Final Report for CYYZ and CYFB Airports for the AvRDP Project

For:

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Summary

This report summarizes ECCC's contributions contributions to the AvRDP project. Key points are:

1) Science and Technology Branch (STB) contributed two AvRDP "host" airports, namely CYYZ and CYFB, to the project. CYYZ represented a wintertime mid-latitude airport and CYFB represented a cold, near-Arctic climate airport.

2) During several intensive operation periods (IOPs), STB collected met observations including surface, advanced remote sensing and NWP data at CYYZ and CYFB. These observations are available upon request to AvRDP participants.

3) STB demonstrated a variety of nowcasting systems (both research and operational) and performed a verification study of these systems at CYYZ during IOP1.

4) Due to ECCC's organizational structure and the Meteorological Service of Canada's (MSC) contractual nature with NAV CANADA, STB was unable to fulfill any AvRDP Phase 2 goals. Moving forward, recommendations are for future WMO aviation projects to:
    a) Engage MSC's Aviation and Defense Weather Services for their representation on future project committees; and/or
    b) Engage NAV CANADA separately via CAEM and/or ICAO.

5) Additional information and links to on-going and related ECCC R&D projects are provided in this report for interest to the reader.

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1 Introduction

Environment and Climate Change Canada's (ECCC) contributions to the World Meteorological Organization's (WMO) Aviation Research Demonstration Project (AvRDP) are:

1) Enhanced meteorological observations and a cold-season nowcasting demonstration at Toronto Pearson International Airport (CYYZ) in Toronto, Ontario;
2) Enhanced meteorological observations at Iqaluit, Airport (CYFB) in Iqaluit, Nunavut; and
3) Capacity to provide high-resolution (2.5km, 1km, 250m) numerical weather prediction (NWP) case studies for international sites.

Specific to items 1 and 2 above, ECCC contributed these two AvRDP "host" airports to the project and this report serves to summarize our activities at CYYZ and CYFB, mainly towards AvRDP Phase 1 activities. For this project, ECCC demonstrated a variety of point-based nowcasting methodologies at CYYZ, including a climatology-based system, a radar-based system, and a number of blended NWP-observation systems during the first intensive operation period (IOP) in winter 2015-2016 (IOP1). An overview of the airport weather observation sites, the evaluated nowcasting systems and their verification are provided in this report. The report concludes with a summary list and references to other research activities that are applicable to CYYZ and CFYB, and to short-term forecasting, for interest and completeness.

For more information on high-resolution NWP, please contact ECCC research scientist Stéphane Bélair.

2 CYYZ

2.1 Airport and meteorological site overview

ECCC's STB operates an enhanced meteorological observation site at Toronto Pearson International Airport (CYYZ, 43°41N, 79°38W). Toronto Pearson is Canada's busiest airport, handling 49.5 million passengers and 473 K flights in 2018. For AvRDP, CYYZ represented a high-density, northern hemisphere airport with a focus on winter weather. Collecting data since 2007, the Pearson site is home to a suite of specialized weather instruments that support research and development into short-term forecasting and nowcasting of high impact weather, NWP verification and weather instrument performance evaluation. Co-located with the existing staffed weather observation station in the southeast corner of the airport, the site at certain periods in time has been furnished with an icing detector, lightning sensor, multi-view camera system, vertically pointing X-band radar, visibility meter, multiple ceilometers and surface weather station with temperature, relative humidity and wind sampled at WMO standard heights. The site has hosted a number of precipitation sensors including weighing gauge-type instruments and optical and radar-based systems. Overall, multiple measurements of the same weather element allow for instrument inter-comparisons and facilitate the exploration and assessment of new observational technologies.

2.2 Meteorological instrumentation

Table 1 lists the weather instrumentation that were available during IOP1 (November 1, 2015-March 31, 2016) and IOP2 (November 1, 2016-March 31, 2017) at CYYZ. The exception is the Vertically Pointing

Radar (VPR), which was only available during IOP1. The majority of data were collected at 1-min intervals. Met data collected during IOP1 and IOP2 are available upon request to Janti.Reid@canada.ca.

