EGU2020-21290
https://doi.org/10.5194/egusphere-egu2020-21290
EGU General Assembly 2020
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Ground-based lidar processing and simulator framework for comparing models and observations

Peter Kuma[1], **Adrian McDonald**[1], Olaf Morgenstern[2], Richard Querel[3], Israel Silber[4], and Connor Flynn[5]

[1]School of Physical and Chemical Sciences, University of Canterbury, New Zealand
[2]National Institute of Water & Atmospheric Research (NIWA), Wellington, New Zealand
[3]National Institute of Water & Atmospheric Research (NIWA), Lauder, New Zealand
[4]School of Meteorology, University of Oklahoma, Norman, OK, USA
[5]Pacific Northwest National Laboratory, Richland, WA, USA

Automatic lidars and ceilometers (ALCs) are well-established instruments for remote sensing of the atmosphere, with a large network of instruments deployed globally. Even though they provide a wealth of information about clouds and aerosol, they have not been used extensively to evaluate models. They complement active satellite observations, which are often unable to accurately detect low clouds due to obscuration by mid and high-level clouds. ALCs cannot be used directly for atmospheric model cloud scheme evaluation due to the wavelength-dependent attenuation of the lidar signal by clouds. Therefore, a forward lidar simulator has to be used to transform model fields to simulated backscatter comparable to backscatter measured by ALCs. Here we describe the Automatic Lidar and Ceilometer Framework (ALCF), an open source lidar processing tool and forward ground-based lidar simulator capable of transforming widely-used reanalysis and model output into a data structure which can be directly compared with observations. It implements steps such as conversion, absolute calibration, resampling, noise removal, cloud detection, model data extraction, and forward lidar simulation. The simulator is based on the Cloud Feedback Model Intercomparison Project (CFMIP) Observation Simulator Package (COSP), previously used with spaceborne lidars, with extensions for several ground-based ALCs. The forward simulator is essential to get from raw ALC and model data to a one-to-one backscatter profile. It also allows statistical comparison of cloud between models and observations. Four common commercial ALCs (Vaisala CL31, CL51, Lufft CHM 15k and Sigma Space MiniMPL), three reanalyses (ERA5, JRA-55, and MERRA-2), and two NWP models and GCMs (AMPS and the Unified Model) are supported. We present case studies evaluating cloud in the supported reanalyses and models using multi-instrument observations at three sites in New Zealand. We show that at these sites the reanalyses and models generally underestimate cloud fraction and overestimate cloud albedo. We demonstrate that the ALCF can be used as a generic cloud evaluation tool. It can assist in improving model cloud simulation, which has been identified as a critical deficiency in contemporary models limiting the accuracy of future climate projections.