Reports

Solar Radiation: An Anomalous Decrease of Direct Solar Radiation

Abstract. *Beginning in November 1963, measurements made at the South Pole of solar radiation at normal incidence indicate a decrease of from 5 to 78 percent of the normal intensity. Similar measurements made at Mauna Loa, Hawaii, show a similar though smaller reduction. The causal factor is believed to be a layer of atmospheric dust resulting from the eruption of Mt. Agung, Bali, in March 1963.*

In November 1963, a sharp decrease occurred in the normal-incidence solar radiation measured at the Amundsen-Scott (South Pole) station in Antarctica. The mean monthly value was 5.3 percent below the 1957–62 monthly normal. In 1957–62 the mean monthly values ranged from −0.9 percent to +0.6 percent of the normal for November. Since then the values have ranged from 23 to 78 percent below normal for all months.

An Eppley pyrheliometer with an aperture of 5°43′ was used to make the measurements at the South Pole. To minimize the possibility of instrumental error, the pyrheliometer in use was replaced by another one, but the results remained unchanged. A year later, in November 1964, the instrument in use at the South Pole was compared *in situ* with a Sub-Standard (secondary standard) taken to the station for that purpose. When both instruments were exposed simultaneously, the measurements were identical and the observed low values were confirmed.

Since instrumental error had been eliminated as a probability, an examination was made of immediately available data from other stations at which similar instrumentation was being used. Solar radiation data for normal incidence were examined from five U.S. stations (*1*) as published by the U.S. Weather Bureau in the monthly Climatological Data, National Summary. These values also appeared to indicate a decrease, though the percentages were considerably smaller and occurred earlier than at the South Pole.

Figure 1 shows a comparison of the data for 1963 (dots) and 1964 (light lines) with the 1957–62 monthly normals at the South Pole and Mauna Loa, Hawaii. All the data have been normalized for the mean earth-sun distance. The daily maximum values began to decrease at the South Pole in November 1963 and remained low through November 1964, the latest period for which data were available. At Mauna Loa, the noon TST (*2*) values show a reduction of 3 to 6 percent, with 5 percent in March and April 1963, and 6 percent in May 1963. A larger reduction of 3 to 14 percent is indicated at a zenith angle of 78.7°. For the same zenith angle at the South Pole, which occurs in October and February, the data show reductions of 36 to 48 percent. Price (*3*) indicated that the Mauna Loa values for a zenith angle of 60° were approximately 8 percent below normal and, as of December 1964, were still decreasing.

A cursory examination of the total measurements for horizontal-incidence solar radiation at the South Pole indicates a maximum possible reduction of 4 percent. The Mauna Loa data, according to Price, show a greater reduction.

Hogg (*4*), in describing the optical phenomena and variation of atmospheric turbidity at the Mt. Stromlo Observatory in Australia, mentions a report of a 5 percent reduction in solar radiation measured at horizontal incidence in New Zealand and Fiji. He ascribes this reduction and the optical and turbidity effects to the eruption of Mt. Agung, Bali, at 8°25′S, 115°30′E on 17 March 1963. Similar reports of optical phenomena elsewhere in the Southern Hemisphere are mentioned by Burdecki (*5*) and Hogg. Meinel and Meinel (*6*) have discussed the late twilight glow observed at the Steward Observatory in Arizona in early September 1963 produced by the eruption at Mt. Agung.