Instrument	Measurement
Vaisala FD12P	- Forward scatter visibility meter (50 km) - Precipitation intensity and type (11)
OTT Parsivel	- Laser-based optical disdrometer - Liquid (0.2-5 mm), Solid (0.2-25 mm) - Precipitation type, intensity, drop size distribution, radar reflectivity, visibility
Precipitation Occurrence Sensor (POSS)	- Bi-static X-band Doppler radar - Precipitation intensity and type
OTT Pluvio2 Precipitation Gauge	- Weighing gauge - Precipitation amount and intensity
Vaisala CT25K Ceilometer	- Lowest 3 cloud ceilings (up to 25 kft) - Backscatter profile (normalized)
Jenoptik CHM15 Ceilometer	- Lowest 3 cloud ceilings (up to 50 kft) - Cloud penetration depth - Vertical visibility - Raw backscatter profile
WXT520 Weather Station	- Temp, RH, Pressure, Ultrasonic Wind - Precipitation amount and type
Vertically Pointing Radar (VPR)	- 9.65 GHz X-band radar from McGill University - Time-height profiles of reflectivity and vertical velocity, particle type - Doppler spectra - Note: Data only available during IOP1.
Web Cameras	- Images collected in 4 fixed directions
Rosemont Icing Detector	- Ice accumulation
Kipp Zoner Pyranometer (@ 2m)	- Solar radiation
Vaisala WS425	- Ultrasonic wind (speed, direction, gust)
T, RH, P@2m sensors	- Additional temperature, RH and pressure measurements

Table 1: List of instrumentation at STB's enhanced meteorological site at CYYZ during IOP1 and IOP2.

2.3 Impacting weather

For reference from ECCC's historical climate archives, the 1981-2010 climate normals at CYYZ are shown in Figure 1.

From the Canadian Meteorological Aviation Centre (CMAC), the main weather concerns for CYYZ are:

- Thunderstorms with 60 NM of the airport
- Wind
- Snowfall rate
- Airborne icing
- Low visibility and/or runway visual range (RVR)

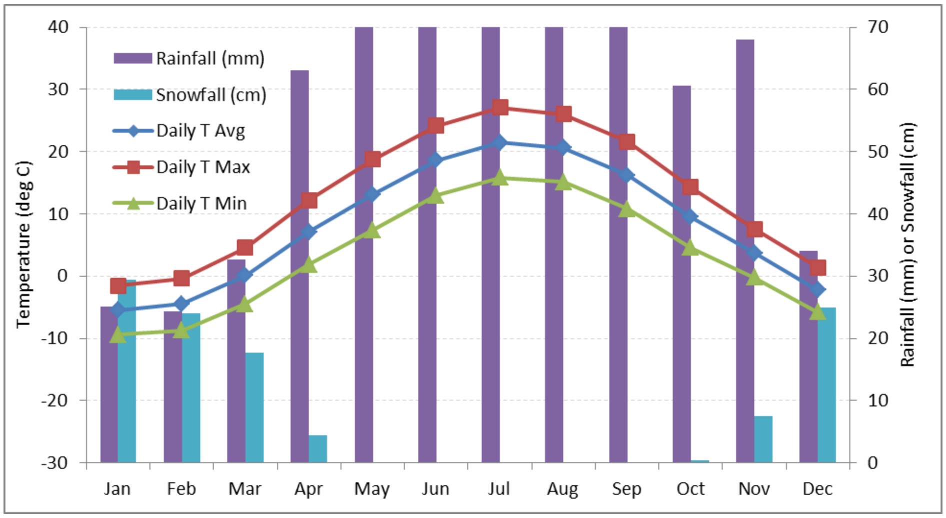

Figure 1: 1981-2010 monthly climate normals for rainfall, snowfall, daily temperature (T) average, maximum and minimum for CYYZ (WMO ID: 71624). Source: http://climate.weather.gc.ca/

3 CYFB

3.1 Airport and meteorological site overview

STB has also established an enhanced observation site at Iqaluit Airport (CYFB, 63°45N, 68°33W) in Iqaluit, Nunavut on Baffin Island in the eastern Canadian Arctic. The site was strategically selected at the loci of synoptic storm tracks and a primary transportation corridor and the airport is a major aviation hub for the Canadian North. For AvRDP, CYFB represents a cold, high-latitude airport representing a (near) Arctic climate. The enhanced site is co-located with an operational upper air site, which has instrument test facility infrastructure with a co-located Double Fence International Reference (DFIR) for solid precipitation measurements. The site includes a Ka-band radar, water vapour lidars, Doppler lidars, ceilometers, radiation flux and precipitation sensors.

