WP5–NA5: Clouds and aerosol quality-controlled observations

Deliverable D5.7: Updated retrieval algorithms

Objectives

The extension of the existing cloud-observing network to new sites through Task 5.1 of WP5 requires standardised retrieval algorithms that can be applied to different instrument combinations, since each site has its own specific suite of instruments. The requirement is for automated retrievals that can take into account a variable combination of instruments in an objective sense, so that the resulting retrievals can be compared across different sites and time periods, and for multiple models when evaluating model performance in Task 5.4.

The following updates and additions are described in more detail in this deliverable:

- Improvements to target categorization
- Improved drizzle retrievals
- Eddy dissipation rate of turbulent kinetic energy
- Model evaluation
- Framework for new retrievals

Improvement to target categorization

The target categorization dataset (Hogan and O`Connor, 2004) is the basis from which almost all retrievals begin. This particular product provides the harmonized dataset that contains all instrument uncertainties and quality control flags for propagation through the various retrieval algorithms, as well as providing the underlying target identification for these retrievals to operate on (Illingworth et al., 2007).

The target categorization includes profiles of temperature, humidity and horizontal winds for assisting in quantifying uncertainties in particular retrievals, initialising a background state, estimating temporal or spatial scales, and for determining constants or variables that are temperature or humidity dependent where appropriate. Certain instrument uncertainties also require these parameters as an input. The profiles of temperature, humidity and horizontal winds are normally taken from the output of a high resolution weather forecast model. Now, radiosoundings can be used if required, and the ingest code will provide them in a format that emulates the weather forecast model input file. In addition, horizontal winds from a wind profiler can also be incorporated if preferred.

A wide variety of instruments can now be ingested, along with the appropriate instrument errors for propagating uncertainty through to every retrieval product. The framework allows similar instrument types to provide a variable list of parameters; i.e. depending on operational requirements, some instruments are set up to provide more parameters than others, even if of the exact same type.

Drizzle retrieval below cloud base

The drizzle retrieval algorithm of O`Connor et al. (2005) has been included as a standard product within Cloudnet. The method utilises a combination of Doppler cloud radar and lidar to provide profiles of various drizzle parameters below cloud base. The retrieval method combines up to 4 observables from the Doppler cloud radar, together with lidar attenuated backscatter. Initially, the algorithm was implemented for a specific instrument fit: a 94 GHz Doppler cloud radar and a ceilometer operating at 905 nm.

Algorithm basis

The algorithm basis is that, in principle, the ratio between radar reflectivity and lidar extinction is directly related to drizzle droplet size. Together with the use of the radar Doppler spectral width, which indicates the shape of the drizzle drop size distribution, iteration then provides three parameters of a gamma distribution (number concentration, equivolumetric median diameter and distribution shape) which is assumed to be a suitable representation of the observed drizzle droplet size distribution.

Once the three parameters of the normalised gamma distribution are obtained, the following parameters can also be retrieved from the size distribution: drizzle liquid water content (DLWC), drizzle terminal fall velocity, and drizzle liquid water flux (DLWF). Comparison of the retrieved drizzle fall velocity with the observed Doppler velocity provides the air velocity, w.

In practice, the radar Doppler spectral width should be corrected for turbulent broadening, which is possible using the parameter, $\sigma_{\bar{v}}$, the standard deviation of the mean velocity over a given time period, and the lidar extinction is usually retrieved through iteration from the attenuated lidar backscatter coefficient. Since the original algorithm was defined using attenuated backscatter from an instrument at 905 nm, the impact of molecular scattering was neglected.

Both instruments must be calibrated for this retrieval, which provides uncertainty estimates for all output parameters based on the input instrument uncertainties.

Requirements

Figure 1 provides a flowchart describing the products that can be obtained depending on the input parameter availability. In summary:

Minimum: Radar reflectivity and lidar attenuated backscatter. This retrieval will provide equivolumetric median diameter, D_0, using an assumed exponential shape for the size distribution. A normalised number concentration (N_w), DLWC and DLWF can then be derived.

Ideal: Radar reflectivity, Doppler velocity, Doppler spectral with,$\sigma_{\bar{v}}$ and lidar attenuated backscatter. This retrieval will provide equivolumetric median diameter, D_0, N_w, size distribution shape parameter, DLWC, DLWF and air velocity, w.

Updates

To apply this algorithm across the network, major improvements have been made so that the retrieval can cope with different combinations of instruments, and for instruments operating at different frequencies/wavelengths.

