RASCAL AND CRUISER MOBILE TANDEM: A SYNERGISTIC APPROACH TO AIR QUALITY

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ABSTRACT

A mobile scanning lidar facility called RASCAL (Rapid Acquisition SCanning Aerosol Lidar) embarked on a 10000 km journey that begun in November 2004 and ended in September 2005. The field measurements included stops in Windsor, Ontario, interior and coastal British Columbia including the Gulf Islands and concluded southeast of Edmonton, Alberta. RASCAL was part of a tandem of highly specialized vehicles providing mobile measurements using dual-wavelength scanning lidar technology and a sophisticated high-temporal resolution chemistry package providing real-time in-situ measurements. The synergistic approach allowed detailed measurements of the complex three-dimensional structure of the atmosphere and coincident detailed chemistry observations of the constituents near the ground. Examples include the town of Golden, British Columbia, a small town nestled between the Purcell Mountains on the west and the Rocky Mountains on the east. The poor air quality in Golden is attributed to local industrial, residential (wood smoke) and vehicular sources as well as the steep mountains rising on both sides, and the absence of wind. These factors provide a unique airshed for air quality observations which include the complex re-circulation of pollutants due to upslope and downslope flows. In addition, the springtime months of March and April provide an opportunity to measure the long-range transport of trans-Pacific pollutants that impact the coastal areas of British Columbia frequently and sometimes even penetrate to the borders of Ontario and Quebec. A variety of highlights will be presented including a rare opportunity to measure a Saharan Dust event impacting the coast of British Columbia.

1. INTRODUCTION

The remote sensing technique of lidar is critical in understanding the vertical structure, mixing and transport of pollutants in a highly inhomogeneous atmosphere. Aerosol lidars are a subset of lidars particularly suited to measuring the small aerosol particles (particulate matter), not generally visible to the naked eye, with high spatial and temporal resolution. Environment Canada currently has four aerosol lidar systems; a simultaneous upward/downward airborne lidar called (AERIAL [1] – AERosol Imaging Airborne Lidar), a downward pointing aircraft lidar aboard a Cessna 207 called SALSA (Small Aircraft Lidar System for Aerosols), a ground-based zenith pointing lidar at the Centre For Atmospheric Research Experiments (CARE) called ALIAS (Aerosol Lidar Instrument for Atmospheric Studies) and a mobile scanning lidar facility also known as RASCAL [2,3] (Rapid Acquisition SCanning Aerosol Lidar). RASCAL can operate in two primary data collection modes: mobile transects along roads and highways, vertically sampling the atmosphere directly above the vehicle or parked in a single location obtaining scanning profiles from near ground height to the zenith.

RASCAL along with another mobile lab (CRUISER – Canadian Regional and Urban Investigation System for Environmental Research), with a sophisticated chemistry package, formed a research tandem making coincident measurements across three provinces. The main field measurement areas were Windsor, Ontario, Golden, British Columbia, coastal British Columbia and Miquelon Lake Provincial Park, southeast of Edmonton Alberta (Fig. 1 shows the locations of the western field sites). Each field site provided its own unique story and therefore research focus. For example, Golden, British Columbia was chosen for several reasons. The provincial government has been making measurements in Golden for several years and currently has three monitoring stations: one upwind of Golden, one in the Town centre and one at the eastern limit of the town. The main thrust of RASCAL and CRUISER was to provide a source apportionment of the main sources in the Golden airshed at time of year where the PM10 and PM2.5 showed the greatest variability. The poor air quality in Golden is attributed to local industrial, residential (wood smoke) and vehicular sources. The main industry is at the western edge of town (generally upwind) and manufactures plywood and other laminated wood products. In the winter months most of the residents of Golden burn wood as a heating source because it is abundant and cheap. For the past couple of years a program has been in place to help local residents purchase more efficient word burning stoves/fireplaces to reduce emissions. The vehicular sources are diesel emissions from the local CPR facility and the heavy truck traffic that passes through and overnights in Golden. Due to winter conditions, Golden can routinely be the refuge of 500-600 trucks until the main highway re-opens. A secondary component of vehicular sources of significance is the re-suspension of road traction material primarily from vehicle traffic. The air quality in Golden is further exasperated by the tall mountains surrounding the area and stagnant conditions. This implies that the pollution that is created there, stays there, unless a synoptic "cleansing" event passes through the area.