3.2 Meteorological instrumentation

Table 2 lists the weather instrumentation that were available during IOP2 at CYFB. The majority of surface data were collected at sub 1-min intervals. The radar and lidar had a 10-min and 5-min scanning strategy, respectively. Met data for CYFB collected during IOP2 are available upon request from Janti.Reid@canada.ca.

Instrument	Measurement
METEK Ka-Band Radar	- Line-of-sight wind speed and direction, cloud and fog backscatter, depolarization ratio
Vaisala CL31 Ceilometer (CL31)	- Cloud intensity and height, aerosol profiles, PBL height
Vaisala PWD52 Visibility Sensor (PWD)	- Visibility, precipitation type
HALO Doppler Lidar	- Line-of-sight wind speed and direction, aerosol backscatter, depolarization ratio - Vertical wind profile

NASA Precipitation Imaging Package (PIP)	-	Particle imagery, DSD, precipitation rate and density estimation
Surface temperature sensor	-	Temperature, dew point
Pressure sensor	-	pressure
Vaisala WS25 Wind Sensor	-	Ultrasonic wind (speed, direction, gust)
Web cameras	-	Camera views in 4 directions
Sky camera	-	All-sky camera view
Rosemont Icing Detector	-	Ice accumulation

Table 2: List of instrumentation at STB's enhanced meteorological site at CYFB during IOP2.

3.3 Impacting weather

For reference from ECCC's historical climate archives, the 1981-2010 climate normals at CYFB are shown in Figure 2.

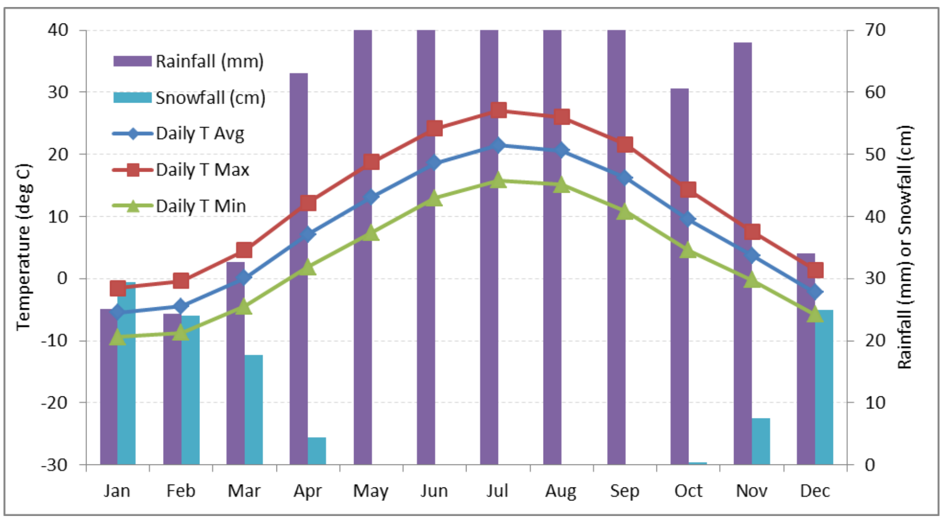

Figure 2: 1981-2010 monthly climate normals for rainfall, snowfall, daily temperature (T) average, maximum and minimum for CYFB (WMO ID: 71909). Source: http://climate.weather.gc.ca/.

Information received from CYFB Airport Manager / Director John Hawkins in January 2016 indicated that key issues for the airport concern:

- Temperature, temperature gradients, fog, visibility
- Surface conditions, for example: drastic surface temperature changes, frost, ice, etc.
- Forecasted temperature changes > 8°C

It was also noted by the Airport Manager that IR measurements of the runway surface are taken and that the temperature difference between that and 6 inches below the soil would be a very useful piece of information to infer low-level fog, frost and ice.

