Climate Change Research: Evaluation and Policy Implications
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The reduction of solar radiation by anthropogenic aerosol in the Netherlands

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Abstract

Nitrate appeared to be dominant aerosol species in the local "direct" aerosol radiative cooling forcing, which was of order -5 $W.m^{-2}$ on cloudless days. A first approach to the local influence of anthropogenic aerosols on cloud microphysics and radiation transfer in clouds was the measurement, in a large cloud chamber, of the number and composition of the cloud droplets formed in marine air. In anthropogenically "polluted" marine air, five times more cloud nuclei were formed than in clean (arctic) marine air. Approximately half of the anthropogenic aerosol particles with the right size were not soluble in water and did not serve as extra cloud nuclei.

1. INTRODUCTION

Aerosol particles in the atmosphere reflect short-wave radiation of the sun and absorb very little infrared terrestrial radiation. Both natural and anthropogenic aerosols are a cooling factor, however, it are the aerosols of anthropogenic origin which exert a forcing, known as the "direct" aerosol effect [1]. This forcing has a local/regional character because of the limited life time of aerosol particles in the atmosphere and thus requires local studies [2].
Aerosols also act in an indirect way as a coolant. They are the nuclei on which the water vapour condenses when clouds form. Anthropogenic aerosol particles serve as extra cloud nuclei in addition to the natural nuclei. Clouds with extra cloud droplets reflect more solar radiation but do not intercept more terrestrial radiation. The increase in reflectance (albedo) of anthropogenically influenced clouds is known as the "indirect" aerosol effect. Its magnitude is very uncertain [1,2].

2. DIRECT EFFECT

Reflection of solar radiation on anthropogenic aerosol in Europe [1] is estimated to (over)compensate the "warming" by the manmade greenhouse gases. However, these estimates are based on the assumption that sulfate is the sole aerosol component and that the same relation between sulfate and light-reflection, as measured (at ground-level) in the US, was applicable for Europe.
The relation between sulfate and light-reflection in West-Europe was investigated. Also the magnitude of the reduction of solar radiation by aerosol on cloudless days was measured and compared to the amount extrapolated from the ground-level measurements, in so-called "closure" experiments.

2.1 Experimental

In the study automated monitors for the dominant aerosol species in the Netherlands, viz. sulfate and nitrate, were applied. In this way the relation between these parameters and the light-reflection by the aerosol could be determined for the relevant (midday) hours.

During a period with cloudless skies the aerosol optical depth (OD) was compared to the OD extrapolated from the light-reflection measured at the ground in integrating nephelometers. LIDAR-data (RIVM) gave the height of the aerosol layer. The growth of the hygroscopic aerosol, caused by the increase in humidity with height, and the resulting increase in scattering were taken from measurements with a laboratory "humidograph" [3] in front of the nephelometer, in which the humidity can be varied.

2.2 Results

Extrapolated and measured aerosol OD were comparable, see fig 1. On the measuring days the concentrations of nitrate were (up to five times) higher than sulfate and thus nitrate dominated the aerosol extinction and the hygroscopic growth of the aerosol. This is in contrast to the current opinion [1] that sulfate is the dominant radiative forcing aerosol-component. Carbonaceous aerosol seemed as important as sulfate.

The measured OD's were translated to aerosol radiative forcing, which then was of order -20 $W.m^{-2}$ at midday. The 24-hour averaged aerosol forcing was -5 $W.m^{-2}$.

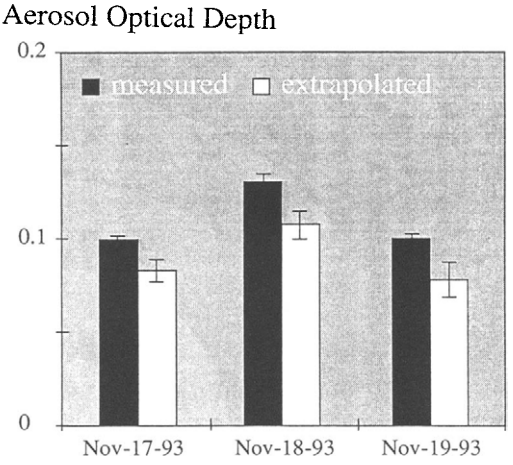

Figure 1. Comparison between measured and nephelometry derived aerosol optical depth

3. INDIRECT EFFECT

3.1 Introduction

Sensitivity studies show that the "indirect" effect is most important in marine stratus clouds near polluted continents. The reason is that these clouds have small numbers of droplets because there are very few natural cloud nuclei and thus can be a maximally influenced by small numbers of extra anthropogenic cloud nuclei.

