Processed SWEX Wyoming Cloud Lidar (WCL) Level 1 data

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1.0 Data Set Description

This data set contains the processed WCL data collected on board of Naval Postgraduate School (NPS) Twin Otter airplane during the SWEX (Sundowner Winds Experient) field project from April 1- May 15, 2022. This data set is in NetCDF file.

Data version: 0.1 (2022-07-26)

Data Status: Preliminary

Time period covered by the data: April 1 – May 15, 2022

Physical location (including lat/lon/elev) of the measurement or platform:

The WCL was on board of NPS Twin Otter, which flew in the following domain:
Maximum (North) Latitude: 36.00, Minimum (South) Latitude: 34.00
Minimum (West) Longitude: -120.00, Maximum (East) Longitude: -118.00

Data Frequency - Frequency of data collection: 2 Hz

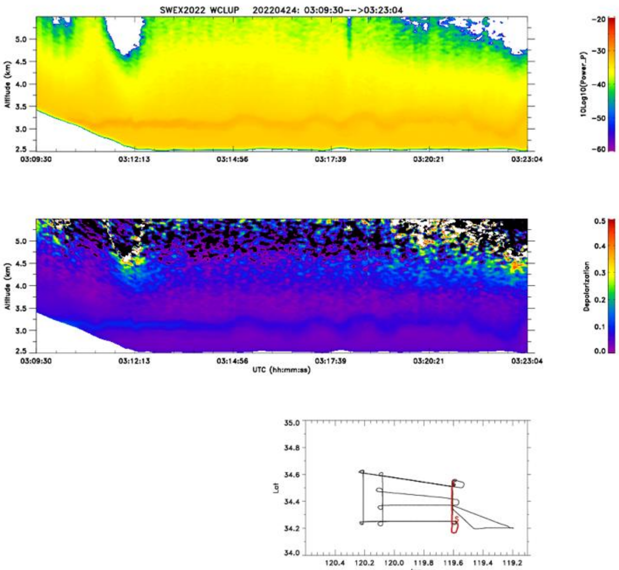
Related project: SWEX: Sundowner Winds Experiment

UW WCL Web address references: https://www.uwyo.edu/atsc/uwka/wyoming-cloud-lidar.html

Data set restrictions (i.e., requires password)

2.0 Instrument Description

The upward two Fields of View (2FOV) WCL is a compact four-channel elastic lidar with depolarization measurement. With the size, pulse energy, and eye safety of the laser for aircraft installation in mind, a small telescope of 10 cm diameter combined with a relatively high pulse-energy laser is used: Ultra Pulsed Nd:YAG Laser from the Big Sky Laser Technologies, Inc. It provides 20 Hz and 12 mJ output at 355 nm. This wavelength not only makes it easy to achieve eye-safe operation, but also provides a stronger molecular backscatter signal than a lidar operating at 532 or 1064 nm with the same laser energy. This is important for calibrating backscatter coefficients. The laser beam is expanded 5 times to a diameter of 15 mm before entering into the atmosphere, making the system eye safe beyond a distance ~65 m. For more details about WCL system specifications and its applications, please refer to Wang et al., (2009). WCL linear depolarization ratio measurements provide important information on aerosol particle shapes, especially when combined with backscatter intensity. The WCL is sensitive enough to provide high spatial resolution measurements of boundary layer aerosols, which, in turn, provides new opportunities for boundary layer aerosol studies. During the SWEX, the WCL data is complementary with downward-looking Compact Raman Lidar data to provide the whole atmosphere profile of aerosol and clouds.



The aerosol layer in Figure 1 indicated by high backscattering and depolarization ratio below 3.5 km is apparent. The aerosol layer shows stronger wave patterns as the Twin Otter flew northward.

Figure 1. From the top to bottom are WCL measured attenuated backscattering, depolarization ratio, and the flight leg (red line) over the entire IOP flight track (black line), where the leg's starting and ending points are noted as S and E, correspondingly.

3.0 Data Collection and Processing

The WCL was turned on to work after the Twin Otter flew above the eye-safety level over a predesignated flight pattern. As the laser pulse travels along, part of it is scattered by molecules, water droplets, or other objects in the atmosphere. A small portion of the scattered light is scattered back, collected by the telescope, and detected by the photomultiplier tubes (PMT). The collection of bins for each pulse is called a profile. The following instrument-level corrections have been applied to produce the standard Level 0 and Level 1 data.

3.1 Background noise correction

Background noises due to the sunlight at 355 nm and the PMT noise are collected in addition to atmospheric backscatter signal, and they need to be subtracted. As the WCL is designed, pre-trigger values (data before the laser pulse is transmitted) are recorded for the average background noise correction. We can also use the far range average for subtraction assuming no atmospheric signal. In the SWEX data processing, we use the averaged noise from the far range (9-10 km) data. First, there are no clouds observed. Second, the measured clear-sky backscatter signal after noise correction is checked to be parallel to the simulated atmospheric Rayleigh scattering, which indicates that no additional atmospheric backscatter signal is subtracted using the far range data.

