The Microstructure of Clouds in the High-Frequency Hail Area of Kenya

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ABSTRACT

During June 1977 ground-based measurements of the CCN spectrum were made twice daily near Kericho, Kenya, and two flights were flown in that region to investigate the microstructure of the clouds. Both the CCN and the cloud-droplet distribution measurements show that the cloud microstructure is continental.

1. Introduction

The Kericho tea growing area, situated in western Kenya, experiences hailstorms on approximately 100–150 days per year (Alusa, 1976). Two hail suppression projects have been carried out in this area in an effort to reduce the hail damage to tea. The first project, reported by Sansom (1968), used Italian anti-hail rockets launched over select tea estates from July 1963 to September 1967. The second project, an operational program, involved seeding at cloud base with pyrotechnics, and lasted from October 1967 to October 1975 (Henderson, 1975). There also has been some recent interest in conducting a randomized hail suppression experiment in the area (J. Flueck and J. McCarthy, private communications). The high frequency of hail would greatly reduce the period of time needed to detect a statistically significant result. Sansom and Gichuiya (1969) and Alusa (1976) have presented data on thunderstorm growth and hailfall characteristics in the Kericho area in an attempt to define the conditions in which these local hailstorms occur.

In spite of the interest in the hailstorms in this area, measurements of the microphysical structure of these clouds have not been reported. Consequently, when the NCAR Electra was stationed in Nairobi, Kenya, during June 1977 as part of MONEX 77, arrangements were made for two special flights to the Kericho area to investigate the microstructure and mesoscale dynamics of actively growing cumuli in that region. Additionally, ground-based measurements of cloud condensation nuclei (CCN) and ice nuclei (IN) were made twice daily during the month of June 1977 in the Kericho area. This note reports the results of the ground-based observations of CCN and IN and preliminary microphysical results from the aircraft observations.

2. Ground-based measurements

Measurements of CCN and IN were made twice daily at about 0900 and 1400 LT from an isolated private home about 6.5 km due east of Kericho. The location was at 2160 m elevation at the western edge of the southwestern Mau Forest on an isolated knoll in the Chepgowen tea estate. Air samples for both the CCN and IN measurements were taken about 3 m above the ground on the northwest side of the house. Commonly the wind was calm or very light and variable at the time of the 0900 measurements but by 1400 the wind was primarily from the west at 2–5 m s^{-1}, presumably due to the onset of mountain-induced upslope winds or sea breeze winds from Lake Victoria. The measurements are considered to be free from local contamination and representative of the low-level air mass from which the storms develop. Recent evidence by Rogers and Vali (1978) supports

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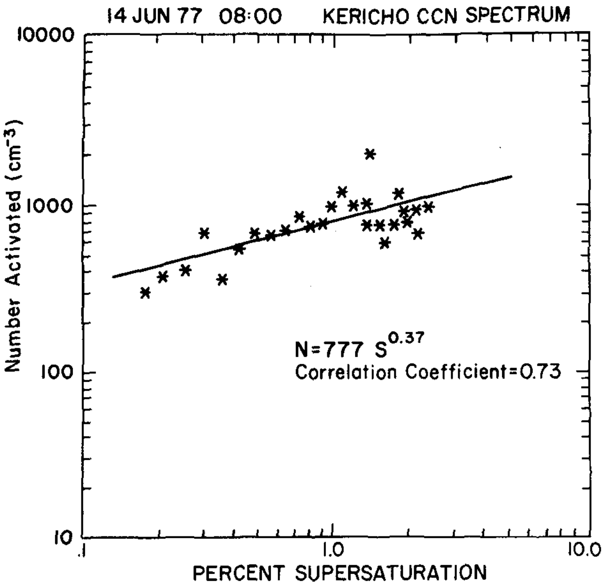

FIG. 1. The CCN spectrum measured at 0800 LT 14 June 1977 near Kericho, Kenya.

the hypothesis that surface measurements of aerosol and nucleus content can be representative of the inflow air to cumulus clouds.

