



## WEATHER-AWARE INTEGRATED AIRPORT/AIRSPACE CAPACITY PREDICTION TECHNOLOGIES

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### Abstract

Weather impacts on the capacity of different parts of the aviation system can make strategic Air Traffic Management (ATM) especially challenging. This paper describes an integrated suite of technologies being developed with NAV CANADA for Toronto Pearson International Airport to enable more effective weather-aware decision support for ATM needs. Technologies tailored to specific needs in terms of weather situational awareness and impact translation at the airport and its associated terminal and enroute airspace resources are described. Overviews of each technology, examples of their operational use and the plan for their integration and deployment are described. These activities could provide valuable insights for other world regions experiencing similar ATM challenges and with similar visions to move towards a Trajectory Based Operations (TBO) system.

**Keywords:** weather, capacity, ATM, TBO.

### 1. Introduction

One of the primary objectives of strategic Air Traffic Management (ATM) is to balance expected demand with available capacity at airport, terminal and enroute airspace resources throughout the system for multiple (e.g., up to 12) hours into the future, as illustrated in Figure 1. The process starts with effective forecasts of the weather and demand profiles over this time period. Then there is a need to translate these weather forecasts into capacity impacts on the different parts of the aviation system, as shown in the blue box. Next is the need to assess the temporal and spatial profiles of these capacities relative to demand from which imbalances can be identified. The right side of Figure 1 illustrates a notional example of the capacity impacts of weather moving through an airport region, causing its capacity to fluctuate, as shown by the blue line. If demand exceeds the forecast capacity (i.e., demand over-delivery shown by the solid red line), there will be operational challenges requiring responses such as airborne deviations, holding and diversions. More efficient strategies involve proactively managing the demand to bring it back into balance with the expected capacity as a function of time, as shown by the dotted red line. Similar demand/capacity balancing assessments need to occur at the terminal and enroute airspace resources too, as illustrated by the stacked grey boxes in Figure 1. A range of so-called Traffic Management Initiatives (TMIs) can be used when imbalances occur (shown by the feedback loop in Figure 1), modifying demand at locations and times when it is expected to exceed capacity. For example, strategic re-routes can be used to avoid large regions of convective weather or airspace flow programs can be used to limit arrivals into an airport for the duration of a weather event. Such strategies need to be initiated many hours before the weather impact. Other initiatives, such as flow programs or time-based metering with an Arrival Manager (AMAN), can be applied more tactically at shorter timeframes to help manage demand more surgically.

Predicting demand and capacity profiles many hours into the future to support these TMI decisions can be very challenging due to highly dynamic conditions (which generate considerable forecast uncertainty, illustrated by the shading around the capacity and demand profiles in Figure 1), especially during periods of adverse weather.

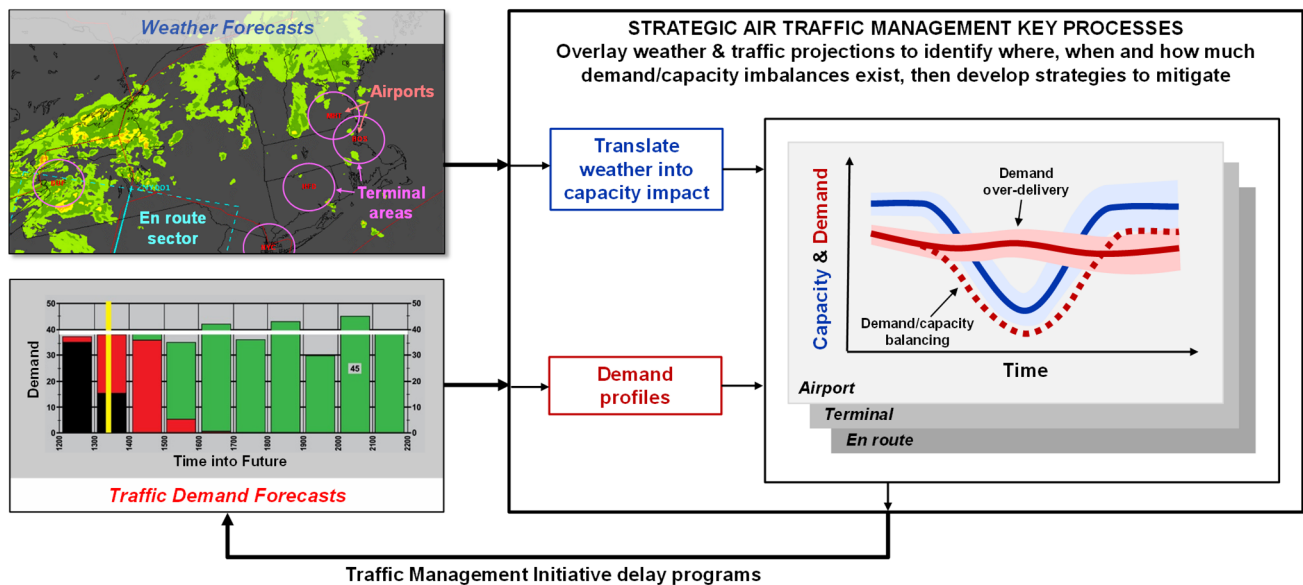


Figure 1 – Strategic ATM processes to balance capacity & demand during weather events.

Currently, ATM decision support technologies are largely limited to aviation-specific weather forecasts over 0-12 hour timeframes, but the translation to capacity impacts and demand/capacity imbalance prediction components are largely missing. In the absence of this, traffic managers need to mentally estimate weather impacts on capacity and then combine their estimates with demand and other constraints in the future for various regions of airspace of relevance to their TMI decision-making. This is a challenging endeavor which often leads to high workload, inconsistent decision-making and sub-optimal use of resources, leading to either excess delay (over-delivery of demand) or inefficient use of available system capacity (under-delivery of demand). In addition, there is not a common source of weather information used by all stakeholders, often leading to inconsistent information being used as a starting point for (and hence complicating) collaborative decision-making discussions.