3.2 Overlap factor correction

Overlap factor correction is applied as a function of range to account for loss in the near-field receiver efficiency, which is deliberately minimized to avoid the detector saturation from strong lidar signal. Prior to the project deployment, the WCL was aligned and tested in the test flights.

3.3 Range- square correction

The PMT signal needs to be range-corrected to derive backscatter coefficients of the atmospheric scatters. The noise residue or random noise is magnified in the range correction. Therefore, as the range increases, the noise residue in the signal also increases in the range-square correction, resulting in a decreasing signal-to-noise ratio (SNR) with range.

3.4 Lidar depolarization ratio (LDR) calibration

To improve lidar LDR measurements, a 1/2 λ wave plate is placed after the beam expander and coupled with a cubic polarization beam splitter in the receiver path to split the received backscatter light into parallel and perpendicular channels. During the LDR test in the lidar lab, the offset angle between the half-wave plate and the cubic polarization beam splitter is adjustable with one-degree steps. The WCL calculated LDR of variant offset angles are fitted with the simulated LDR of clear sky to find the exact offset angle and the WCL LDR calibration constant.

3.5 Attenuated backscatter coefficient calibration

To generate the standard Level 1 data of calibrated attenuated backscatter coefficient, we simulated molecular range-corrected backscatter profiles using in situ measurements of temperature and pressure at the flight level, assuming standard atmospheric profiles. The calibration factor is the ratio of the simulated molecular backscatter and the WCL clear sky measurement. Due to the decreased SNR with range, the calibration factor is averaged between

1–3 km range and above boundary layer to avoid significant noise effect and low-level aerosol contamination. The data over two fields of view channels are combined and optimized into one set of backscattering and depolarization ratio in the WCL L1 dataset.

More detailed data processing information can be found in Deng et al 2022. Variation in the calibration factor can be significant due to laser variations and flight situations. A cross comparison with Compact Raman Lidar data would be desirable when the data is available.

4.0 Data Format

- Data file structure and file naming conventions

  Data files are in NetCDF format. All filenames submitted to the catalog conform to the following convention:

  ```
  category.platform.YYYYMMDDHHmmss.product.extension
  ```

  Example:

  The NetCDF file of the data:

  aircraft.CIRPAS_NPS_Twin_Otter.20220414040909.WCLUP_Backscatter_Depol_L1.nc

  The quick look image file of the corresponding data file:

