Ground-based lidar processing and simulator framework for comparing models and observations

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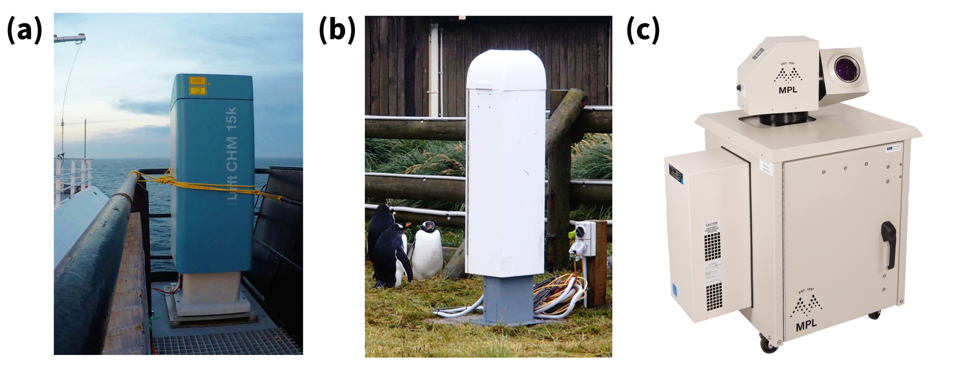
- **What?** We developed the Automatic Lidar and Ceilometer Framework (ALCF), an open source lidar processing tool and a lidar simulator (https://alcf-lidar.github.io).
- **Why?** A large number of automatic lidars and ceilometers (ALCs) are deployed worldwide, but there is a lack of tools for processing lidar data and comparison with general circulation models (GCMs) and numerical weather prediction (NWP) models.
- **How?** ALCF processes data from ALCs and runs a lidar simulator on model atmospheric fields to enable one-to-one comparison between observations and models.

1 | ALCs

ALCs are ground-based lidars operating by emitting pulses of laser radiation in the near-infrared or visible spectrum and measuring the backscattered radiation. Derived products include cloud base, cloud layers, cloud phase, boundary layer height and aerosol concentration.