Updates to algorithm – cloud radar

Mie scattering: As described in O`Connor et al. (2005), the Rayleigh scattering assumption may not always apply to drizzle droplets at cloud radar wavelengths, only for individual droplets smaller than around 300 micron at 94 GHz and 1 mm at 35 GHz. This also has implications for the retrieval of the distribution shape from the Doppler spectral width, and the reflectivity-weighted fall velocities derived from the retrieved drop size distribution.

The retrieval now has look-up tables to account for the Mie scattering factor for radars at typical cloud radar operating frequencies, including 10, 24, 35 and 94 GHz. Look-up tables for new radar operating frequencies will be added as required.

Turbulent correction: Not all Doppler cloud radars provide the parameter $\sigma_{\bar{v}}$ as standard. If not available, the use of the Doppler spectral width for refining the shape parameter for the drizzle droplet size distribution becomes rather uncertain. In this case, the algorithm resorts to the default value of an exponential size distribution (see Fig. 1). The likely impact that this has is described in O`Connor et al. (2005).

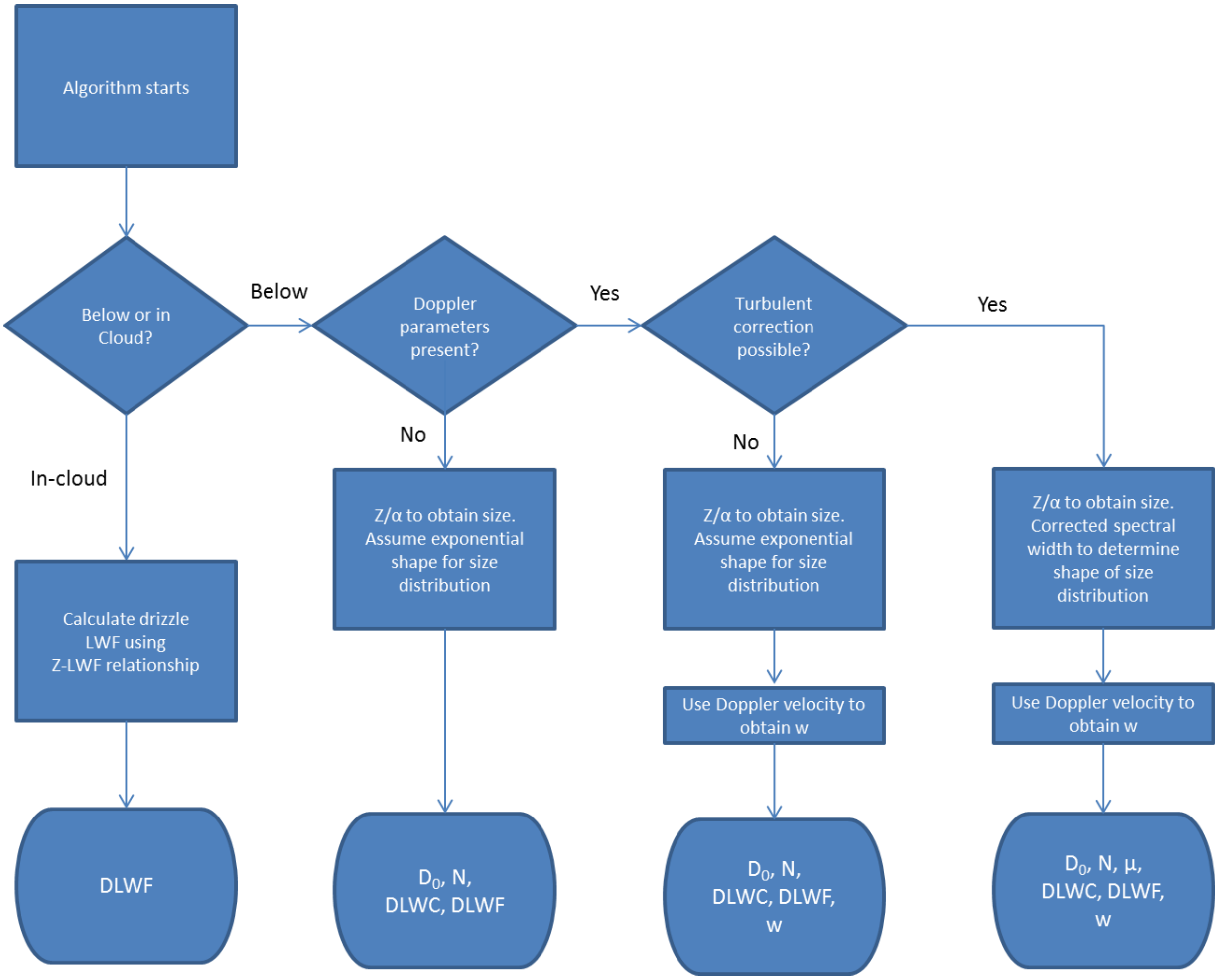

Figure 1: Drizzle algorithm flowchart

Updates to algorithm – lidar

Mie scattering: As described in O`Connor et al. (2005), the lidar extinction coefficient profile is derived from the attenuated backscatter coefficient profile through iteration to retrieve the appropriate lidar ratio for the median equivolumetric diameter of the drizzle droplets at each height in the profile. The process starts from the ground up for each profile, and at each height, once the iteration is stable, the optical depth up to that height is then used to correct the attenuated backscatter coefficient at all heights above. In principle, this provides the true backscatter coefficient profile within drizzling profiles, but currently this is discarded.

