Remote sensing of aerosol-cloud interaction at Mace Head, Ireland

Jana Preißler, Giovanni Martucci*, Aditya Vaishya, Colin O'Dowd

Centre for Climate and Air Pollution Studies (C-CAPS), School of Physics, National University of Ireland, Galway

*now with: Département fédéral de l'intérieur (DFI), Office fédéral de météorologie et de climatologie MeteoSwiss, Payerne, Switzerland

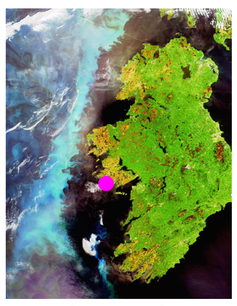
contact: jana.preissler@nuigalway.ie

Motivation and introduction

Both aerosols and clouds cause a direct radiative forcing by scattering and absorbing solar and infrared radiation. Besides that, aerosols also have an indirect effect on the radiation budget by altering cloud properties. Twomey first proposed an influence of aerosols on the cloud albedo by affecting the cloud droplet number concentration (Twomey, 1977). Furthermore, aerosols can alter the cloud lifetime, the water content of clouds and the droplet size distribution. They decrease the precipitation efficiency of warm clouds and thereby cause an indirect radiative forcing associated with the changes in cloud properties.

The aerosol optical thickness is an integrated variable that can be used to determine the aerosol direct radiative effect. In combination with microphysical cloud properties, their indirect effect can be estimated.

The Remote Sensing Devision at the Mace Head Observatory



53.33°N, 9.90°W
21 m above sea level

MIRA36 K-band cloud radar

Vertically pointing
Ka-Band 35.5 GHz
Range resolution: 30 m
Dual polarization receiver
Measured quantities: Reflectivity, linear depolarisation ratio, Doppler velocity

