BC Clean Air Research Fund

Final Report

April 1, 2013 to March 14, 2014

May 31, 2014

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PROJECT OVERVIEW

Abstract

The primary goal of this endeavour was to provide British Columbia with a mobile continuous aerosol vertical profiling capability as a complement to existing aerosol and air quality monitoring facilities, and to demonstrate the utility of such a system. The system selected for this purpose was the mini-Micropulse Lidar (mini-MPL) from SigmaSpace Corp. in Lanham, MD. Previous experience with lidar and ceilometers in the region demonstrates that a three dimensional perspective is essential to an understanding of processes affecting local air quality, especially since aerosol pollution from transport (potentially over long distances) of forest fire smoke, desert dust, ship plumes and industrial emissions is of critical and growing concern in British Columbia. The mini-MPL will provide an inexpensive and versatile platform for investigating these processes for years to come.

Over the course of the last year, the mini-MPL has been deployed to three locations in southwest BC: Vancouver, Whistler, and Ucluelet. Each deployment provided an unique opportunity to support research and monitoring efforts for which this kind of high-resolution atmospheric profile was both valuable and otherwise unavailable. At UBC, the mini-MPL provided calibration support for the newly-upgraded lidar run by Environment Canada. In Whistler it was used both as support for air quality monitoring efforts and to support a team of UBC researchers interested in ice nucleation processes. In Ucluelet, where the lidar currently resides, it is being used to provide the first-ever high resolution profiles of the atmosphere in a region where the severe weather had previously made lidar deployment unfeasible.

FINANCIAL OVERVIEW

Revenue Description

Table 1 Projected Total Project Revenue (cash and in-kind)

Organization	2012/13		2013/14		Total
	Cash	In-kind	Cash	In-kind	
BC CLEAR - Fraser Basin Council	$0	$0	$20,000	$0	$20,000
Organization: CFI	$0	$0	$80,000	$0	$80,000
Other Organization: NSERC	$0	$0	$10,000	$0	$10,000
Other Organization: SigmaSpace Corp.	$0	$0	$0	$10,000	$10,000
TOTAL	$0	$0	$110,000	$10,000	$120,000

Table 2 Actual Revenue for Reporting Period (cash and in-kind)

Organization	2012/13		2013/14		Total
	Cash	In-kind	Cash	In-kind	
BC CLEAR - Fraser Basin Council	$0	$0	$15,000	$0	$15,000
Organization: CFI	$0	$0	$87,000	$0	$87,000
Other Organization: NSERC	$0	$0	$0	$0	$0
Other Organization: SigmaSpace Corp	$0	$0	$0	$10,000	$10,000
TOTAL	$0	$0	$97,000	$10,000	$107,000

Note: Please attach copies of letters or agreements confirming additional funds.

Please explain revenue discrepancies (if any)

$5,000 is still outstanding from Fraser Basin Council, contingent on acceptance of this report. $10,000 was originally expected from NSERC but was not required.

Expenses Description

Table 3 Projected Expenses for Reporting Period (cash and in-kind)

Project Costs	**Expenses**		
	All Sources		
	Cash	*In-kind*	*Total*
Salaries and fees	$17,500	$0	$17,500
Travel and accommodation	$1,500	$0	$1,500
Equipment and supplies	$90,000	$10,000	$100,000
Communications and outreach	$1,000	$0	$1,000
Analysis	N/A	N/A	N/A
TOTAL PROJECT COSTS	$110,000	$10,000	$120,000

Table 4 Actual Expenses for Reporting Period (cash and in-kind)

Project Costs	**Expenses**		
	All Sources		
	Cash	*In-kind*	*Total*
Salaries and fees	$8,080	$0	$8,080
Travel and accommodation	$506	$0	$506
Equipment and supplies	$87,414	$10,000	$97,414
Communications and outreach	$1,000	$0	$1,000
Analysis	N/A	N/A	N/A
TOTAL PROJECT COSTS	$97,000	$10,000	$107,000

Please explain expense discrepancies (if any)

RESULTS OVERVIEW

Activity Description

Table 5 Summary of Activities for the Reporting Period

Activity*	Completion Date	Description of Results
Obtain mini-MicroPulse lidar (MPL) system with GPS and enclosure	August 28, 2013	Lidar arrived, and initial test of functionality completed.
Operation at UBC for CORALNet cross-calibration	Data collection: September 01, 2013 - November 01, 2013 Analysis: October 10, 2013 - December 15, 2013	Collected data in tandem with CORALNet lidar to discern any discrepancies in depolarization ratios. Significant differences were identified, leading to a correction of calibration constants for the CORALNet system.
Operation at Whistler to monitor boundary layer activity and to support ice nucleation experiments run by UBC Atmospheric Chemistry group and Environment Canada. Co-location with BC Ministry of Environment air quality monitoring station.	Data Collection: January 07, 2013 - April 10, 2013 Analysis: January 17, 2013 - Ongoing	Data collection for this deployment included monitoring of the boundary layer height and identification of long-range transport events in the free troposphere during ice nucleation experiments carried out on Whistler Peak. The collected data have been made available to researchers as an ongoing resource to support their work.
Operation at Amphitrite Point (Ucluelet) to monitor boundary layer activity, Asian dust and smoke transport events, and other aerosol activity in BC's coastal environment. Co-location with Environment Canada monitoring station.	Data Collection: April 20, 2013 - Ongoing Analysis: May 01, 2013 - Ongoing	Several interesting events have been observed at Ucluelet, including over a month of continuous boundary layer monitoring, large dust transport events throughout May, and several currently unexplained layers observed in the free troposphere, not directly correlated to known long-range transport mechanisms. This is the first lidar deployment to Vancouver Island and data sets from this deployment will prove useful to researchers for years to come.
Development of automated analysis and posting software	March 15, 2014 – May 31, 2014	This software was developed using Python and WinSCP to automatically update new lidar files to a central server, process

		the files into daily images, and update an image with the last 24-hours of data. Processing includes calculating normalized relative backscatter and lidar ratios, and masking out areas where attenuation or low signal to Noise ratios make results unreliable.

*As outlined in the project contribution agreement or contract.

Please explain activity discrepancies (if any)

Discrepancies with original proposal are due in part to scheduling delays resulting from late delivery of the lidar, and in part to the desire of the team to respond to a new research opportunity that arose in Whistler. Details of the change were provided in the Interim Progress report submitted October 15, 2013 and in Amendment submitted November 18, 2013.

Deliverable Description

Please include copies of all deliverables with the final report (e.g. publications, presentations, research reports, etc.). The final report will be considered incomplete without copies of the project deliverables.

Table 6 Summary of Key Deliverable Accomplishments for the Reporting period

Deliverable*	Description	Description of Results
UBC-CORALNet cross-calibration Technical Report	Report on the use of the mini-MPL to aid in calibration of CORALNet lidar detector upgrades.	Mini-MPL provided depolarization data that led to an important correction to calibration coefficients for CORALNET lidars at UBC and elsewhere.
Whistler preliminary results	Summary of interesting events and useful applications of the lidar to aerosol research activities during Whistler deployment	While in Whistler, the lidar revealed several instances of aerosol layers in the free troposphere, and helped to determine whether the instruments on Whistler peak were sampling form the free troposphere or the boundary layer.

Ucluelet preliminary results	Summary of interesting events and useful applications of the lidar to aerosol research activities during Ucluelet deployment	While in Ucluelet, the lidar has provided the first continuously monitored observations of the marine boundary layer at this location. In addition, there were multiple clear instances of long-range dust transport from Asia, the details of which are still being investigated.
Mini-MPL website	Website open to general public and updated with new results on an hourly basis	Contains first-look results and data files for download: http://dunlin.geog.ubc.ca

*As outlined in the project contribution agreement or contract.

Please explain deliverables discrepancies (if any)

Discrepancies with original proposal are due in part to scheduling delays resulting from late delivery of the lidar, and in part to the desire of the team to respond to a new research opportunity that arose in Whistler. Details of the change were provided in the Interim Progress report submitted October 15, 2013 and in Amendment submitted November 18, 2013.

DELIVERABLES

Appendix 1: *mini-MPL – CORALNet Cross-Calibration Technical Report*

METHODOLOGY

The measurements for the calibration were collected over several days from September 12 – October 21, 2013. The CORALNet lidar is located on the UBC grounds at Totem Field and typically operates 24 hours a day except for periods of rain and occasional service activities. The mini-MPL was installed on the roof of a nearby building and was operational on most days during this period as well. The relative positions of the two systems are shown in the map in Figure 1.

