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SOLAR-RADIATION
STATION

(WITH FOUR PLATES)

BY

A. F. MOORE

Astrophysical Observatory, Smithsonian Institution



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SCOUTING FOR A SITE FOR A SOLAR-RADIATION STATION

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(WITH 4 PLATES)

During the early part of 1930 it became apparent that if measurements of the solar constant of radiation were to be made by the Smithsonian Institution with sufficient accuracy on a large percentage of the days of the year to make possible dependable analyses of the various cycles included in the changes in the sun's radiation, it would be very desirable, if not necessary, to find a location for a solar-radiation station in the Eastern Hemisphere, which would be nearly, if not quite the equal of the Montezuma station in northern Chile. This was becoming all the more desirable because of the increasing interest being manifested in the investigation of the possibility of weather forecasting, particularly long-range forecasting, by means of changes in solar radiation.

In 1930 the Smithsonian Institution was operating three solar stations in widely separated parts of the globe, viz: on Mount Montezuma in the Atacama Desert of northern Chile; on Table Mountain in the Sierra Madre range, bordering upon the Mojave Desert in southern California; and on Mount Brukkaros in the south-central part of Southwest Africa. The Chilean station was established near Calama in 1918 and two years later was moved to Mount Montezuma, where it has since been in continuous operation. Its elevation is about 9,000 feet above sea-level, and the large percentage of clear, uniform skies found there has not been equalled elsewhere to date. The Table Mountain station was moved to its present site in 1925, from Mount Harqua Hala in western Arizona where it had been located since 1920. Table Mountain is 7,500 feet above sea-level, and although the percentage of observable days approximately equals that of the Chilean station, the quality of the skies, particularly as regards uniformity, falls considerably short of that of the latter. Observations were begun at Mount Brukkaros in 1926, and this station was built and operated for about four years under a grant from the National

Geographic Society. Later a friend of the Institution furnished the funds for its operation. Unfortunately, the Mount Brukkaros site did not prove as good as had been anticipated, owing to the cloudiness, haziness, and high winds prevailing there at certain seasons. The elevation was considerably less than the other two stations, being only about 5,200 feet above sea-level.

Through the generosity of the same friend of the Institution, it was planned to send an expedition to Southwest Africa early in 1931 to investigate several widely separated mountain peaks in that country, all of them considerably higher than Mount Brukkaros, the idea being, if possible, to get above the haze that was causing so much trouble there. The writer was chosen to head this expedition and it was arranged that Mrs. Moore should accompany him.

From past experience it had been learned that visual observations are not sufficient for selecting a site of a solar-radiation station, and also that a few days' visit to a place, even by an experienced observer, would not suffice to judge its qualifications. Hence it was planned to equip the expedition with various portable instruments to measure the meteorological conditions prevailing on the peaks under investigation, and it was also arranged for the expedition to visit the sites at different seasons.

The prime meteorological requisites of a good observing location are: 1, that it have skies which, for a large percentage of the days throughout the year, are free of clouds, haze, dust, smoke, etc., and with little wind; 2, that the sky conditions remain nearly constant, especially from sunrise until an hour or two before noon; 3, that the site be at an elevation of at least 7,000 feet above sea-level in order to rise above the low-lying haze, dust, and smoke.

A brief description will now be given of the various instruments carried and their purpose. In order to get an accurate measure of the uniformity of the transparency of the atmosphere over a peak, the expedition was equipped with an Ångström pyrliometer for the purpose of measuring the radiation of the sun at the earth's surface. This instrument consists of two blackened strips of manganin foil, each provided with an electric thermocouple in contact with the lower surface of the strip. It is also arranged that an electric heating current can be passed through each strip at will. The thermocouples are connected so that the electromotive forces generated when the strips are heated oppose one another. The remaining terminals are connected to a fairly sensitive moving-coil galvanometer. The strips are alternately exposed to the radiation. A measured current is passed through the other strip such that its temperature is raised to exactly that of the

strip exposed to the radiation. When the current is adjusted so that this condition prevails, no current will pass from the thermocouples to the galvanometer. From the measured current which passed through the strip and the constant of the instrument, the intensity of the radiation can readily be computed.

