5.3 OLYMPEX CANADA

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1. INTRODUCTION

The primary contribution by Environment and Climate Change Canada (ECCC) to OLYMPEX is to support the validation of products derived from the Global Precipitation Measurement (GPM) mission in complex terrain. The focus was to monitor the precipitation processes occurring on the lee side of the Olympic Mountains (House et al., 2016). It was an ideal complement to similar measurements made by NASA and NSF facilities on the windward side of the Olympic Mountains. (McMurdie and Houze, 2016). The OLYMPEX project is a continuation of the rich history of collaborating between ECCC and NASA on ground validation activities in support of space-based missions. Examples of such programs conducted in Canada include the Canadian CloudSat/CALIPSO Validation Project in the winter of 2006/07 (C3VP) (Barker et al., 2008) and the GPM Cold Season Precipitation Experiment in 2011/12 (GCPEx) (Hudak et al., 2014).

The specific ECCC objectives for OLYMPEX are,

a) To contribute to microphysical studies of the precipitation formation mechanisms around and to the lee of Hurricane Ridge (Fig. 1) by documenting microphysical properties at high elevations and their variability particularly within and above the rain/snow transition zone.
b) To evaluate GPM products in complex terrain – coast/water/orography. Participation in OLYMPEX will enable an assessment of the quality of the measurements for the Canadian climate and enhance the development of applications that makes use of this information.
c) To support studies in model validation and data assimilation of the Canadian Meteorological Centre High Resolution Deterministic Prediction System (HRDPS).

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2. EXPERIMENTAL SETUP

The core ECCC activity was the deployment of a dual polarization X-band “CAX1” portable scanning radar to the southern tip of Vancouver Island on Canadian Forces Base (CFB) Esquimalt Albert Head (AHD) military training area. This site has a direct line of sight at a distance of about 45 km to Hurricane Ridge (HRR) on the Olympic Peninsula where a suite of in-situ and remote sensing sensors were located (Fig. 1).

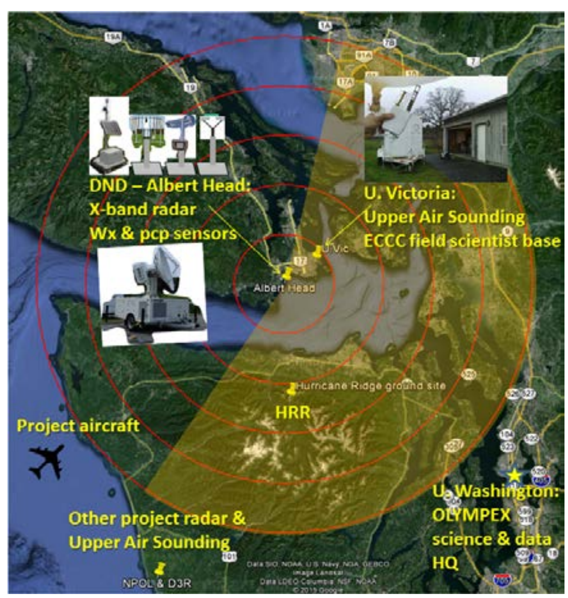

Fig 1: ECCC OLYMPEX setup

Other instrumentation co-located with the CAX1 radar was ground sensors to measure the characteristics of the falling precipitation. These included a visibility sensor (Vaisala FD12P), a Parsivel2 optical disdrometer, a Pluvio2 weighing gauge, and a compact weather station giving temperature, pressure, wind, and solar radiation. At the University of Victoria main campus, approximately 15km east-northeast from AHD, an upper air sounding unit was operated for frequent launches during the field campaign observation periods (Table1).

The CAX1 radar operated continuously during the intensive operation period of the field campaign from November 13, 2015 until March 31, 2016. The radar scanning strategy had a 5 min repeat time. The series of scans in each cycle were 5 vertical cross sections (range height indicator or RHI scans) toward Hurricane Ridge followed by 3 low level azimuthal scans (plan position indicator or PPI scans) at elevation angles of 1.5, 2.5 and 5.0 degrees to a range of 100 km. Details of the radar configuration are given in Table 2.