3.2 Aim and approach

Actual measurement of the "indirect" effect seems impossible as yet and in a first approach to estimate the maximum local "indirect" effect here, the influence of the local anthropogenic aerosol particles on cloud droplet number has been assessed.

3.3 Experimental

The study was performed in a large cloud chamber. The size of the chamber allows collection of particles and cloud droplets for chemical speciation. The effect of anthropogenic aerosols is determined by comparison of the number of cloud droplets formed in clean and polluted air. The cloud chamber is near the coast of the North Sea in the Netherlands. In arctic marine air the concentration of aerosols is low. Anthropogenic aerosol is present in air flows which have passed over the UK; this is with SW to W winds.

Artificially generated aerosols with similar number concentrations served as reference cloud nuclei in experiments in which the cloud formation was tested.

Supersaturation used in the study are of order 0.1%, typical for the relevant clouds. Apart from the number of droplets, the size and composition of the aerosol particles which serve as cloud nuclei are measured. In some occasions also the droplets were collected according to size inside the chamber and the chemical composition of the droplets was measured.

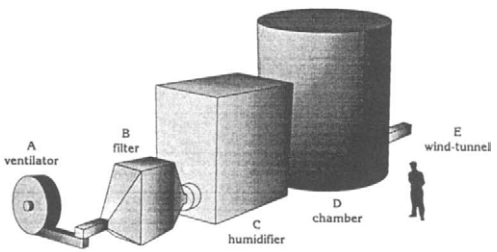

Figure 2. Sketch of Cloud Chamber; note size

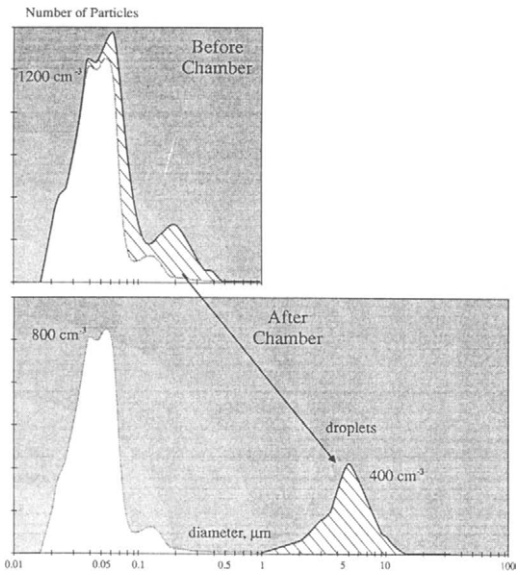

Figure 3. Results of test on 16 June 1994

3.4 Results and preliminary conclusions

The number of cloud droplets in the polluted air is higher by a factor of five compared to that in the clean air. The increase in total particle number is a factor of ten. The difference in the increase in aerosol number as compared to cloud nuclei is explained by the fact that particles with the proper size for cloud nuclei are non-soluble and therefore cannot act as cloud nuclei. Measurement of the actual amount of non-soluble particles, presumably of carbonaceous material, is very difficult because cloud nuclei are small and thus present very little mass.

4. GENERAL CONCLUSIONS AND RECOMMENDATIONS

-Additional experiments are required to validate estimates of the local "direct" aerosol effect
-Nitrate of is of more importance for the "direct" effect than sulfate in the Netherlands.
-Carbonaceous material is a key component both in the direct and indirect aerosol effect.

5. ACKNOWLEDGEMENT

Financing by the department of Economic Affairs of the Netherlands; additional funding:
-Indirect effect: National Research Program on Global Air Pollution and Climate Change; project No. 852066
-Direct effect: CEC-Environmental Research Programme/ Climatology and Natural Hazards; project No. EV5V-CT92-0171

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