  aircraft.CIRPAS_NPS_Twin_Otter.20220414040909.WCLUP_Backscatter_Depol_L1.gif

- Data format and layout

```
Netcdf aircraft.CIRPAS_NPS_Twin_Otter.20220405002752.WCLUP_Backscatter_Depol_L1 {

dimensions:
    profile = 1387 ;
    range = 7935 ;
    vector3 = 3 ;

variables:
    double Time(profile) ;
            Time:long_name = "Profile acquisition time" ;
            Time:units = "seconds since 2022-04-05 00:00:00 +0000" ;
            Time:strptime_format = "seconds since %F %T %z" ;
    double time(profile) ;
            time:long_name = "Profile acquisition start time" ;
            time:units = "seconds since 1970-01-01 00:00:00 +0000" ;
            time:strptime_format = "seconds since %F %T %z" ;
    float Range(range) ;
            Range:long_name = "Range from Aircraft to the center of lidar range gates" ;
```

```
		Range:units = "meters" ;
	float CopolPowerR2(range, profile) ;
		CopolPowerR2:long_name = "Backscatter Pr2 from the parallel channel of High gain" ;
		CopolPowerR2:status = "mean noise subtracted, overlap corrected, no attenuation correction" ;
		CopolPowerR2:_Fillvalue = -32767.f ;
		CopolPowerR2:units = "/km" ;
		CopolPowerR2:Vertical_Resolution = "1.5 m" ;
	float CrossPowerR2(range, profile) ;
		CrossPowerR2:long_name = "Backscatter Pr2 from the perpendicular channel of High gain" ;
		CrossPowerR2:status = "mean background noise subtracted " ;
		CrossPowerR2:_Fillvalue = -32767.f ;
		CrossPowerR2:Vertical_Resolution = "1.5 m" ;
		CrossPowerR2:units = "mW" ;
	float DepolarizationRatio(range, profile) ;
		DepolarizationRatio:long_name = "volume depolarizationr ratio" ;
		DepolarizationRatio:status = "lab corrected deplorization ratio" ;
		DepolarizationRatio:_Fillvalue = -32767.f ;
		DepolarizationRatio:Vertical_Resolution = "1.5m" ;
		DepolarizationRatio:units = " " ;
	float height_2d(range, profile) ;
		height_2d:long_name = "2D height from range and zenith angle" ;
		height_2d:status = "corrected WCL height according to aircraft zenith angle " ;
		height_2d:_Fillvalue = -32767.f ;
		height_2d:Vertical_Resolution = " " ;
		height_2d:units = "m" ;
	short Prof_qc_flag(profile) ;
		Prof_qc_flag:long_name = "quality control check flag" ;
		Prof_qc_flag:status = "1 - good profile, 0 - bad profile due to missing WCL or aircraft data" ;
	float ALT(profile) ;
		ALT:long_name = "Lidar platform Altitude above MSL" ;
		ALT:units = "meters" ;
		ALT:source = "NPS_TwinOtter, GPS altitude (MSL), GGALT" ;
	float Ralt(profile) ;
		Ralt:long_name = "Lidar platform Altitude above ground" ;
		Ralt:units = "meters" ;
		Ralt:source = "NPS_TwinOtter, Radar altimeter altitude (AGL)" ;
	float Pitch(profile) ;
		Pitch:long_name = "IRS Aircraft Pitch Angle" ;
		Pitch:units = "degree" ;
		Pitch:source = "NPS_TwinOtter" ;
	float Roll(profile) ;
		Roll:long_name = "IRS Aircraft Roll Angle" ;
		Roll:units = "degree" ;
		Roll:source = "NPS_TwinOtter" ;
	double LON(profile) ;
		LON:long_name = "GPS-Corrected Inertial Longitude" ;
		LON:units = "degree_E" ;
		LON:source = "NPS_TwinOtter" ;
	double LAT(profile) ;
		LAT:long_name = "GPS-Corrected Inertial Latitude" ;
		LAT:units = "degree_N" ;
		LAT:source = "NPS_TwinOtter" ;
	double trf(profile) ;
		trf:long_name = "Static Temperature (In-house Reverse Flow)" ;
		trf:units = "degree_C" ;
		trf:source = "NPS_TwinOtter" ;
	double pmb(profile) ;
		pmb:long_name = "static pressure (Rosemount 1201)" ;
		pmb:units = "mb" ;
		pmb:source = "NPS_TwinOtter" ;
```

```
    float Zenith(profile) ;
            Zenith:long_name = "Laser beam Zenith Angle" ;
            Zenith:units = "degree" ;
    float BeamVector(profile, vector3) ;
            BeamVector:long_name = "(East,North,Up) lidar beam unit vectors" ;
            BeamVector:units = " " ;
            BeamVector:dependencies = "NSP_TwinOtter IRS variables" ;

// global attributes:
            :Source = "University of Wyoming, Department of Atmospheric Science" ;
            :Version = "FirstRun" ;
            :Address = "1000 E. University Ave., Laramie, WY 82071" ;
            :Phone = "(307)766-6334" ;
            :Email = "atsc-cc@uwyo.edu" ;
            :ProjectName = "SWEX2022" ;
            :Platform = "CIRPAS_NPS_Twin_Otter" ;
            :WCL_aperture_diameter = "76 mm" ;
            :WCL_beam_divergence = "1 mrad" ;
            :WCL_pulse_width = "8 ns" ;
            :WCL_wavelength = "355 nm" ;
            :WCL_pulse_energy = "12 mJ" ;
            :WCL_prf = "2 Hz" ;
            :Profile_Average_Shots = "10" ;
            :ProcessAuthor = "Min Deng, mdeng2@uwyo.edu" ;
            :LidarDataSource = "WCL_2FOV" ;
            :AcquisitionDate = "20220405" ;
            :DateProcessed = "Jul 25 17:05:21 2022(UTC)" ;
```

5.0 Data Remarks

- The WCL worked very well for the SWEX project for 9 IOP and 2 EOP. Only one half flight (April 17 afternoon) was missed because WCL was stopped in the middle of the flight.
- Flight data from the Twin Otter is not available for the first flight, therefore, the corresponding WCL data from that flight were unable to be processed
- The IDL code file to read the WCL L1 Netcdf data file is uploaded: read_image_wcl_nc.pro

6.0 References

- Zhien Wang, Perry Wechsler, William Kuestner, Jeffrey French, Alfred Rodi, Brent Glover, Matthew Burkhart, and Donal Lukens, "Wyoming Cloud Lidar: instrument description and applications," Opt. Express 17, 13576-13587 (2009)

- Deng, M., Wang, Z., Volkamer, R., Snider, J. R., Oolman, L., Plummer, D. M., Kille, N., Zarzana, K. J., Lee, C. F., Campos, T., Mahon, N. R., Glover, B., Burkhart, M. D., & Morgan, A. (2022). Wildfire Smoke Observations in the Western United States from the Airborne Wyoming Cloud Lidar during the BB-FLUX Project. Part I: Data Description and Methodology, Journal of Atmospheric and Oceanic Technology, 39(5), 545-558.

7.0 Acknowledgement

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