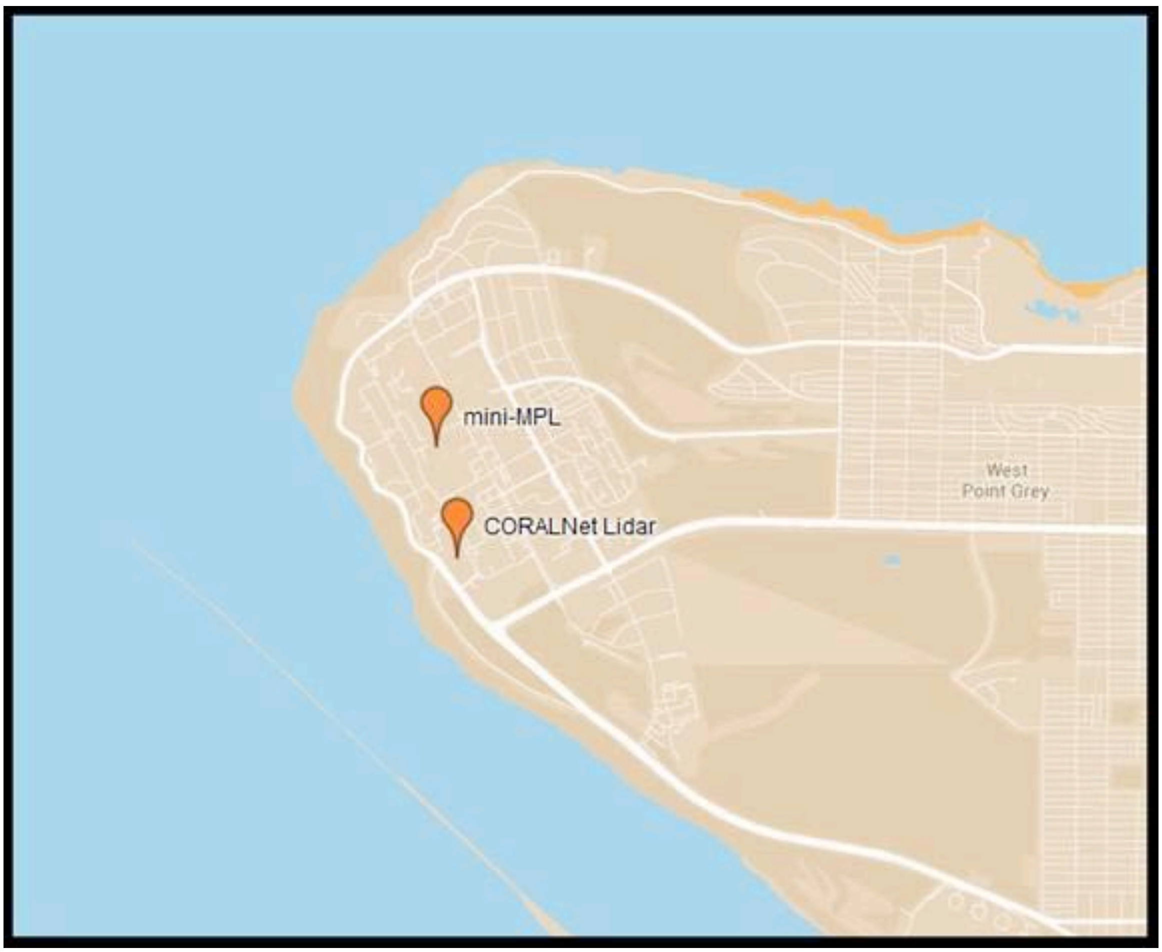

Figure 1: Map of the Point Grey Peninsula where the CORALNet and mini-MPL were located during this experiment

In order to fully test the correlation between the depolarization ratios measured by the two instruments, it is important to obtain data from days during which both systems were operating at the same time and when layers were observed that covered the full range of depolarization ratios typically observed from atmospheric aerosols. These layers must also be of an optical thickness sufficient to maintain a high signal to noise ratio in order to reduce spurious noise in the correlation plots. The most reliable feature that fits all of these requirements is cirrus cloud. Cirrus clouds are composed of a combination of elongated ice crystals (very high depolarization) and spherical water droplets (very low depolarization). The ratio of ice to water, and this the depolarization ratio, depends on environmental factors and thus can vary greatly over time and altitude. During the observation period, there were two days during which both lidars were operational and there was a substantial presence of cirrus clouds: September 19, and October 15. These are the days for which results will be presented.

RESULTS

Backscatter and Depolarization False-Colour Plots

Areas of low signal strength can result is very large variations in depolarization ratio, including values far outside the range of what is physically realistic. Data points from these regions could easily swamp out any relationships that might be revealed in scatterplots of the results from the two lidars. For this reason, only regions of very strong signal can be included in the cross-calibration analysis.

Plots of backscatter strength from the mini-MPL are shown in Figures 2 and 3 along with plots of depolarization ratios. In these plots, the cirrus and cumulus cloud regions can be seen as areas where the normalized radiative backscatter (NRB) exceeds 0.005. By comparing the signal to noise ratio (SNR) in the depolarization results for these regions to the rest of the images, especially for altitudes above 6,000m, it is clear that masking is necessary, so these areas were removed from consideration for this analysis.

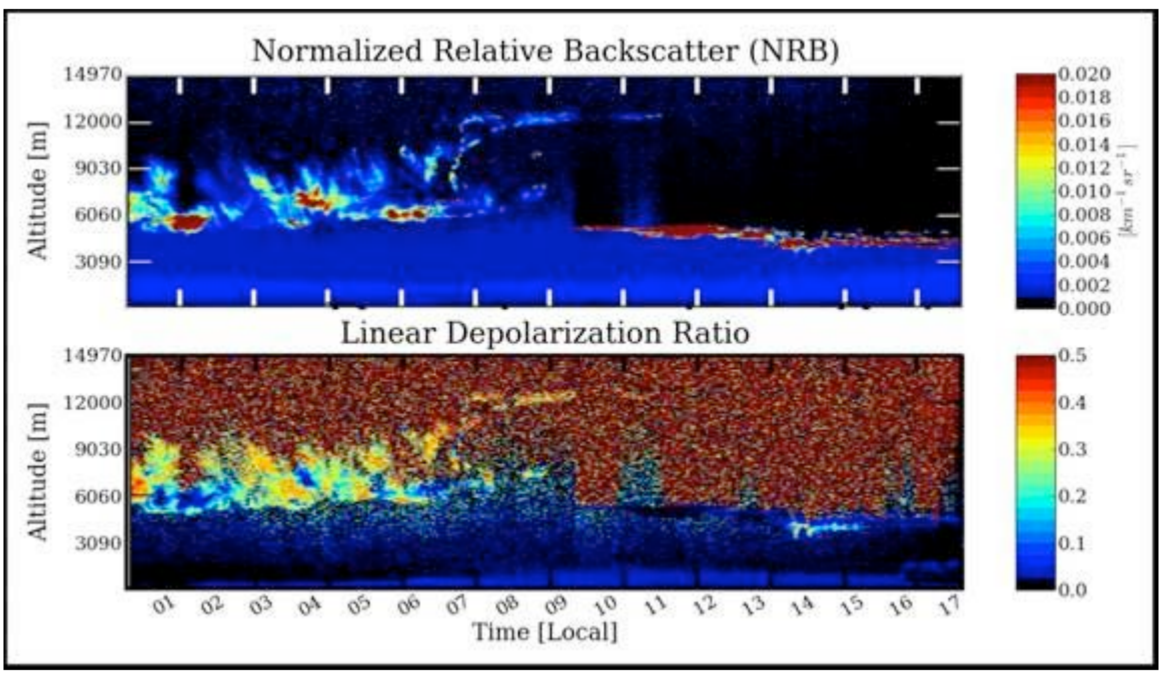

Figure 2: False colour plots of normalized relative backscatter (top) and linear depolarization ratio (bottom) taken by the mini-MPL on September 19, 2013. Cirrus clouds can be seen from 6,000-12,000 m during the first half of the day. These clouds show depolarization ratios from <0.1 up to 0.5.

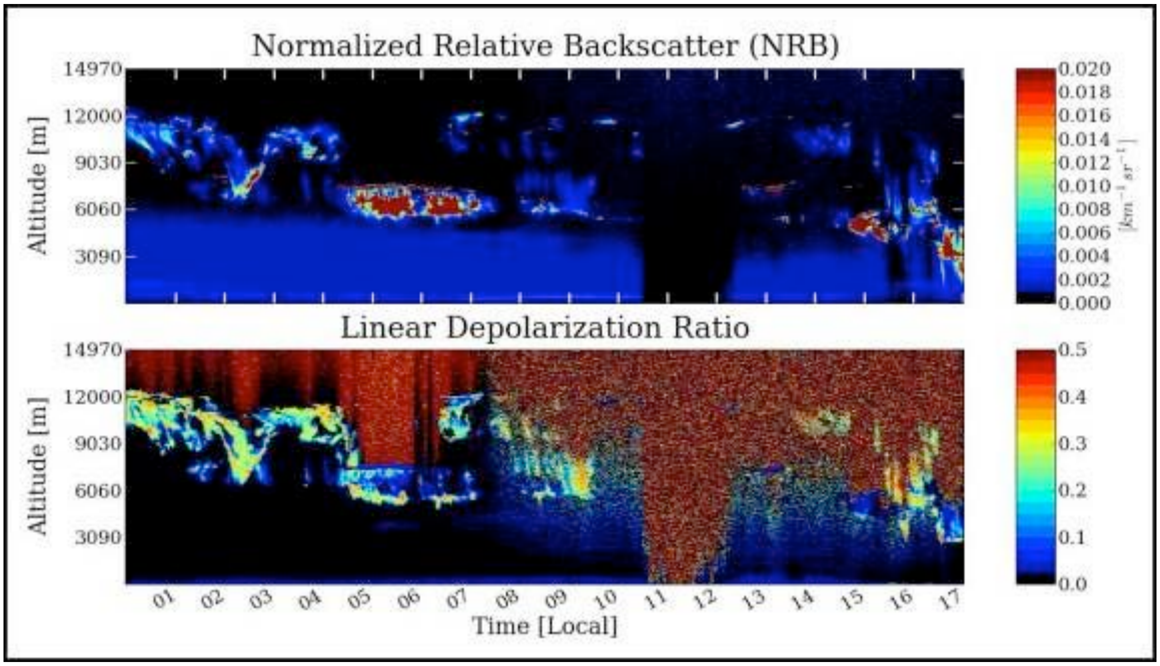

Figure 3: False colour plots of normalized relative backscatter (top) and linear depolarization ratio (bottom) taken by the mini-MPL on October 15, 2013. Cirrus clouds can be seen from 6,000-12,000 m throughout of the day. These clouds show depolarization ratios from 0.2 - 0.5. From 5:00-7:00, a cloud of mixed water and ice can be seen that shows depolarization ratios ranging down to near 0. Areas of high noise levels can be seen above the clouds and from 11:00-12:00, when fog blocked all return signal.