Location	**Instrument**	**Measurement**
Univ of Victoria	Auto met station	T, P, RH, winds and Geonor precip gauge
	Upper Air Sounding system	Vertical profiles of T, P, RH, winds
DND - Albert Head	SELEX METEOR 60DX radar w/ 2.4m reflector	Dual-pol params (dBuZ, dBZ, V, W, SNR, SQI, ZDR, RhoHV, uPhiDP, PhiDP)
	Vaisala WXT520 compact wx station	T, P, RH, winds, and solar radiation
	OTT Pluvio2 precip gauge	Precip rate and accumulation
	Parsivel2 precip disdrometer	Precip rate and accumulation, DSD, reflectivity
	Vaisala FD12P visibility sensor	Visibility and present weather

Table 1: ECCC OLYMPEX instrumentation

Scan Name	**Fixed ele / azi Angle [°]**	**Pulse Width [µs]**	**PRF [Hz]**	**Antenna Speed [°/s]**	**Angular Res [°]**	**Range Res [m]**	**Max Range [km]**	**Scan Duration [s]**
Dopvol1_A.azi	1.5	1.0	1000 / 750	6.5	1.0	0.125	100.0	60
RHI_A.ele	176.0	1.0	1000	6.0	0.4	0.125	100.0	8
RHI_B.ele	178.5	1.0	1000	6.0	0.4	0.125	100.0	8
RHI_C.ele	181.0	1.0	1000	6.0	0.4	0.125	100.0	8
RHI_D.ele	183.5	1.0	1000	6.0	0.4	0.125	100.0	8
RHI_E.ele	186.0	1.0	1000	6.0	0.4	0.125	100.0	8
Dopvol1_B.azi	2.5	1.0	1000 / 750	6.0	1.0	0.125	100.0	60
Dopvol1_C.azi	5.0	1.0	1000 / 750	6.5	1.0	0.125	100.0	60
Birdbath.azi	90.0	1.0	1000	6.5	1.0	0.125	10.0	35

Table 2: ECCC X-band radar (CAX1) configuration

3. RESULTS
3.1 Overall

Overall, the CAX1 radar performed without any significant technical difficulties. It had an absolute up-time of 96.7%. Most outages were related to shutdowns for safety during activities at the site. Technical problems accounted for <0.2% of downtime

Mitigation of clutter in the radar data was a significant challenge. Sea clutter and ship traffic in the Juan de Fuca Strait as well as the severe orography of the Olympic Peninsula needed to be considered. Figure 2 shows the distances to the nearest terrain blockage as a function of CAX1 azimuth bearing. This is discussed in detail in Donaldson et al. (2016).

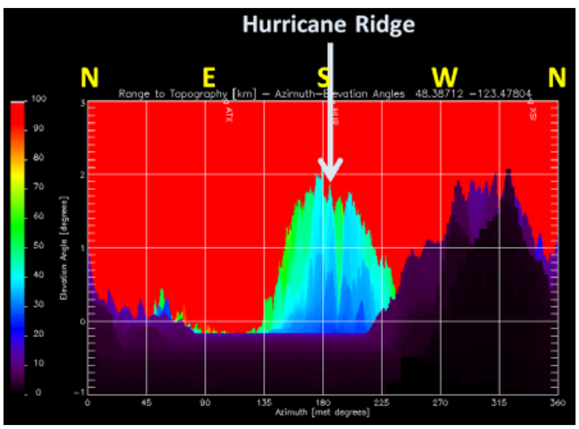

Fig 2: Horizon map

The radiosonde ascents and radar measurements were able to document the precipitation processes occurring on the lee side of the Olympic Mountains. Despite being located in the so-called rain shadow of the Olympics, there were a number of events whose precipitation patterns extended well to the lee of the mountains. Figure 3 provides a daily summary of the precipitation amounts measured at the Albert Head radar site. Overall, there were 13 daily precipitation totals in excess of 10 mm and 3 in excess of 30 mm.

