Compact Raman Lidar (CRL) Water Vapor and Temperature Measurements During SWEX

Zhien Wang, Professor
University of Colorado, Boulder
Laboratory for Atmospheric and Space Physics
Department of Atmospheric and Oceanic Sciences
3665 Discovery Dr.
Boulder, CO 80303-7819
Phone: 303-492-1613 (office)
zhien.wang@colorado.edu
ORCID: 0000-0003-3871-3834

1.0 Data Set Overview:

Compact Raman Lidar (CRL) measurements of water vapor, aerosol, and temperature profiles from the Twin Otter (TO) during SWEX (April 1 to May 15, 2022) are provided.

2.0 Instrument Description:

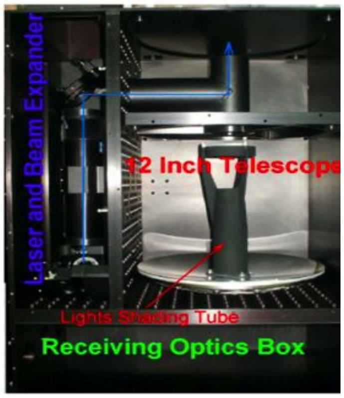

Figure 1. Photograph of CRL inner structure.

The CRL is the first Raman lidar system developed for use on the University of Wyoming King Air (UWKA). It uses a compact, lightweight transmitting-receiving design. As illustrated in Fig. 1, the CRL integrated telescope, laser, and receiving system fits into a box of 13x20x26 inches weighing approximately 100 lbs. The CRL was initially developed to obtain 2-D distributions of water vapor, aerosols, and clouds and was first deployed on the UWKA in 2010 (Liu et al. 2014). In early 2015, low-J and high-J pure rotational Raman channels (J is the rotational quantum number) were added to provide temperature measurements (Wu et al. 2016). Table 1 lists the specifications of CRL. During the SWEX, the old low laser energy (50-mJ) was upgraded to a 150-mJ laser providing significantly improved data for characterizing the spatial variability of aerosol, water vapor, and temperature. CRL water vapor and temperature measurement accuracies generally depend on the range and averaging, as discussed in sections 3 and 4.

Table 1. Main system parameters of CRL and MARLi including the Normal Ocular Hazard Distance (NOHD)

	CRL
Laser	Bigsky DLR, GRM
Wavelength (nm)	354.7
Pulse Energy and width	150 mJ and 9 ns

Repetition Rate (Hz)	30
Beam Expander	5x
Telescope (Cassegrain)	
Size (inch)	12
Field of View (mrad)	1
Receiving System	
Channel Number	5
Detector (PMT)	Hamamatsu H10720
Data Acquisition	NI 16-bit, 250 MHz A/D card
NOHD (meters)	< 200

3.0 Data Collection and Processing:

During SWEX, the TA conducted afternoon and night flights (~3.5 hours), typically for IOPs and EOPs. TA followed predetermined flight patterns for each flight to collect data at 11,000 ft or 8,000 ft. The high flight legs mainly optimize for dropsonde and wind lidar measurements, while the lower legs are for CRL to profile water vapor and temperature down to the surface during the daytime.

CRL data processing involves three critical aspects: near range overlap correction, averaging, and calibration. Because of slightly different near range overlap functions among channels, we need to correct their differences for aerosol lidar scattering ratio (LSR) and temperature determinations. During the SWEX, dropsonde measurements were used to develop near-range overlap correction for temperatures and the cleanest aerosol regions was used for LSR correction development. Due to TA’s flight level limitations (unpressured), low aerosol cases within 1 km below the flight level are difficult to find which introduce additional uncertainties in LSRs.

Realtime CRL data were recorded at 1 Hz and 0.6 m vertical resolution. During the post-data analysis, profiles are averaged to 4-s temporally (~ 200m horizontally) and 6 m vertically, and final results are reported at these resolutions. A 30 m vertical and ~ 2 km horizontal moving averaging window is applied for water vapor mixing ratio (WVMR), temperature, and LSR calculations. Before the moving averaging, surface/treetop detections were performed. To avoid surface contamination, the averaging is only applied to signals above the surface; thus, the near surface has less averaging in the current processing. “Leefilt” (an IDL routine, Lee 1986) is applied for further vertical smoothing to remove high-frequency noise. CRL water vapor calibration has been consistent during the last three years, and the same calibration value was applied to SWEX data. We have to apply time-dependent calibration draft corrections for temperature measurements due to cabin temperature variations.