Figures 4 and 5 show the depolarization results for both systems after masking. In these plots one can directly compare the depolarization results from the mini-MPL and CORALNet lidars. It is already clear at this point that for the cirrus clouds at altitudes above 6,000m the mini-MPL is recording depolarization ratios much higher than the CORALNet lidar. For the mini-MPL, the average depolarization of the cirrus clouds is on the order of 0.4, whereas the CORALNet lidar is showing values of ~0.2 for these regions. This is a significant difference, and a strong indication that the results of this calibration can be used to improve the system settings for CORALNet.

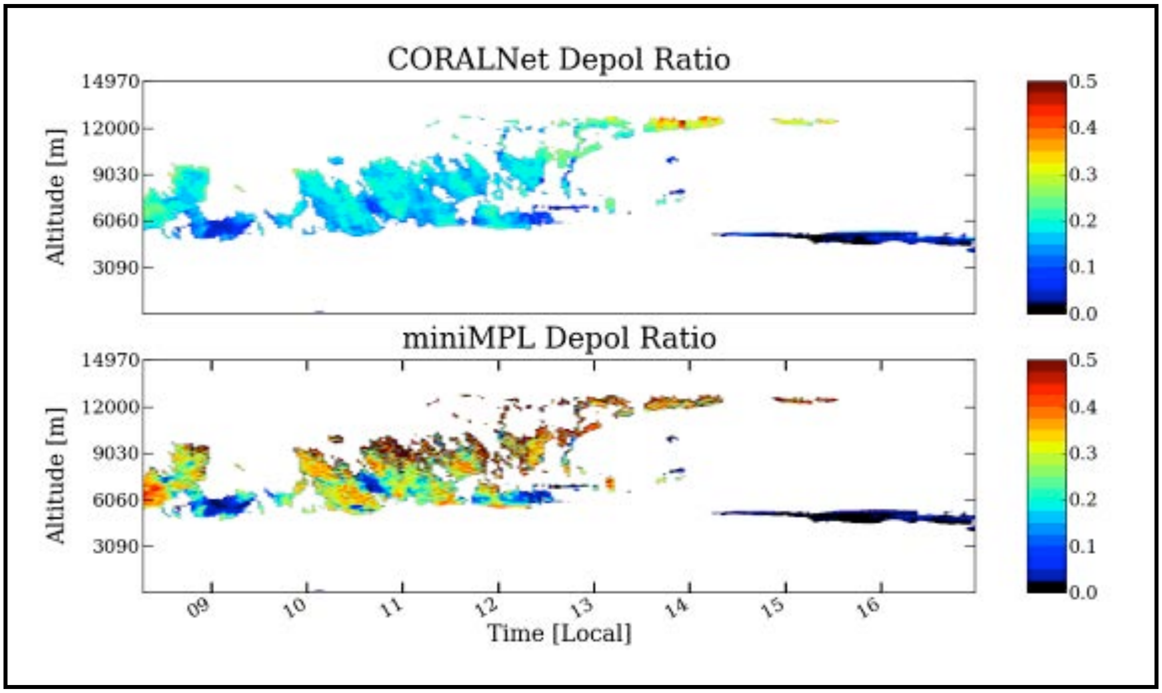

Figure 4: Masked depolarization ratio plots for CORALNet (top) and mini-MPL (bottom) for September 19, 2013. A quick comparison of the two shows the CORALNet ratios appear to be markedly lower than those measured by the mini-MPL. In this plot, only the strongest signal levels are left unmasked to reduce the effects of noise.

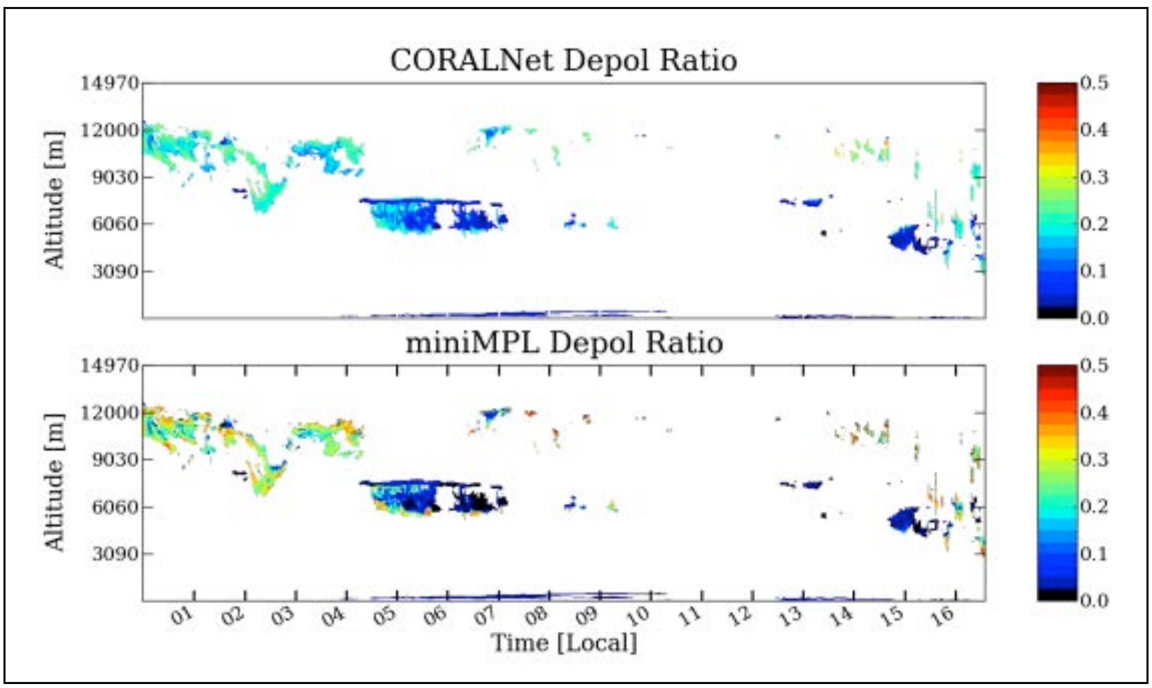

Figure 5: Masked depolarization ratio plots for CORALNet (top) and mini-MPL (bottom) from October 15, 2013. The case here is not as clear-cut in that the mini-MPL shows regions of higher

depolarization among the high cirrus clouds, but appears to give a lower depolarization for the water clouds. In this plot, only the strongest signal levels are left unmasked to reduce the effects of noise.

In order to apply this information to actually calculate improved values for the CORALNet system constants, a linear relationship must be established between the two data sets. In order to accomplish this, further analysis is required.

Difference maps and scatterplots

In order to more clearly identify the differences between the two sets of results, plots were generated of the difference between the two. In Figures 6 and 7, areas where the mini-MPL showed a higher depolarization ratio are shown in red and regions where the CORALNet lidar had a higher ratio are shown in blue. From these figures, what was originally seen in the masked plots is shown in more detail. In regions identified as cirrus cloud on both figures, the difference ranges from near zero up to +0.25. In cumulus cloud areas a slightly negative trend is shown where the difference ranges from zero to -0.05.

