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Analysis of Forecast Upper Winds and Temperature Data in Southern Canadian Airspace

Despite the increasing sophistication of commercial aircraft and air traffic control communication, navigation and surveillance (CNS) systems, flight planning and operations remain strongly influenced by Mother Nature. Winds aloft and to a lesser extent temperature, impact route selection, flight time, fuel burn and ultimately, costs. The use of accurate forecasting of upper winds and temperature data enables higher precision flight planning expressed in terms of reduced fuel burn, as well as improved arrival time and fuel burn estimates. The reduction of planning variance reduces operational costs.

The purpose of this brief study is to compare long and short range upper winds (FD) forecasts between 24,000 ft and 34,000 ft in Southern Canadian airspace to AMDAR (Aircraft Meteorological Data Report) data recorded by Canadian-registered aircraft. The AMDAR data was obtained from the NOAA's AMDAR demonstration web site[1] for the period of 1900-2100Z on June 10th, 2010 across the Pacific, Prairies, Ontario-Quebec and Atlantic regions. The eleven AMDAR data points were selected based on their geographical proximity to AWWS FD forecasting stations. The forecast wind and temperature data were obtained from Nav Canada's public Aviation Weather Web Site (AWWS)[2], these forecast data are based on calculations performed by the National Weather Service (NWS) of the United States. The predicted data were linearly interpolated with respect to altitude to calculate the wind direction and velocity, as well as temperature at the recorded AMDAR altitudes.

The AMDAR data points and the long range forecast points for the period of 1800Z on June 10 th to 0500Z on June 11 th, 2010 are presented in Table 1. The identical AMDAR data set and the short range forecast data for the period of 1700 to 2100Z on June 10, 2010 are presented in Table 2. The long range forecast provides a look ahead of 13 to 24 hours, while the short range forecast looks ahead up to 4 hours.

The errors between the AMDAR and the forecast wind direction, wind velocity and air temperature were calculated for each analysis point. The root mean square (RMS) of the error was calculated for each parameter. For the sake of comparison, the averaged error and standard deviation are also presented. In reality, all three errors will have combined impact on flight planning and operations.

The RMS error values for the temperature forecasts are small, within 2.0°C for both the long and short range forecasts. Note that significant temperature deviations from ISA i.e. exceeding ±10°C will substantively impact aircraft thrust levels and fuel consumption. The RMS errors for wind direction and velocity are more significant. The wind direction RMS errors are 42.2° and 24.2° for the long and short range forecasts, respectively. RMS errors for wind speed are 18.0 knots and 14.2 knots for the long and short range forecasts, respectively. In regards to impact, a wind direction error of 42° would change a quartering wind into a headwind, a tailwind or a pure crosswind. A tailwind, a headwind or a crosswind would become a quartering wind. A headwind component of +18 knots would result in 2.5 extra minutes of flight time and 221 lb (+4.2%) of extra fuel burn for a Boeing 737-700W (winglet-equipped aircraft) to cover 450 NM, which is the baseline distance covered by the aircraft in one flight hour under ISA no wind conditions, flying at M0.78 at FL360 with 66,000 lb of payload and a total fuel flow of 5,300 lb/hr[3]. The converse would apply for an equivalent tailwind component.

Therefore, temperature forecasts in the 24,000 ft to 34,000 ft altitude range are relatively accurate for both long and short range outlooks. Both wind direction and velocity forecasts have RMS error values that could impact flight planning calculations and actual operations, however the direction error is substantially reduced, while the velocity error is slightly reduced with the shorter outlook period.

The challenge with atmospheric forecasting is that real weather in the troposphere is a dynamic and three-dimensional continuum, whereas Canadian public forecasts are presented twice daily for three time periods [0 to +4 hrs], [+4 to +13 hrs], [+13 to +24 hrs] based on observations acquired at 0000Z and 1200Z for a set of discrete locations. The observation data which set the initial modeling conditions are already 5 hours old at the start of the first forecast period at 0500Z or 1700Z.