Developing techniques to forecast weather-impacted capacity of different airport and airspace resources has received a lot of attention in the research literature. In the airport domain, a standard approach to predicting airport capacity has been to use empirically-derived throughput envelopes [1], then using convex hulls at selected high percentile levels of the achieved throughputs to estimate capacity in different configurations. Explicitly accounting for weather impacts and uncertainty on airport capacity has also been widely studied using a variety of approaches, e.g., [2], [3]. Modern machine learning techniques are now also being explored for modelling the impact of adverse weather on airport capacity, e.g., [4]. Assessing weather impacts on airspace has also been studied extensively, for example in the terminal [5] and enroute [6] domains, which resulted in the development of the Convective Weather Avoidance Model (CWAM) concept which is now used extensively within the aviation community, e.g., [7]. But there has been limited focus on either (1) explicit prediction of demand/capacity imbalances in the airport and airspace domains, or (2) common technologies that integrate the coupled effects of weather in an ATC ecosystem in terms of airport, terminal and enroute airspace impacts. This paper will describe an integrated suite of technologies being developed with NAV CANADA for Toronto Pearson International Airport (YYZ) to enable more effective weather-aware decision support for ATM needs consistent with the process shown in Figure 1. Section II will describe the foundational aviation weather forecast system (consistent with the top left box in Figure 1) being developed to cover NAV CANADA's large airspace domain which will ultimately be used by the capacity prediction tools. The following sections describe the weather-to-capacity translation and demand/capacity impact assessment (consistent with the boxes on the right of Figure 1) for the airport, terminal and enroute environments in Sections III through V respectively. Finally, Section VI will describe the implementation plan to support NAV CANADA's long-term TBO vision.

## 2. Canadian Aviation Weather System (CAWS)

CAWS is a prototype technology which provides foundational weather capabilities to enhance weather situational awareness for aviation stakeholders and will ultimately provide weather inputs to the other prototypes. CAWS leverages MIT Lincoln Laboratory's long history of aviation weather technology development, including the Corridor Integrated Weather System (CIWS) [8], Consolidated Storm Prediction for Aviation (CoSPA) [9] (both of which will ultimately be integrated into the NextGen Weather Processor (NWP) [10]) and Offshore Precipitation Capability (OPC) [11] technologies developed for the Federal Aviation Administration (FAA). CAWS is optimizing these technologies for Canadian operations as discussed below.

CIWS is a fully automated weather analysis and 0-2 hour forecast system designed to address ATM needs for tactical decision-making. It provides radar-like forecasts that predict timing and extent of regions of weather impacts, aids in the selection of clear air routes, and provides foundational weather data for other FAA decision support tools. Strategic air traffic management decision-making requires longer lookahead forecasts, and CoSPA was developed to provide forecasts out to 8 hours to address these needs. As shown in Figure 2, CIWS/CoSPA technology combines data from weather radars, satellites, surface observations, and numerical weather models to provide high accuracy forecasts of storm intensity (Vertically Integrated Liquid (VIL)) and height (Echo Top (ET)) information. This allows traffic managers to determine whether storms should be deviated around or can be over-flown. CIWS forecast accuracy scores are provided on both the precipitation and echo tops forecast animation displays so that the user can determine how much confidence exists in the forecast information at various forecast lead times. A winter mode can be enabled to display the phase (snow, mix, rain) of the precipitation.

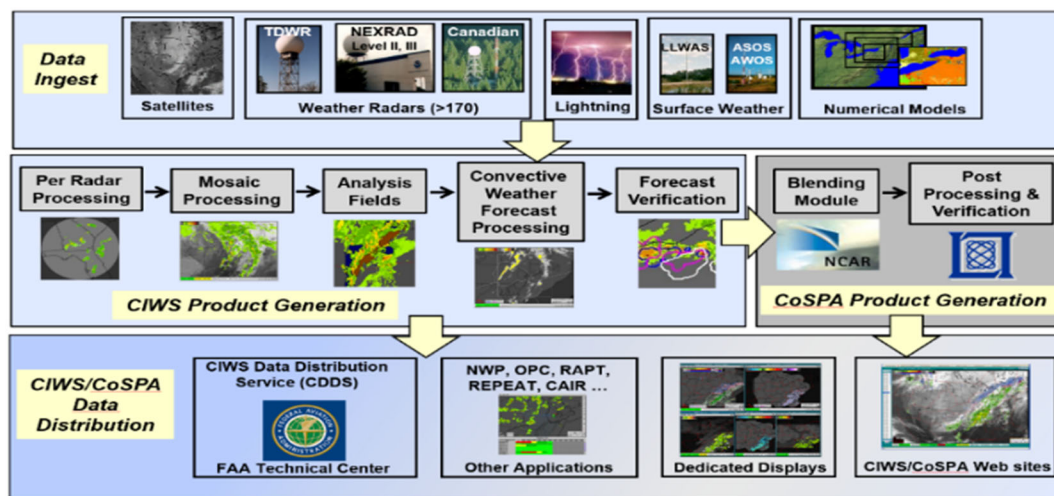


Figure 2 – CIWS/CoSPA product generation and dissemination.

Much of NAV CANADA's airspace includes high northern latitudes (their airspace goes up to the North Pole) as well as the western half of North Atlantic oceanic airspace. These regions lack weather radar coverage and hence OPC technologies are also being integrated into CAWS. OPC combines infrared and visible satellite data, global cloud-to-ground lightning and atmospheric analysis fields from numerical weather prediction models. Using a machine learning framework, the OPC algorithm is trained in regions where radar and non-radar data are available and then it is applied in regions without actual weather radar coverage to create a "synthetic weather" radar output. The algorithm produces six-level precipitation intensity and storm echo top height estimates similar to CIWS/CoSPA which traffic managers are accustomed to interpreting.

CAWS is building upon and optimizing these technologies for Canadian operations by ingesting additional weather radar feeds and combining with Global Forecast System (GFS) numerical weather prediction model data. In regions without weather radar data, CAWS uses Canadian Lightning Detection Network (CLDN) and Geostationary Operational Environmental Satellite (GOES) imagery to re-train

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OPC algorithms for the northern Canadian domestic, Atlantic and Pacific airspaces beyond the reach of weather radars. The resulting synthetic weather estimates are blended with existing radar-based systems to create a seamless mosaic that provides full weather situational awareness over NAV CANADA's domestic and oceanic airspace. Figure 3 shows these inputs and an example VIL mosaic display over this spatial domain for the initial CAWS prototype. The latest prototype release includes other products such as storm growth and decay regions, storm height tags, storm motion vectors and a 0-8 hour forecast capability to support strategic ATM decision-making.