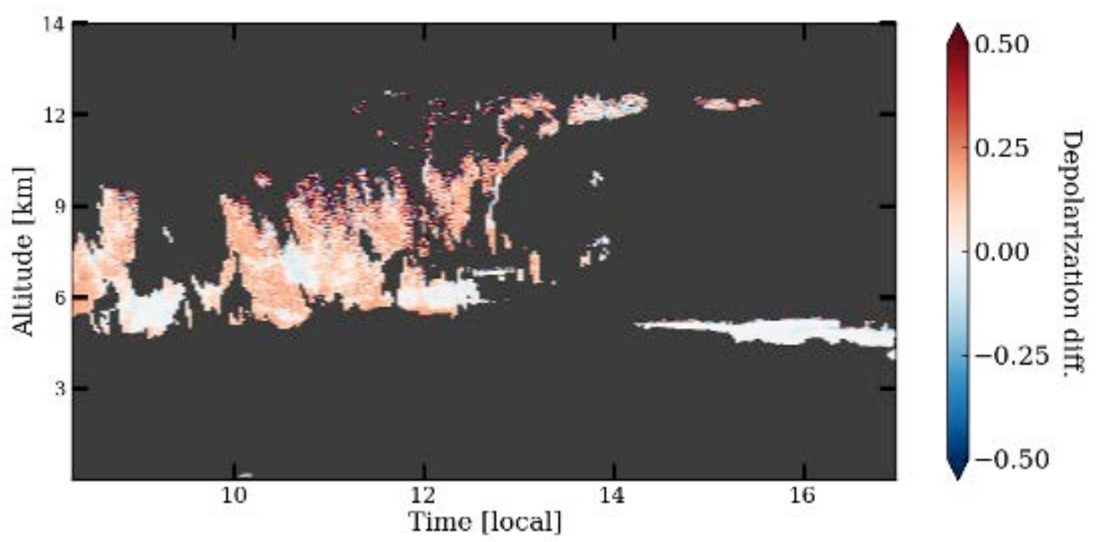

Figure 6: Plot of the difference in polarization results between the two systems for September 19, 2013. In this plot, positive values indicate the mini-MPL depolarization was higher than that from CORALNet.

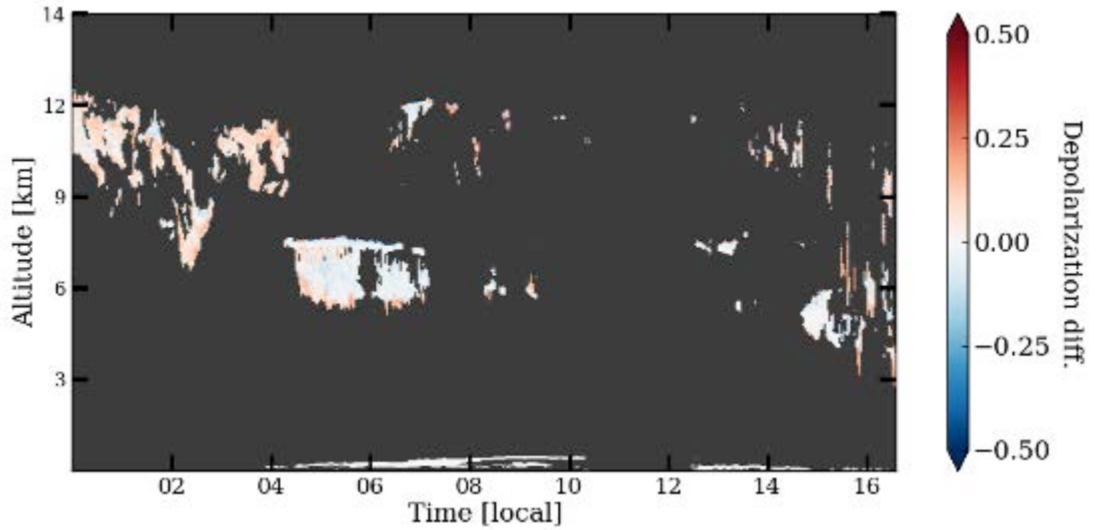

Figure 7: Plot of the difference in polarization results between the two systems for October 15, 2013. In this plot, positive values indicate the mini-MPL depolarization was higher than that from CORALNet.

Now that the trend has been fully established it is necessary to determine if a linear relationship between the two data sets can be established. One way to visually depict such a relationship is with scatterplots. Figure 8 shows scatterplots between the CORALnet and mini-MPL depolarization ratios. As expected, the data from the mini-MPL is shown to be significantly higher than from CORALNet. However, from these plots it is not immediately clear that there is a well-defined linear relationship between the two data sets.

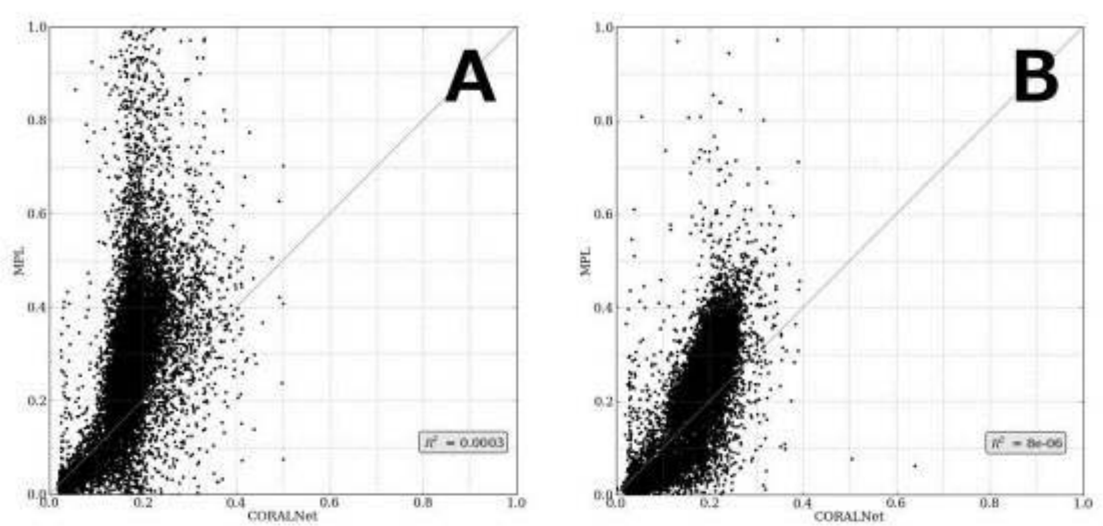

Figure 8: Scatterplots comparing depolarization results for CORALNet and mini-MPL. Plot A shows results for September 19, 2013 and Plot B shows results for October 15, 2013. In both plots, the relationship is consistent and clear: the mini-MPL shows higher depolarization ratios than the CORALnet lidar. However, the relationship is not necessarily linear.

As a first attempt at finding such a relationship, a linear least-squares methodology was applied to determine a slope and intercept for a linear regression from the data, but there appears to be a difference in the slope of the data as the depolarization increases. This could be the result of multiple scattering effects that affect depolarization levels as light passes through a cloud. Also, even with the applied mask, the noise levels are still quite high indicating that more data should be collected before a final result is determined. For now, it is recommended that an increase in the system constant of the depolarization channel of the CORALNet lidar of 50% would be appropriate as a conservative starting point to improving the accuracy of the depolarization ratios.

Conclusions and Future Work

For this study, a mini-MPL lidar was installed near the CORALNet lidar in an attempt to perform a cross-calibration that could be used to improve the system settings that determine the CORALNet depolarization ratios. Data were collected by both systems over multiple days in September and October of 2013, but only two proved to be suitable for analysis: September 19 and October 15. After analyzing data from these two days, it was shows clearly that the CORALNet depolarization ratios were consistently lower than those of the mini-MPL. Due to the more direct method used by the mini-MPL to calculate depolarization ratios, it was determined that the CORALNet system constants should be altered to match the data more closely. A linear least squared method was attempted to determine a quantitative change to be applied, but a combination of noise levels and non-linearity of the results made this less than fully effective. Nevertheless, from these data a first approximation can be made that an increase in the system constant of the depolarized channel of CORALNet of ~50% would improve the accuracy of the results.

In the coming months, these data will be studied further in an attempt to determine the relationship between the two data sets with more precision. Noise reduction and filtering techniques will be applied and non-linear fits will be attempted to see if the data comport to a quadratic relationship, or if there is any difference in the values with altitude. Finally, revised system constant will be applied to the CORALNet data and the analysis repeated to determine whether the data have improved as a result.

ACKNOWLEDGEMENTS

The author would like to acknowledge the important contribution of Annie Seagram, who provided the software tools used to calculate and plot the difference maps and scatter plots. CORALNet data were provided courtesy of Kevin Strawbridge of the Air Quality Processes Research Section, Environment Canada. The mini-MPL was designed and manufactured by SigmaSpace Corp. of Lanham, MD, USA. This research was supported by a financial contribution from the BC Clean Air Research (BC CLEAR) Fund. BC CLEAR is sponsored by the BC Ministry of Environment, jointly managed with Metro Vancouver and Environment Canada. The Fraser Basin Council administers the program in partnership with the BC Lung Association.

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[2] Flynn, Connor J., et al. "Novel polarization-sensitive micropulse lidar measurement technique." *Optics Express* 15.6 (2007): 2785-2790

[3] Strawbridge, K. B. "Developing a portable, autonomous aerosol backscatter lidar for network or remote operations." *Atmospheric Measurement Techniques* 6.3 (2013): 801-816.

