SLRCONSULTING.COM

Atmospheric LIDAR Cloud Calibration

To help protect your privacy, PowerPoint has blocked automatic download of this picture.

31 August 2026

SLR

Acknowledgements

- NSW Department of Environment, Climate Change and Water – provided Rozelle CL-51 ceilometer data for study
- SLR Consulting – funded participation in CASANZ Clean Air 2026

Presentation

- Introduction and purpose
- Some cloud observations (Mark-1 eyeball)
- Basic aerosol and cloud optical properties
- LIDAR measurements of aerosols and cloud particles
- Stratocumulus cloud calibration method
- Results
- Conclusion

Introduction

Airport Ceilometers and LIDAR

Australia has an existing network of approximately 80-100(?) **laser ceilometers** used for reporting cloud height for aviation.

Other ceilometers and LIDARs are used by research groups.

LIDAR measurements can be used to provide mixing layer properties for the purpose of air quality impact assessment; e.g.,

1. **Mixing layer height** using returned signals from mixing layer aerosols and clouds.
2. Height/range profiles of **aerosol optical properties** that – potentially, (care needed!), could be used to estimate aerosol concentrations near ground level.

Purpose

LIDAR measurements of stratocumulus clouds have been extensively studied as a contribution to climate research

Could the Air Quality Impact Assessment community:

1. **Draw on existing ceilometer/LIDAR network to establish databases of mixing layer height as a matter of routine?**
2. Most commonly airport ceilometers and research LIDARs are used for studies of clouds – **what is capability for retrieving optical properties at/near ground level?**
   a. ***Holy grail for AQIA – LIDAR retrievals of $PM_{2.5}$ and/or $PM_{2.5}$ – care needed!***

Some Observations

- For the Mark-1 eyeball
  - Stratocumulus (Sc) clouds
    - Large Sc ‘decks’ can be formed in the uppermost layers of marine boundary/mixing layers and tend to dissipate as they advect over land.
    - Decks tend to cap a mixing layer with heights less than approx. 2000m
      - **e.g. in SE Australia typical deck height 1000m in winter, 2000m in summer**
        - ***Nocturnal Sc (as we’ll see later – 500m typical)***
  - Therefore, LIDAR measurements showing an extensive layer ~<2000m in height apparently capping a mixing layer, very likely stratocumulus.

Some Observations

Some Observations

Some Observations

- Dissipating stratocumulus
(if height ~1000-2000m could be confirmed by LIDAR)
    - Diffraction rings subtending angles approx. 5°, 7.5°, 15° indicative of scattering by water droplets with radii approx. 5-15 micron
    - Mature cloud
    - Not drizzling (confirm by LIDAR)
    - Possibly a perfect LIDAR calibration target!

Some Observations

Some Observations

- Not stratocumulus!
  (height >2500m
  as confirmed by LIDAR)
  - 22° (“hand-span”) halo
    - Caused by randomly oriented hexagonal ice crystals

Basic aerosol and cloud optical properties

Transmittance T is given by,

$$T = e^{-\tau} \tag{1}$$

where τ is the optical depth, given by,

$$\tau = \int_{z0}^{z1} \sigma(z) dz \tag{2}$$

σ is the volume extinction coefficient; units m^2/m^3 (m^{-1}).

A multiple scattering factor (η) may be introduced to equation (2), with $\eta < 1$; for stratocumulus clouds, typically $\eta \approx 0.8$.

$$\tau = \eta \int_{z0}^{z1} \sigma(z) dz \tag{2'}$$

For the purposes of this paper, it is assumed all the extinction is due to scattering by cloud particles, aerosols, and molecules:

$$\sigma_{Total} = \sigma_{sca}^{c} + \sigma_{sca}^{a} + \sigma_{sca}^{m} \ (m^{-1}) \tag{3}$$

LIDAR measurements of aerosols and cloud particles

For a LIDAR, the volume backscatter coefficient is used to quantify the backscattered laser light received by a telescope with narrow field-of-view aligned, (or approximately aligned), with the laser beam:

$$\beta_{Total} = \beta_c + \beta_a + \beta_m \; (m^{-1} sr^{-1}) \tag{4}$$

Simplified; e.g., for a strong returned signal from a cloud, the range corrected, attenuated backscatter is proportional to,

$$\beta_{Total} T^2(z_0, z_1) \tag{5}$$

Stratocumulus cloud calibration method

LIDAR equation for the received signal voltage (V) from a height (z) metres may be expressed as,

$$V(z) = C.z^{-2}\eta\beta(z)T^2(0,z) + V_0, \qquad (1)$$

Useful parameter is attenuated backscatter (χ) (units steradian) – system-independent, range-corrected, LIDAR equation:

$$\chi(z) = \beta(z)T^2(z_0,z). \qquad (2)$$

Following Platt (1973) the attenuated backscatter coefficient integrated over the LIDAR height profile:

