WP22- JRA3: A framework for cloud – aerosol interaction studies
Deliverable D22.3: Cloud categorization and cloud – aerosol interaction descriptors

The aim of this work package is to establish a strategy for cloud – aerosol interactions observation. In the Task 22.2 we focus on forming an observation method of cloud formation. This method should help to determine if variations in the aerosol background result in variations of the cloud structure. The work within this task was focused on two points:

1) Cloud categorization

2) Cloud – aerosol interactions descriptors

Task 22.2.1 – Cloud categorization

In order to study the effect of the change in aerosol background on the cloud microstructure it is essential to keep other influential factors constant. Therefore, it is necessary to divide clouds into groups based on their characteristics. The cloud categorization criteria include:

A) Liquid Water Path (LWP);

B) Vertical extent;

C) Presence/absence of drizzle;

D) Level of adiabicity.

The importance of those criterias is specified in detail below.

A. Liquid Water Path

The aerosol indirect effect described by Twomey (Twomey, 1977) suggests that with the increased concentration of the atmospheric aerosols the concentration of cloud condensation nuclei (CCN) will be higher, cloud droplet concentration will increase and the droplets will be smaller. Twomey clearly stated that the hypothesis applies to clouds of the equal liquid water content. Without the consderation of the LWP, Twomey's effect might be obscured, as the cloud droplets may be smaller because the cloud has less water and therefore has less potential to grow large droplets (Feingold, 2003).

B. Vertical extent

Liquid water path is calculated by integrating the liquid water content over two points, which can be cloud base and cloud top. Therefore, it is essential that the geometrical thickness of clouds (vertical extent) is kept constant within each cloud class.

C. Presence/absence of drizzle

Drizzle particles can strongly influence radar mesurements. Therefore, it is important to detect the drizzle fraction and characterize it. As radar reflectivity is proportional to the sixth moment of the droplet size distribution (DSD), even the small number of drizzle particles can produce the major part of the clouds reflectivity, without strong contribution to the liquid water content. As a result of radar reflectivity high sensitivity to the presence of big drops, the ratio of drizzle to droplets reflectivities can be selected to characterize the presence of drizzle fraction and to estimate its amount. However, some studies show (Krasnov and Russchenberg, 2006a) that radar reflectivity alone cannot characterize the presence and amount of drizzle. Radar reflectivity to optical extinction ratio (Z / α) can be used to detect the presence of big drops in water clouds (drizzle fraction) and to characterize their amount (Krasnov and Russchenberg, 2006b). A resulting radar-lidar ratio can be used to categorize cloud range cells on vertical profile into three classes:

– “cloud without drizzle fraction” $\log_{10}(Z / \alpha) < -1$

Contribution of drizzle into LWC is negligible, for the DSD it is possible to use a standard three parameters distribution (modified gamma or log normal)

– “cloud with light drizzle” $-1 < \log_{10}(Z / \alpha) < 1.8$

Contribution of the drizzle fraction in less than 0.03 g/m^3, growing of the Z / α ratio as a function of the effective radius is very fast

– “cloud with heavy drizzle” $\log_{10}(Z / \alpha) > 1.8$

Contribution of the drizzle fraction into LWC is essential, the Z / α ratio as a function of the effective radius grows slowly, for the DSD description it is necessary to use the model of the mixture of independent DSD.

For every resulting class the different Z – LWC relationship have to be used:

– for “clouds without drizzle fraction” class: $Z = 0.012*LWC^{1.16}$

– for “clouds with light drizzle” class $Z = 57.54*LWC^{5.17}$

– for “clouds with heavy drizzle” class $Z = 323.59*LWC^{1.58}$

By applying the Z-LWC relationships to the radar reflectivity profiles the LWC profiles can be produced. The LWC profiles integrated over the height produce the liquid water path (LWP) and can be compared with the LWP from the microwave radiometer for the results validation.