Appendix 2: *Preliminary results from Whistler deployment: January 17 – April 10, 2014*

METHODOLOGY

The lidar deployment to Whistler was initiated to support a UBC Chemistry Department study into the impacts of various aerosol types on ice nucleation. Lidar data are applicable to this study in two specific ways. First, the lidar can be used to monitor the height of the atmospheric boundary layer. This is valuable information to those collecting data from Whistler peak because moving in and out of the boundary layer can cause fluctuations in their data that might otherwise be misinterpreted as aerosol layers in the free troposphere. Second, the depolarization data provided by the lidar provides the researchers with some indication of the shapes of individual particles and the vertical aerosol profile provides a more complete picture of the distribution in altitude of clouds and aerosol layers detected at the peak.

Although this deployment was not part of the initial plan for the mini-MPL, responding to such impromptu research needs is an excellent demonstration of the unique capabilities of the mini-MPL system as compared to other lidar installations. Once the lidar team was approached by the researchers, it took approximately two months to scout an appropriate location, obtain Transport Canada authorization, and set up the lidar for over three months of autonomous operation. The lidar was actively collecting data in Whistler from January 17 – April 10, 2014.

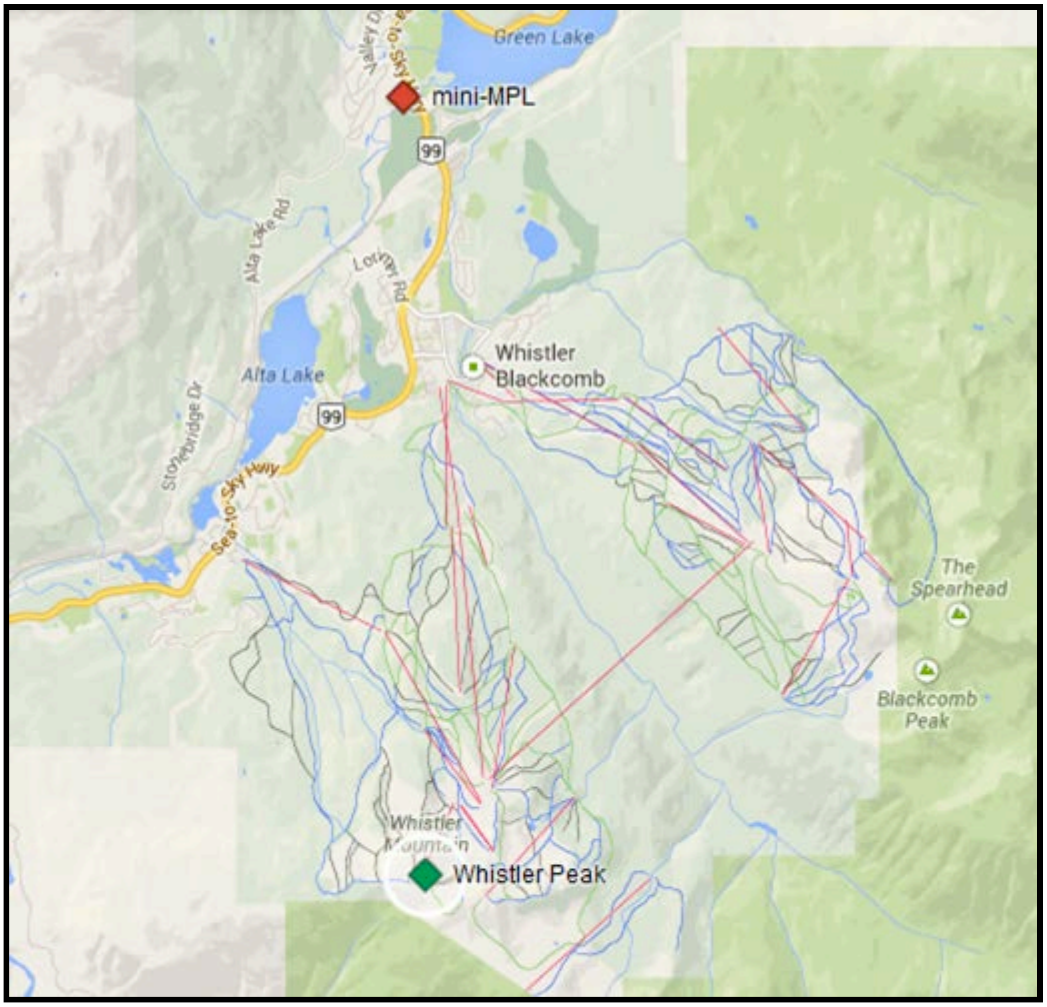

Figure 1: Map showing locations of Whistler Peak High Elevation Research Site and mini-MPL.

RESULTS

Although winter is typically a time when little activity is monitored by lidar, the months during which the mini-MPL was located there were unusually clear and many days of useful data were collected. For example, from March 11-12, the following images were generated:

Among these, the researchers for the ice nucleation study were particularly interested in the following five days:

- February 28
- March 20

- March 27
- March 30
- April 7

These days will be discussed in some detail below.

February 28, 2014:

The ice nucleation research team were collection data on February 28, and were wondering if their results were influenced by the Planetary Boundary Layer (PBL). The results from the lidar revealed that, in fact, the Whistler peak was within the PBL for the entire day. This is very unusual for this time of year, and would not have been assumed to be the case without direct observational evidence.

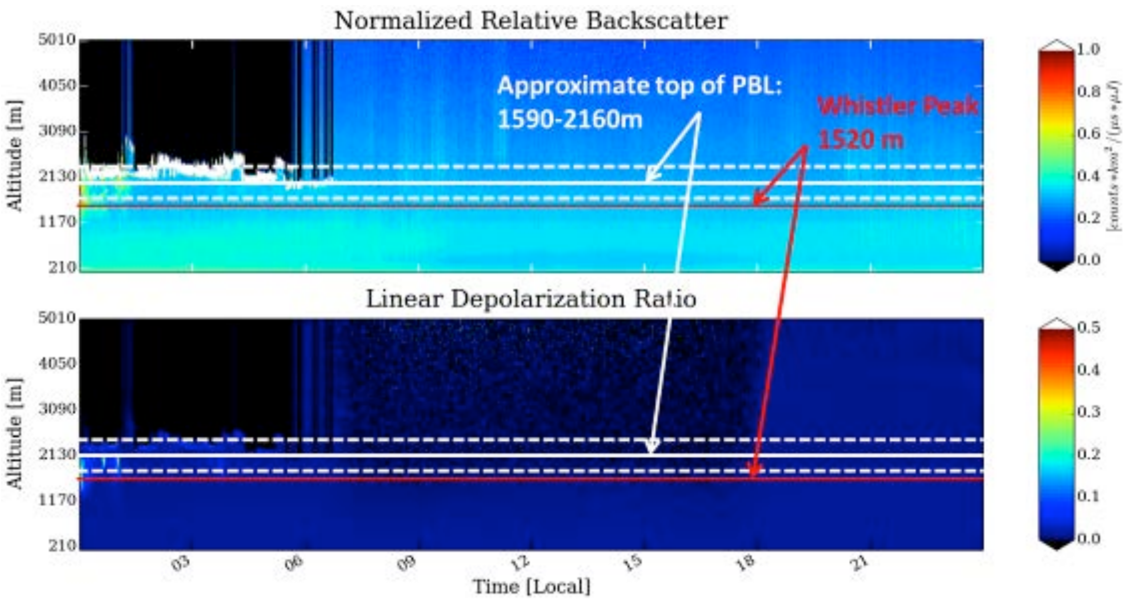

Figure 2: Mini-MPL data from Feb. 28, 2014 showing Whistler peak within the PBL. Altitudes are measured in AGL units from the valley floor, putting the peak at 1520m.

In this instance, a combined slope-threshold methodology was used to estimate the thickness of the PBL. Despite a substantial range of variation in PBL thickness throughout the day, the estimated top of the layer rarely dipped below the altitude of the peak. This makes Feb. 28 a relatively poor day for monitoring ice nucleation activity, despite the clear weather.

March 20&27, 2014:

On the 20th and 27th, the Whistler High Elevation site saw complex returns including periods of elevated PM2.5 concentrations and black carbon, interspersed with clouds and precipitation. The lidar results revealed that the peak had been moving into and out of cloud banks, but remained above the PBL for the day. During periods when the peak was not covered in cloud, the lidar reveals enhanced backscatter levels of relatively spherical, (i.e. low depolarization) particles. Furthermore, depolarization results reveal clouds consisting of mixed ice and water, indicating changes throughout the day in ice nucleation activity, making it an excellent day for collecting samples related to ice nucleation.