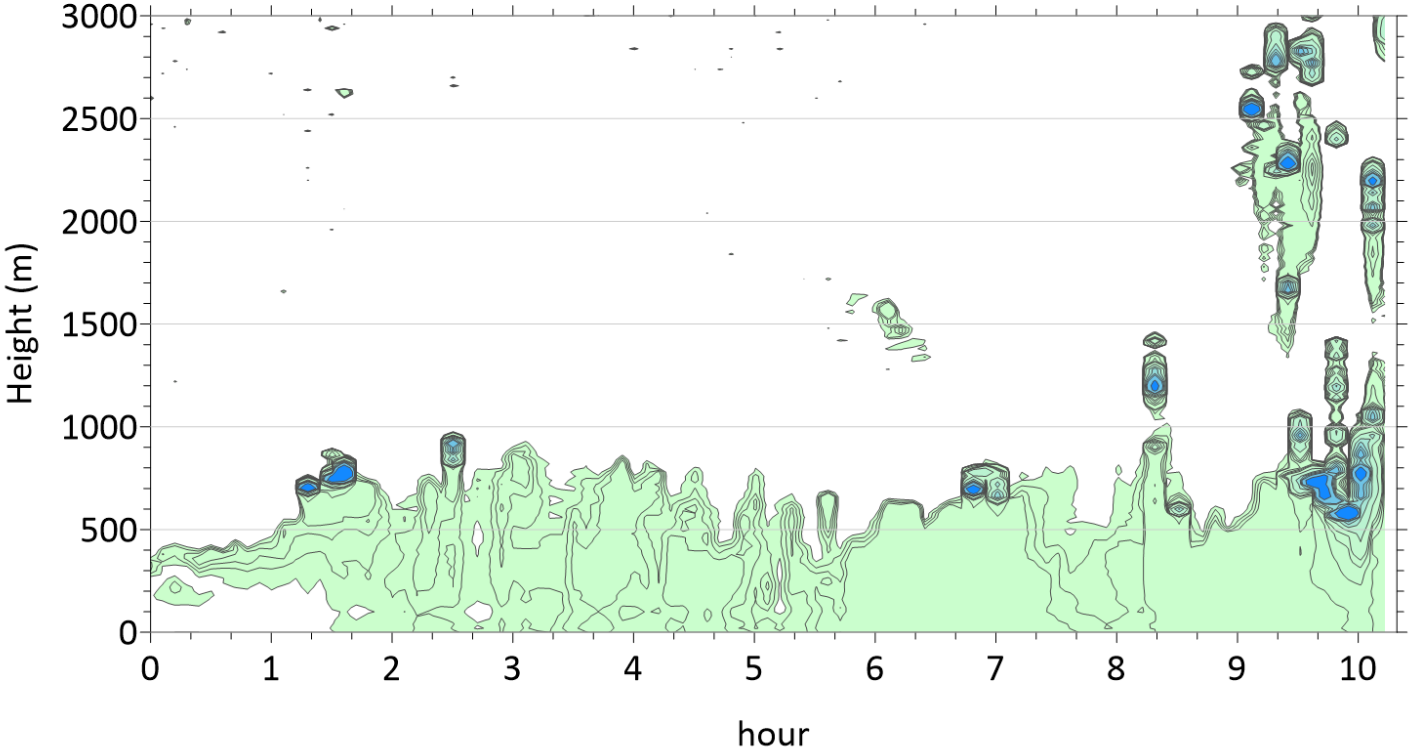
$$\chi' = (2\eta S)^{-1}(1 - e^{-2\eta\tau}), \qquad (3)$$

Note in (3) as $\tau \rightarrow$ large, $\chi' \rightarrow (2\eta S)^{-1}$ – this is the crux of the cloud calibration method.

- Maximum values of χ' are obtained by integrating over each height profile in a large sample of (range-corrected) LIDAR returns from stratocumulus clouds, which must include some deep, fully attenuating clouds.
- Values of ηS estimated from measurements and theory e.g. Pickett (1999) obtained 14.5 sr ± 0.5 sr for clouds approximately 250 metres in depth.