The CCN measurements were made with an NCAR-modified version of the Allee thermal gradient diffusion cloud chamber (Langer and Baird, 1978) in which the temperature difference is generated by heating the top plate of the chamber. The sample volume of the CCN counter was calibrated by drawing samples of air containing known concentrations of monodisperse NaCl particles into the chamber and photographing the resulting droplets. For the Kericho experiment, photographs of the activated droplets were taken over a range of supersaturations from about 0.2 to 3% as the top plate slowly warmed up and then cooled down. Generally, 20–30 individual points at different supersaturations were takn for each CCN spectrum over a period of about 30 min. An example of one of the spectra is shown in Fig. 1. The concentration and slope parameters (c and k) for the commonly used $N=cS^k$ representation of the CCN spectrum were determined by a least-squares fit to each set of points.

The results of the CCN measurements are presented in Fig. 2, while the c and k values for all of the CCN spectra are shown in Fig. 3. When compared with Twomey's (1959) classification of CCN spectra according to either maritime (c values of roughly 10 to 100 cm^{-3}) or continental (c values of roughly 100 to >1000 cm^{-3}), it is apparent that the low-level air masses during the period of measurement were continental. The average c and k values during this period were 1129 and 0.60, respectively, with standard deviations of 375 and 0.34. By comparison, Rogers and Vali (1978) found average surface values of $c=900$ and $k=0.54$ for June and July 1976 in northeast Colorado, a region in which summer clouds are known to be highly continental (Dye *et al.*, 1974).

In order to determine ice nucleus populations 0.45 μm millipore filters were also exposed twice daily during the time that the CCN measurements were being made. The volume of air sampled for each filter was about 150 liters. The exposed filters were returned to Boulder, Colorado, and processed in the NCAR ventilated diffusion chamber (Langer and Rodgers, 1975). One-fourth of each filter was processed at $-16°$C ($\sim$17% supersaturation with respect to ice) and another fourth at $-20°$C ($\sim$20% supersaturation with respect to ice). Typical background counts for unexposed filters processed in this manner are about 3–5 counts per $\frac{1}{4}$ filter at $-20°$C and about 0–2 counts per $\frac{1}{4}$ filter at $-16°$C.

The counts and apparent ice nucleus concentrations obtained from each processed filter segment are

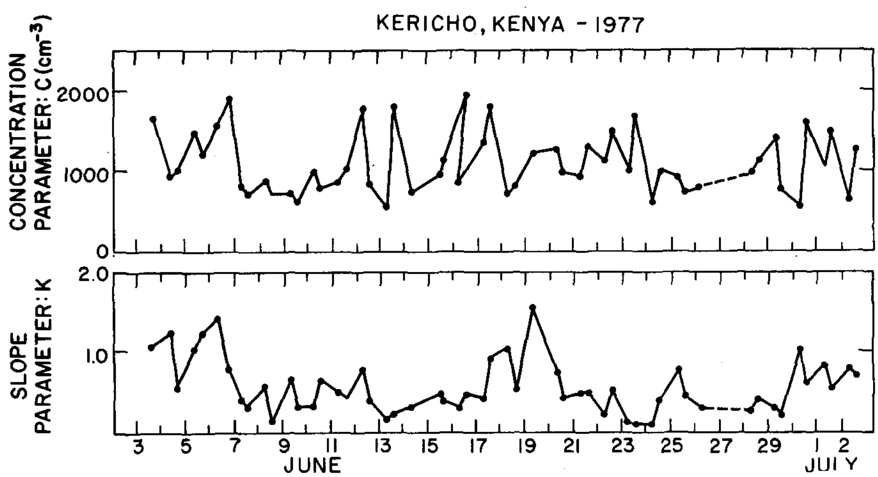

FIG. 2. The c and k parameters of the CCN spectra measurements, plotted as a function of time.

presented in Fig. 4. The apparent ice nuclei concentrations at both −16 and −20°C seem low when compared with ice nucleus concentrations measured using filters in some regions (e.g., Rogers and Vali, 1978; Gagin and Neumann, 1974), but comparable to concentrations reported by other investigators (e.g., Jiusto *et al.*, 1976).

3. Airborne measurements

Special flights to the Kericho area were made on 7 and 14 June 1977. A number of penetrations were made through several growing cumulus congestus clouds with vertical developments of about 2–3 km on both days. These towers were growing out of a layer of broken stratocumulus. The horizontal dimensions of the clouds varied from 1 to 3 km and updrafts at 1 to 2 km above base were typically 3–5 m s^{-1} with a maximum observed updraft of 9 m s^{-1}. The cloud base for the 7 June case was at 12°C and 3.2 km MSL; for the 14 June case, 15°C and 2.5 km. On both days peak liquid water contents measured by the Johnson-Williams (JW) hot-wire liquid water content meter were between 1.5 and 2.0 g m^{-3} at 1–2 km above cloud base and were at most 40% of adiabatic.