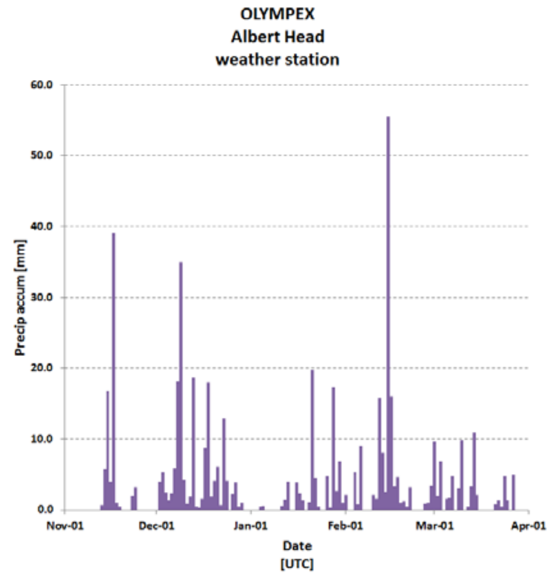

Fig 3: OLYMPEX AHD daily accumulations

3.2 Examples

The siting of the CAX1 radar on the southern coast of Vancouver Island provided about 200° of clear scanning, from approximately 040° to 240° bearing. Hurricane Ridge was due south of the radar at a range of 46.3 km. The five radar RHIs taken to the south on azimuths 176° to 186° provided insight into the vertical structure of the microphysical properties at high elevations over Hurricane Ridge. The following subsections provide example that illustrate the value of the measurements for GPM ground validation studies. Further details on all the cases can be found at **http://OLYMPEX.atmos.washington.edu/index.html?x=Science_Summaries**.

3.2.1 Heavy Rain

November 17, 2015 was an example of an "atmospheric river" producing major rainfall. The first part of this 24 h period was dominated by a warm sector. Moisture flux into the region during the first half of the day was massive. Toward the end of the period, a cold frontal sector passed over the OLYMPEX region.

Figure 4 displays a time height (HTI) cross section near Hurricane Ridge. It was constructed from the 5 min RHI scans at 181° at a range of 41 km in a relatively clutter free zone. The horizontal red line indicates height threshold (350 m) below which partial beam blockage invalidates the measurements. The drop in the bright band's height between 21 UTC and 22 UTC denotes the passage of the cold front. Figure 5a show an RHI during the moist flow. There is a radar bright band evident at ~ 2.25 km and echo tops were quite high, at ~ 10 km. Also evident in the RHI is an embedded precipitation core. During the passage of the cold front (Fig. 5b), echo tops were considerably less with a sloping, lowering bright band. During this time, the bright band was at about the height of HRR and ground particle imagery at HRR (not shown) indicates a transition from rain to snow.

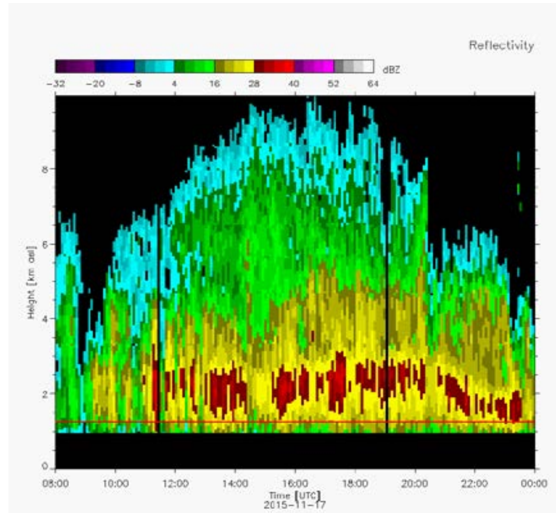

Figure 4: The time height reflectivity 41 km from CAX1 based on the 181° RHI.