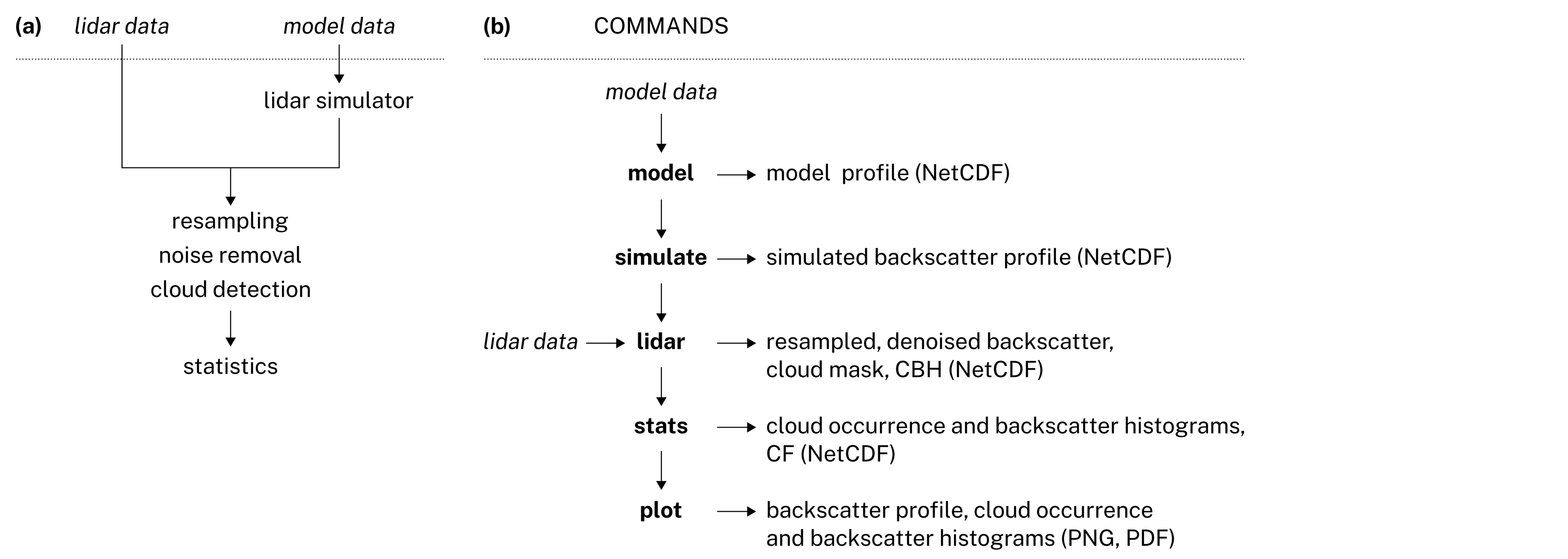


◀ ALCs supported by the ALCF: (a) Lufft CHM 15k ceilometer operating at 1064 nm wavelength, (b) Vaisala CL51 ceilometer operating at 910 nm, and (c) Sigma Space MiniMPL micropulse lidar operating at 532 nm.

2 | Model evaluation using ALCs

Model cloud fields cannot be directly compared with ALCs observations. Due to strong signal attenuation by clouds a lidar simulator has to be used. ALCF extends and integrates the spaceborne lidar simulator in the CFMIP Observation Simulator Package (COSP) with additional processing. The simulator transforms model cloud liquid and ice fields to backscatter profiles. The same post-processing steps can be applied on observed and simulated backscatter.

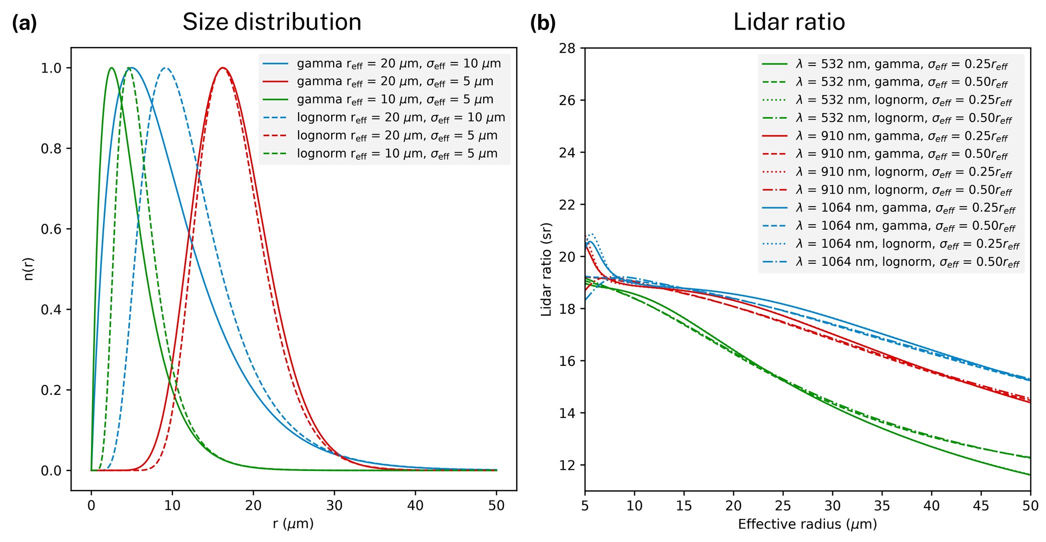
▼ Schematic illustrating the operation of the ALCF.



3 | Mie scattering

Laser signal interaction with cloud droplets and ice crystals can be approximated by the Mie scattering theory. Backscattering depends on the laser wavelength and particle size distribution. We modified the spaceborne lidar simulator in COSP to account for different ALC wavelengths and viewing geometry.