CRL WVMR and temperature measurements are compared with dropsonde measurements. Figure 2 shows the time-height plot of CRL WVMR and temperature overplotted with dropsonde measurements. Dropsonde data are merged with CRL data smoothly, indicating that the two measurements are consistent. Figure 3 shows a profile comparison between the two measurements supporting the same conclusion. Under an environment with significant spatial and temporal variations, comparisons of CRL and dropsonde measurements could be challenging because dropsonde could drift a considerable distance horizontally. The statistical comparison in Fig.4 shows a mean T difference of -0.34 and a mean WV difference of 0.06 g/kg, indicating reliable CRL measurements when signal-to-noise ratios are good.

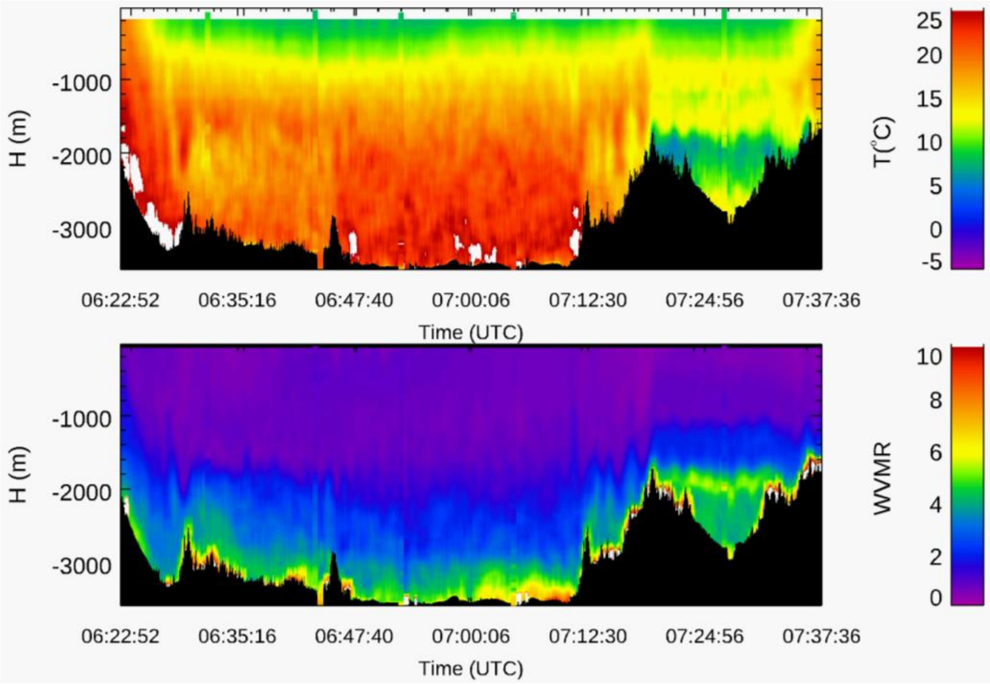

Figure 2. An example CRL WVMR and temperature measurements on April 5th, 2022, showing large spatial variations of WVMR and temperature. Five dropsonde profiles are overplotted, which can be identified at the top 200 m in CRL temperature plot.

