Note on the global variation of stratospheric turbidity since the eruption of Agung Volcano

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ABSTRACT

Available data of attenuation due to dust from the eruption of Agung Volcano on Bali in March 1963 are compared with turbidity from earlier great eruptions. While abnormal twilights have been observed first in September 1963 in U.S.A., and in November in Europe, measurements of twilight at Weissenau indicate a small increase of stratospheric turbidity already in May 1963. Relevant investigations are summarized.

More data are slowly accumulating on the effects of the great eruption of the Agung Volcano on March 17, 1963, on Bali, on optics of the atmosphere and on concentration and chemistry of particles in the stratosphere. Here we would like to comment on some optical data regarding the global variation of atmospheric turbidity since the eruption.

Over the Southern Hemisphere, *turbidity* (Fig. 1) increased soon after the Agung explosion to the level known from other violent eruptions (Fig. 2). Intensity of direct solar radiation dropped between April 20 and 22, 1963, by 5 per cent at Pretoria, South Africa (BURDECKI, 1964). In Chile, 30°S visual extinction increased suddenly in the first days of May and reached peak values in May and September (MORENO & STOCK, 1964). Also shown in Fig. 1 are even higher values obtained by HOGG (1963) in Australia and by UNZ (1964) in South Africa, which were also hardly influenced by low level haze. For 1964, only turbidity values from Chile (UNZ) during June and July, and from Australia (Miss. B. HARRIS, 1965) for December came to my knowledge. The latter value of $B = 0.07$, measured near Melbourne, is probably influenced locally.

There are three more volcanic eruptions for which turbidity has also been measured on the hemisphere on which the eruption took place. In Fig. 2, the events in Chile and Australia after the Agung eruption are compared with turbidity at Mt. Pelee (1902, 15° N 61° W) according to KIMBALL (1910), of Katmai (1912, Alaska) from the measurements by DORNO (1919), and of an apparently weaker eruption in the South American Andes (10 April 1934), observed by RIMMER (1937). Turbidity of the Andes and Agung eruptions (southern hemispheric Fall) have shown early maxima of turbidity on the hemisphere of eruption, while in the other cases of eruptions in the northern hemispheric spring the maximum is delayed by about one year.

The attenuation increase after the Agung eruption over the Northern Hemisphere was certainly smaller. Only a few easily interpretable mountain data are available, which indicate a latitudinal effect. In Arizona, a slight abnormal attenuation was observed in fall 1963 (MEINEL & MEINEL, 1963, 1964). B-values from a Hawaiian mountain (20.3° N) varied from 0.02 to 0.06 by April 1964, and the daytime sky showed strong high altitude dust scattering (BULLRICH & EIDEN, 1964). At Zugspitze (2960 m, 47° N), B was smaller than 0.015 during the time of maximum twilight effects in winter 1963/64, but in spring I could also observe traces of high altitude dust scattering during the day.

Very strong *daytime and twilight sky disturbances* after the Agung eruption have been observed since May 1963 over the Southern Hemisphere (BURDECKI, 1964; MORENO & STOCK, 1964; HOGG, 1963; MEINEL & MEINEL, 1963, 1964). More normal conditions returned by March 1964 (BIGG, 1964). In the southern United States, unusual twilight glows, often accompanied by horizontal striations, started in the first week of September 1963 (MEINEL & MEINEL, 1963). My own visual observations at

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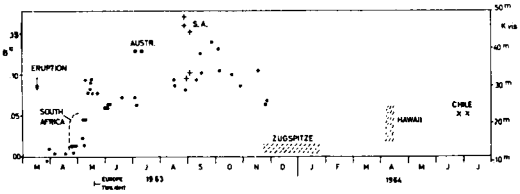

FIG. 1. Variation of aerosol extinction over the Southern and Northern Hemisphere in 1963 and 1964. Chile Cerro Tolodo, 2200 m (MORENO & STOCK, 1964); ×, Southwest Africa, 1000 m, and +, Chile, 3000 m (UNZ, 1965); ○, Melbourne, Australia (B. HARRIS, 1965). *B*, Decadic attenuation coefficient by dust, λ 500 mμ.

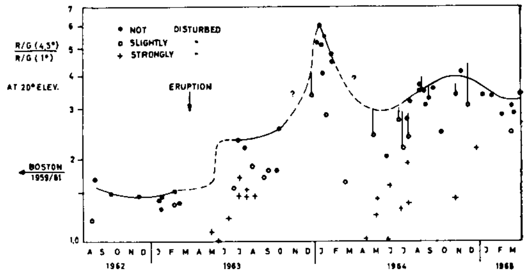

FIG. 3. Peak of color ratio Red/Green from twilight measurements at 20° elevation, Weissenau. ●, Fully developed twilights, ○, slightly and +, strongly cloud disturbed.

Berkeley during the last week of August were already suspected of a slight increase of the purple glow; the change had certainly occurred after continuation of observations at Boulder, Colorado, in the first days of September. In Germany, however, stronger twilights were not observed before the middle of November; strong colorations and small dust clouds were often reported in December and January (VOLZ, 1964). A similar latitudinal progress of the dust cloud from the Krakatoa explosion in fall 1883 has been studied in detail by WEXLER (1951).