In order to lessen the weight of the equipment to be carried up the high and rugged peaks, no theodolite was included, but instead, the altitude of the sun was obtained by measuring the length of a shadow cast upon a level surface over a triangle 10 centimeters in height. With low sun the angle was increased by 45° in order to get a shorter and sharper shadow. From the length of the shadow the elevation of the sun (neglecting refraction) was obtained, and from this the air-mass was read from a Bemporad "air mass versus altitude" plot.

When sky conditions permitted, 10 observations were made at approximately equal spacing of air mass, between air mass 5.60 (about 10° solar altitude) and nearly meridian sun. The logarithm of the solar calories per square centimeter per minute was plotted versus the air mass through which the solar beam had passed. Such a plot should be nearly a straight line (slightly convex toward the origin), with a sky of uniform transparency. If such a line were not obtained in the plot, it would indicate nonuniformity of transparency in the atmosphere above the peak during the observations.

Disregarding small changes in the heat radiated by the sun, the main terrestrial causes of nonuniformity in atmospheric transparency are changes in invisible water vapor, haze, dust, smoke, and ozone. Visible clouds should, of course, be included, but solar observations are never undertaken through clouds. The changes of radiation due to changes in ozone in the path of the beam are small and were not taken into account in the work of this expedition. But the first four agencies mentioned are very important causes of nonuniformity of transparency of the atmosphere, and instruments were carried to measure fairly accurately their effect.

Invisible water vapor is perhaps of first importance, and for determining the uniformity of water vapor prevailing in the path of the solar beam a new (and as yet unnamed) instrument was included in the equipment. The instrument is essentially a spectroscope, so arranged that the difference in radiation of the selective absorption water-vapor band called ρ , and the radiation of the region immediately adjacent to this band, is indicated by a small, sensitive thermocouple. In addition, by suitably interposing a shutter the difference between the ρ band and zero radiation (given by the shadow of the shutter), is obtained. Figure 1 represents the solar-radiation curve as measured

at the earth's surface, in the vicinity of the ρ water-vapor band. a indicates the depth of the ρ band, and b shows the intensity of the radiation of the band itself as compared with no solar radiation. In other words, b represents the minimum value of radiation in the water-vapor absorption band, ρ , and $b + a$ is the so-called "smooth-curve" value as given in Smithsonian publications, or the intensity of the radiation of the infra-red region adjacent to the ρ band, as compared with no solar radiation. The ratio "minimum/smooth-curve" is a measure of the precipitable water vapor prevailing in the path of the solar beam through the earth's atmosphere. By plotting "log 'minimum/smooth-curve' versus air mass" a curve similar to the corresponding "log pyrheliometry calories versus air mass" is obtained.

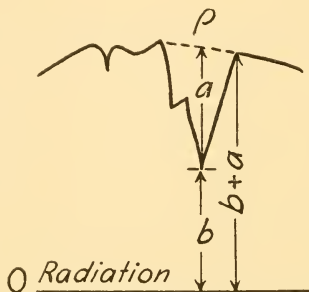


FIG. 1.

Hence by such a plot the uniformity of the water vapor prevailing in the path of the solar beam can be determined, and by comparing the plot with the corresponding pyrheliometry plot, it can be concluded whether any nonuniformity in the pyrheliometry was caused by changing amounts of water vapor or by other agencies such as haze, dust, and smoke.

In order to ascertain the amount and uniformity of the haze, dust, and smoke prevailing in the atmosphere, the Ångström pyrheliometer was again employed, but this time with the direct sunlight shaded off, so that the radiation from a concentric ring of sky around the sun of approximately 17° outer radius was measured. During the observations on Fogo Peak and those in Southwest Africa including part of the first visit to Ganzberg Mountain, a much larger area of sky was seen by the instrument. Throughout the remainder of the observations in Southwest Africa and in all of the Sinai observations, an

arrangement as shown in Figure 2 was employed. *a* was a circular disk of slightly larger diameter than the opening in the hood, *b*. The latter was blackened within as was the under surface of disk, *a*. *c* represents the Ångström pyrheliometer with the two blackened strips on which the radiation fell. This arrangement gave a fairly accurate measurement of the sky radiation adjacent to the sun, and while water vapor also entered into the readings, it was possible to determine in a general way whether the haze near the sun was due mostly to water vapor or to scattering caused by dust and smoke particles. In other words, on most days any deviation from the curve of uniform pyrheliometry could be explained by nonuniformity in water vapor, haze, dust, or smoke, or by combinations of these agencies.