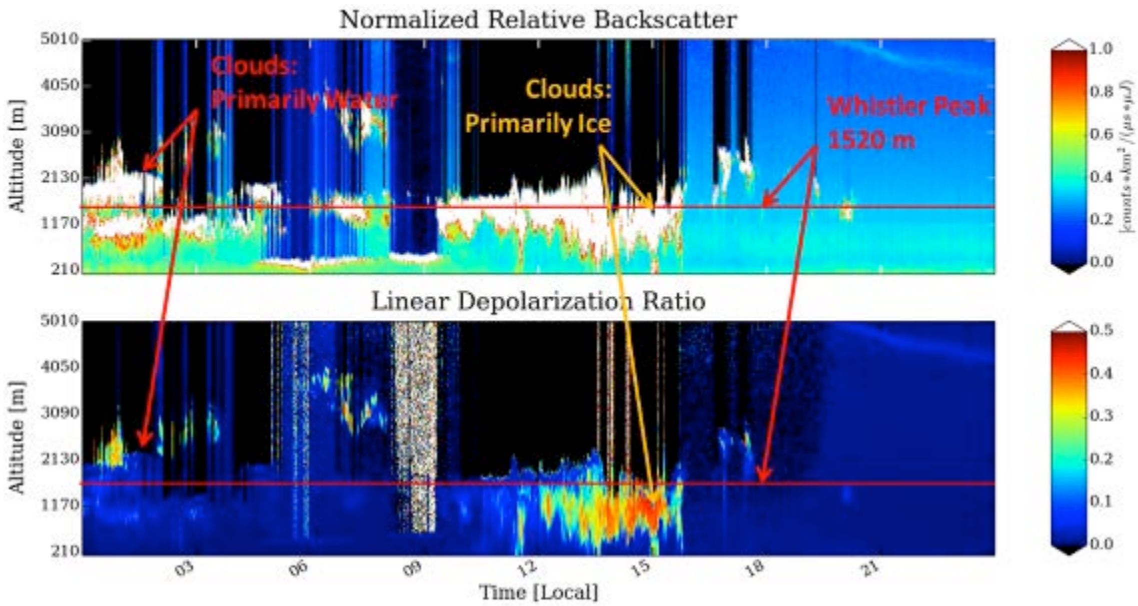

Figure 3: Mini-MPL returns for March 20, 2014. On this day, the PBL did not extend above ~1170m AGL. Clouds near the peak consisted of mostly liquid water until ~12:00, when icier clouds emerged.

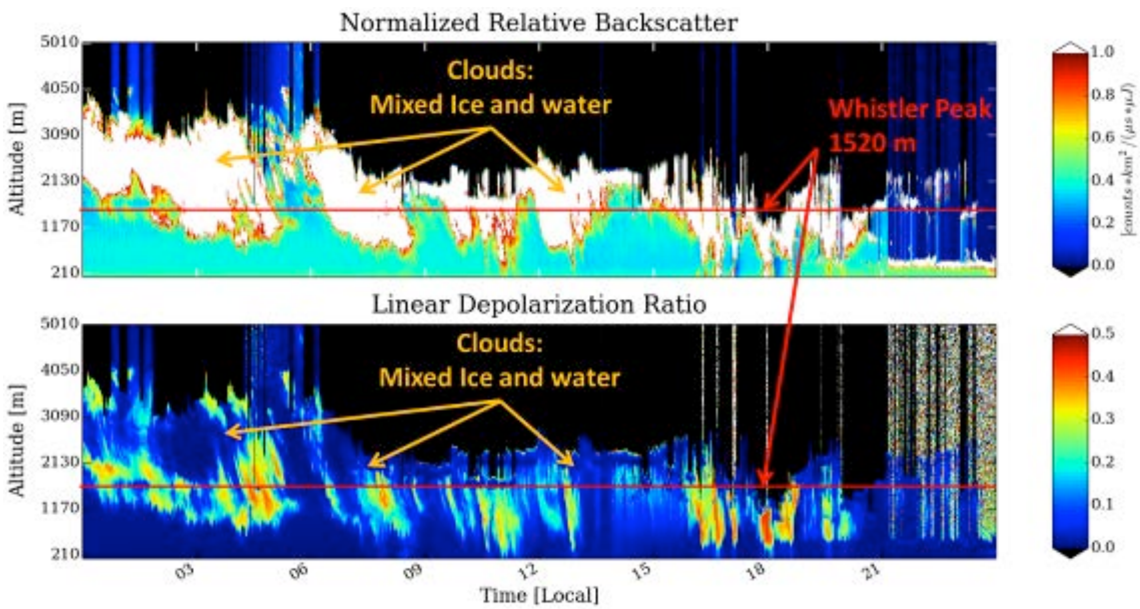

Figure 4: Mini-MPL returns for March 27, 2014. On the 27th, the peak passed into and out of ice and water clouds intermittently throughout the day. In between, it appears that periods of elevated aerosols levels were seen at the peak.

March 30&April 7, 2014:

During these days, the lidar was collecting data, but low clouds prevented any useful observations from the region around Whistler peak in the mornings. In the afternoons, the clouds lifted, revealing intermittent cloud and aerosol layers. In these cases, the lidar actually proved to not be as useful to the researchers as on other days, but at least shows that whatever measurements were taken at the peak were taken from the free troposphere, above the PBL.

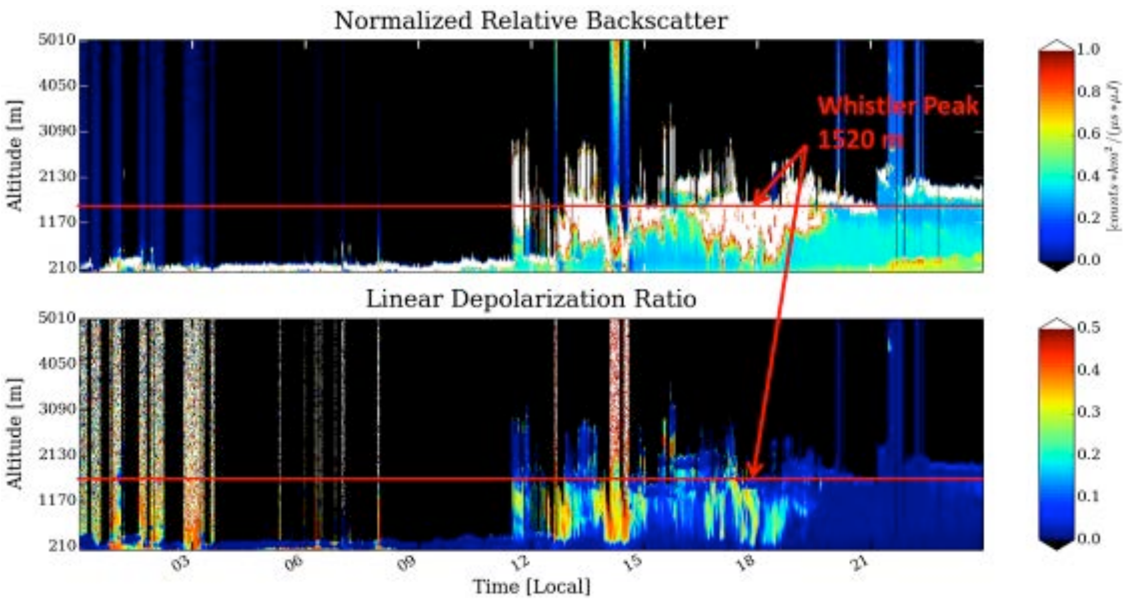

Figure 5: Mini-MPL returns for March 30, 2014. No useful observations before 12:00 due to low clouds. After that, the peak sees intermittent clouds and aerosol layers.

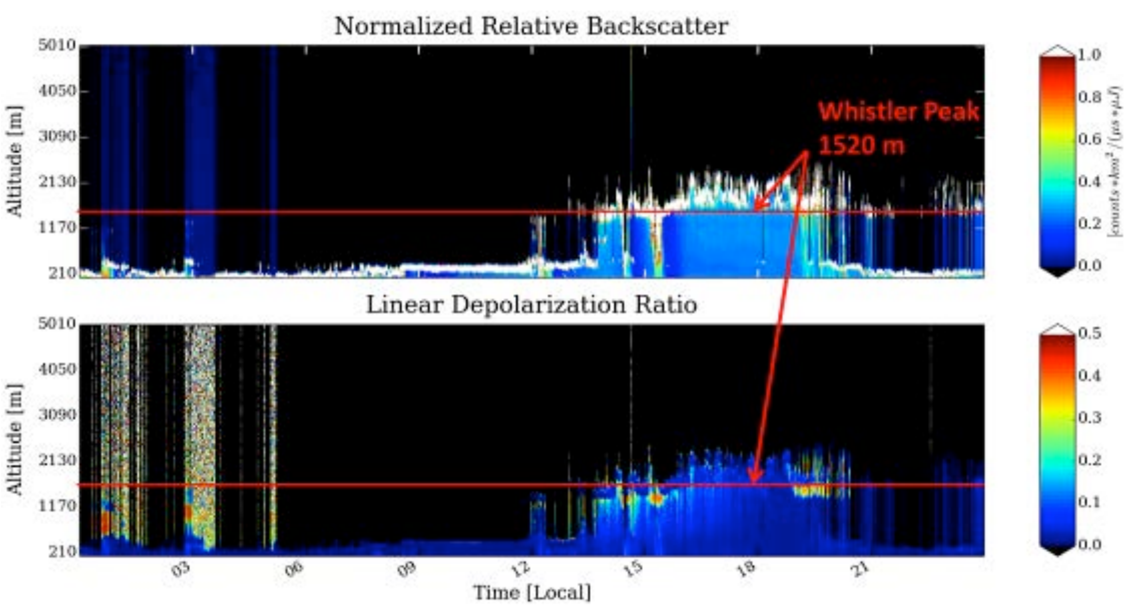

Figure 6: Mini-MPL returns for April 7, 2014. No useful observations before ~13:00 due to low clouds. This recurs after 21:00. In between these periods, the peak is

shown to experience clouds (primarily water clouds) and low levels of background aerosol.