FIG. 1. A map of British Columbia and Alberta showing the four different locations of RASCAL and CRUISER (indicated by the arrows).

2. INSTRUMENTATION

2.1 RASCAL (Rapid Acquisition SCanning Aerosol Lidar) Facility

A mobile laboratory, called RASCAL (see Fig. 2), was designed to provide rapid lidar scanning profiles of the lower troposphere in remote locations. The vehicle has an electronic levelling system to provide a stable, level environment for scanning lidar operation. The basic components of a scanning lidar system consist of a laser, beam directing/collection optics and a telescope with a detection package to convert the signal for a data acquisition system that can process, display and save the data in real-time. A pulsed laser emits a burst of photons into the atmosphere. A detection system measures the amount of light scattered back from the particles in the atmosphere. The analog signal from the detector is digitized along a set range (typically 12 km) providing a resolution of 3m along the beam axis. For an individual elevation scan, the scanned region is best described by a pie shape, bounded by the upper and lower scan limits. Therefore, the spatial resolution is a function of the distance from the laser. The scattering volume will be defined by the 3m resolution along the beam axis and the scan speed. RASCAL is based on a two-mirror design with the first mirror being fixed and the second mirror free to rotate via an azimuth and elevation rotational stage (see Fig. 2). The detector employed was a 35.6 cm Celestron Schmidt-Cassegrain telescope with an 8 mrad field-of-view that focused the captured light into a detection package that splits the light into two wavelengths. The detectors were connected to logarithmic amplifiers made by Optech Inc. to increase the dynamic range. This is particularly important when operating the lidar where aerosol concentrations vary significantly within the scan range. The amplifiers were calibrated prior to the experiment via a transfer function to convert the signal to a linear scale in addition to second order corrections provided by Optech Inc. The signals were then sent to a Gage

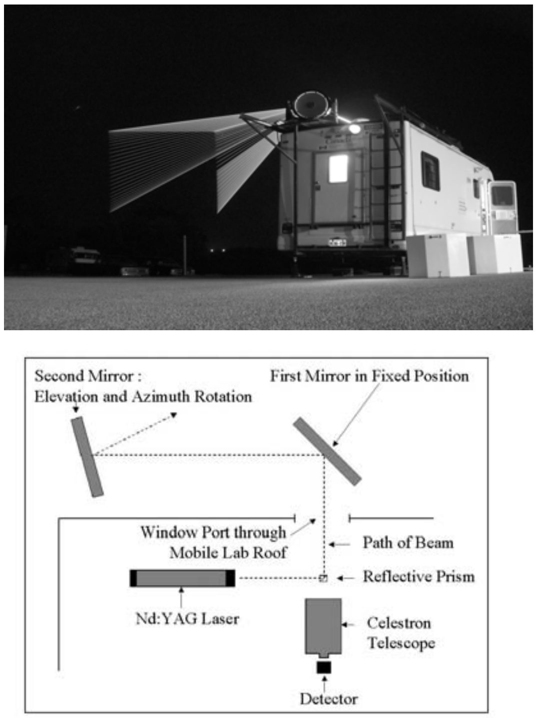

FIG. 2. A time-lapse picture of RASCAL (left). A schematic diagram showing the optical layout of RASCAL (middle).

14-bit, PCI card where the information was digitized at 50 MHz (3m resolution along the beam axis). The laser was a Continuum Powerlite 8020 Nd:YAG with a measured output energy of 850mJ and 400mJ at 1064nm and 532nm respectively. The a-scope display and false-colour backscatter ratio plots are shown in real-time with the ability to zoom in and out during data collection. This is extremely valuable when working with other research platforms which depend on real-time information for their data collection.

2.2 CRUISER (Canadian Regional and Urban Investigation System for Environmental Research)

CRUISER (see Fig. 3) is a new facility (2004) developed under the auspices of a new Federal Government initiative known as the Border Air Quality Strategy. The vehicle platform is a GMC 7500 series diesel truck with a Unicell body housing several in-situ measurement packages. Similar to RASCAL, CRUISER has an onboard generator to allow remote, mobile measurements. While under generator power, care must be taken to not sample the generator exhaust. Several feet of ducting material and monitoring the wind direction generally negate the risk. A primary inlet for particle sampling protrudes from the top of the body, pointing forward. The two main instruments aboard CRUISER are an Aerodyne Aerosol Mass Spectrometer (AMS) and Ionicon Analytik Proton-Transfer Reaction Mass Spectrometer (PTRMS) making high temporal resolution measurements of particle and gas-phase chemistry. The AMS [4] allows size-segregated, speciation of particles – sulfate, nitrate, ammonium and organic carbon. The PTRMS is currently targeting compounds such as benzene, toluene, xylenes, acetaldehyde, isoprene and PAN. In addition to the AMS and PTRMS, CRUISER has a TEOM, Condensation Particle Counter, GRIMM particle counter, Aetholometer and Meteorological Station mounted on a telescoping tower with a range of approximately 10m above ground.