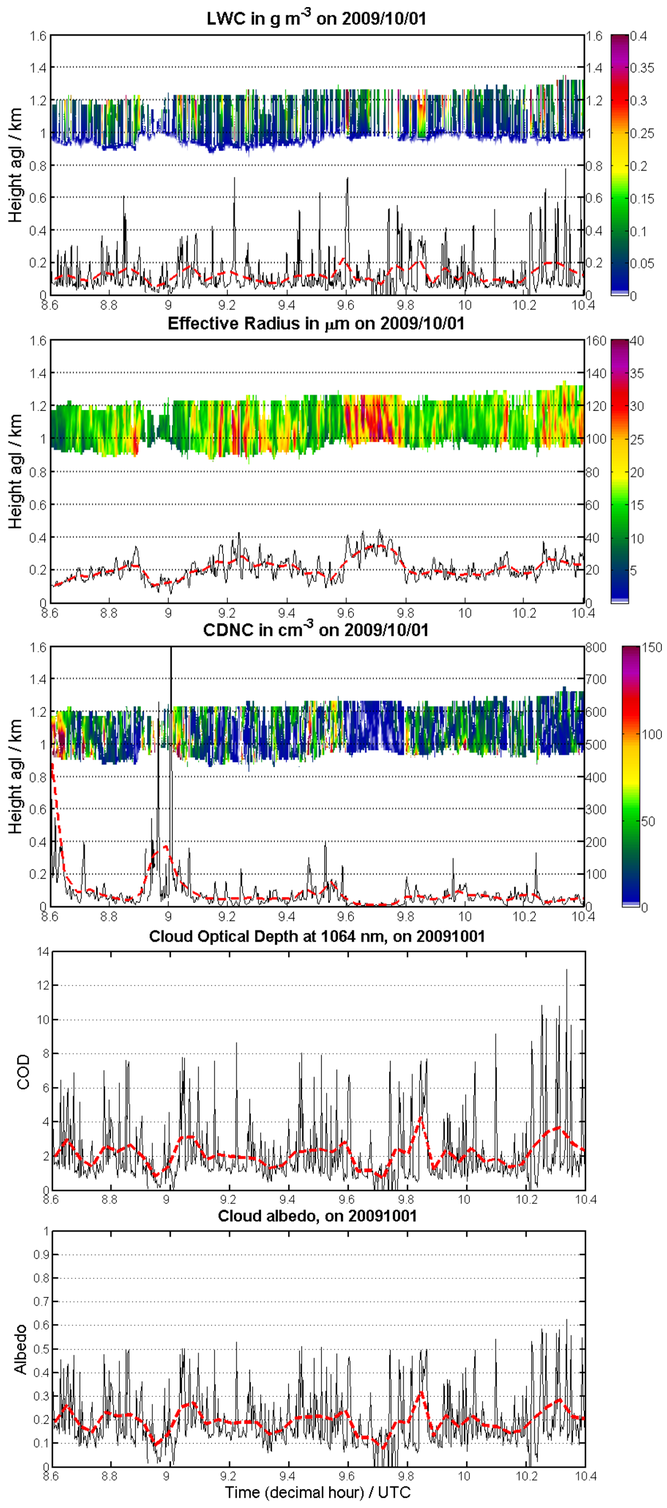
Jenoptik ceilometer CHM15K

Based on lidar principle (wavelength: 1064 nm)
Range: 30 m - 15 km
Minimum resolution: 15 m, 15 s
Measured quantities: Cloud heights, penetration depth, vertical visibility, height of PBL

RPG-HATPRO microwave-radiometer

Tropospheric (zenith) and boundary layer (scanning) measurements
Infrared channel for cloud boundary detection
Measured quantities: profiles of temperature and humidity

Cloud properties from SYRSOC

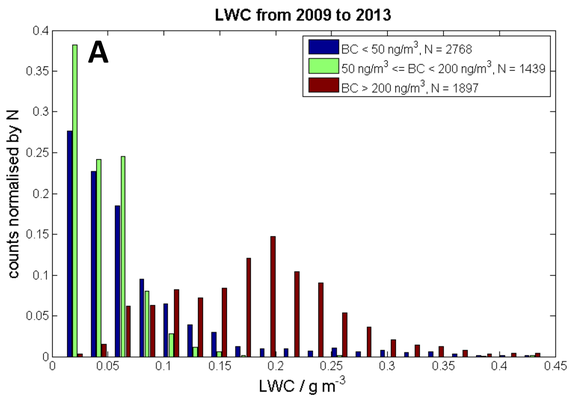


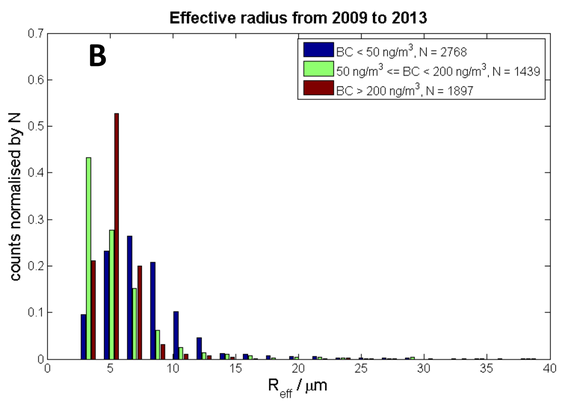
From top to bottom: Liquid water content, effective radius of the cloud droplets, cloud droplet number concentration, cloud optical depth and cloud albedo of a water cloud between 800 and 1400 m above ground level (agl) observed at Mace Head on 1 October 2009 (marine case). Black lines are vertically integrated values and red lines are those values averaged over 15 points.

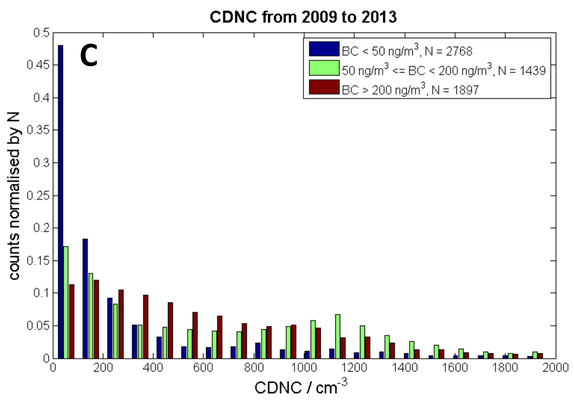
Ground-based remote sensing instrumentation can provide microphysical cloud properties from continuous measurements. Synergistic information from passive and active co-located remote sensors enables the retrieval of cloud microphysics based on a number of assumptions. The algorithm SYRSOC (SYnergistic Remote Sensing Of Clouds, Martucci and O'Dowd, 2011), is capable to retrieve microphysical properties of single-layer, homogeneous, non-precipitating liquid water clouds by combining data from a cloud radar, a ceilometer and a microwave radiometer. It provides cloud droplet number concentration (CDNC), cloud droplet effective radius, liquid water content (LWC), cloud albedo and cloud optical depth (COD).