[1] Demonstration AMDAR Data Display from ESRL/GSD: http://amdar.noaa.gov/demo_java/
[2] AWWS Forecasts and Observations: http://www.flightplanning.navcanada.ca
[3] Tech Ops Forum: http://www.airliners.net/aviation-forums/tech_ops/read.main/145284

Furthermore, the extended duration of trans-continental and trans-oceanic flights increases the uncertainty of the predicted upper winds and temperature as the flight progresses due the fact that FD forecasts are inherently perishable. Other variable weather phenomena impacting commercial flight operations are the jet stream, which is highly localized, convective activity and turbulence.

This statistical analysis does not constitute an in-depth study due to the limited number of data points evaluated. Aside from the looking ahead time parameter, other potential sources of error include:

- Wind direction forecast accuracy is ± 5° based on the AWWS data format;
- On-board measurement accuracy of the AMDAR data;
- Radial distance between the AMDAR point and the forecast station.

The maximum distance from the aircraft to the forecast station is just under 94 NM (Point 3) and the minimum distance is just under 9 NM (Point 4) with the average distance being 47 NM. No clear relationship between distance and forecast error is easily discernable in the data e.g. in Table 2, Point 4 has less error than Point 3, though further from its station. Intuitively, less radial distance would be expected to be more accurate. The results warrant further error investigation.

The accuracy of the prediction of upper winds is critical to the precision of flight planning and for operational conformity to the flight plan. The results presented indicate that the closer the forecast data is to the flight time, the more accurate they will be. An argument could be made that using quality-controlled AMDAR data for nowcasting could further improve flight planning i.e. confirming the adage that the real weather what you see outside of your windscreen or on your FMS display (CDU).

Finally, increased precision in wind prediction is beneficial and complementary to advanced procedures such as Continuous Descent Approaches (CDA), where accurate wind data permit the Top of Descent (TOD) point to be better defined. Increased FD forecast precision will improve RNP and RNAV approaches by allowing aircraft to perform more optimized descents into the Initial Approach Fix (IAF) or Final Approach Course Fix (FACF), respectively.

The minimization of operational variance will reduce operational costs. It is proposed to confirm these results with further analysis and to assess the accuracy of forecast data on flight operations.

		AMDAR Data							Long Range Forecast Data				Error		
Pt.	Forecast Station (High-Level FD)	Time	Lat. (deg.)	Long. (deg.)	Altitude (ft)	Wind Dir. (deg.)	Wind Vel. (kts)	Temp. (deg. C)	Wind Dir. (deg.)	Wind Vel. (kts)	Temp. (deg. C)	Stn. Dist. (NM)	Wind Dir. (deg.)	Wind Vel. (kts)	Temp. (deg. C)
Pacific Region															
1	Prince George (CYXS)	1901Z/10	52.90	-122.48	29990	227	13	-49.8	330	9	-51.0	59.6	103	-4	-1.2
2	Puntzi Mountain (CYPU)	2012Z/10	52.62	-123.43	30020	280	10	-49.5	300	31	-48.0	40.0	20	21	1.5
3	Kamloops (CYKA)	1941Z/10	50.82	-117.98	32050	13	8	-52.3	325	23	-51.6	93.9	-48	15	0.7
4	Penticton (CYYF)	2008Z/10	49.41	-119.81	33010	46	14	-52.0	350	22	-52.3	8.7	-56	8	-0.3
Prairies Region															
5	Edmonton (CYEG)	2047Z/10	53.42	-113.28	33990	193	15	-51.5	N/A	0	-54.0	12.8	N/A	-15	-2.5
6	Regina (CYQR)	1911Z/10	50.34	-103.37	23560	250	41	-26.8	230	54	-28.0	50.0	-20	13	-1.2
7	Winnipeg (CYWG)	2053Z/10	50.20	-99.00	29590	251	93	-36.8	251	83	-36.1	70.8	0	-10	0.7
Ontario-Quebec Region															
8	Maniwaki (CYMW)	1948Z/10	46.70	-76.12	27000	345	19	-38.8	330	57	-35.5	26.2	-15	38	3.3
9	Maniwaki (CYMW)	1929Z/10	46.23	-77.54	29990	333	58	-41.8	330	76	-42.0	64.4	-3	18	-0.2
10	Dorval (CYUL)	1913Z/10	45.28	-73.38	33010	328	28	-46.0	332	51	-47.3	18.9	4	23	-1.3
Atlantic Region															
11	Fredericton (CYFC)	1942Z/10	45.78	-68.23	24970	333	11	-34.0	307	9	-32.6	71.2	-26	-2	1.4
												RMS Error	42.2	18.0	1.6
												Avg. Error	-4.0	9.6	0.1
												Std. Dev. Error	42.0	15.2	1.6