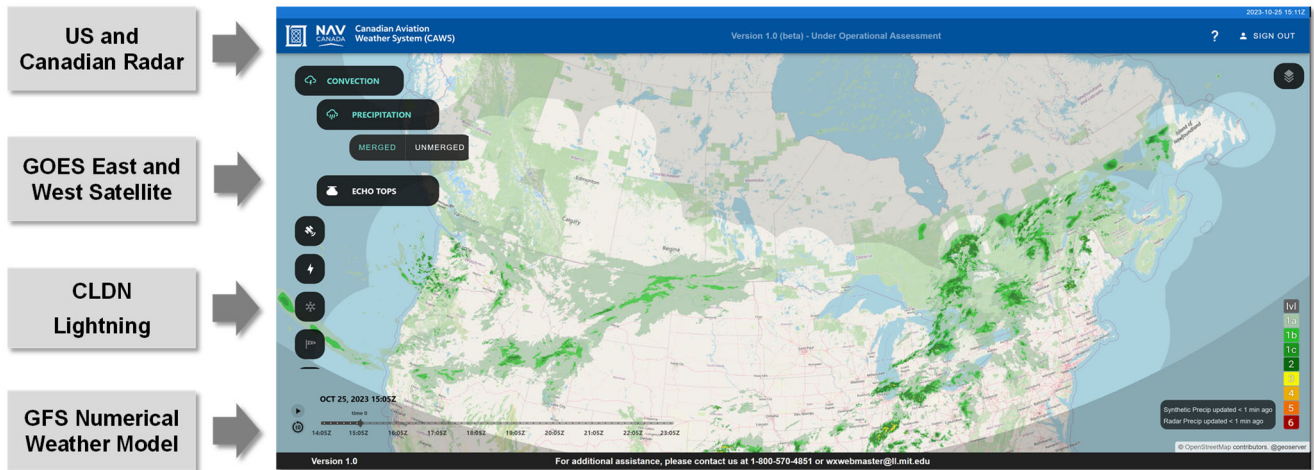


Figure 3 – CAWS current inputs & prototype display.

### 3. Airport Capacity Evaluation & Prediction Tool (ACEPT)

#### 3.1 Overview

ACEPT is a prototype technology currently being tested to predict airport capacity and demand imbalances to guide “day of” strategic planning and decision-making for NAV CANADA and relevant stakeholders. ACEPT integrates multiple weather forecast sources, together with information on operational constraints and flight demand as shown in Figure 4.

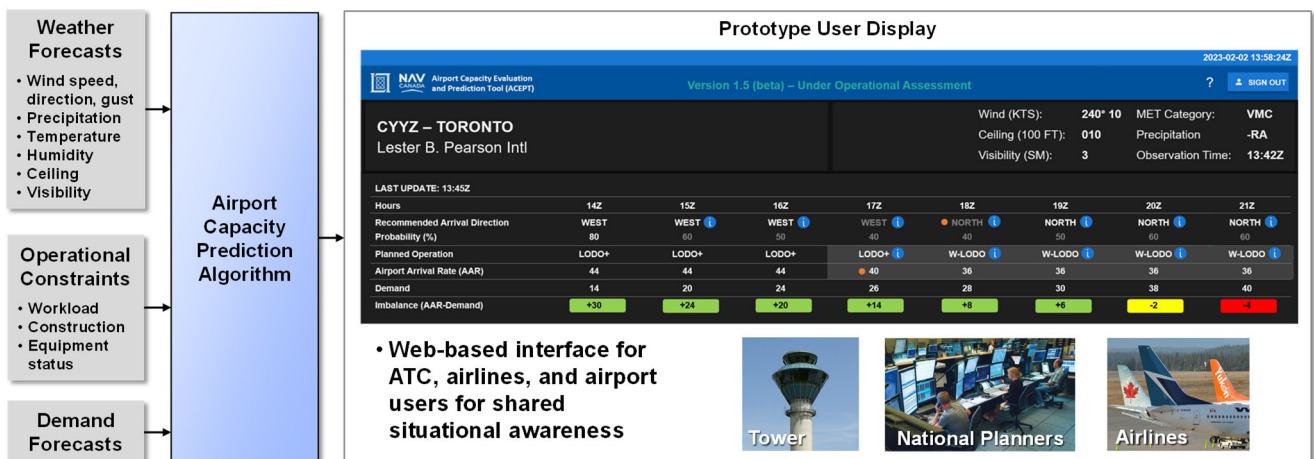


Figure 4 – ACEPT inputs & current prototype display.

The display gives users an objective assessment of weather conditions at the airport over the next 8 hours, together with an explicit translation of the weather into recommended airport arrival direction (categorized at YYZ as NORTH, SOUTH, EAST and WEST) accounting for factors such as winds, runway surface condition, ceiling and visibility (C&V): see details in [12]. Combining the recommended

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arrival direction with the other operational constraints leads to an estimate of the planned operation at the airport (e.g., triple, dual, single or land-one-depart-one (LODO) arrival runway operations), which in turn leads to an estimate of the airport arrival rate (AAR) and potential periods of demand/capacity imbalance. AARs in EAST/WEST configurations are typically higher than NORTH/SOUTH due to an extra arrival runway being available. As such, recommendations involving transitions from EAST/WEST to NORTH/SOUTH or vice versa are especially impactful from an operational perspective. All of this information is made available to a range of stakeholders via a web application to support effective collaborative decision-making so proactive traffic management strategies can be developed hours in advance of the actual situation. A key element of the recommended arrival direction is a probability associated with the prediction. In the current ACEPT prototype, this is determined by making an arrival recommendation based on 35 different weather forecast ensembles (5 different time-referenced forecasts at 7 different spatial points at and around the airport). The displayed probability shows the percentage of these 35 different predictions which result in the majority recommendation displayed. Users who desire more information on the rationale for the recommendations have access to more detailed information via drill-downs on the ACEPT display as shown in Figure 5. For example, when the probability of a recommended arrival direction is below 100%, probabilities associated with alternate arrival directions are presented in the blue pop-up to support risk-based decision-making. More information on the weather forecast is available via a collapsible panel below the main user guidance. This provides expected variability in winds (speed, direction and gusts) based on ensembles of weather models, C&V, meteorological conditions (visual or instrument), precipitation type and runway surface condition. Figure 5 also shows details of the input panel on the right which is available to a subset of users to enter operational constraints for a given hour, or across a specified time period. This includes options to over-ride the ACEPT-recommended arrival direction; changing the default planned operation; adjusting the default AAR and capturing constraints and comments supporting these decisions to provide context for other users if such inputs are required in order to account for non-weather factors which may dictate any of these parameters.