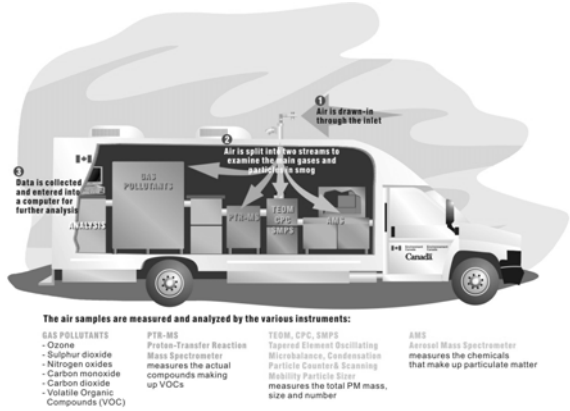

FIG. 3. A detailed schematic of CRUISER showing the instrument layout.

3. RESULTS AND DISCUSSION

RASCAL was located at the Golden airport which provided an excellent "view" of the entire airshed. The map of Golden (see Fig. 4) shows the direction of the elevation scans. These were chosen to provide information upwind of the town, near individual sources and down the valley axis to the east. Two grayscale RASCAL images corresponding to two elevation scans are also shown in Fig. 4. The top image represents a "slice" just downwind of the "plywood" plant. The cross-sectional slice of the plume is quite evident in the image (brighter colours represent higher particle concentrations). RASCAL images are plotted using a logarithmic colour scale to permit the higher concentration of particulates in the boundary layer to be displayed with the significantly lower concentration in the free troposphere. The image also shows some local sources on the mountainside and both images show the re-circulation of pollutants forming aerosol layers aloft. The lower RASCAL image goes directly over the CPR rail yard. The top of the boundary layer resides at about 300-400m (typical during winter time measurements in Golden).

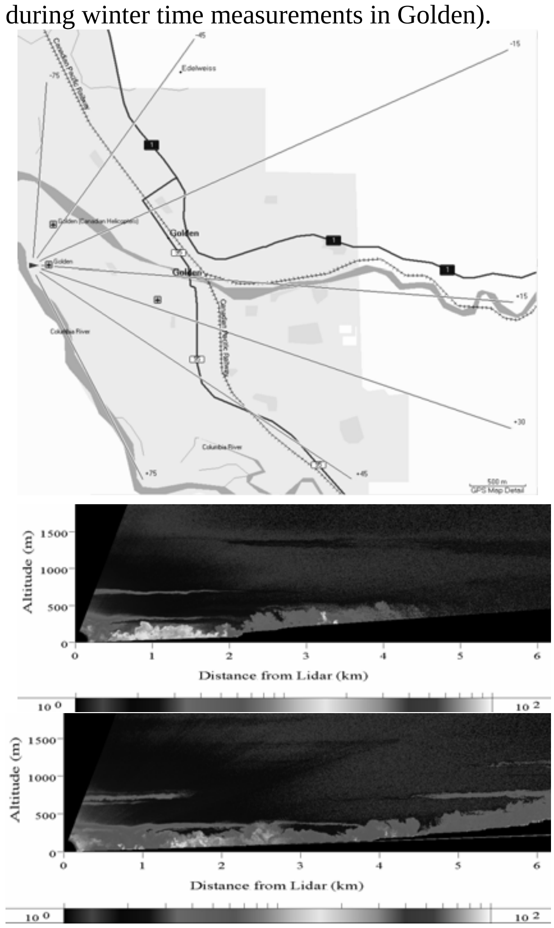

FIG 4: The map of Golden to the left is superimposed with the various scan angles of interest over the Golden airshed. The two RASCAL scans show the variability of aerosols across the valley floor and complex re-circulation of pollutants aloft.