In addition to instruments for measuring the state parameters and vertical and horizontal winds, the Electra was equipped with a Particle Measuring Systems Axially Scattering Spectrometer Probe (ASSP) (Knollenberg, 1976) mounted out of the left forward window of the Electra with the sampling area of the probe about 51 cm from the fuselage. The JW hot wire probe was mounted on the nose boom. The ASSP was checked and calibrated by the manufacturer immediately prior to the field program. Additionally, glass bead-size calibrations and alignment checks were performed before and after the trip to Kenya and before each special flight. All four of the size calibrations showed consistent agreement. Because of this consistency and the consistency noted in the aircraft observations, the accuracy of the droplet size measurements should be about ±10%. Unfortunately, an exceptionally long delay time in the strobe circuit of the ASSP, coupled with the high airspeed of the Electra (~125 m s^{-1}), produced high coincidence errors so that the measured droplet concentrations were too low and cannot be trusted or reliably corrected. However, since the sizing is considered to be fairly reliable, and the coincidence error would not influence the shape of the distribution, and the liquid water content (LWC) was independently measured by the JW, an estimate of the true droplet concentration can be made by correcting the measured concentration by the ratio of the JW measured LWC to the ASSP derived LWC. The excellent agreement between the shape of the ASSP derived LWC and the shape of the JW measured LWC during individual cloud passes lends credence to this procedure. However, the cumulative error of this estimate may be as much as 50% since the JW measurements are generally considered to have an accuracy of ±20% and the accuracy in sizing of ±10% by the ASSP could yield as much as a 30% error in the liquid water content derived from the ASSP measurements.

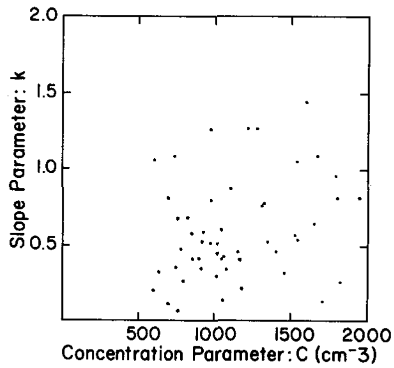

FIG. 3. The *c* and *k* parameters plotted in *c*-*k* space for the CCN spectra measurements.

When the measured concentrations (which had peak 1 s values of 150 to 200 droplets cm^{-3}) are corrected using this technique the peak concentrations in different clouds ranged from 1500 to 2000 droplets cm^{-3} on 7 June and 1000 to 1500 droplets cm^{-3} on 14 June. Although the corrected concentrations seem higher than might be expected (600–1000 cm^{-3}) based on the

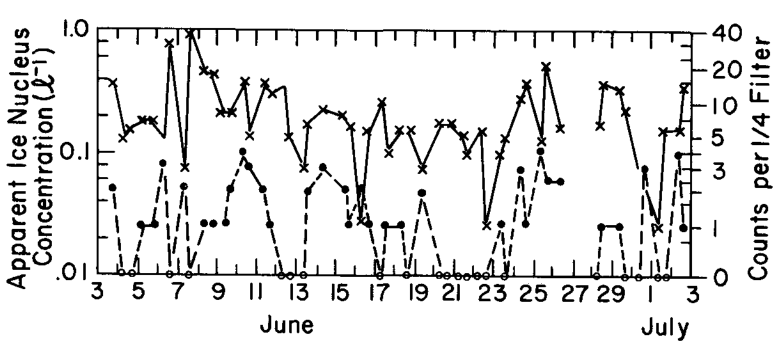

FIG. 4. The apparent ice nuclei concentration at −16 (dashed) and −20°C (solid) plotted as a time history. The number of activated sites counted per 1/4 filter are shown on the right-hand scale.