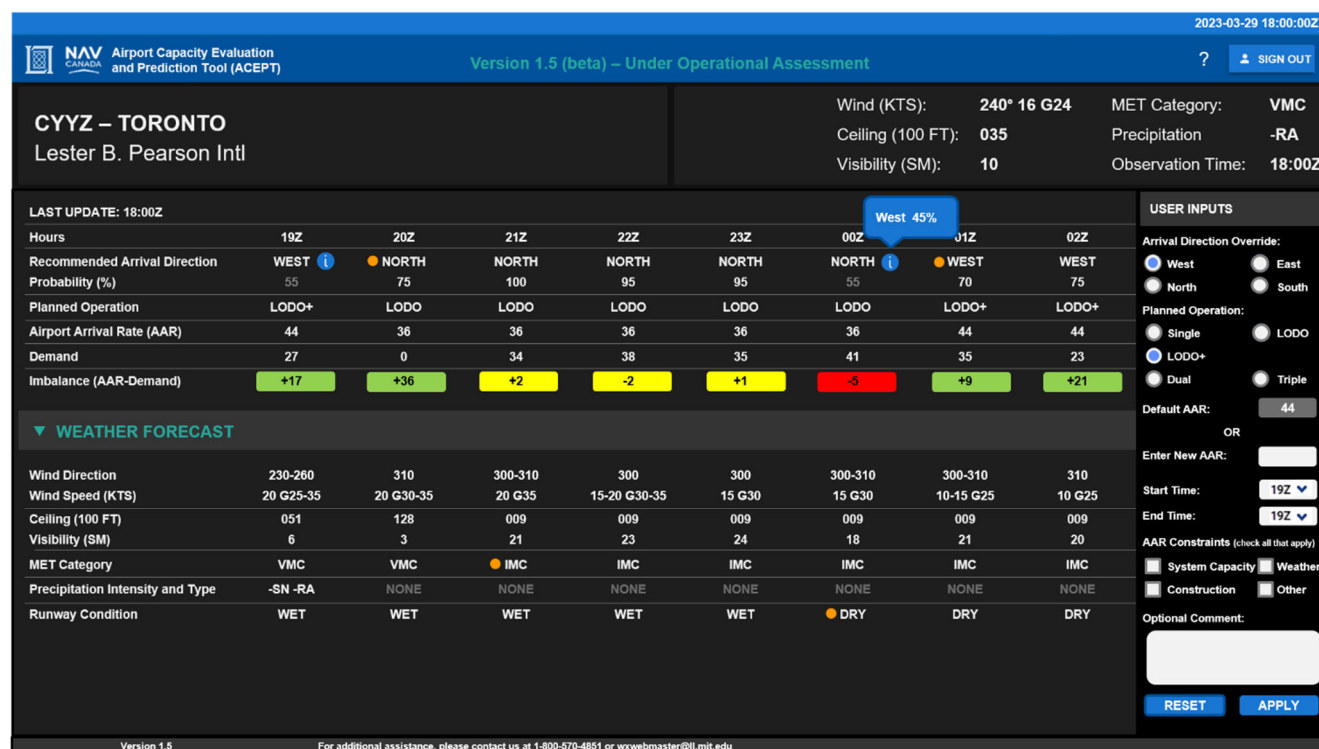


Figure 5 – Expanded ACEPT information display showing alternate arrival direction recommendations, more detailed weather information and the user input panel.

The initial ACEPT prototype was developed for operations at YYZ and released to users via a web

application in 2020. Since then, a number of iterative refinements have been made to increase the fidelity and accuracy of the weather information, airport configuration options and arrival capacity and demand prediction elements. It is currently being evaluated to determine future refinements.

### 3.2 ACEPT Use Case

In order to illustrate how ACEPT can be used to manage operations at the airport during a challenging wind event, conditions from 2 February 2023 are described below. The schedule on this day was expected to be similar to a typical winter demand day. Strategic air traffic managers were aware of the chance for strong north-west winds which might force the airport to transition from a WEST (AAR=44) configuration to a NORTH (AAR=36) configuration during the evening arrival peak in the 2300-0000Z time period. However, due to uncertainty in the weather forecast, it was decided to plan to remain in the WEST configuration during the event to maintain the higher AAR given the expected demand. The strong winds did materialize, necessitating an airport configuration shift from WEST to NORTH at 2345Z. Because demand had not been reduced in anticipation of a 44 AAR, the forced configuration shift with a lower AAR led to 7 diversions, 30 aircraft holds, 69 gate holds, a Ground Stop to prevent additional holding/diversions and a ground delay program to manage recovery during the reduced capacity period. During this event, ACEPT was being operated in “shadow mode” (i.e., available for situational awareness but not operational decision-making). Figure 6 shows the ACEPT display during the 1700Z hour. It is apparent that the likely transition from WEST to NORTH (with associated AAR reduction and demand/capacity imbalance) was forecast with high confidence 6 hours ahead of the actual event. In hindsight, this information turned out to be an accurate representation of the situation as it occurred. This use case highlights how differences of opinion among stakeholders on the validity of a forecast and its impact on operations can sometimes lead to inefficient operations, and hence illustrates how ACEPT information could potentially be used to proactively plan airport operations.

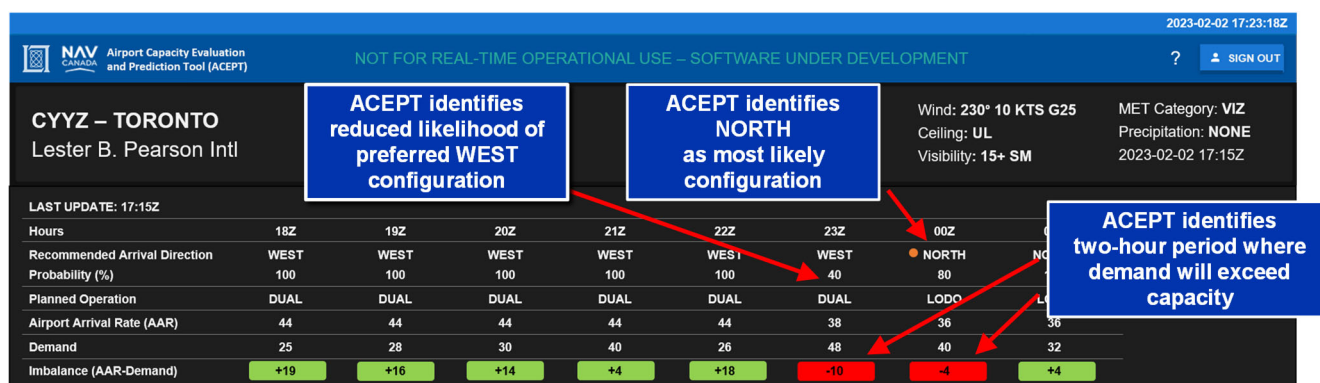


Figure 6 – ACEPT display on use case day (2 February 2023).