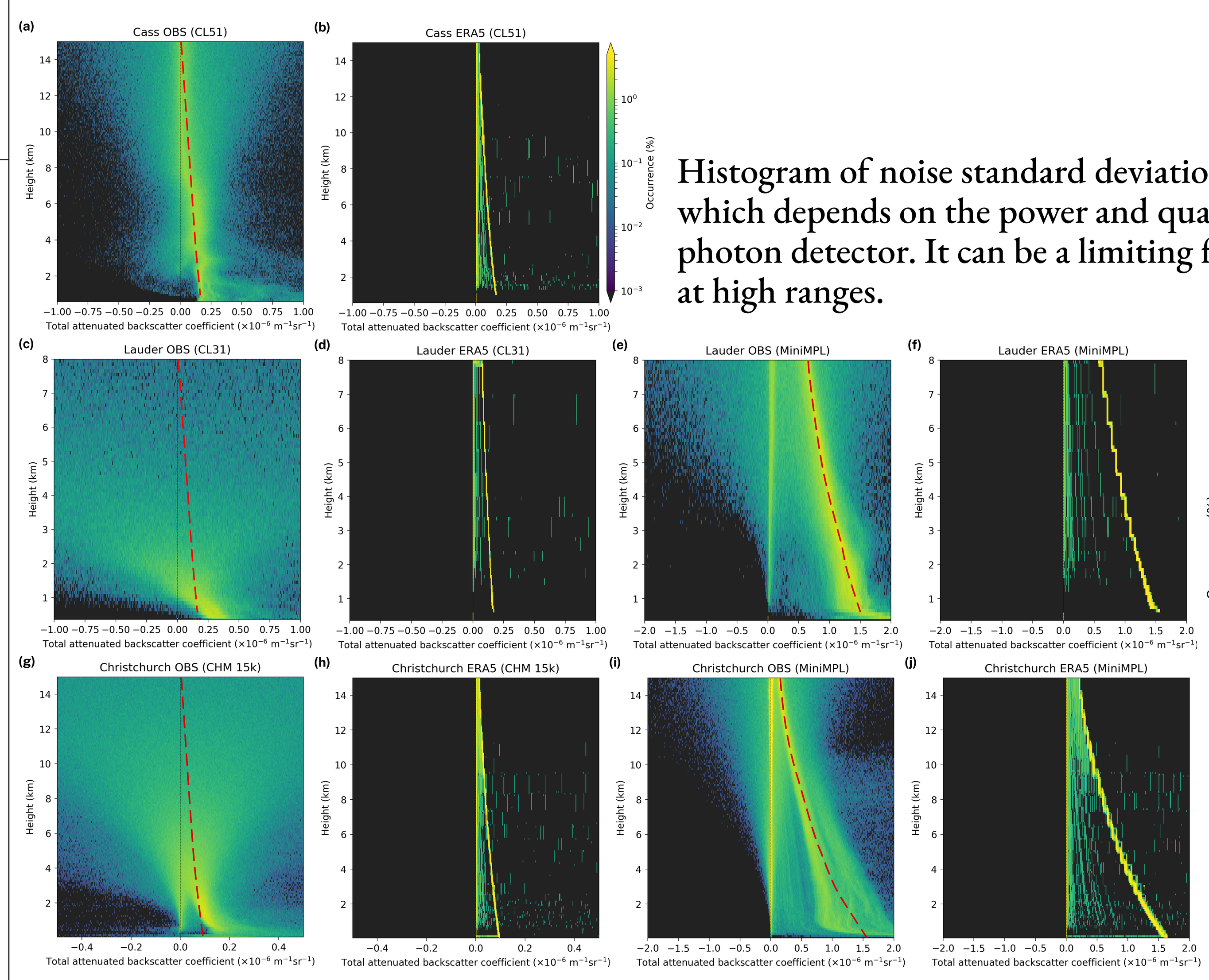
▼ Figure showing (a) theoretical droplet size distributions and (b) the resulting lidar ratio (extinction-to-backscattering ratio) calculated by the Mie theory.