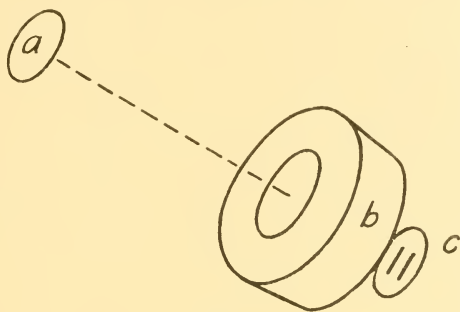


FIG. 2.

In addition to these measurements, general meteorological records were kept of the relative humidity, dry shade temperatures, wind direction and approximate intensity, and of cloudiness, fogginess, etc.

It was planned that the expedition should leave the United States, in January, 1931. A few weeks before the time of departure, H. H. Clayton of Canton, Mass., who has done much in correlating weather changes with changes in solar radiation, suggested that the expedition should include in the itinerary a high peak on the island of Fogo in the Cape Verde Islands, about 500 miles off the west coast of Africa. About 25 years before, Mr. Clayton had been a member of a French meteorological expedition that had visited Fogo, and he had found such clear skies and other promising conditions on the island that he thought it worth our investigation.

A stop of a few days was made at Washington prior to sailing, in order to acquaint ourselves with the apparatus and other details of

the expedition. Unfortunately, cloudy weather prevailed during most of our stay in Washington, so that it was impossible to test the instruments properly, particularly the water-vapor instrument, before our departure.

The expedition sailed from New York on the American freighter *West Kebar* on January 31, 1931, bound directly for the port of

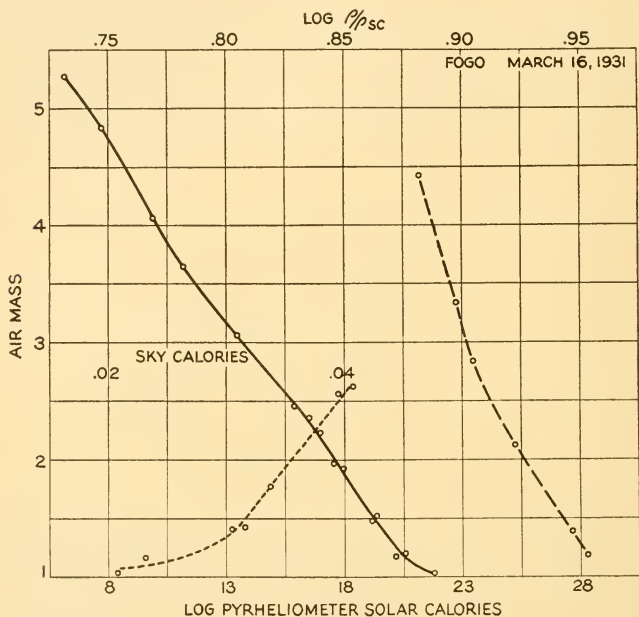


FIG. 3.

(NOTE.—This day was much better than the average as regards haze at Fogo. Used this day because it was the only one on which both the Ångström pyrheliometer and the p/p_{sc} instrument were operating satisfactorily.)

St. Vincent in the Cape Verde Islands. Upon arriving at St. Vincent we learned that the small inter-island steamer was not due to sail for at least two weeks, so we took passage on the little two-masted sailing schooner *Ernestina*, bound for the island of Fogo. With fair winds it would have been a 24-hour trip. However, a calm necessitated our remaining aboard the craft an additional night, since landing through the surf at San Filipe, the chief town and port of the island,

was not possible in the darkness. Owing to the great skill of the native boys, the landing of ourselves and our boxes was made without mishap.

The ascent of the peak or "vulcan," as the Portuguese call it, was to start from the town of Cova Figuiera, about 20 miles from San Filipe. There being no roads of any consequence outside of the town of San Filipe, we proceeded mule-back to Cova Figuiera, accompanied by our guide and interpreter whom we had brought with us from St. Vincent. The boxes were carried from San Filipe to Cova Figuiera on the shoulders of native men, and up the ascent from the latter place to the peak by men and women. The Cape Verde Islanders are truly marvels at carrying heavy burdens up mountains. The women carried boxes weighing around 70 pounds on their heads up the 4,500-foot climb with apparently no exertion whatever.