## 4. Terminal Capacity Evaluation & Prediction Tool (TCEPT)

### 4.1 Overview

Weather impacts on the terminal airspace can be especially challenging due to the importance of specific arrival fix (“bedpost”) and departure route regions which act as the interface between airport and enroute airspace regions. TCEPT is a technology specifically designed to help traffic managers, airlines and other users to have an objective assessment of weather impacts on terminal airspace regions. This will allow proactive re-routing of arrivals and departures to available fixes and more effective conditioning of arrival demand for transitioning to time-based arrival management during convective weather. TCEPT integrates multiple weather forecast products and combines them with extensive historical analysis of forecast accuracy and actual traffic flows to generate an objective, validated display of terminal airspace weather impacts. The technology underlying TCEPT is based on the Convective Weather Avoidance Model (CWAM) [5,6] developed over many years at MIT Lincoln Laboratory and which was the basis for our Route Availability Planning Tool (RAPT) which is currently

operational with the FAA. CWAM has been augmented by modern machine learning algorithms pioneered in our Traffic Flow Impact (TFI) prototype [13,14] and TCEPT tailors them specifically to the terminal airspace environment. The display of the current TCEPT prototype being tested at Toronto is shown in Figure 7. It currently comprises a weather forecast situational awareness display zoomed into the YYZ terminal area. The arrival bedposts (named IMEBA, RAGID, LINNG, NUBER and BOXUM) are visible in cyan text within the weather display. The left side of the TCEPT display provides a tabular representation of the weather impacts on the terminal region, where the rows of the table correspond to the status of each bedpost (as well as a row for the overall Terminal Control Unit (TCU)), and the columns are times into the future in 30 minute time bins. Additionally, TCEPT provides estimated bedpost arrival demand over the next 2 hours (see bottom left of Figure 7) utilizing a combination of radar-derived aircraft data and flight plan message data. This combination of predicted weather impact and arrival demand allows users to evaluate potential flight over-delivery and plan mitigations.

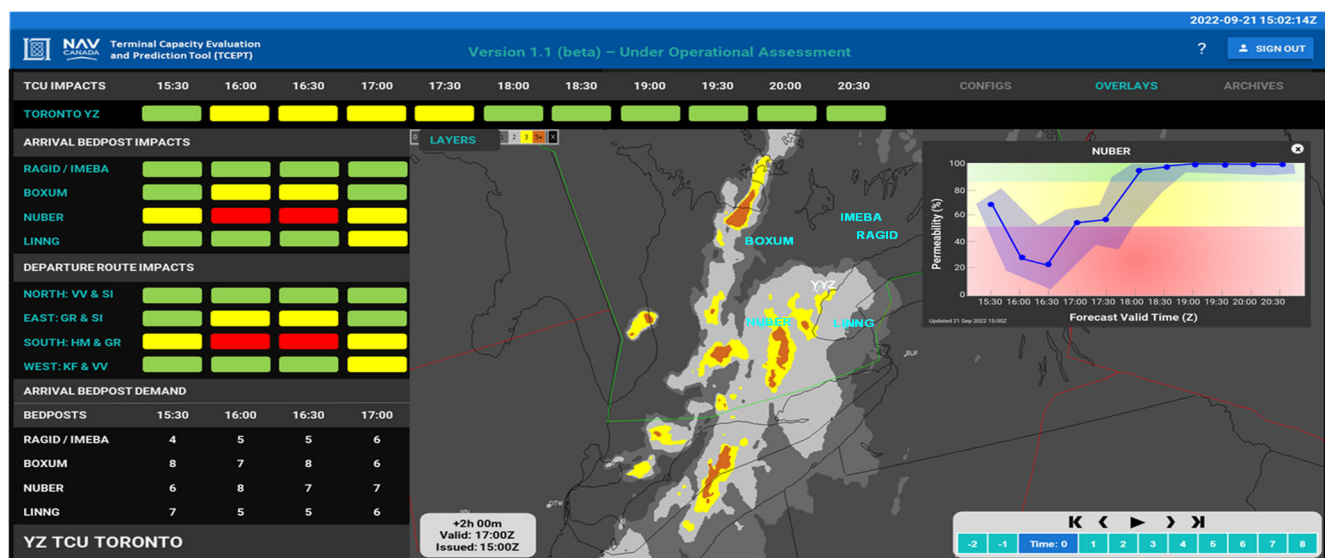


Figure 7 – TCEPT current prototype display.

For the day shown, convective weather is moving into the terminal area from the west to east and the south-west bedpost (NUBER) is being impacted over the next few hours as shown by the yellow and red impact colors in the cells of the table. By clicking on a bedpost, TCEPT also provides a graphical representation of the estimated “permeability” of the airspace around it over the available forecast horizon. Permeability represents the degree to which traffic flows are constrained by convective weather in a given airspace region. Permeability can be translated into a categorical impact metric (e.g., low/green, moderate/yellow, severe/red) or a quantitative measure of the achievable or sustainable traffic flow rates. These can be generated through a large statistical analysis of historical traffic flow rates, which can then be used to estimate capacity. In the figure, the weather impacts to NUBER over the next several hours are clearly visible, followed by recovery in the permeability as the weather moves away. This graph also displays 20th-80th percentile uncertainty bounds around the estimates so users can factor the confidence levels of the estimates into their decision-making. TCEPT is currently being assessed by users at Toronto as a real-time prototype product. It is accessible to approved users (e.g., NAV CANADA, airline and other stakeholders) via a web application, which allows for easy access and rapid iterative development of refined capabilities. Note that the permeability metric is related to capacity but future work will more explicitly translate weather into capacity impacts.

## 4.2 TCEPT Use Case

In order to illustrate how TCEPT can be used to manage operations in the terminal area during a convective weather event, Figure 8 illustrates four time snapshots of a case day from 3 August 2023 when convective weather moved through the Toronto area.