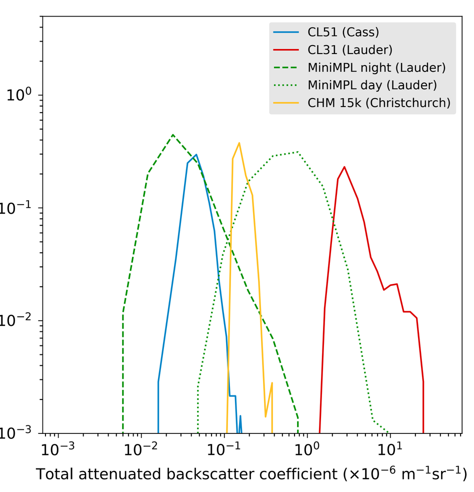
4 | Post-processing

Post-processing involves absolute calibration by comparing fully opaque liquid stratocumulus lidar ratio and molecular backscatter with a theoretical value, noise removal and determination of noise standard deviation, and cloud detection by applying a threshold-based algorithm.

▼ Figure showing backscatter histograms by height. Visible is Rayleigh (molecular) backscattering and noise increasing with the square of range.



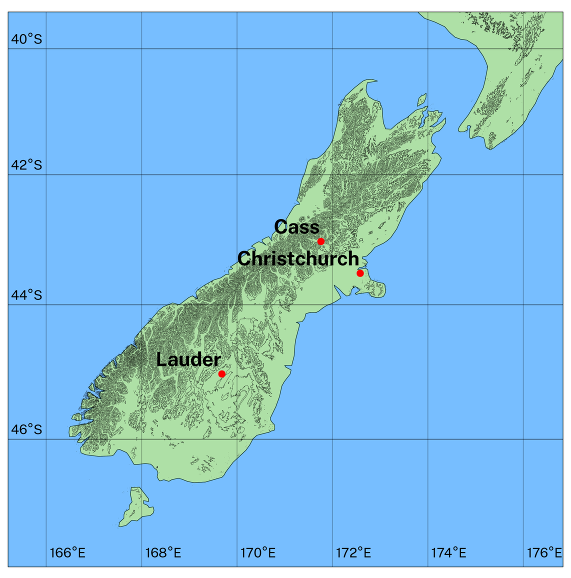
Histogram of noise standard deviation of a number of ALCs, which depends on the power and quality of the laser and photon detector. It can be a limiting factor for cloud detection at high ranges. ▼



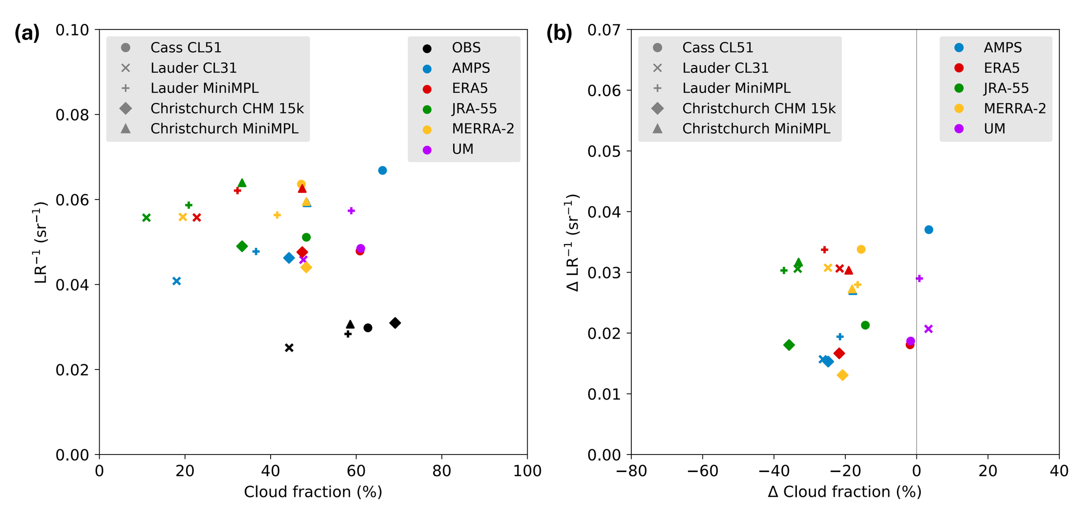
5 | Case studies

We applied the ALCF on ALC data from Vaisala CL31, CL51, Lufft CHM 15k and Sigma Space MiniMPL at 3 sites in New Zealand and compared the observed cloud with 3 reanalyses (ERA5, JRA-55 and MERRA-2), the Antarctic Mesoscale Prediction System (AMPS) and the Unified Model (UM).