Table 1 – AMDAR Data for June 10 1900-2100Z and Long Range Forecast Data for June 10 1800Z - June 11 0500Z per June 10 0000Z Data *[13-24 Hour Forecast]*

		AMDAR Data							Short Range Forecast Data				Error		
Pt.	Forecast Station (High-Level FD)	Time	Lat. (deg.)	Long. (deg.)	Altitude (ft)	Wind Dir. (deg.)	Wind Vel. (kts)	Temp (deg. C)	Wind Dir. (deg.)	Wind Vel. (kts)	Temp. (deg. C)	Stn. Dist. (NM)	Wind Dir. (deg.)	Wind Vel. (kts)	Temp (deg. C)
Pacific Region															
1	Prince George (CYXS)	1901Z/10	52.90	-122.48	29990	227	13	-49.8	260	7	-51.0	59.6	33	-6	-1.2
2	Puntzi Mountain (CYPU)	2012Z/10	52.62	-123.43	30020	280	10	-49.5	310	30	-49.0	40.0	30	20	0.5
3	Kamloops (CYKA)	1941Z/10	50.82	-117.98	32050	13	8	-52.3	20	17	-52.5	93.9	7	9	-0.2
4	Penticton (CYYF)	2008Z/10	49.41	-119.81	33010	46	14	-52.0	0	2	-50.8	8.7	-46	-12	1.2
Prairies Region															
5	Edmonton (CYEG)	2047Z/10	53.42	-113.28	33990	193	15	-51.5	190	12	-54.0	12.8	-3	-3	-2.5
6	Regina (CYQR)	1911Z/10	50.34	-103.37	23560	250	41	-26.8	250	62	-27.0	50.0	0	21	-0.2
7	Winnipeg (CYWG)	2053Z/10	50.20	-99.0	29590	251	93	-36.8	259	83	-38.0	70.8	8	-10	-1.2
Ontario-Quebec Region															
8	Maniwaki (CYMW)	1948Z/10	46.70	-76.12	27000	345	19	-38.8	325	28	-38.0	26.2	-20	9	0.8
9	Maniwaki (CYMW)	1929Z/10	46.23	-77.54	29990	333	58	-41.8	320	28	-46.0	64.4	-13	-30	-4.2
10	Dorval (CYUL)	1913Z/10	45.28	-73.38	33010	328	28	-46.0	308	21	-48.5	18.9	-20	-7	-2.5
Atlantic Region															
11	Fredericton (CYFC)	1942Z/10	45.78	-68.23	24970	333	11	-34.0	298	11	-33.4	71.2	-35	0	0.6
												RMS Error	24.2	14.2	1.8
												Avg. Error	-5.3	-0.9	-0.8
												Std. Dev. Error	23.6	14.2	1.6

Table 2 – AMDAR Data for June 10 1900-2100Z and Short Range Forecast Data for June 10 1700-2100Z per June 10 1200Z Data *[0-4 Hour Forecast]*