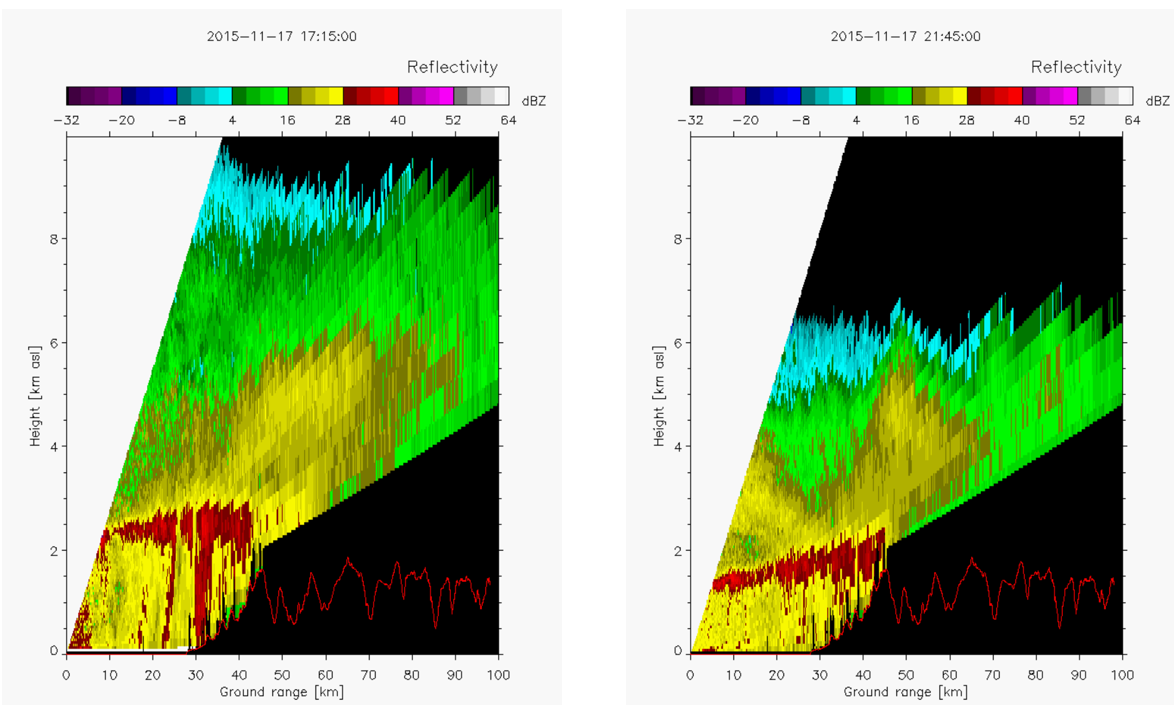

Figure 5: RHI scans on the 181° radial from CAX1 at a) 17:15 UTC during the warm moist flow; b) 21:45 UTC during the passage of the cold front.

Figure 6 gives a comparison of radar reflectivities at 17:15 UTC between 1.6 km and 3.5 km as deduced from a CAX1 RHI profile over HRR and the vertically pointing Micro Rain Radar (MRR) at HRR. The close comparison illustrates the capability of the two data sets to provide a comprehensive time history of the complete vertical profile of radar reflectivity at HRR. This will prove invaluable in documenting precipitation evolution at HRR. (Data at the bottom of the profile were suppressed due to partial blockage of CAX1 radar beam.)

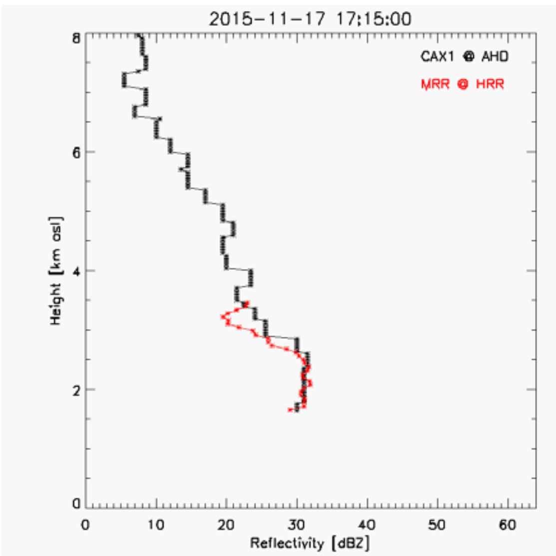

Figure 6: A comparison of the reflectivity from CAX1 (black) and MRR (red) over HRR.

3.2.2 BC Outflow

On November 24, 2015, a weakening frontal system passed south of the OLYMPEX area. In the early part of the day, the flow ahead of the oncoming ridge resulted in a moist north-easterly outflow from mainland British Columbia. The precipitation amounts were the largest amounts on the northeast side of the Olympic Range since that side of the mountains was anomalously the windward side. The aircraft flew patterns centred on Hurricane Ridge during this period.