Coincident measurements were made with CRUISER located at distance of 1800 m from RASCAL on the ridge face. Fig. 5 represents RASCAL data obtained directly over the site where CRUISER was deployed to sample the air along the lidar's path. A location near the bottom of the mountain ridge was chosen to park CRUISER where it would be impacted by pollutants flowing up the slope. The RASCAL images give an example of the variability over one hour. The aerosols where mixing within a 200 m layer over the valley floor, getting compressed as they go up the mountain slope. Again there is evidence of recirculation of pollutants forming aerosol layers aloft. CRUISER data shows the variability in particle size as a function of time with the composition being predominately organic matter with a small nitrate component.

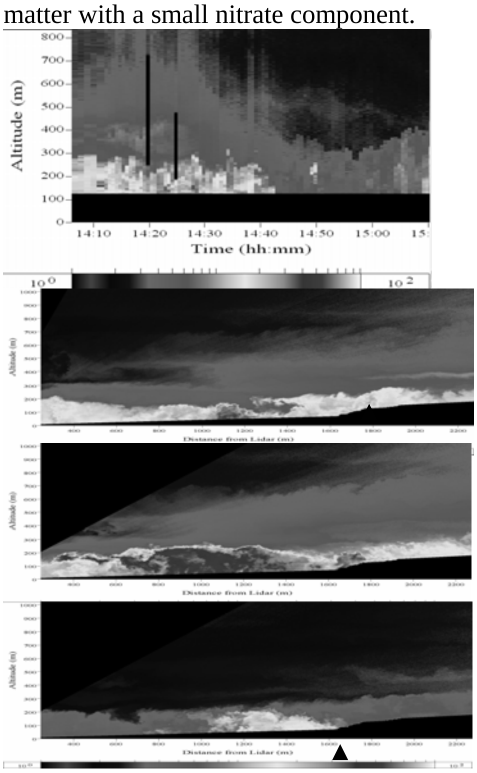

FIG. 5: A composite plot of RASCAL images collected over the location of CRUISER (top). The other three panels show 40 second elevation scans spaced apart by approximately 30 minutes. A high degree of variability is clearly shown. The arrow indicates the location of CRUISER

4. SUMMARY AND FUTURE WORK

Since PM transport is a three-dimensional problem, lidar has the advantage over ground-based in-situ measurements in determining the vertical extent and spatial distribution of PM over such regions as the Golden airshed. RASCAL has both the resolution (spatially and temporally) and sensitivity to measure the dynamics of the tropospheric aerosol burdens. The large optical path and laser pulse power of RASCAL allows one to measure highly variable aerosol concentrations. The Golden airshed is complex due to the topography and local meteorology providing a challenge to source apportion the area. The tandem of RASCAL and CRUISER will provide detailed measurements of the local sources and there transport characteristics. The re-circulation of pollutants increases the complexity of the airshed and underlines the importance of making measurements aloft with such instrumentation as lidars. The next important step will be to compare RASCAL and CRUISER measurements at all the measurement locations. This should lead to an increased understanding of each complex airshed using state-of-the-art remote sensing and in-situ technology. Plans are already underway this year to deploy RASCAL, CRUISER and SALSA in the Windsor/Detroit area to look at cross-border transport issues within the region.

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6. REFERENCES

1. Strawbridge, K.B., and Snyder, B.J. Daytime and nighttime aircraft lidar measurements showing evidence of particulate matter transport into the northeastern valleys of the Lower Fraser Valley, B.C. *Atmos Environ.* 38 (34): 5873-5886. 2004.

2. Strawbridge, K.B. and Snyder, B.J. Planetary boundary layer height determination during Pacific 2001 using the advantage of a scanning lidar instrument. *Atmos Environ.* 38 (34): 5861-5871. 2004.

3. Reuten, C., Steyn, D.G., K.B. Strawbridge, K.B., Bovis, P. Observations of the Relation between Upslope Flows and the Convective Boundary Layer in Steep Terrain. *Bound. Layer Met.,* 116:37-61. 2005.

4. Brook, J.R., Strawbridge, K.B., Snyder, B.J., Boudries, H., Worsnop, D., Anlauf, K.G., Sharma, S. and Hayden, K. Towards an understanding of the fine particle variations in the LFV: Integration of chemical, physical and meteorological observations. *Atmos Environ.* 38(34): 5775-5788. 2004.