4 Outcomes

4.1 Phase I achievements (MET Capability)

In addition to collecting enhanced met observations at CYYZ during IOP1 and IOP2 (see Table 1) and at CYFB during IOP2 (see Table 2), a verification of a number of nowcasting systems for a subset of weather parameters was performed at CYYZ. This is described in Section 4.1.1.

While no verification was performed at CYFB, nowcasting outputs are available for the IOP2 period for:

1) GEM High Resolution 2.5 km Deterministic Prediction System (HRDPS; near operational)
2) Integrated Nowcasting System (INCS; operational)

4.1.1 Verification at CYYZ

Table 3 lists the nowcasting and NWP systems that were verified with on-site observations at CYYZ. For NWP, the direct model output for the closest point to CYYZ was used for both models being evaluated. The verification methodology and full results are documented in Reid (2016). A short description and/or references for each system is provided in this report in the Appendix.

System	Acronym	Type	Status	Variables verified
GEM High Resolution Deterministic Prediction System (2.5km)	HRDPS	NWP	Experimental	T, RH, WS, WD
GEM Regional Deterministic Prediction System (10km)	RDPS	NWP	Operational, Research for CIG and VIS	T, RH, WS, WD, CIG, VIS
Integrated Nowcasting System	INCS	Blended NWP & Observations	Operational	T, RH, WS, WD
CARDS Point Forecast	PTF	Radar-based	Operational	PR
Integrated Weighted Nowcasting (INTW)	INTW	Blended NWP & Observations	Research	T, RH, WS, WD
Aviation Conditional Climatology	ACC, ACC-OBS	Climatology-based	Operational	CIG, VIS

Table 3: NWP and nowcasting systems that were evaluated during IOP1 at CYYZ. Variables verified included screen-level temperature (T), relative humidity (RH), wind speed (WS), wind direction (WD), precipitation (PR), ceiling (CIG) and visibility (VIS).

Briefly regarding the verification work, for nowcasts of temperature (T) and relative humidity (RH), all evaluated nowcasting systems beat persistence after the first 2-3 hours lead time. Overall, the systems that used blended NWP and observations, such as INTW and INCS, improved upon the NWP-only results. For wind speed (WS) and direction (WD), generally OBS-NWP blended nowcasts improved upon raw models and they were seen to beat persistence already by the 1 hour lead time mark. For ceiling (CIG) and visibility (VIS) parameters, a different set of nowcasting systems, namely the climatology-based systems, were evaluated along with NWP. Aviation-user specific metrics were employed, namely multi-categorical contingency table-type verification metrics, where the 2 categories were CIG IFR < 1000 ft and CIG VFR (including MFVR) >=1000 ft and VIS IFR < 3 SM and VIS VFR (including MFVR) >= 3 SM, for CIG and VIS, respectively. Persistence was difficult to beat, and both the evaluated systems and NWP only started improving on persistence beyond a 4 hour lead time for both parameters. Regarding precipitation, the

CARDS radar-based algorithm was evaluated during IOP1 and it was found not to improve upon persistence during IOP1.

Some of these results are consistent to those shown by Nikitina (2015) during the 2014 Sochi Winter Olympic Games. In that work, INTW was subjectively evaluated as one of the top forecasting systems by Sochi forecasters during the Winter Games for temperature. INTW was also extensively validated during the Toronto 2015 Pan and Parapan American Games in Huang (2016). In this work, INTW was evaluated over 17 sport venue sites across Southern Ontario, Canada in the summer season and compared against direct model output and operational ECCC systems. Using similar metrics and methodologies to the AvRDP IOP1 verification at CYYZ (see Reid, 2016), INTW performed the best for the vast majority of sites and by lead time for T, RH and WS. As INTW operated in near real-time during the Pan Am Games as part of the Environment Canada Pan and Parapan American Science Showcase (EC PASS) Project (Joe et al., 2018), positive feedback was specifically received from the lead meteorologist at one of the sailing venues on Lake Ontario who cited INTW as one of the most useful nowcasting systems available during the Games (Ron Bianchi, lead Pan Am meteorologist for Royal Canadian Yacht Club, *personal communications*). CARDS was also evaluated during the 2015 Pan Am period, and similar to AvRDP IOP1, persistence generally beat CARDS, particularly for trace and light precipitation categories. It did, however, seem to hold more promise and skill during widespread rain cases (Reid and Huang, 2016). Conversely, however, during the 2014 Sochi Winter Games, CARDS was shown to give the best overall scores for precipitation compared to other research systems that were evaluated (Nikitina, 2015). These works have shown that NWP and nowcasting system results can validate differently depending on season and/or climate region.