The lidar ratio in drizzle varies with size, the shape of the size distribution, and with the lidar wavelength (see Fig 2.). Typical drizzle droplet median equivolumetric diameters lie in the range 50 μm to 1 mm, and for most of this size range, the shape parameter does not have a major impact on the relationship between lidar ratio and median equivolumetric diameter. Figure 2 shows that shorter wavelengths display slightly more dispersion with shape parameter than IR wavelengths.

Molecular scattering: The relative impact of molecular scattering varies greatly with wavelength. At wavelengths of 905 nm and above, molecular scattering and extinction is much smaller than the scattering from drizzle; therefore it can be neglected. At shorter wavelengths, however, both molecular scattering and extinction can no longer be ignored, with molecular scattering at 355 nm potentially greater than the scattering from light drizzle. The algorithm now includes molecular scattering and extinction. The theoretical values for the molecular scattering and extinction profiles are derived from the temperature and pressure profiles given in the target categorization input file (obtained from either radiosoundings or NWP model output) using standard formulas (e.g. Bucholtz, 1995).

As discussed above, the process starts from the ground up for each profile. At each height, the molecular scattering component is subtracted from the total attenuated backscatter coefficient to leave the drizzle component. The drizzle component only is then used within the Z/α calculation; at each height, once the iteration is stable, the total transmission, including molecular transmission, up to that height is then used to correct the total attenuated backscatter coefficient at all heights above.

Internally, the algorithm also contains placeholder variables for aerosol scattering and extinction, currently assumed to be negligible relative to drizzle scattering and extinction (and to molecular scattering and extinction at shorter wavelengths). Testing of this assumption remains to be undertaken, but there is the potential for inclusion of an aerosol component in the future if deemed necessary.