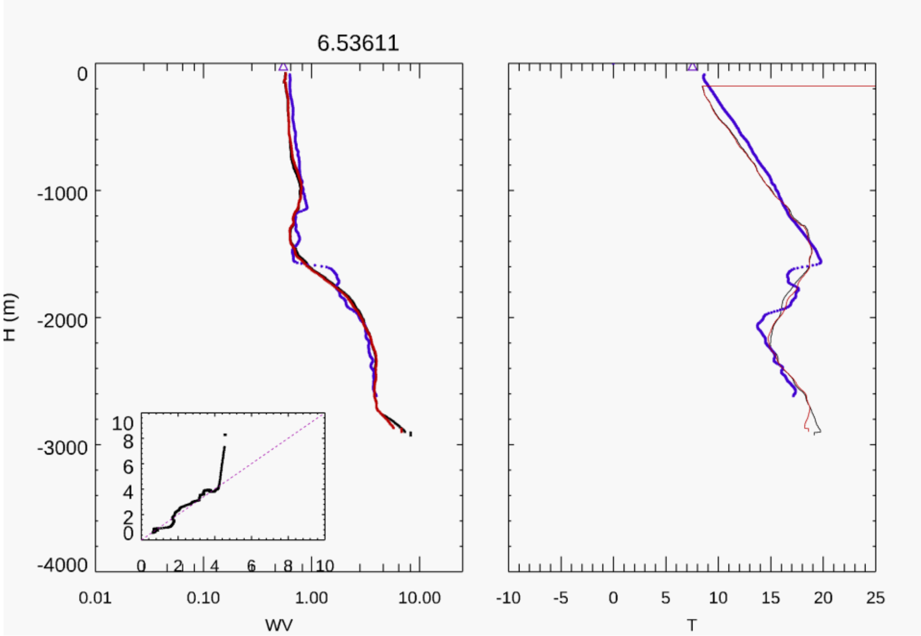

Figure 3. An example of comparison of CRL and dropsonde (blue) WV and temperature profiles. The y-axis is the height below the flight level. Triangles near the flight level indicate TO's in situ measurements. For this case, dropsonde drifted over 2-km horizontally.

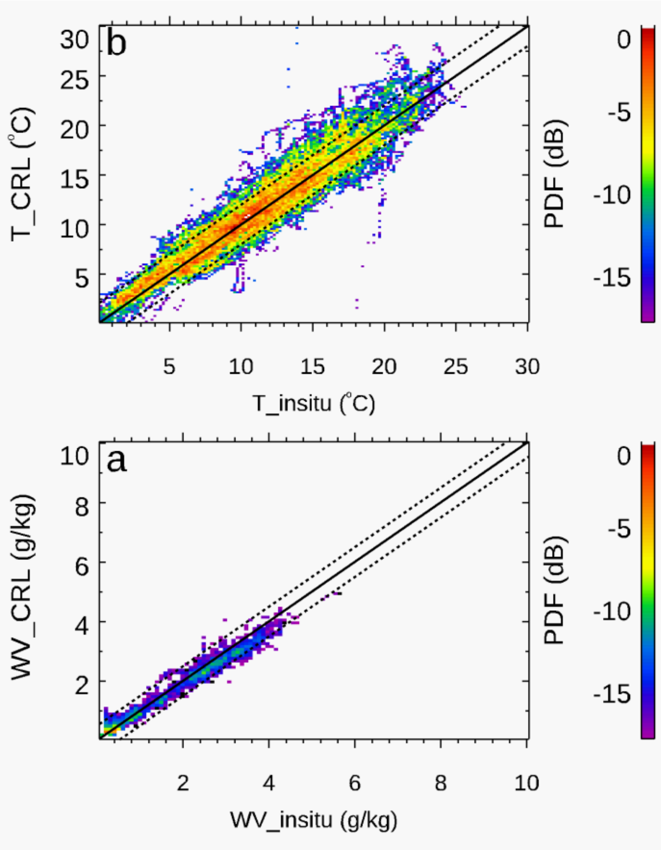

Figure 4. Scattering plots of CRL and dropsonde measurements based on nighttime collocated measurements during the SWEX.

A wave example in Fig. 5 highlights CRL's capability to resolve sub-km spatial/ variations of PBL structures within the SWEX targeted area. Wave structures can be easily identified with CRL water vapor measurements. The distance from the peak over the mountain top to the trough is ~5 km. Cooling and warming structures of waves are clearly observed by CRL. A lower TO cruise speed than the other research aircraft makes such an observation possible.