The effects of a volcanic eruption indicated above are similar to those observed for the Krakatoa eruption in 1883 (*7*), though on a lesser scale. Wexler has discussed the reduction in normal-incidence solar radiation observed in France following the Krakatoa eruption (*8*) and the variation in arrival time of the dust layers in various parts of the world (*9*). The arrival times noted thus far for the 1963 phenomena suggest that they are related to the Mt. Agung eruption. A November 1963 arrival time at the South Pole is due to the sudden influx

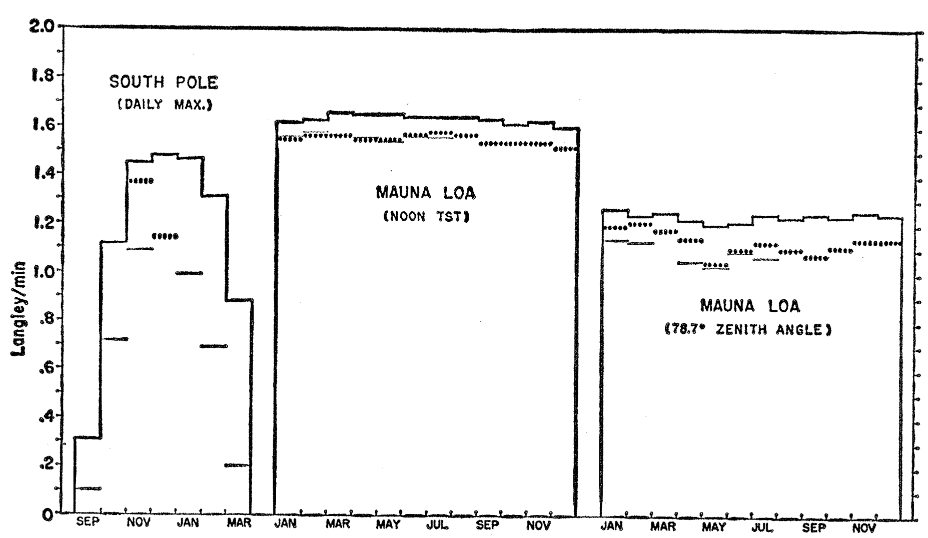

Fig. 1. A comparison of the 1963 and 1964 normal-incidence solar radiation with the 1957–62 monthly normals at the South Pole and at Mauna Loa, Hawaii. The heavy lines represent the 1957–62 monthly normals, the light lines represent those for 1964, and the dots for 1963.

of the volcanic material following the spring breakdown of the Antarctic circumpolar circulation.

Daily values of the normal-incidence radiation at the South Pole indicate that the initial influx of the material occurred in several bursts in late November and early December, 1963. Analysis of the stratospheric circulation over Antarctica for these months shows that the dates of arrival at the South Pole coincide with a change in the circulation from circumpolar to meridional. The late arrival of the material in Antarctica is due to the stability of the stratospheric circumpolar circulation during the fall and winter seasons, which effectively restrained the influx until the breakdown of the circulation in the spring (*10*).

As a working hypothesis for the investigation of the radiation decrease, we are assuming that the observed effects were due to the eruption of Mt. Agung in March 1963. Other explanations, including an increase of extraterrestrial material (*11*), have been carefully examined and rejected as unlikely.

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References and Notes

1. Mauna Loa, Hawaii; Albuquerque, N.M.; Madison, Wis.; Tucson, Ariz.; and Blue Hill, Mass.
2. True Solar Time, TST.
3. S. Price, private communication.
4. A. R. Hogg, *Australian J. Sci.* **26**(4), 119 (1963).
5. F. Burdecki, *Newsl., Weath. Bur. Pretoria* **1963**, 96 (June 1963).
6. M. P. Meinel and A. B. Meinel, *Science* **142**, 502 (1963).
7. Royal Society of London, Krakatoa Committee, *The Eruption of Krakatoa and Subsequent Phenomena*, G. J. Symons, Ed. (Trüleer, London, 1888).
8. H. Wexler, *Bull. Am. Meteorol. Soc.* **32**(1), 10 (1951).
9. H. Wexler, *ibid.* **32**(2), 48 (1951).
10. A detailed paper discussing the relationship between the normal-incidence radiation observations at the South Pole and the Antarctic circulation is now in preparation.
11. B. A. McIntosh and P. M. Millman, *Science* **146**, 1457 (1964); C. D. Ellyett and C. S. Keay, *ibid.*, p. 1458.