D. Level of adiabicity

The designation from the adiabatic conditions (Betts, 1983) can be calculated from the liquid water path according to the following formula:

$LWP = ½ A_d (1 – D)h^2$,

where A_d is the vertical gradient of liquid water content under adiabatic conditions, D is the parameter designating departure from the adiabatic conditions and h is cloud thickness. When the value of D is equal to zero it implies that the layer is adiabatic. For the values above zero, departure of the cloud liquid water from the adiabatic value is implied (Boers, 2000).

It should be noted that many of the above mentioned characteristic have a strong dependence on the liquid water path. Therefore, the accurate measurement of the LWP is crucial.

Task 22.2.2 – Cloud – aerosol interactions descriptors

Within each cloud class the relationship between the lidar-derived aerosol extinction and the cloud parameters will be derived, quantified by the indirect aerosol effect index (Feingold *et al*, 2003). Currently quantifying the radiative forcing due to clouds (cloud albedo forcing) is done by studying the change of representative cloud microphysical variables (e.g., R_{eff}) against a representative sub-cloud aerosol quantity (e.g., extinction). The cloud albedo depends on the cloud (geometrical and optical) thickness, the LWC and the CDNC and it is a way to express the amount of reflected solar radiation by a cloud. McComiskey and Feingold (2007) have indicated that the radiative forcing of the aerosol indirect effects (IE), which is the difference in radiative flux that occurs as a result of changes in cloud properties for post- versus pre-industrial aerosol concentrations, ranges from -3 to -10 W m^{-2} for each 0.05 increment in IE ($IE = - (dR_{eff}/d\alpha)$), where α is the aerosol amount). Therefore, the accurate quantification of the aerosols IE is necessary for better prediction of climate change.

The general definition of the aerosols IE can be expressed by IE = - (dC_{var}/dA_{var}), where Cvar and Avar are the representative variables for cloud and aerosol amounts. New proxies can be defined through:

- IE = - (dN_{cloud} / $dN_{aerosol}$)
- IE = - (dZ_{cloud} / $d\alpha_{aerosol}$)
- IE = - ($dR_{cloud,eff}$ / $d\alpha_{aerosol}$)
- IE = - ($dR_{cloud,ef}f$ / $dR_{aerosol}$)
- IE = - (dZ_{cloud} / $d\alpha_{aerosol}$)

The IE values obtained from the above equations are affected by different types of uncertainty resulting from the errors related to the individual microphysical variables of both clouds and aerosols. In the next step a sensitivity study of new proxies can be performed in order to narrow down the range of parameters to be considered.

Indirect Effect index calculations

First calculation of the Indirect Effect Index during ACTRIS were performed in Leipzig, Germany (Schmidt, 2013). In this case study Raman lidar MARTHA from the LACROS Observatory was used in a following configuration: dual-FOV Raman lidar for obtaining the effective radius of cloud drops and multiwave Raman lidar for obtaining extinction coefficient of the aerosol load. The goal was to test the dependence of effective radius on extinction coefficient and optical thickness. Cloud properties were compared during the observed different aerosol loads. For the aerosol properties the optical thickness of 800 m thick aerosol layer was used, this layer was located 300 m below the cloud base. For the high aerosol load optical thickness (α) reached values of 0.021 and for the low aerosol load α=0.008. The measurements indicated that when the aerosol load is higher, the droplets are smaller, which is in accordance with Twomey's theory. To describe the strength of the aerosol-cloud interaction the IE index was used, defined as IE = - ($dR_{eff}/d\alpha$)), where Reff is the cloud droplet effective radius and α is the aerosol optical depth (Feingold, 2001). The measurements of R_{eff} where taken in the lowest 70 m of cloud and the aerosol optical thickness α was considered as a 800 m thick layer located 300 m below the cloud. Presented results analyzed 17 cloud measurements. The IE index value obtained was 0.28. When sorting of the measurements according to the LWC was applied, the IE value was equal to 0.20 for the clouds with LWC higher than 0.08g/m^3 and 0.31 for the clouds with LWC lower than 0.08 g/m^3. Those results show that categorizing clouds according to the LWC is important.

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