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CloudnetPy: A Python package for processing cloud remote sensing data

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Summary

Active ground-based remote sensing instruments such as cloud radars and lidars provide vertical profiles of clouds and aerosols with high vertical and temporal resolution. Cloud radars typically operate in the sub-millimeter wavelength region, around 35 or 94 GHz, and are sensitive to clouds, particularly ice clouds, rain and insects. Lidars operating at visible and near-infrared wavelengths on the other hand, are more sensitive to liquid clouds and aerosols. Combining these two complementary data sources with temperature and humidity profiles from a numerical weather prediction model or radiosonde makes it possible to accurately classify the various scattering hydrometeors in the atmosphere, diagnosing them as: rain drops, ice particles, melting ice particles, liquid droplets, supercooled liquid droplets, drizzle drops, insects and aerosol particles. Furthermore, adding a passive microwave radiometer, an instrument measuring liquid water path, attenuation corrections and quantitative retrievals of geophysical products such as ice water content, liquid water content and drizzle properties become feasible (Hogan, Mittermaier, & Illingworth, 2006; O'Connor, Hogan, & Illingworth, 2005).

Methodology and prototype software to combine these different data sources, and to retrieve target classification and other products, were developed within the EU-funded Cloudnet project (Illingworth et al., 2007). Since Cloudnet started in 2002, the network has expanded from 3 stations to a coordinated and continuously operated network of around 15 stations across Europe. The network routinely collects, processes and distributes Cloudnet data (http://cloudnet.fmi.fi). While the current methodology has been validated, it is important to develop the Cloudnet software so that it can efficiently handle large amounts of data and reliably perform continuous data processing. In the forthcoming years, Cloudnet will be one of the key components in ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure) (Häme, Saporano, Kivekäs, Kaukolehto, & Rodriguez, 2018), where the Cloudnet framework will process gigabytes of cloud remote sensing data per day in near real time. The ACTRIS RI is now in its implementation phase and aims to be fully operational in 2025.

CloudnetPy is a Python implementation of the Cloudnet processing scheme. CloudnetPy covers the full Cloudnet processing chain starting from the raw measurements and providing similar functionality to the original, proprietary Cloudnet software written in Matlab and C. The output from CloudnetPy is no longer identical to the original scheme because several methods have been revised and improved during the refactoring process. For example, as most modern cloud radars are polarimetric, CloudnetPy uses the linear depolarization ratio to improve the detection of the melting layer and insects. Liquid layer detection is now based on the lidar attenuated backscatter profile shape instead of relying only on threshold values (Tuononen, O'Connor, & Sinclair, 2019). Detailed verification of the updated methods is a subject of future studies. The CloudnetPy API is designed to serve the operational cloud remote sensing data processing in ACTRIS, but it will be straightforward for site operators and the scientific community with access to the raw data to run the software, improve existing methods and develop new products.

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References

Häme, S., Saporano, G., Kivekäs, N., Kaukolehto, M., & Rodriguez, E. (2018). *ACTRIS stakeholder handbook 2018*. Painotalo Trinket Oy. ISBN: 978-952-336-066-2

Hogan, R. J., Mittermaier, M. P., & Illingworth, A. J. (2006). The retrieval of ice water content from radar reflectivity factor and temperature and its use in evaluating a mesoscale model. *Journal of Applied Meteorology and Climatology*, *45*(2), 301–317. doi:10.1175/JAM2340.1

Illingworth, A. J., Hogan, R. J., O'Connor, E. J., Bouniol, D., Brooks, M. E., Delanoé, J., Donovan, D. P., et al. (2007). Cloudnet: Continuous evaluation of cloud profiles in seven operational models using ground-based observations. *Bulletin of the American Meteorological Society*, *88*(6), 883–898. doi:10.1175/BAMS-88-6-883

O'Connor, E. J., Hogan, R. J., & Illingworth, A. J. (2005). Retrieving stratocumulus drizzle parameters using doppler radar and lidar. *Journal of Applied Meteorology*, *44*(1), 14–27. doi:10.1175/JAM-2181.1

Tuononen, M., O'Connor, E. J., & Sinclair, V. A. (2019). Evaluating solar radiation forecast uncertainty. *Atmospheric Chemistry and Physics*, *19*(3), 1985–2000. doi:10.5194/acp-19-1985-2019