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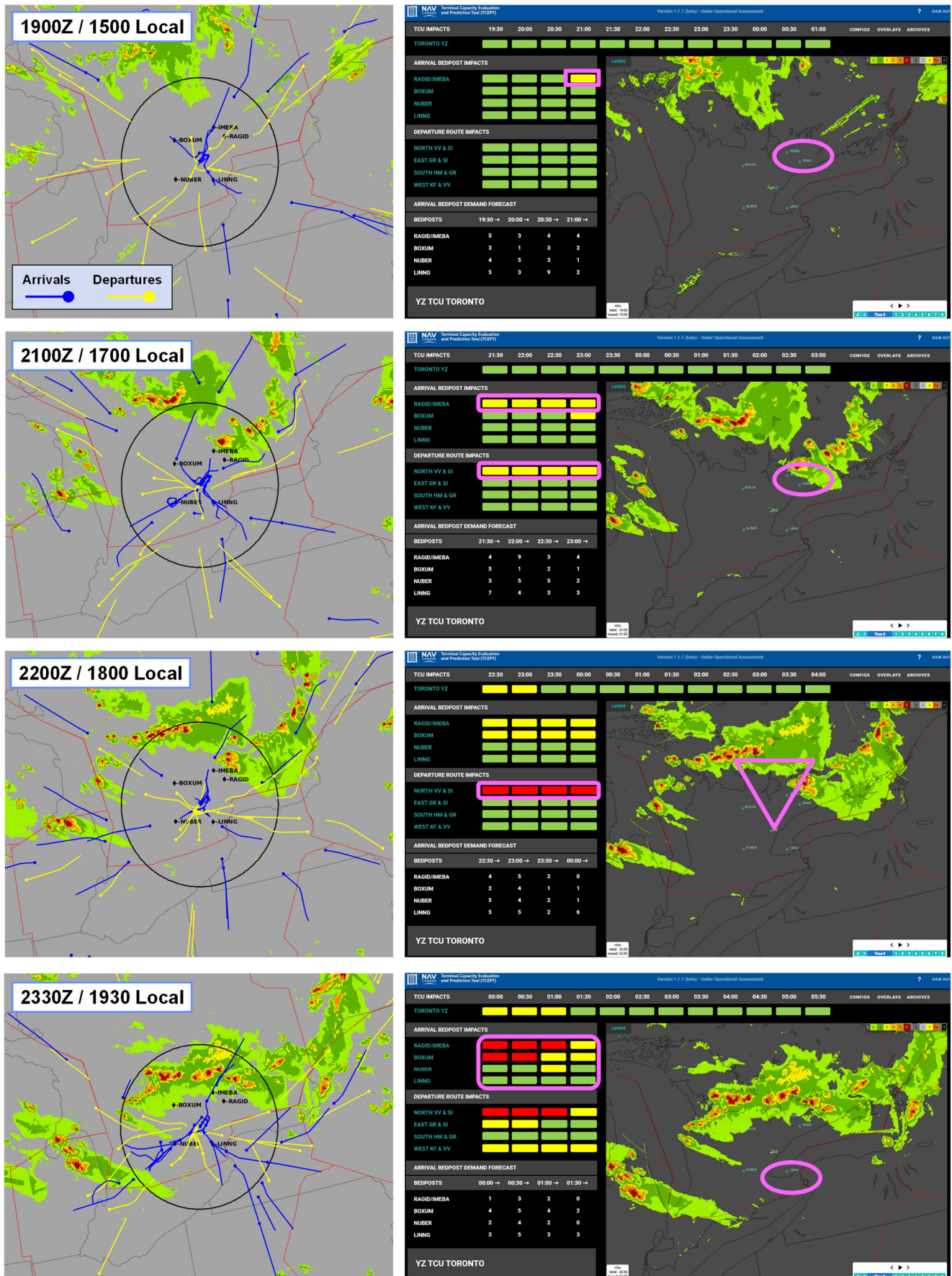


Figure 8 – TCEPT display on use case day (3 August 2023).

The left panel for each time shows a snapshot of the arrival and departure flight paths, while the right panels show the corresponding TCEPT display. At 1900Z, weather activity can be seen moving in from the north-west of the airport. TCEPT is predicting a yellow weather impact over the RAGID/IMEBA bedposts (those north-east of the airport) in two hours' time (i.e., at 2100Z). Traffic flow in and out of the airport bedposts is normal at this time, but this is the first indication to terminal controllers of potential impacts in the future. Two hours later at 2100Z, the RAGID/IMEBA bedposts are now showing yellow impacts extending at least the next two hours, while the northern departure routes are now showing impact as well as the weather moves further east and intensifies. The traffic flows are showing evidence of controllers having to tactically deviate flight tracks in order to avoid the weather, but are still largely able to cross the bedposts just downstream. At 2200Z, yellow weather impacts are occurring out two hours at the RAGID/IMEBA and BOXUM (north-west) bedposts, while the northern departure routes are now showing red weather impacts over the next two hours. The flight tracks show that departures to the north are now largely blocked and arrivals from the north-east are deviating so much they are no longer crossing the bedposts themselves. TCEPT also shows that at the same time, the other arrival and departure bedposts have much lower weather impacts (green cells), providing alternate routing options for terminal controllers. As the weather gets worse over the northern (RAGID/IMEBA and BOXUM) arrival bedpost, by 2330Z the controller are now utilizing the clearer routes to the south by deviating the arrivals from the north-east over to the south-east bedpost (LINNG). This case study illustrates how weather forecasts translated into bedpost impacts can be used to more proactively manage traffic and utilize available terminal capacity as efficiently as possible during challenging weather conditions.

## 5. Enroute Capacity Evaluation & Prediction Tool (ECEPT)

ECEPT refines and adapts existing Traffic Flow Impact (TFI) technology [13] (currently being prototyped with FAA users) for the enroute airspace regions upstream of the TCEPT terminal arrival regions at Toronto as shown in Figure 9. The flight density plots in this Figure only show tracks of aircraft cruising in the FL330-370 range.

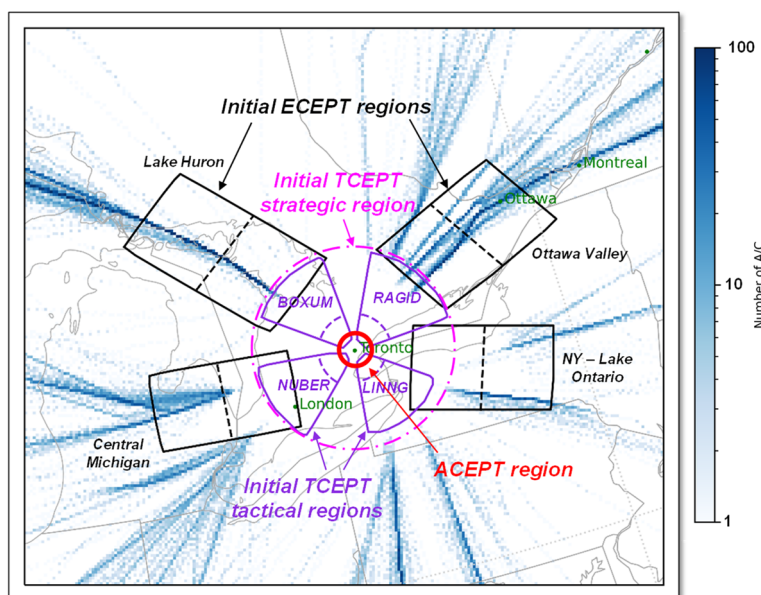


Figure 9 – ECEPT regions in relation to TCEPT and ACEPT regions at Toronto.