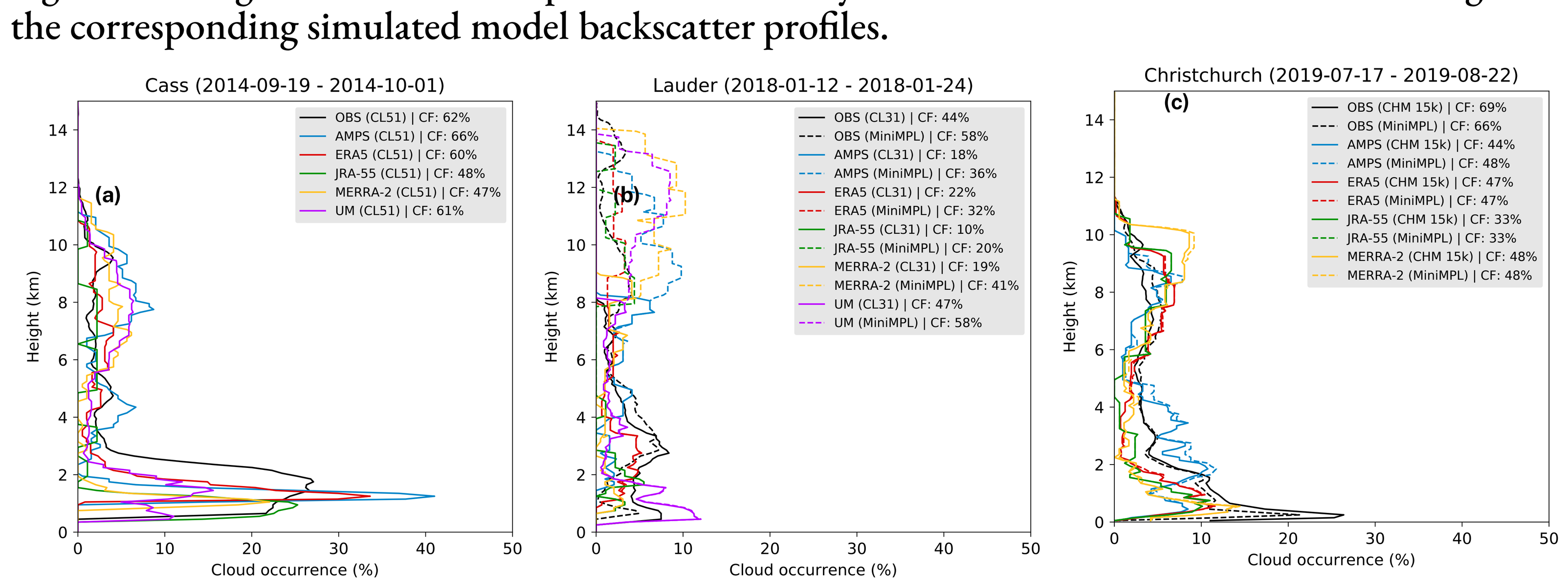
▼ Map of the 3 sites in New Zealand.