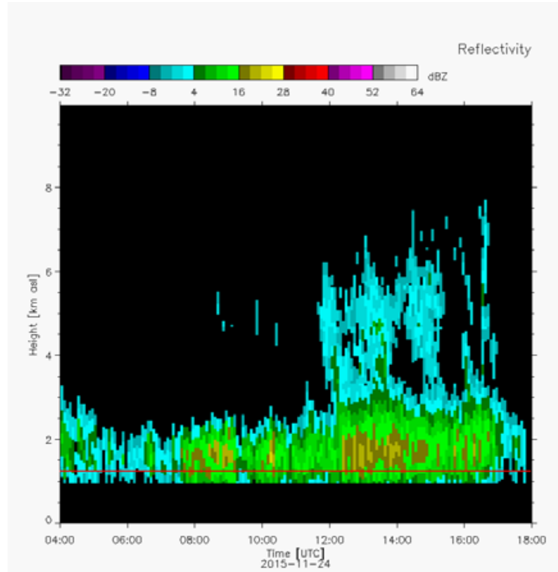

Figure 7: same as Fig. 4 for Nov. 24, 2015

The time height radar reflectivity pattern near HRR (Fig. 7) showed shallower and less intense echoes than the previous case. Maximum reflectivities in the vertical were at about the height of the crest of HRR and weakened quickly higher up. The RHI (Fig. 8a) showed the precipitation reaching the surface beginning on the south shore of the Juan de Fuca Strait and increasing in intensity up the mountain slope. During this time, the low level flow was north easterly and unstable to about 1.5 km height as evidenced by an U. Victoria sounding profile (Fig. 8b).

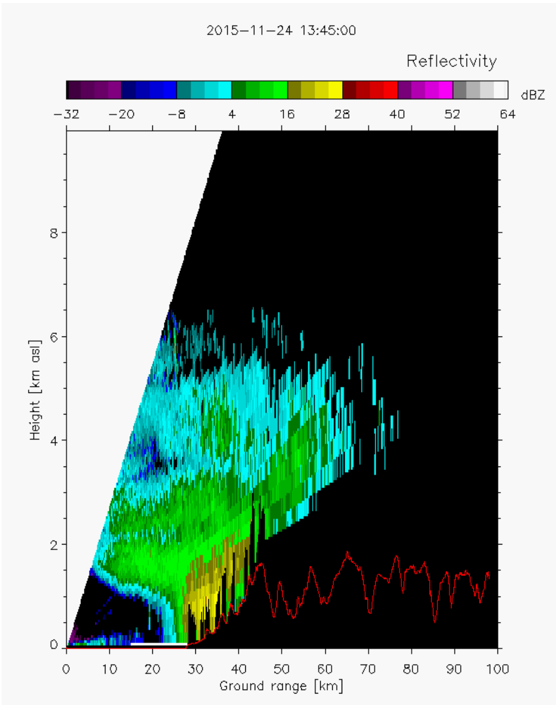

Figure 8a): same as Fig. 5 at 13:45 UTC, Nov. 24, 2015.

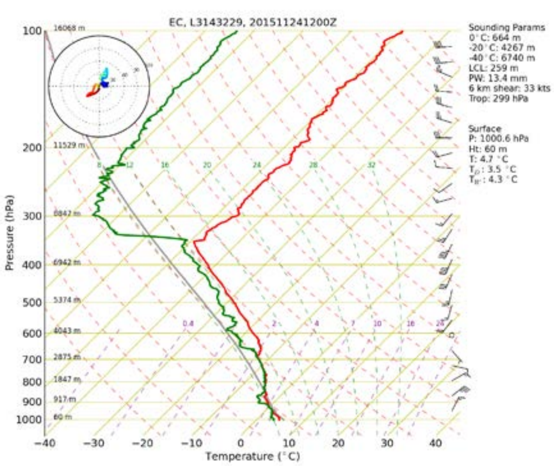

Figure 8b): U. Victoria skewT at 12 UTC, Nov. 24, 2015: unstable, wind outflow from BC; drying later on

3.2.3 GPM Overpass

On December 3, 2015, the GPM core observatory passed directly over the Olympic Mountains during a rainy period associated with a complex baroclinic system. The wind at most levels was strong south-southwesterly, which accounted for strong orographic enhancement at the time of the overpass.