CONCLUSIONS

During the winter deployment in Whistler, the mini-MPL was used to respond to an impromptu request to support a research effort of the Atmospheric Chemistry team from UBC. As the team was investigating the effects of free-tropospheric aerosols on ice-nucleation in clouds, the ability to differentiate between periods when their instruments on Whistler Peak were within the planetary boundary layer was highly desirable. In addition to this function, depolarization ratios from the lidar provided insight into cloud types at and near the peak during observation days and some information regarding aerosol particle shapes. These are both important things to consider when studying ice nucleation.

This deployment will also provide legacy calibration data for the lidar team. The aerosol analysis suite at the peak can provide specific details about particle size and composition that can be used to verify analysis results from lidar data.

ACKNOWLEDGEMENTS

The location of this deployment was generously provided by BC Ministry of Environment and supported by the efforts of Air Quality Technician Lorne Nicklason. This research was supported by a financial contribution from the BC Clean Air Research (BC CLEAR) Fund. BC CLEAR is sponsored by the BC Ministry of Environment, jointly managed with Metro Vancouver and Environment Canada. The Fraser Basin Council administers the program in partnership with the BC Lung Association.

Appendix 3: *Preliminary results from Ucluelet deployment: April 15, 2014 - ongoing*

METHODOLOGY

The Ucluelet deployment was one of the primary goals of the team when purchasing the mini-MPL. The Environment Canada researchers who operate at Amphitrite Point have long been interested in learning more about the development of the boundary layer at their location. It is also interesting to them to identify if and when ship plumes pass and aerosols from long-range transport pass over their location at higher altitudes. This location has not been a good candidate for a permanent lidar installation due to the weather conditions there. Frequent rainstorms, fog, and strong winds are common throughout most of the year. In addition, the location is quite remote, requiring an 11-hour round trip from Vancouver in the event that maintenance is required. Thus, the capability of the mini-MPL to move there during the summer months and operate almost completely autonomously has provided a new capability to investigate these phenomena.

Figure 7: Map showing location of mini-MPL during Ucluelet (Amphitrite Point) deployment.

RESULTS

The spring of 2014 proved to be a very interesting time for the lidar to be in Ucluelet. Repeated incursions of aerosol layers of various types were observed throughout April and May, despite high levels of stray light during peak sunlight hours and some extended periods of fog and low clouds. 2014 turned out to be an especially active year for long-range transport of aerosols from Asia to North America. Strong Asian dust storms in April and May and as a result, Ucluelet received layers of Asian dust aerosols on several days throughout the month of May. There were also ample opportunities to monitor the development of the marine boundary layer at this location. What follows are three interesting cases of aerosol transport and/or boundary layer monitoring that were collected by the lidar at Amphitrite Point.

May 03, 2014:

The aerosol activity above Ucluelet on this day was complex, involving several layers that have yet to be fully identified. In the early hours of the morning, before the sun came up, the marine boundary layer remained a consistent ~500m thick, occasionally topped by clouds. Throughout this period, multiple thinner aerosol layers were consistently observed above the boundary layer. After ~3:00AM, the thickness of this region increased as multiple additional layers were entrained into the lidar field of view, reaching up to ~2000m. The depolarization ratios for these layers were very low, indicating highly spherical particles. This is not consistent with dust or even wildfire smoke, and air parcel back trajectories for this time period do not point to any obvious paths for long-range transport from Asia or elsewhere on the North American coast. Based on this circumstantial evidence, these layers are considered to be good candidates for plumes of ship exhaust.

Later in the day, low clouds appeared along with occasional light drizzle. The resulting wet deposition cleared out most of the low-lying aerosols, but in the lower free troposphere (~1500-3000m), substantial amounts of aerosol remained to interact with thin, mostly watery, clouds.

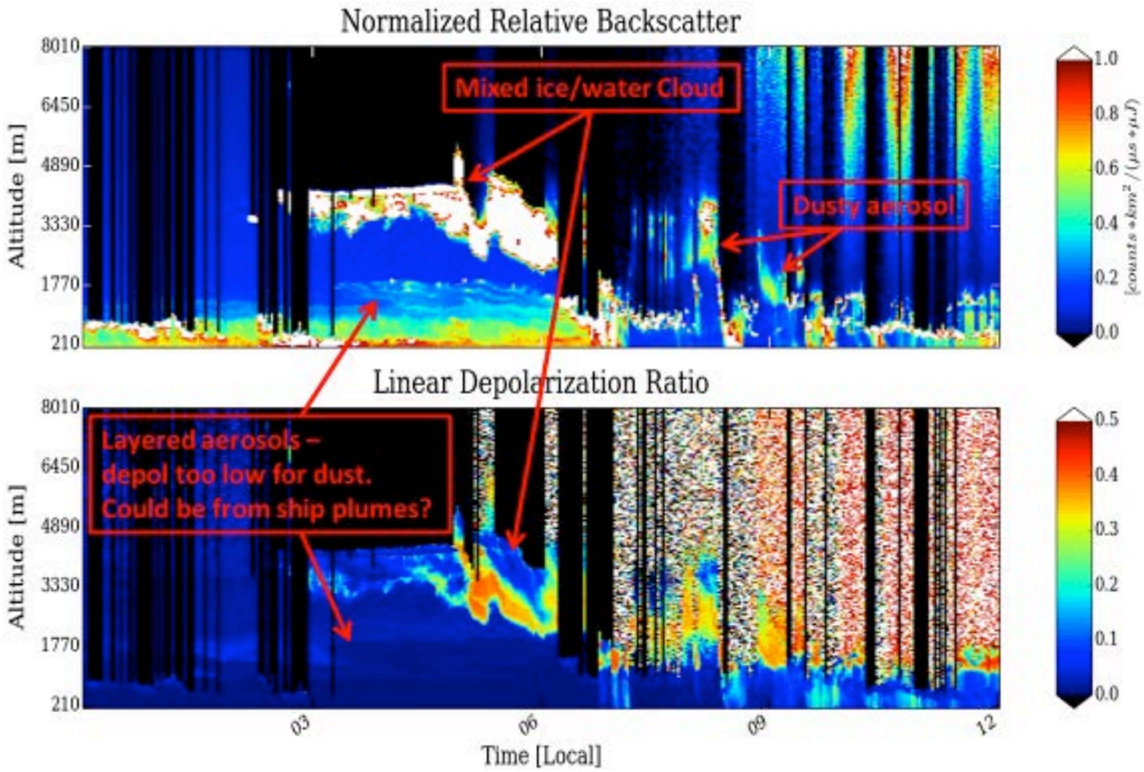

Figure 8: Lidar returns from the morning of May 03, 2014. This day is a good example of the complexities that can be observed at this location. The early hours of the morning was typified by a deep boundary layer, topped with intricate layers of highly spherical aerosols up to ~2000m. Then, from 7:00AM to noon, light rain cleared out the aerosols near the surface while dusty aerosols interacted with thin clouds from 1500-3000m.

These events are still being analyzed with the aid of particulate and air quality data collected from the other instruments co-located with the lidar at Amphitrite Point. However, the intricacy of the layers and processes observed above this location clearly demonstrate the value of using the lidar here.

May 05-May 08, 2014:

The first observation of sustained aerosol layers from Asia this year occurred on the evening of May 05. This year saw a combination of an especially active dust storm season in central Asia, combined with large drought-driven wildfires, and ever-increasing outflows of sulfates from industrial centers in central and coastal China. As a result, aerosol transport models showed multiple aerosol species, in various levels of mixing, being transported across the Pacific to North America.

In Figure 8, we see the lidar returns from May 05-07, showing multiple layers continuously streaming over Amphitrite Point for several days. Although the lidar returns were too attenuated by low clouds at the top of the boundary layer during some periods of this time-frame (e.g. 06:00-17:40 on May 06), there is every reason to believe the Asian aerosol layers persisted throughout.