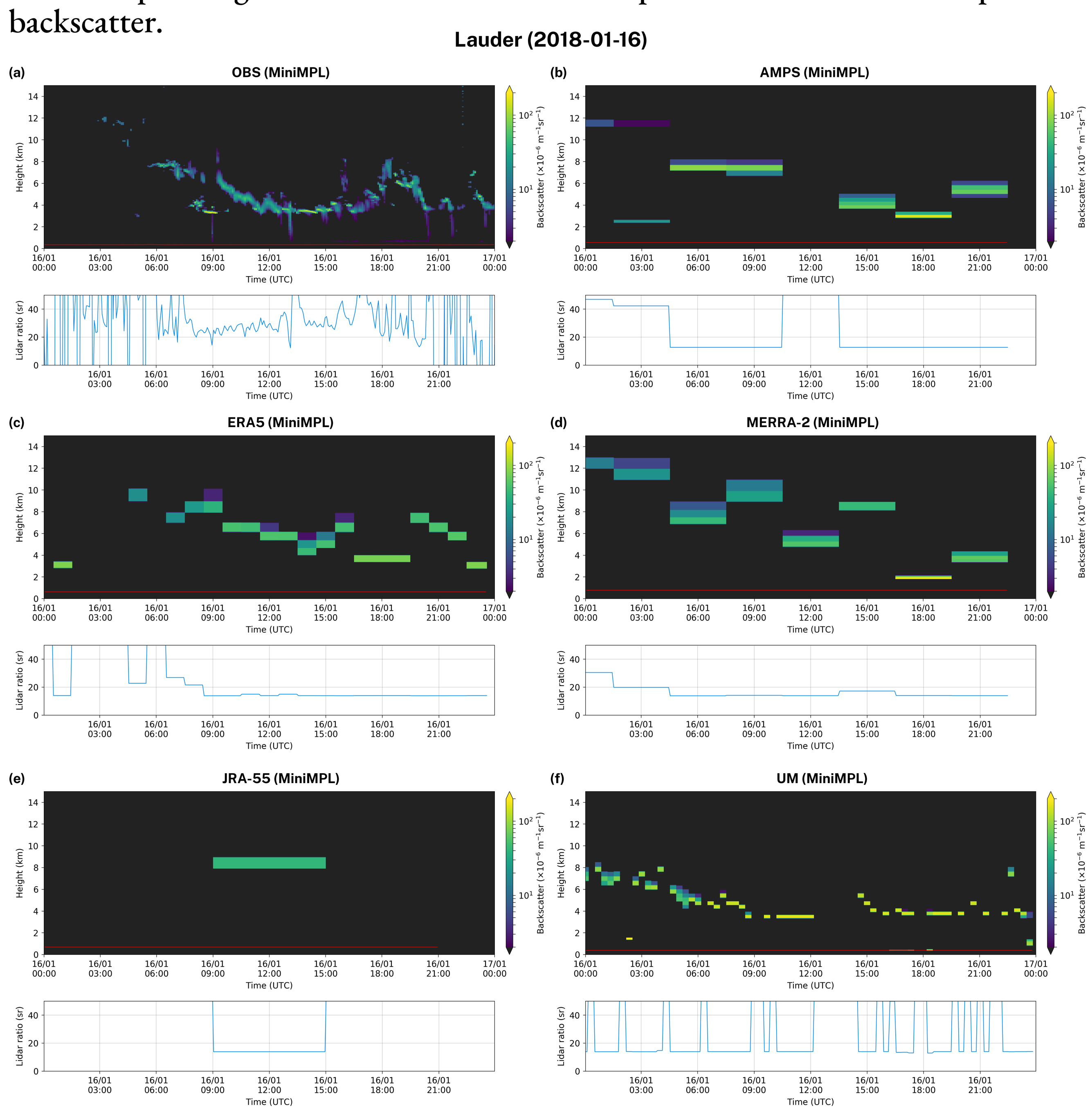
▼ Scatter plot of (a) absolute and (b) relative cloud fraction and inverse of the lidar ratio (a proxy for cloud albedo) in observations and the models.



▼ Figure showing cloud backscatter profiles observed by the MiniMPL at the Lauder site during 24 hours and the corresponding simulated model backscatter profiles.



▼ Figure showing cloud backscatter profiles observed by the MiniMPL at the Lauder site during 24 hours and the corresponding simulated model backscatter profiles. Lidar ratio corresponds to the vertically-integrated backscatter.



6 | Case study: Southern Ocean model cloud evaluation

We used ALCF to evaluate Southern Ocean cloud in the HadGEM3/GA7.1 GCM and the MERRA-2 reanalysis (Kuma et al., 2019). We compared the models with ship observations collected over 4 years using the Lufft CHM 15k and Vaisala CL51. We found that the models underestimate low cloud below 500 m and fog and the total cloud cover is underestimated by up to 18%.

▼ Figure showing cloud occurrence by height and total cloud fraction in ceilometer observations (OBS) on the TAN1802, TAN1502, HMNZSW16, Aurora Australis and N.B. Palmer Southern Ocean voyages and simulated by GA7.1 and MERRA-2.