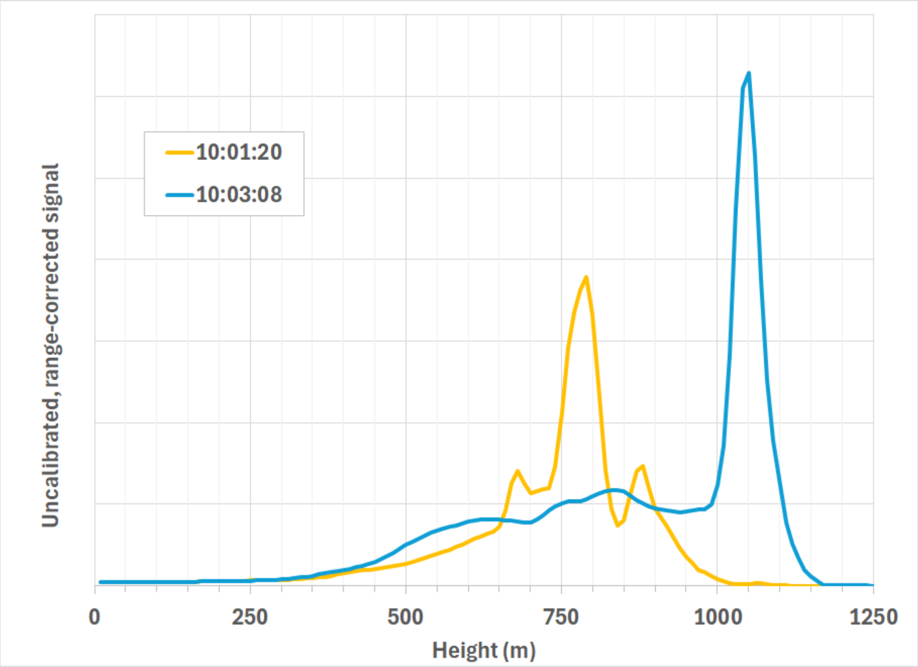
Results

- Range-corrected, uncalibrated, (twice-)attenuated backscatter



Results

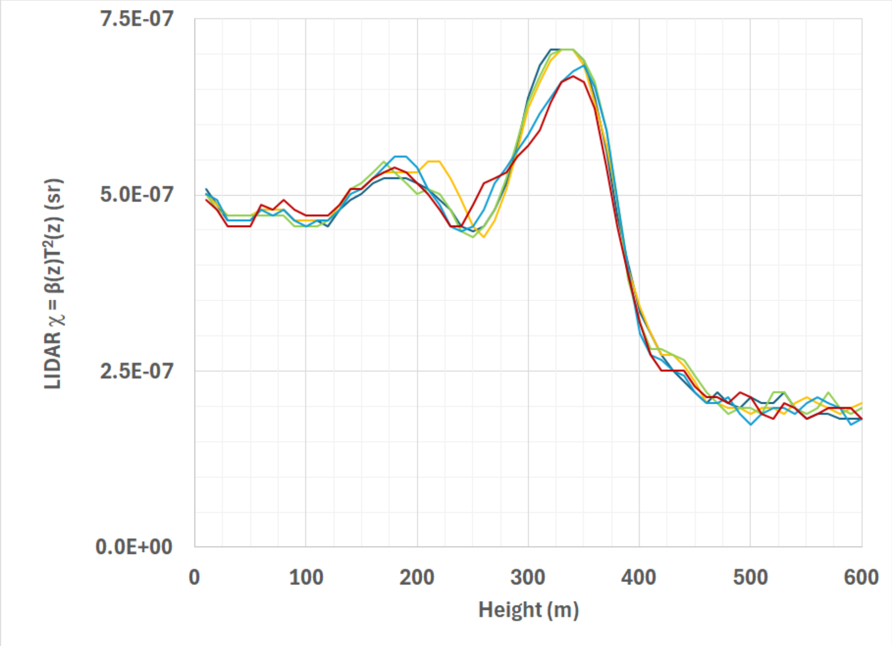
- Search for the (optically) thickest clouds



Results

To help protect your privacy, PowerPoint has blocked automatic download of this picture.

- Calibrated results – boundary layer aerosols
  - Effectively a nephelometer measurement of "B_{sca}", but height profile – useful!



Final calibrated result:

$$\chi(r) = \beta(z)T^2(z_0, z)$$

Example analysis:

$$T^2 \sim 0.9\text{-}0.95$$

$$\chi(z) \sim \beta(z)$$

LIDAR ratio (σ/β) depends on aerosols e.g. 40 sr

$$\sigma(z) \sim 40 \times \beta\ (m^{-1})$$

Conclusions

- Cloud ceilometers have improved!
    - Can provide height profiles of (attenuated) backscatter from boundary layer aerosols.
    - Height of boundary / mixing layer obtained relatively easily.
- Results of investigation demonstrate stratocumulus cloud calibration method can be applied (to at least some) ceilometer measurements.
    - Ceilometers not used for this purpose often if at all(?) - mostly used for aviation.
- Method opens way to height- (or range-) profiling of boundary layer aerosols using existing ceilometer equipment and networks.
    - How many airport ceilometers in ANZ and S.E. Asia? (~100 in Aus.?)
- Aerosol optical properties such as optical extinction retrieved relatively easily.
    - Similar to current nephelometer measurements (but LIDAR not limited to point measurements).
- With some further work, estimates for the particulate matter indicators PM_{10} and $PM_{2.5}$ could be obtained, near ground-level, and within mixing layer.
    - Would require some independent measurements.

Questions

Making Sustainability Happen

SLRCONSULTING.COM

Dr Matthew Pickett

Principal Consultant – Air Quality

M +0427 00 4564
E Matthew.Pickett@slrconsulting.com