Figure 9a shows the GPM-derived near surface field of radar reflectivity with the nadir line and the edge of the dual frequency swath (Ka left) indicated. Figure 9b gives the corresponding CAX1 low level PPI from the DOLVOL1_A scan with its finer horizontal resolution. Point A (over the Juan de Fuca Strait) and Point B (over the higher terrain of the Olympics) in Fig. 9 highlight two important differences. At point A, the reflectivity is higher on GPM than CAX1. At point B it is the reverse, GPM having lower reflectivity values. Figure 10 gives the GPM cross section along the “Ka left” line of Fig. 9. The blind zone of GPM following the ground results in some significance discrepancies. At a satellite swath range of ~ 100 km in this figure (Point A in Fig. 9) the GPM data is overestimating the low level reflectivity due to bright band contamination. At a swath range of ~ 150 km (Point B in Fig. 9) GPM is underestimating low level reflectivity due to clutter removal. In fact, some GPM pixels in the B area are undetermined and appear transparent to the light green land background

The shaded region of the vertical slice in Fig. 10 depicts the geometric region in which CAX1 can be used to both validate and supplement the low level GPM measurements. It is noteworthy that both radars have limited ability at low levels above the surface. However it also shows the advantage of supplementing surface observation with a surface based radar that is measuring the same volume aloft that the satellite is sampling.

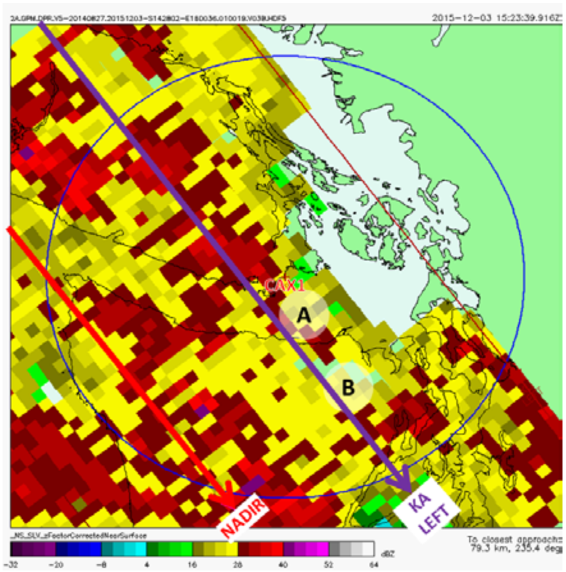

Figure 9a): GPM corrected near surface reflectivity.

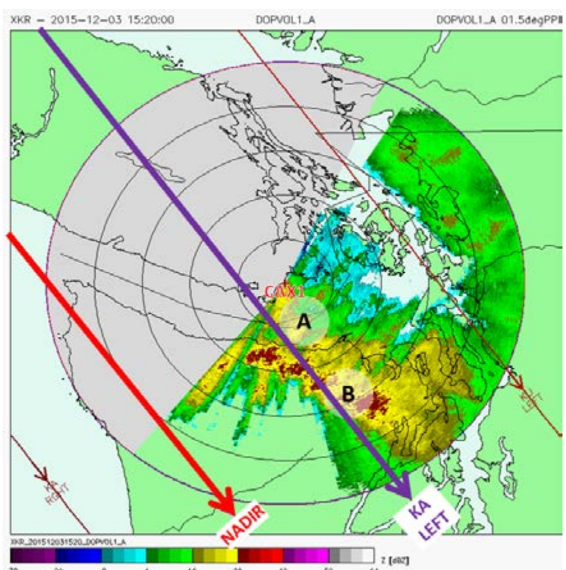

Figure 9b): CAX1 corresponding low level PPI (Dopvol1_A).

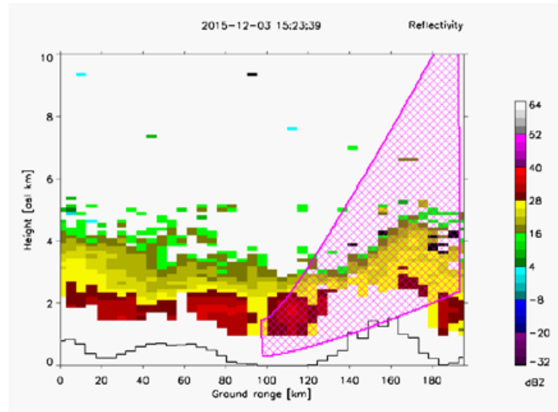

Figure 10: GPM overpass: cross section taken at the edge of the Ka-band swath to the northeast. The shaded area is the combined coverage of the PPIs from CAX1.