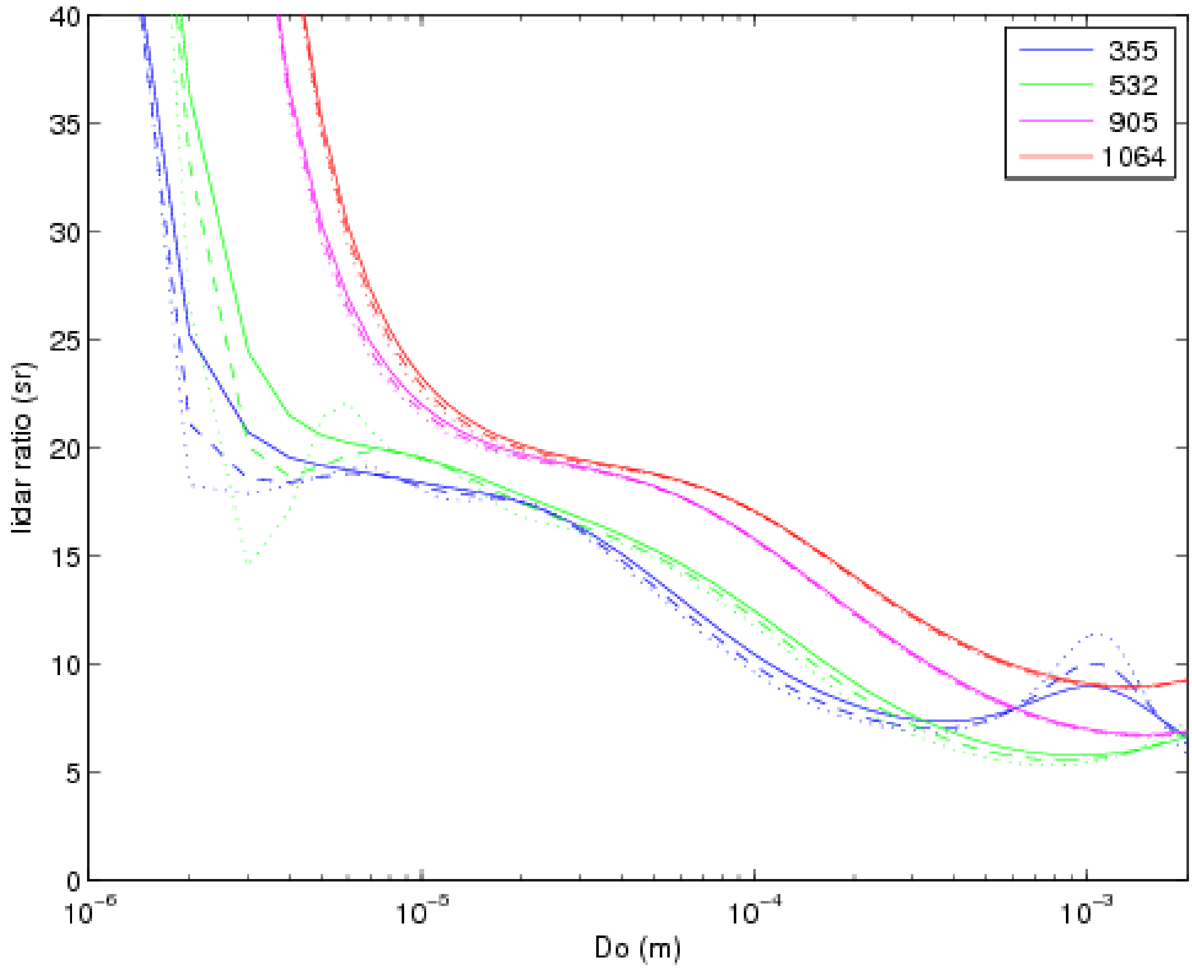

Figure 2: Lidar ratios for the median equivolumetric diameter, D_0, of a drizzle droplet size distribution at different wavelengths (in nm). Different values of the shape parameter of a normalised gamma distribution have been plotted, from exponential through to more monodispersed: solid line, μ=0, exponential; dashed, μ=2; and dotted, μ=5.

Drizzle optical depth: Internally, the profile of drizzle optical depth is also calculated. This is usually rather small and is not yet output as standard. In principle, the direct use of extinction profiles from either Raman Lidar or High Spectral Resolution Lidar (HSRL) could be used, negating the need to perform an iterative calculation from the attenuated backscatter coefficient profile. In practice, however, reliable extinction profiles require longer averaging times (30 minutes) than the typical timescale for drizzle variability (< 2 minutes), and this, coupled with the need for high vertical resolution, means that attenuated backscatter coefficient profiles are more suitable. Note that, although the total drizzle extinction is typically small, it may occasionally reach optical depths of 0.3 or so; in these cases, there is the possibility of using the direct extinction profiles as a constraint.

Drizzle retrieval in cloud

In addition, the drizzle algorithm also derives drizzle liquid water flux in-cloud through radar reflectivity alone using a Z-DLWF relationship appropriate to the radar frequency (O`Connor et al., 2005). The diagnosis of `below cloud` or `in-cloud` is taken from the target categorization. Uncertainties in the retrieved drizzle liquid water flux are provided via the uncertainties in the radar reflectivity contained within the target categorization dataset.

Turbulent kinetic energy dissipation rate

The primary input for this parameter is the standard deviation of the mean radar Doppler velocity over a given time period, termed $\sigma_{\bar{v}}$. The dissipation rate can then be determined from $\sigma_{\bar{v}}$ through assuming the Taylor `frozen turbulence` hypothesis if the spatial scales are known using the technique of Bouniol et al. (2003). The spatial scales are derived directly from horizontal winds, which can be from a forecast model, radiosounding, or wind profiler.