4.2 Phase II achievements (MET-ATM Integration)

ECCC was unable to achieve any of the AvRDP Phase 2 goals, specifically with regards to engaging our national ATM and assessing ATM impact. From the perspective of Science and Technology Branch, it was not possible to engage NAV CANADA, our country's owner and operator of Canada's civil air navigation service, due to the Meteorological Service of Canada's (MSC) contractual nature with this organization.

5 Summary & Remarks

5.1 Overall benefits & Gaps identified

In summary:

1) ECCC's STB contributed two AvRDP "host" airport for this research demonstration project, namely CYYZ and CYFB.
2) During several IOPs, STB collected meteorological observations including surface, advanced remote sensing and NWP data at CYYZ and CYFB. These observations are available to AvRDP participants, in part for them to execute nowcasting or model simulations over the airport for they own studies.
3) STB demonstrated a variety of nowcasting systems (both research and operational) and performed a verification of T, RH, WS, WD, CIG and VIS specifically at CYYZ during IOP1.

4) Blended observations-NWP nowcasting systems provided the best verification results over raw model output. In particular, INTW showed good results for T, RH and wind speed both in the winter and summer season.
5) Persistence was difficult to beat for CIG and VIS out to 4h forecast lead time.
6) CARDS generally could not beat persistence for precipitation forecasting during IOP1, however, other winter studies, namely those during the 2014 Sochi Winter Games, evaluated CARDS as one of the top forecasting systems. Overall, it is seen that nowcasting systems can validate differently in different seasons and/or climate regions.
7) Point nowcasting has other potential clients in addition to aviation; venue forecasting such as during international sporting events has shared the benefits of this technology.
8) Due to ECCC organizational structure and MSC's contractual nature with our national ATM NAV CANADA, STB was unable to fulfill any AvRDP Phase 2 goals in engaging ATM. Moving forward, some recommendations for similar, future aviation projects is for WMO to:
    a) In addition to STB, engage MSC's Aviation and Defense Weather Services for their representation on project committees; and/or
    b) Engage NAV CANADA separately via CAEM and/or ICAO.

5.2 Resources for sharing

Finally, additional information regarding several ECCC R&D projects is provided here for the reader's interest as they may have applicability to aviation and/or short-term forecasting.

5.2.1 R&D Projects

Canadian Arctic Weather Science (CAWS) Project

At ECCC, the Iqaluit enhanced observation site (see Section 3.1) was established in part to support the Canadian Arctic Weather Science (CAWS) project. The main objectives for CAWS (Joe et al., 2019) are:

1) identifying and testing future operational monitoring technologies for the Arctic;
2) validating satellite retrievals primarily for precipitation and wind;
3) understanding Arctic weather phenomena;
4) validating/verifying prediction (NWP and post-processed) products
5) quantifying societal benefits and impact; and
6) collaborating and supporting other national and international projects, including WMO's Year of Polar Prediction (YOPP).

First results have focused on exploiting the specialized observations to better characterize the near-Arctic environment from a weather perspective. Another key focus is the evaluation of new technologies to replace and/or augment costly radiosondes, namely using a scanning Doppler lidar. Results from STB (see Mariani and Crawford, 2018) have shown excellent agreement between the Halo Doppler lidar wind profile observations and that from radiosondes to up to 2 km altitude. It is further noted by Mariani and Crawford (2018) that lidar range is significantly reduced at CYFB due to lower aerosol concentrations and that at lower latitudes that the vertical range would be greater, such as up to 3.5 km AGL at Toronto. Future work with lidar observations could include NWP evaluation and possibly assimilation.