4. SUMMARY AND FUTURE STUDIES

ECCC successfully deployed a scanning dual polarization X-band radar to the southern tip of Vancouver Island. The radar performed near flawlessly and as illustrated in the three cases collected a wealth of information on the meteorological conditions to the lee of the Olympic Mountains. This information will be used to support the stated objectives.

To further mine the data, the dual polarization parameters will be examined to describe the precipitation characteristics. Donaldson et al. (2016) discussed some of the quality control issues involved. In addition, the radial wind field can be used in conjunction with the wind profiles collected by the radiosonde ascents to describe the flow regimes in the lee of the Olympics. Figure 11 displays the complex topography and the position of the 5 RHIs that were routinely done. Careful unfolding of the radial wind data will be required.

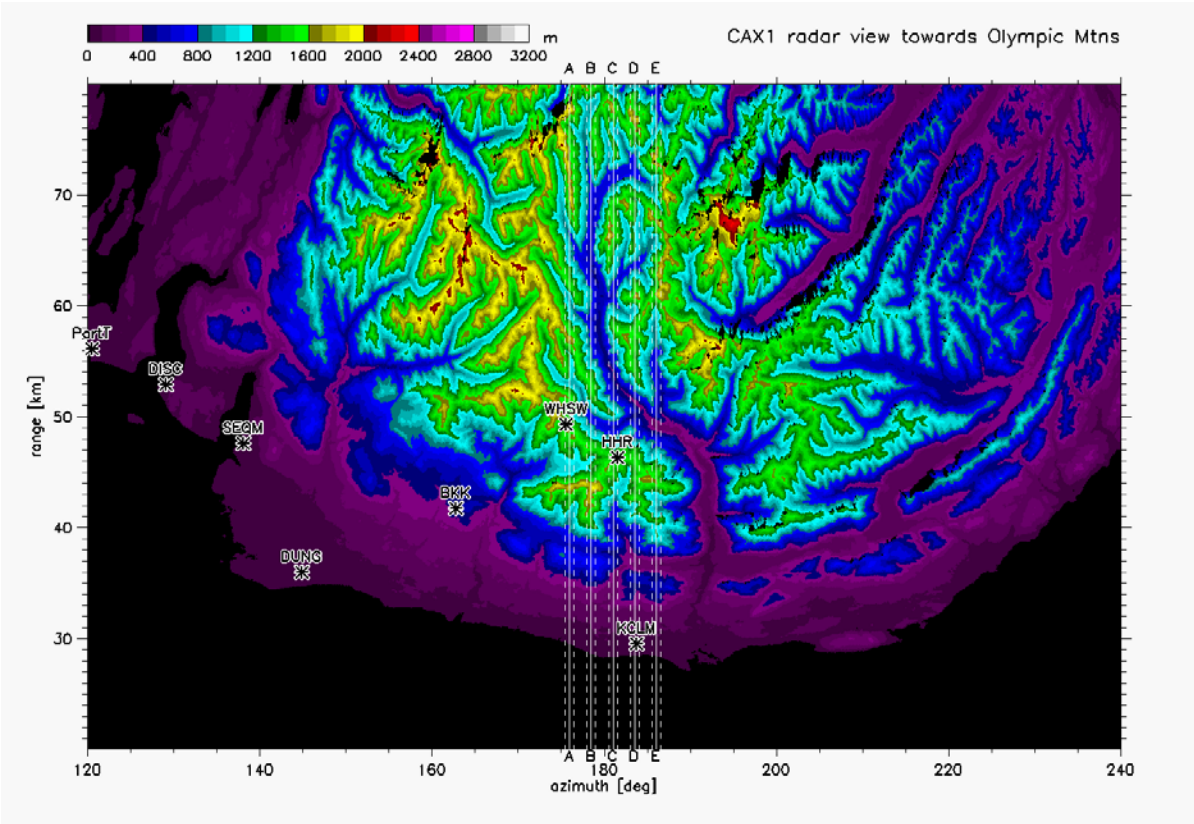

Figure 11: The complex topography to the lee of HRR. Superimposed is the location of the 5 RHI scans done routinely by CAX1. Surface stations are also located.

Future application of the data collected on OLYMPEX will also include ensemble forecasts of OLYMPEX events at varying grid resolutions using ensemble regional ensemble Kalman Filtering (REnKF) boundary conditions. The main goal will be to determine the added value of ensembles and higher resolution.

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