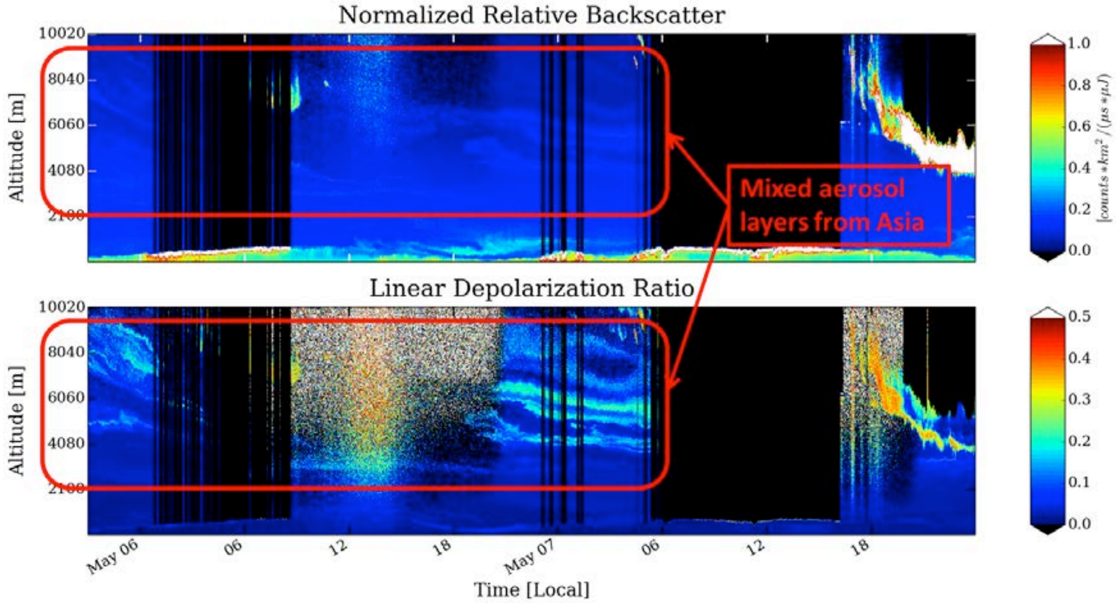

Figure 9: Lidar returns from May 05 - May 07, 2014. During this period, aerosol returns from 2-10km were connected to strong outflows of dust and smoke from Asia.

The depolarization ratios for these layers vary widely from 0.05 to 0.27. The lower depolarization ratios (<0.1) are consistent with sulfates and other industrial emissions. Depolarization ratios in the middle range (0.1-0.2) are more common for wildfire smoke. The highest ratios (>0.2) are indicative of aged dust. Although it is becoming more and more common for all of these aerosol types to be transported across the Pacific, it is quite unusual for them to remain so distinct. Considering the distance these aerosols had travelled, it is more typical for the various particle types to have been thoroughly mixed in the interim. These layers would never have been detected using ground-based observations due to the fact that they passed over at >1km.

The planetary boundary layer was interesting in its own right during this period, as can be seen clearly when one focuses on the lower 2km of the atmosphere (see Figure 10).

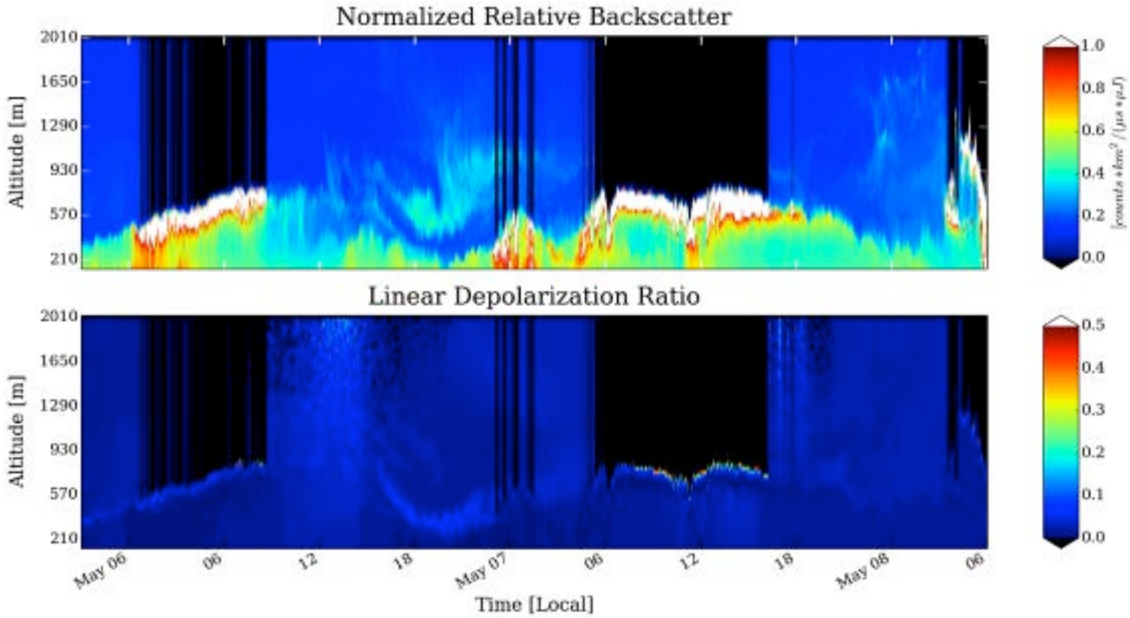

Figure 10: Lidar returns focusing on the planetary boundary layer over Amphitrite Point from May05-08, 2014. This diurnal effect is typical of the daily encroachment of a marine layer.

On each of the days in question, periods of fog and low clouds occurred in the pre-dawn early mornings caused by an encroachment of cool, moist air from the ocean. As the front caused by this marine layer continues inland, the altitude of the capping inversion rises and the fog clears, replaced by low-lying clouds from ~06:00-12:00. Then, as the air near the surface warms, the inversion slowly dissipates. As the low clouds clear, allowing for mixing to occur at the edge of the boundary layer, resulting in the top of the boundary layer slowly dropping toward the surface as the sun descends and the solar heat dissipates, reaching a minimum sometime around midnight.

May 10-15, 2014:

From May 10-15, another dramatic series of aerosol layers form Asia were seen from 2-10km over Amphitrite Point. In this case, the range of depolarization ratios was not as large as in the previous event, ranging from 0.12-0.22. This is likely due to a higher degree of mixing between layers than was seen during the May05-08 events.

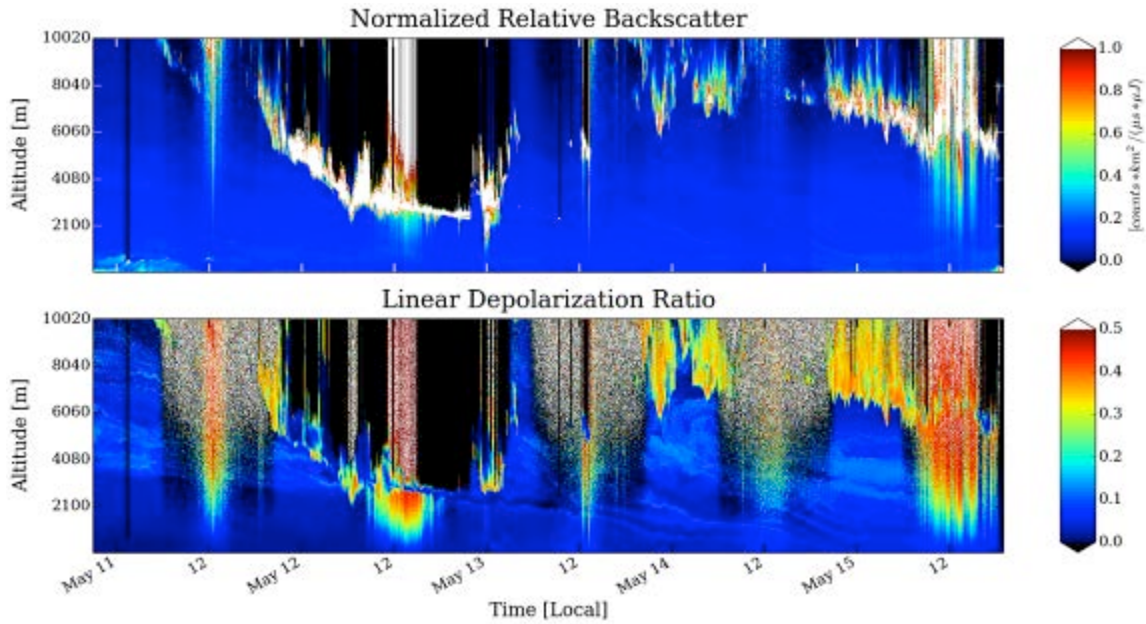

Figure 11: Lidar returns from May 10-15, 2014. Multiple layers of aerosols observed from 2-10km with depolarization ratios varying from 0.12-0.22. As in the results from May 05-08, these layers have been associated with outflows of aerosols from Asia.

In this case, unlike the events of May 05-08, there was no marked cloud layer indicating a strong capping inversion at the top of the boundary layer. This is not conclusive evidence that no capping inversion existed, just that there was no marked change in aerosol concentration to indicate one. In fact, the boundary layer is not visible at all in these lidar returns.

The next step for this and other instances of aerosol transport events monitored in May (and on into June) will be to compare these results to time-series data from the air quality monitoring instruments co-located at Amphitrite point, and others in the lower mainland to determine more about the types of aerosols that were transported to the area during the month of May.

CONCLUSIONS

Over the two short months of the Ucluelet deployment, the mini-MPL showed exactly what makes it such a useful instrument for atmospheric research in British Columbia. Over the course of two days, the lidar was moved to a location that had previously been considered largely unfit for lidar operations for most of the year. While operating there, the lidar was able to provide interesting results on several fronts including long-range transport of aerosols from Asia, continuous monitoring of the boundary layer, and possibly identifying plumes of ship exhaust. The results from the Ucluelet deployment will be combined with other results to contribute to at least one published paper on the large degree of transport of Asian aerosols across the Pacific in 2014.

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