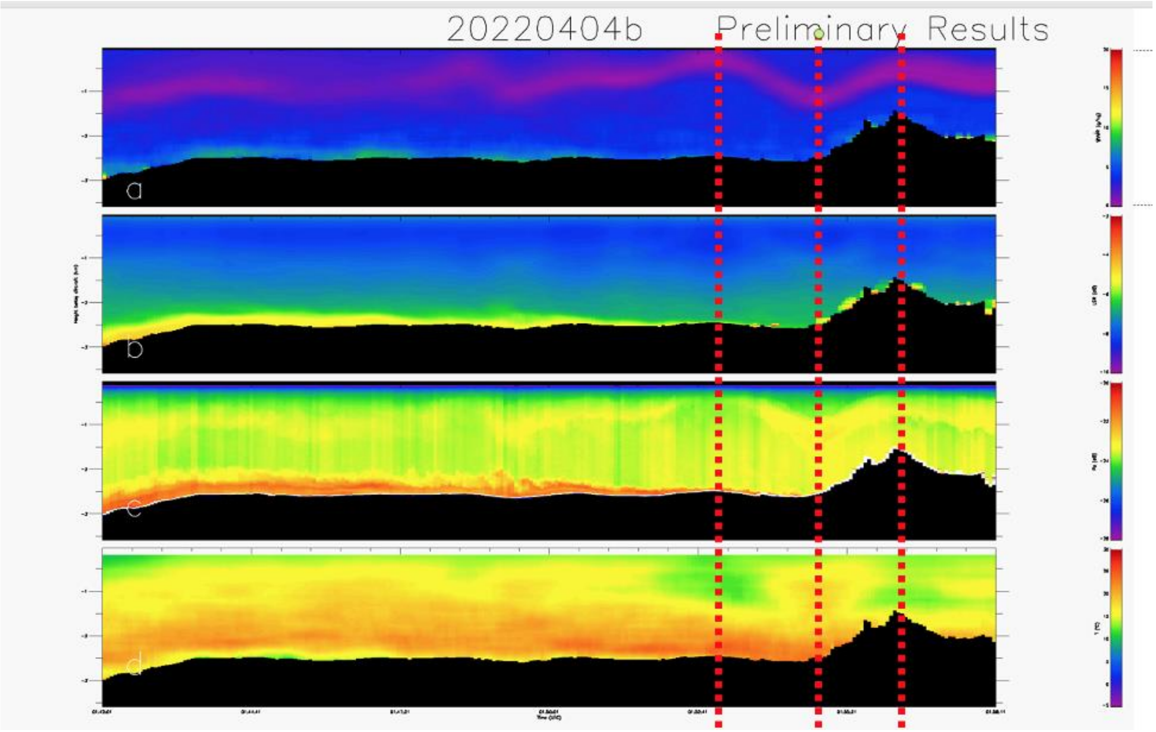

Figure 5. A quick look image showing WVMR, T, and aerosol cross-sections from ocean to mountains with strong wave activities over mountains. Y-axis is the height below the flight level. Three red dashed vertical lines indicate wave peaks or troughs, where consistent T and WV structures are observed.

4.0 Data Format:

CRL Data for each flight is saved into a NETCDF file containing related information for each variable. Other than CRL data, TO flight location and altitude are provided to geo-locate CRL measurements. JPG image is also provided for each NetCDF file.

5.0 Data Remarks:

The data were processed to provide high spatial resolutions to resolve fine-scale PBL structures. The same averaging is used for day- and night-time data processing. Due to the high solar background, daytime water vapor measurements beyond 2 km of the flight level are noisy. We could improve SNR for data beyond 2 km of the flight level by increasing horizontal and vertical averaging. If you need specific processing of CRL measurements for selected SWEX cases, feel free to contact the instrument PI.

6.0 References:

Wu, D., Z. Wang, P. Wechsler, N. Mahon, M. Deng, B. Glover, M. Burkhart, W. Kuestner, and B. Hesen, 2016: Airborne compact rotational Raman lidar for temperature measurement. *Optics express*, **22** (17), to be submitted.

Wang, Z. et al., 2015: AIRBORNE RAMAN LIDAR AND ITS APPLICATIONS FOR ATMOSPHERIC PROCESS STUDIES, Presented at Twenty Seventh International Laser Radar Conference, July 5 - 10, 2015, New York City, NY.

Liu B., Z. Wang, Y Cai, P. Wechsler, W Kuestner, M Burkhart, W Welch, 2014: Compact airborne Raman lidar for profiling aerosol, water vapor and clouds, *Optics express*, **22** (17), 20613-20621.

Wang, Z. and Co-authors, 2011: Observations of boundary layer water vapor and aerosol structures with a compact airborne Raman lidar. 5th Symposium on Lidar Atmospheric Applications, 91st AMS Annual Meeting, Seattle

Lee, Jong-Sen, 1986: Speckle suppression and analysis for synthetic aperture radar images, Opt. Eng. 25(5), 255636, https://doi.org/10.1117/12.7973877.