For CAWS and the Iqaluit site, real-time instrument plots, site and instrument information and recent publications can be found at: http://obrs.ca/iqaluit-output.php. Work is currently in progress to make the Iqaluit observations publically available on the aforementioned website and on the Canadian government Open Data website: https://open.canada.ca/en/open-data.

ECCC Contact: Zen Mariani (STB Research Scientist, Zen.Mariani@canada.ca)

Automated nowcasting of thunderstorms based on lightning jumps

A lightning jump is defined as a rapid increase in a storm's total lightning activity. With this, MSC and STB have been involved in prototyping an automated nowcasting tool for severe thunderstorms using total lightning jumps (Yang et al., 2017). Using a sophisticated 3-D lightning mapping array system deployed across Southern Ontario (SOLMA), lightning algorithms were applied to lightning source data to identify lightning flashes and jumps. While the SOLMA system has since been phased down in 2018, on-going work is being done to apply these algorithms to data from the operational Canadian Lightning Detection Network (CLDN) and the Geostationary Lightning Mapper (GLM) aboard the GOES-R series satellites.

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6 Acknowledgements

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ECCC STB:

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Appendix: Nowcasting Systems & NWP

1) ACC

The Aviation Conditional Climatology (ACC) system was developed by ECCC. It is a climatology-based system that generates probabilistic forecasts of ceiling and visibility using airport climatology, observations and NWP. Given information such as the current observational conditions, site location, time of day, Julian date and model forecasts of temperatures, winds and present weather, a 30-year site climate database is searched for similar resultant conditions. The retrieved set of hourly climatological-based visibilities and ceilings comprise the probabilistic forecasts. This methodology is described by Hansen (2007). A variation of ACC was also examined in this work (ACC-OBS) in which no NWP forecast is used in the forecasting process and instead the trend of recent observations is employed in the climate database search.

2) CARDS Point Forecast

Precipitation nowcasts were generated using the Point Forecast (PTF) module from the Canadian Radar Decision Support (CARDS) system. For this method, point nowcasts every 10 minutes (forecast length 2:50 hours) were created using the extrapolation of radar echo motions computed using the cross correlation of successive CAPPI images (see Bellon and Austin, 1986). The Point Forecast for CYYZ used CAPPI 1.5km images from King Radar (WKR).

3) INCS

The Integrated Nowcasting System (INCS) was developed by the Canadian Meteorological Centre (CMC) at ECCC (see Verville and Landry, 2014). Inputs to this system include surface observations, NWP, Canadian Updateable Model Output Statistics (UMOS) and algorithms that include radar and lightning extrapolation routines using MAPLE. INCS outputs are point-based winds, precipitation/probability of precipitation (POP), visibility/obscuration, cloud and temperatures every hour for 12 hours. Operational documentation and data are available publically on ECCC's Data Mart:

http://dd.weatheroffice.ec.gc.ca/nowcasting/doc/README_INCS-SIPI.txt

http://dd.weatheroffice.ec.gc.ca/nowcasting/matrices/

4) INTW

The Integrated and Weighting nowcasting system (INTWO) was developed in STB at ECCC (see Huang et al., 2012, Huang et al., 2014a, Huang et al., 2014b). INTW blends observations and *n*-number of input NWP forecasts to form a single integrated nowcast out to 8 hours. The nowcast is produced by weighing models based on past performance and by performing a bias correction. INTW has been successfully demonstrated for a number of Canadian airports for the CAN-Now project (Isaac et al., 2012) and it has widespread application as it has been used successfully in meteorological support of the Vancouver 2010 and Sochi 2014 Winter Olympic Games and the 2015 Toronto Pan Am Games.

5) NWP Models

NWP data described in this report come from ECCC's operational 10 km resolution Regional Deterministic Prediction System (RDPS) (Mailhot et al., 2006) and experimental 2.5 km High Resolution Deterministic Prediction System (HRDPS) (Milbrandt, 2014) NWP models. Model parameters were outputted at 7.5

minute and 5 minute time steps for the RDPS and HRDPS, respectively. Forecasts using the closest model grid point to CYYZ were used in the verification described in this report. Research algorithms for ceiling (see Ling and Crawford, 2016) and visibility (see Boudala et al., 2012 and 2009) using RDPS NWP output were also tested in this work.