ECEPT integrates multiple weather forecast products with extensive historical analysis of forecast accuracy and traffic flows, to generate an objective display of airspace permeability. This is based on the Lincoln-developed Convective Weather Avoidance Model (CWAM) [9], augmented by modern machine learning algorithms. Airspace permeability is displayed as a percentage along with a

red/yellow/green categorical impact indication similar to TCEPT, but for enroute airspace regions. Augmenting the display is an indication of forecast confidence appropriate to the current situation based on historical analysis of weather forecast performance. The prototype ECEPT display (see Figure 10) looks very similar to TCEPT, except the table rows are different enroute regions and the columns are one hour time bins out 12 hours to support the different decision needs in the enroute domain. With ECEPT, all stakeholders have a common picture of the statistical distribution of capacity reduction for hours into the future so that ATM collaborative decision-making discussions can focus on risk assessment, rate setting and determining the start and end times of TMLs.

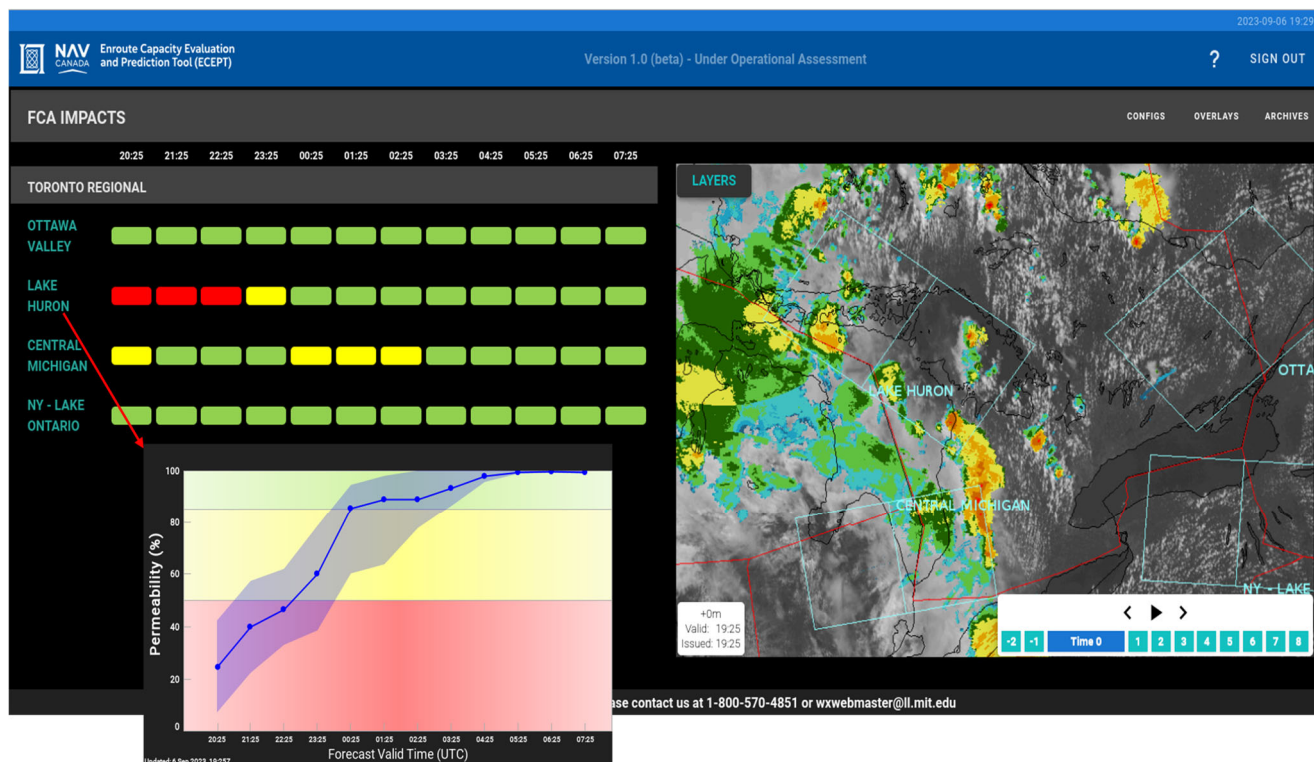


Figure 10 – ECEPT prototype display.

## 6. Integration Plan

In order to deliver the ultimate objective of weather-aware ATM decision support, the individual technologies described in the previous sections need to be integrated, not only with each other but also into the wider automation ecosystem being used by NAV CANADA. A potential integration concept is shown in Figure 11. On the left, CAWS provides the foundational weather situational awareness to support the operational needs of Canadian airspace users. This information is then used by the technologies of ACEPT, TCEPT and ECEPT to understand the weather impacts to critical airport, terminal and enroute resources. The right side of Figure 11 shows the broader automation environment within which these weather decision support systems need to operate. This includes the NAV CANADA backbone automation systems which currently exist, such as the Arrival Manager (AMAN) which performs time-based flow management to critical airports in Canada, including Toronto Pearson. Indeed, integration of ACEPT, TCEPT and ECEPT with AMAN is a critical development activity to ensure the most accurate demand information is available to the weather tools. In time, their weather impacted capacity predictions could be used to modify the time-based metering rates being used by AMAN subject to appropriate two-way integration.

One of NAV CANADA's main priorities for the future is to evolve its system towards a full implementation of the Trajectory Based Operations (TBO) concept [15]. The full set of weather technologies discussed in this paper, once effectively integrated, has the potential to revolutionize collaborative decision-making which is at the heart of effective ATM decision-making, and to be a key enabler for the TBO evolution. These technologies provide a basis for shared situational awareness of weather impacts on different

parts of the system. They also identify specific operational challenges which may result, what to do about them and then to effectively disseminate and operationalize an effective plan to mitigate impacts. With effective integration into future automation systems (e.g., a network manager), these weather technologies could help determine weather-aware time targets to be implemented to enable the ultimate TBO vision to become a reality.