In total, 117 cloud cases (6120 data points) from the years 2009 to 2013 were analysed. Back-trajectories revealed 34 continental (polluted) and 83 marine (clean) cases. SYRSOC results were combined with aerosol in-situ measurements. The black carbon concentration (BC) was measured at ground by a multi-angle absorption photometer (MAAP). The median of BC was 140 ng/m^3 (quartiles: 40 and 220 ng/m^3) for continental and 10 ng/m^3 (quartiles: 6 and 23 ng/m^3) for marine cases. Figures **A** to **E** show the distributions of LWC, effective radius, CDNC, COD and cloud albedo depending on the black carbon concentration.

Combination of remote sensing and ground based in-situ measurements





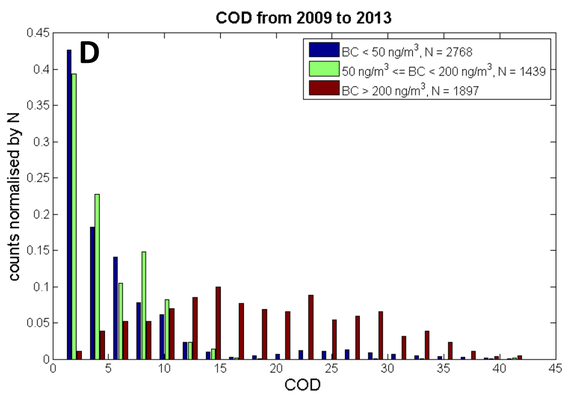


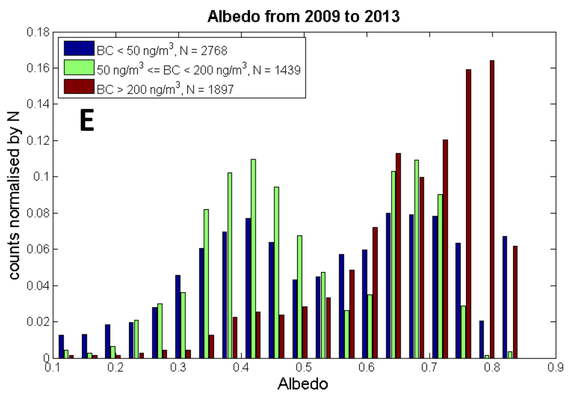
For clean cases, LWC and CDNC were generally lower than for polluted cases. The moderately polluted class (BC between 50 and 200 ng/m^3) includes both, typical polluted and rather clean cases. This explains the slightly bimodal distribution of the CDNC for this class. The effective radius was on average smallest for moderately polluted cases. For clean cases, the highest effective radii were observed.

The COD was lowest for clean cases and highest for polluted cases. Also the cloud albedo was highest for polluted cases. Clean and moderately polluted cases show a strong bimodal distribution of the cloud albedo, suggesting effects which are not well represented by SYRSOC. Ground based measurements of BC can be another source of uncertainties. Aerosol plumes can be transported over large distances in the free troposphere and influence cloud properties without being detected at ground.

Differences between clean and polluted cases are well visible for the liquid water content and the cloud optical depth. An increase of the COD and the Albedo with increasing aerosol load is in agreement with the Twomey effect. Brenguier et al. (2003) confirmed the expectations by Twomey (1977) of a negative correlation between the cloud optical thickness and cloud droplet effective radius. Strongly polluted clouds however can have a positive correlation.

The extensive instrument suite at Mace Head offers a variety of additional possibilities, e. g. aerosol speciation with a mass spectrometer (AMS), or condensation particle counter (CPC). Also the aerosol indirect effect index (Feingold, 2001) will be investigated.





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