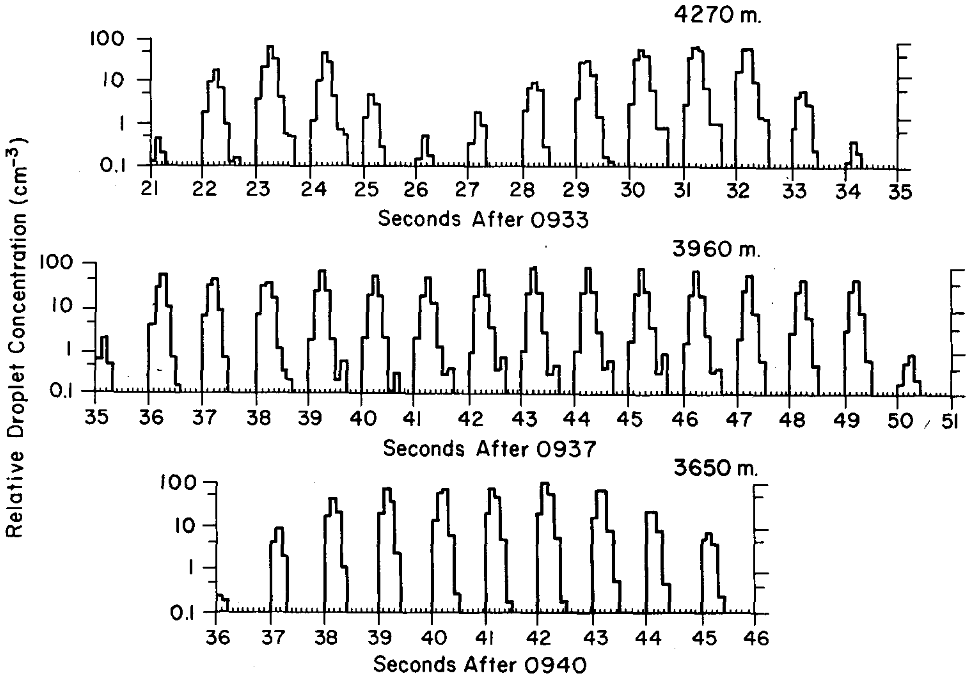

FIG. 5. Cloud-droplet distributions shown at 1 s intervals during three separate passes through the same cloud on 14 June 1977 (see text).

ground-based CCN spectrum measurements and cloud-base updrafts measured from the Electra, the clouds are clearly continental. Indeed, even the uncorrected concentrations of 150 to 200 droplets cm^{-1} are more continental than maritime.

Examples of some of the measured droplet size distributions taken during three different passes at different altitudes through the same cloud are shown in Fig. 5. The first pass was made at about 4270 m, 0°C (roughly 300 m below cloud top and 2000 m above cloud base) with the second and third pass made at 3960 m, 3°C and 3650 m, 6°C, respectively. Cloud base on this day was at 2480 m, 15°C. The concentrations are shown as relative concentration and have not been corrected for the coincidence error. Each channel of each distribution is 4 μm wide and are centered on 4, 8, 12, 16, . . . μm. The mean droplet diameter (excluding measurements near the edges of the cloud) for the first, second and third pass are 11.9, 11.5 and 8.6 μm, respectively, with corresponding maximum droplet sizes at concentrations of $\geqslant 1$ drop cm^{-3} of 24, 20 and 16 μm. The relatively narrow spectrum with small droplet diameters is definitely continental in nature (Squires, 1958).

4. Discussion

Both the ground-based measurements of CCN concentration and the aircraft measurements of droplet sizes and concentrations are characteristic of continental clouds. From this standpoint one might expect the coalescence mechanism of precipitation formation to be relatively inactive in the clouds near Kericho. However, the relatively warm cloud bases which typically are +10 to 15°C (Alusa, 1976) would make more cloud water available for coalescence growth than is found in northeast Colorado where cloud bases are typically +5°C and precipitation formation is predominantly through the ice process (Dye *et al.*, 1974). For this reason it is not possible to definitely rule out the possibility of precipitation formation through the coalescence mechanism and the presence of large water drops, which could act efficiently as hail embryos. However, it is interesting to note that the clouds near Kericho are very similar in droplet microstructure and cloud-base temperature to those investigated by Gagin and Neumann (1974) in Israel, where the ice process appears to be dominant. Although the measurements presented here were obtained only during June, one of the months with a relatively high frequency of hail, the prevailing mid-level and low-level winds during the hail seasons of April–June and September–November also have a westerly component, from the interior of the continent.

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