Here we may also mention the dark moon eclipses in December 1963, June and December 1964 as the results of the decrease in horizontal transmission of the stratosphere.

In addition to the visual observations, progress in the evaluation of my twilight measurements at Weissenau shows now clearly, that a slight deviation from normal conditions started here already around the middle of May 1963, i.e. with little delay to the events over the Southern Hemisphere. Fig. 3 shows the change of the peak color ratio Red/Green (λ 715 and 477 mμ) at about 4.5° sun depression, referred to the color ratio at 1° sun depression, since August 1962. Up to March 1963, the peak ratio of undisturbed twilights is still at the level of measurements at Boston 1959 to 1961 (VOLZ & GOODY, 1962). The first high peak ratio of twilights, obviously unaffected by interference of solar illumination with tropospheric clouds below the horizon, was measured on July 14. However, the peak ratio of the slightly cloud-disturbed twilight of May 21 may have been already as high. Correspondingly, the change of the general course of Green intensity with sun depression, which is not subject to the cloud effect, occurred between 12 and 21 May. These early changes of twilight conditions were certainly caused by an unusual increase of turbidity at about 17 km, which apparently was unnoticed otherwise. (According to simply constructed trajectories of the 100 mb level, the air arriving at Weissenau on 21 May at about 16.5 km may have been 2 weeks previously as far south as 25° (north of Hawaii).

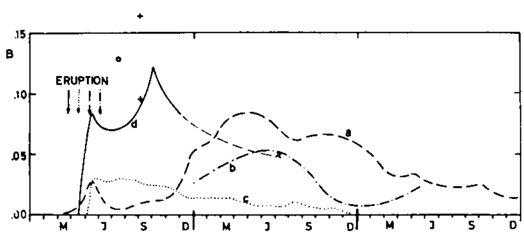

FIG. 2. Course of turbidity after great volcanic eruptions on the hemisphere of eruption. Data *a* to *d* have been derived from monthly means of total solar radiation under approximate consideration of the annual course of water vapor and solar elevation. This results in a much smaller turbidity in winter than summer for the same relative radiation depletion. (*a*) Mt. Pelee eruption, measurements at Washington D.C., Warsaw, Lausanne, and in Russia (KIMBALL, 1910); (*b*) Katmai eruption, measurements by DORNO (1919) at Davos; (*c*) Volcano in South American Andes, measurements by RIMMER (1937) at Mt. Stromlo, Australia; (*d*) Agung eruption, measurements in Southern Hemisphere (see Fig. 1).

Unfortunately, details of the further strong increase of the peak color ratio resp. of stratospheric turbidity in early winter 1963 and the intermediate decrease in spring 1964 could not be obtained by the twilight method because of bad weather conditions. The apparently slight increase in the following winter 1964/65 seems to have been nourished by the still much higher turbidity over the Southern Hemisphere.

Presently, the peak ratio seems to decrease again. Twilig htmeasurements taken by Miss. B. HARRIS (1965) in December 1964 near Melbourne, Australia, indicate that there the turbidity conditions are still comparable with our extreme conditions during winter 1963/64.

In the only case comparable with the effect of the Agung eruption on seasonal variation of turbidity over Europe, the Krakatoa explosion on 27 August 1883 in the same geographical area, the maximum turbidity in Switzerland ($B \approx 0.1$) seems to have been reached as late as early 1885. Twilight effects in Europe started by the end of November 1883 (see WEXLER, 1951), and lasted, also with revivals in the fall and winter, until the beginning of 1886. So, it may even over Europe take at least one year more for restoration of normal aerosol properties of the stratosphere.

The increase of the peak color ratio may be roughly proportional to the increase of the aerosol concentration over a height range of some 10 km, which is the resolution of twilight measurements. Since the thickness of the layer (at about 17 km) was only in the order of a few kilometers (MEINEL & MEINEL, 1964; KROENING, 1964), the concentration of optically effective particles over Germany might have been higher by a factor of 10 in summer 1963 and by a factor of 20 in winter 1963/64 than in the ordinary Junge sulphate layer.

Apart from the complete evaluation of our twilight measurements (in progress), more details on vertical distribution of aerosol over the Northern Hemisphere were obtained by balloon-borne optical particle counters by KROENING *et al.* (1964) and by searchlight by ELTERMAN (1964), but we will not discuss them here. Concentration and nature of stratospheric particles over Australia have been investigated by MOSSOP (1963, 1964). In December 1963 and April 1964, he found some 7 times more fine particles than up to May 1963, and from that time, 10 to 20 per cent of particles appeared to be of volcanic origin. Sun-light reflected from a balloon during sunset was investigated by Miss. B. HARRIS (1965) in Australia. Regarding the problem of interchange between the hemispheres, we may only compare the new optical results on the debris of the volcanic eruption at 9° S with radioactivity of rain (Sr 90) from the 1956–59 bomb tests north of the Equator, which in 40° S amounted to about 16% of the radioactivity found in 40° N (STEWART, 1960).

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