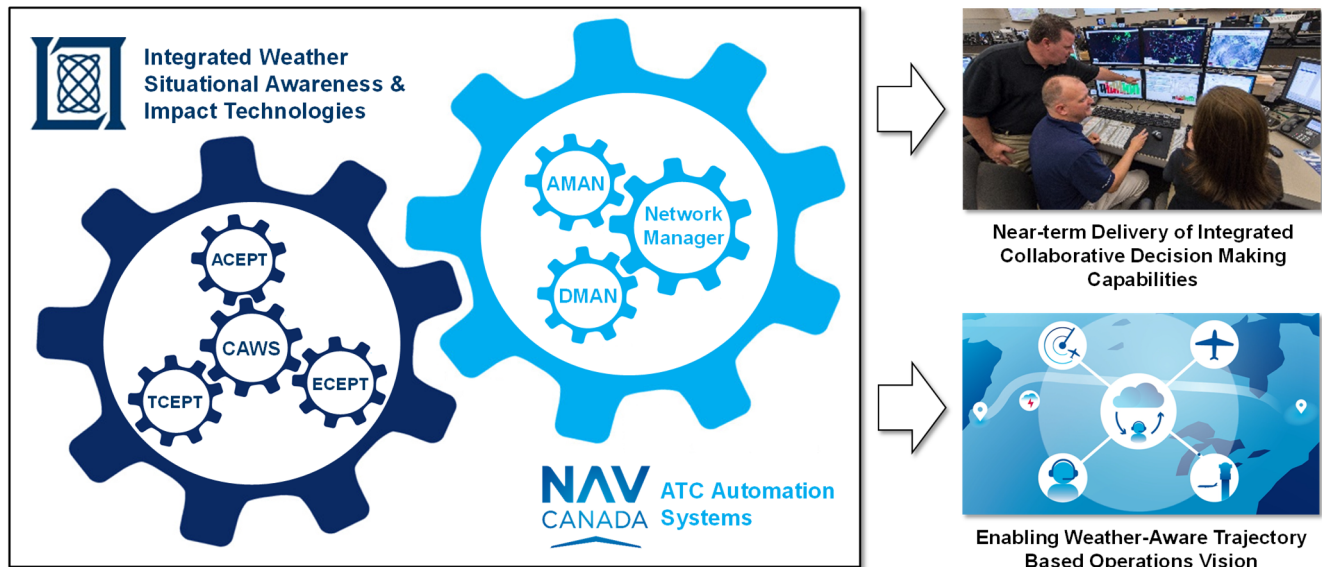


Figure 11 – Weather-aware technology integration plan.

## 7. Summary

Developing weather-aware, integrated ATM technologies will be critical to enabling more efficient air transportation systems and future TBO concepts around the world. This paper has discussed the development of a range of technologies in collaboration with NAV CANADA to assess weather impacts on the capacity of airport, terminal and enroute airspace resources. Initial prototype deployments at Toronto Pearson International airport are currently underway. Future activities will focus on iterative refinements of these technologies through close consultation with stakeholders, followed by integration with other ATM automation systems and ultimately technology transfer to NAV CANADA for long-term deployment.

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### References

- [1] E. P. Gilbo, "Airport Capacity: Representation, Estimation, Optimization", *IEEE Transactions on Control System Technology*, Vol. 1, No. 3, pp. 144-153, 1993.
- [2] Y. Wang, "Prediction of Weather Impacted Airport Capacity using RUC-2 Forecast", *IEEE/AIAA 31st Digital Avionics Systems Conference (DASC)*, pp. 3C3-1-3C3-12, 2012.
- [3] R. Kicing, J. T. Chen, M. Steiner & J. Pinto, "Airport Capacity Prediction with Explicit Consideration of Weather Forecast Uncertainty", *Journal of Air Transportation*, Vol. 24, pp. 18-28, 2016.
- [4] R. Dalmau, J. Attia & G. Gawinowski, "Modelling the Impact of Adverse Weather on Airport Peak Service Rate with Machine Learning", *Atmosphere*, Vol. 14, No. 10, 2023, <https://doi.org/10.3390/atmos14101476>.

- [5] M. Rubnich & R. DeLaura, "Initial Validation of a Convective Weather Avoidance Model (CWAM) in Departure Airspace," *30th Digital Avionics Systems Conference (DASC)*, Seattle, WA, Oct. 16-20, 2011.
- [6] R. DeLaura, M. Robinson, M. Pawlak & J. Evans, "Modeling Convective Weather Avoidance in Enroute Airspace," *13th Conference on Aviation, Range, and Aerospace Meteorology (ARAM)*, New Orleans, LA, 2008.
- [7] NASA, "Dynamic Weather Routes (DWR)", <https://aviationsystems.arc.nasa.gov/research/strategic/dwr.shtml>.
- [8] J. Evans & B. Ducot, "Corridor Integrated Weather System", *Lincoln Laboratory Journal*, Vol. 16, No. 1, pp. 59-80, 2006.
- [9] M. Wolfson, W. Dupree, R. Rasmussen, M. Steiner, S. Benjamin & S. Weygandt, "Consolidated Storm Prediction for Aviation", *IEEE Integrated Communications, Navigation and Surveillance Conference*, 2008, <https://doi.org/10.1109/ICNSURV.2008.4559190>.
- [10] FAA, "NextGen Weather Processor", <https://www.faa.gov/nextgen/programs/weather/nwp>, accessed 10 June 2024.
- [11] M. Veillette, H. Iskenderian, M. Wolfson, C. Mattioli, E. Hassey & P. Lamey, "The Offshore Precipitation Capability", MIT Lincoln Laboratory Report ATC-430, 2016, <https://www.ll.mit.edu/r-d/publications/offshore-precipitation-capability>.
- [12] Reynolds, T., M. Matthews, G. Enea & B. Cushnie, "Weather-Aware Integrated Air Traffic Management Technology Development", *SESAR Innovation Days*, Seville, Spain, <https://doi.org/10.61009/SID.2023.1.24>, 2023.
- [13] M. Matthews, M. Veillette, J. Venuti, R. DeLaura & J. Kuchar, "Heterogeneous Convective Weather Forecast Translation into Airspace Permeability with Prediction Intervals", *Journal of Air Transportation*, Vol. 24, No. 2, 2016.
- [14] S. Campbell, M. Matthews & R. DeLaura, "Evaluation of the Convective Weather Avoidance Model for Arrival Traffic", *12th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*, 2012, <https://doi.org/10.2514/6.2012-5500>.
- [15] NAV CANADA, "Strategic Direction: Trajectory Based Operations", <https://www.navcanada.ca/en/our-strategic-direction/trajectory-based-operations.aspx>, accessed 10 June 2024.