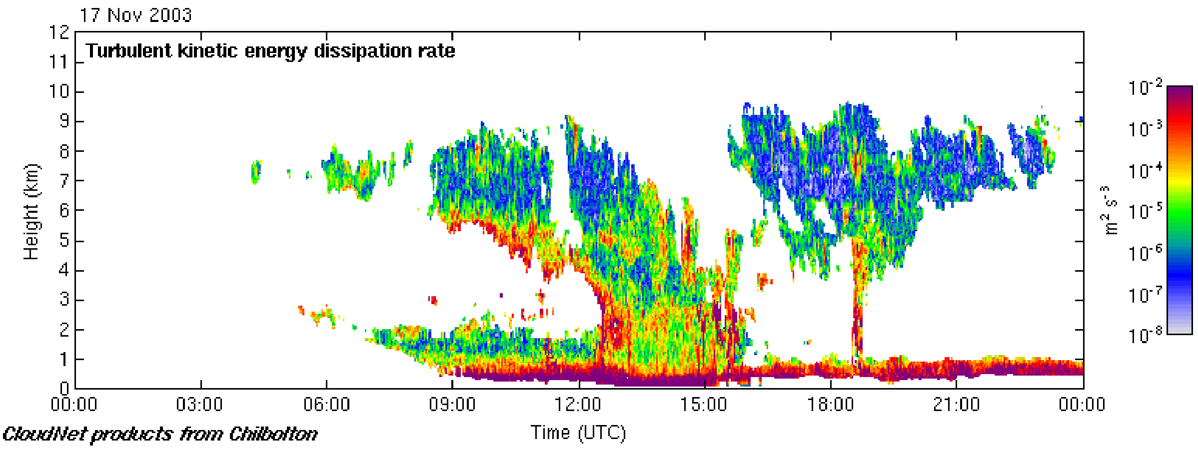

Figure 3: Time-height plot of turbulent kinetic energy dissipation rate from Chilbolton, UK, during 17th November 2003.

The random error in dissipation rate is estimated from the error in model winds (assumed to be 1.5 m s-1) and the random error in $\sigma_{\bar{v}}$, assumed to be $\sigma_{\bar{v}}$/sqrt(n), where n is the number of velocity samples used in the calculation, typically between 24 and 30, although may be as low as 15.

This value is only available in precipitation and cloud when calculated from Doppler cloud radar data. An example of the turbulent kinetic energy dissipation rate is given in Fig. 3, and shows the wide range of values encountered in the atmosphere. Typically, stratocumulus shows the highest values, with precipitation displaying more moderate values. In ice clouds, cirrus often exhibits the lowest observed values, but ice experiencing evaporation can have values 3-4 orders of magnitude higher.

Requirements

The radar instrument should provide $\sigma_{\bar{v}}$. The caveat is that this parameter must be calculated over suitable timescales. In the example given in Fig3., $\sigma_{\bar{v}}$ was calculated using the standard deviation of the 1.25 s-mean Doppler velocity over 30 seconds. This provides 24 samples and a reasonable random error, while still ensuring that the spatial scales are well within the inertial subrange of the Kolmogorov spectrum of turbulence. Increasing the number of samples may reduce the random error, and calculating $\sigma_{\bar{v}}$ over longer time periods is also possible, but with an increase in the risk that the largest spatial scales (commensurate with the overall sampling period) may no longer fall within the inertial subrange, rendering the technique invalid.

Improvements for model evaluation

The provision for multiple sources of horizontal wind profiles for ingest to the target categorization is also available for the model evaluation component. Horizontal winds are vital for determining the advective scale (Hogan et al., 2001; Brooks et al., 2005) for comparing a series of vertical profiles at a point to a model grid box. The use of the advective scale rather than a simple single temporal scale (e.g. one hour) also provides an objective method for model intercomparison. Utilising horizontal winds from a radar wind profiler or radiosounding can be used as an independent means of determining appropriate scales where necessary, and can also be used to test the model performance when generating composite plots such as Bony diagrams (using omega at 500 mb).

Additional Community retrievals

The design of the processing framework also makes it simple to add new retrieval methods that can be applied across all sites and instruments. The new algorithm should respect the in-built quality control flags, and propagate the instrument uncertainties through to the retrieved parameters. The standard procedure is to start from the target categorization dataset where possible, as this contains the relevant information required for providing consistent uncertainty estimates.

Examples include:

SYRSOC (SYnergistic Remote Sensing Of Cloud); a technique for retrieving warm cloud microphysics using Doppler cloud radar, lidar and a multichannel microwave radiometer (Martucci et al., 2011).

IPT (Integrated Profiling Technique); a method for the simultaneous retrieval of profiles of the following atmospheric state parameters: temperature, humidity, and liquid water content. The method combines measurements from a microwave profiler, cloud radar, and ceilometer, within an optimal estimation procedure (Loehnert et al., 2007).

Inclusion of new instruments can also be undertaken by utilising the same framework, as shown in deliverable WP5_D5.8 `Modified Software for aerosol retrievals`. Here, an aerosol classification has been implemented in the same manner as the cloud classification (provided from the target categorization dataset) using multiwavelength Raman lidar.

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