasting). This would be done automatically by the analysis/forecast system once the forecaster has identified the distinguishing features associated with each line and area object to be interpolated over time [such sophisticated time interpolation functionality has been in existence for some time; see, e.g., Trafford (1990)].

As new data arrive throughout the day, the forecaster would produce detailed analyses, compare

[6] It should be noted that the 2006 EGOWS session on the role of the forecaster came to similar conclusions, as did an internal report on the future role of the operational meteorologist at MSC (McCarthy et al. 2005). In addition, Mass (2003) suggests that the building of time-sequenced graphical descriptions of important weather parameters based upon gridded analyses should dominate the work of the forecaster.

observations with the NWP/AI output, evaluate "what if" scenarios, and test and refine hypotheses related to HIW made earlier in the day, leading to revised prognoses—all within the analysis/forecast system. The importance of hypothesis development and testing as part of the forecast process is discussed in numerous publications (Roebber et al. 2004, 2002; Pliske et al. 1997; Hoffman 1991; Doswell 1986).

For convective nowcasting, depictions at even higher spatial and temporal resolution (e.g. every 10 min at 1 km) would be necessary. The forecaster would use radar and satellite imagery, lightning data, and surface observations in conjunction with conceptual models, rapid update cycle/high-resolution model output, and AI algorithms to forecast the future track and intensity of storms, and/or the development of new convection. Storms forecast to cross predefined intensity thresholds would initiate warnings, with enhanced content provided by underlying GIS information (e.g., locations of urban areas, highways, schools, among others).

As recommended at the forums, uncertainty (aside from probability of precipitation) would be expressed via free-form text products combining text and graphics (e.g., cones of uncertainty). More sophisticated users requiring specific uncertainty information for decision making could have direct access to ensemble NWP output.

The resulting weather-object database would be shared digitally with other forecasters, in the same office or in neighboring offices, and would be disseminated to interested users. Weather element matrix data at preselected point locations and gridded weather element data could also be generated from this database. Much of the generation of graphical and textual products—including severe weather watches and warnings—would be automated, though forecasters would review and "sign off" on any mission critical output.

The main idea is that the daily activity of the forecast team would be focused on meteorology, not the details of generating products, thereby maintaining shared situational awareness at all times. This would likely require a forecaster with the specific task of maintaining "the big picture" and coordinating the more detailed activities of others (such as one or more mesoscale analysts). Such tasks were suggested during the forums, and by McCarthy et al. (2005).

The forecaster workstation required to facilitate this role should make best use of human strengths—recognizing patterns; using conceptual models and formulating mental models; judgment and decision making when dealing with complex, incomplete, or conflicting data; applying adaptive strategies in rapidly changing situations—and machine strengths—dealing with large volumes of data; handling complex calculations and complicated parameter interactions; automating product generation—while also enhancing forecaster expertise.

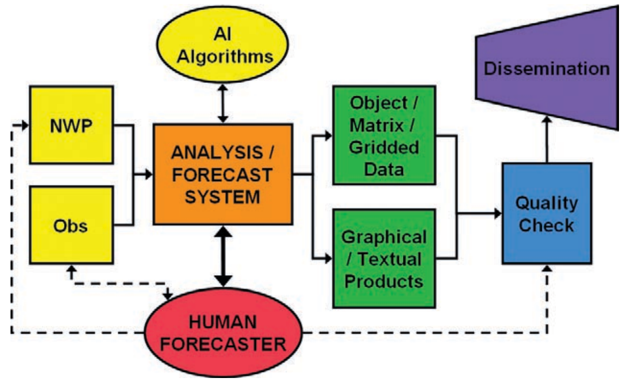

Fig. 2. (left to right) Flowchart showing the proposed role of the human forecaster in the forecast production process. Yellow boxes represent various inputs, while green boxes represent various outputs. Bold arrows indicate that the main interaction is between the human forecaster and the analysis/forecast system. The human forecaster may also influence NWP, observations, and quality checking (all shown as dashed arrows). Public reports of severe weather events are a special type of observation that could go directly to the human forecaster (dashed arrow).

The developers of the NinJo workstation are working toward the ability to incorporate an area-based, object-oriented approach to forecast production. It is important that they pursue this approach in a manner that achieves the optimal human–machine mix, as described above. As has been seen in the past, it is tools that—to a great extent—determine the role of the forecaster.

In addition to the primary prediction role, a significant proportion of the forecaster's annual schedule should be devoted to training/skills development and applied research, such as case studies, techniques development, and verification projects. This proportion might justifiably be as high as 50%, though currently at the MSC it is a nominal 20%.

Effective communication of the forecast to users would be a separate role handled by another class of meteorologists skilled at forecast interpretation and understanding user-related effects. Within the MSC, such a class of meteorologists already exists and is known as the warning preparedness meteorologist (WPM). However, the WPM of the future may need to become more integrated into the forecast team than is currently the case (e.g., work shifts alongside the forecasters) to be more aware of the forecast issues of the day and the uncertainty associated with HIW prognoses.

SUMMARY. Three Forecasters Forum meetings were held by the MSC between 2003 and 2005, providing valuable discussions and significant insight on numerous topics related to operational forecasting in Canada.

Good progress was made on developing a common vision for the role for the human forecaster in the restructured MSC. Most participants believed that the human forecaster needs to maintain a central role in the forecast process, and that sophisticated forecasting tools are needed to cover large areas of responsibility and to facilitate greater emphasis on analysis, diagnosis, and prognosis.

On the question of how routine weather would be discriminated from HIW on a daily basis, it was thought that the forecaster must go through the analysis/diagnosis/prognosis process to have the opportunity to recognize potential HIW events. In addition, it was agreed that the dividing line between routine weather and HIW may differ slightly from region to region and change for single and cumulative events.

Based on the results of the three forums, it is recommended that the primary role of the forecaster should be to develop and maintain a sequence of plan-view composite depictions evolving through time to best represent the current and future states of the atmosphere. This would be accomplished using an area-based, object-oriented analysis/forecast system with a toolbox of NWP guidance and carefully designed AI assistants. The forecaster's work would be focused on HIW events, mainly in the short term but also in the longer term when necessary. Products would be automatically generated from the weather-object database, allowing the forecast team to focus on "hands on" analysis, diagnosis and prognosis, and maintain shared situational awareness at all times.

The human forecaster currently plays a vital role at MSC weather offices and could continue to contribute toward significant improvements in HIW forecasting if supported by tools that achieve an optimal human–machine mix. An exciting, fulfilling future is possible for the human forecaster, but it depends on decisions that senior managers at meteorological services, like the MSC, will make in the coming years. It is hoped that the results from the forums, and the discussion in this article, will help to guide such decisions.

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