10 March 1965

Radiocarbon Determinations for Estimating Groundwater Flow Velocities in Central Florida

Abstract. *Carbon-14 activity was determined from HCO_3^- in samples of groundwater obtained from the principal artesian aquifer in Florida. From these data the "age" of water obtained from a series of wells, each progressively farther down gradient on the piezometric surface, was established. Relative carbon-14 ages indicated a velocity of groundwater movement of 23 feet (7 meters) per year for about 85 miles (137 kilometers) of travel. A velocity of 23 feet per year was calculated independently from Darcy's law.*

For several years we have been working toward the use of naturally occurring C^{14} in the dissolved carbonate species in groundwater to obtain meaningful ages of groundwater. By age we mean the amount of time since the water was last in contact with the atmospheric reservoir of C^{14}. Several studies of C^{14} concentrations in groundwater have been made (*1*); however, determinations were usually made on spot samples and no systematic investigation of C^{14} concentrations in groundwater has been published.

We have collected water samples from the principal artesian limestone aquifer of central Florida and studied the aqueous chemistry and isotopic composition of the aquifer system. The isotopes being investigated include those of hydrogen, carbon, oxygen, and sulfur. This report concerns only results of the C^{14} determinations; results of the complete study will be published elsewhere.

In the area under study (Fig. 1) the hydrologic system is controlled by the large, high piezometric surface (*2*). The wells sampled (Fig. 1) were completed within the Ocala Limestone and other formations of Eocene age; they range in depth from about 150 to 300 m. Water flows from high portions of the piezometric surface, and at right angles to the equipotential contours, to lower points on the surface. The wells sampled were chosen so as to be as nearly as possible directly below one another in a gradient.

Many problems are associated with the use of C^{14} in dating groundwater. Among these are the initial C^{14} activity of the atmosphere and of rain; C^{14} activity of organic carbon in the soil zone; solution of C^{14}-depleted calcite; saturation of the aqueous phase with respect to calcite (*3*); and exchange between carbonate ions in the water and the CO_3 group in the calcite structure (*4*).

Large (approximately 114 lit.) samples of water were obtained from each of the locations shown on Fig. 1. Samples of this size were required in order to obtain the 3 g of carbon needed for the C^{14} dating process. The carbon was obtained from the total dissolved carbonate species by means of equipment and techniques similar to those described by Feltz and Hanshaw (*5*).

Table 1. Summary of C^{14} measurements and hydrologic data used to determine velocities, v, of ground water flow in the principal artesian aquifer of central Florida. We computed the C^{14} ages using 95 percent of the National Bureau of Standards oxalic acid standard as the initial C^{14} activity and 5570 ± 30 years as the half-life of C^{14}. A velocity of 33 feet per year for $v_{hydrologic}$ is equivalent to 10 meters per year.

No. of well and location	Information, between wells	Distance (mi)	Difference in piezometric surface (ft)	Hydraulic gradient (ft/ft $\times 10^4$)	$v_{hydrologic}$ (ft/yr)	U.S. Geol. Surv. Lab. No.	δC^{14} ±20‰	Apparent age (yr)	Difference in age (yr)	$v_{C^{14}}$ (ft/yr)
1. Polk City						W-1442	−657	8,600		
	1 and 2	28	40	2.7	33				5,500	27
2. Ft. Meade						W-1439	−827	14,100		
	2 and 3	14	14	1.9	23				11,070	7
3. Wauchula						W-1444	−956	25,170		
	3 and 4	23	16	1.3	16				3,130	39
4. Arcadia						W-1438	−970	28,300		
	4 and 5	18	14	1.5	18					
5. Cleveland						W-1443	−967	27,460		
	1 and 3	42	54	2.4	29				16,570	13
	1 and 4	65	70	2.0	24				19,700	17
	1 and 5	83	84	1.9	23				18,860	23