A camp site was chosen on a smaller peak just north of the main cone and at 6,000 feet above sea-level. The "vulcan" rises to about 9,000 feet elevation, but its extreme ruggedness and the smoke issuing from the summit precluded its selection for observing purposes. The observing peak was located at approximately latitude $14^{\circ} 57' N.$ and longitude $24^{\circ} 21' W.$

The peak on which observations were made would not have been practical for a permanent station, owing to its proximity to the smoking volcano, but trips were made to both the northern and southern outer rims of the main crater to investigate possible observatory sites at those points. On the north rim a place was found at 6,700 feet elevation, but there was a much better site on the south rim near Ponto Alto do Sul, an 8,000-foot peak. Water would have been available from the San Filipe-Cova Figuiera pipe line, about 3 miles distant.

We spent a few days over a month on Fogo Peak, but found extreme haziness most of the time. Clouds were a negligible factor, but the haze which extended far above the summit of the volcano was much too bad for a station site. The cloudlessness, lack of high winds, dry air, and large range of temperature between day and night were favorable features, but the intense haze and the fact that thunderstorms are prevalent there during the summer months more than offset the good qualities.

Owing to a misunderstanding on the part of the native in charge of our packing from the peak to Cova Figuiera, we had to remain in San Filipe for two weeks awaiting the inter-island steamer to return to St. Vincent and nearly a week longer in the latter place awaiting the steamer for Madeira. A. F. Pacey, our good English friend in St. Vincent, entertained us and rendered us much aid, both before and after

our trip to Fogo. Owing to a revolution in progress in Madeira, the port of Funchal was blockaded, so we found it necessary to proceed to England in order to catch our steamer for Cape Town. Landing at Tilbury one afternoon, we had our boxes transferred, made our reservations, and sailed from Southampton the following afternoon. We arrived in Cape Town 17 days later, and after a few days spent there, journeyed by train to Keetmanshoop, which was to be our headquarters in Southwest Africa. We then went to Mount Brukkaros, where the Smithsonian solar-radiation station was located, and with Mr. Sordahl, in charge of the station, made many comparisons of our instruments with the instruments which were regularly in use at that station. An auto truck was ordered from Cape Town, and on its arrival in Keetmanshoop we returned to that place and made preparations for observing on Lord Hill, in the Great Karras Mountains, 60 miles southeast of Keetmanshoop. This peak has an elevation of about 7,200 feet, and is located at approximately latitude 27° S. and longitude 19° E., being on the Kraikluft farm, owned by Mrs. E. R. West and her son Austin, both of whom were of great assistance to us during our two visits to Lord Hill. This peak was occupied by us from June 17 to 30, and from September 16 to 30, inclusive.

After the first visit to Lord Hill, the long journey was made to the Erongo Mountains, about 20 miles north of Usakos, and at latitude $21^{\circ} 44'$ S. and longitude $15^{\circ} 34'$ E. The only passable road, although much out of a direct line, was via Windhoek, the capital of Southwest Africa. There we obtained passes, permits, and much valuable information from the Government officials, particularly Mr. Smit, the Secretary for Southwest Africa. The Ebrecht farm at the foot of the Erongos was reached July 13, and Erongo Mountain was occupied from the 15th to the 28th of that month, inclusive. This mountain is of granite formation and is extremely steep and rugged, and much difficulty was encountered by the Klip Kafir porters in making the ascent. So rough was the region that no donkeys could be used in packing, since the boxes had to be carried underneath and among enormous boulders in many places in making the ascent. Mr. Ebrecht kindly arranged the details of our packing for us.

While on Erongo Mountain a record was kept also of the apparent sky conditions over the Brandberg Range, about 60 miles to the west. There appeared to be more cloudiness, particularly of the cirrus variety, in the region north of Windhoek than farther south. Although there were some excellent skies seen from Erongo Mountain, the record was not at all encouraging, and Brandberg, which is the highest mountain in Southwest Africa, and in a region of less than 2 inches

annual rainfall, seemed to be enshrouded in cirrus even more than the Erongos. On many days the intense haziness intervening entirely hid Brandberg from view.

We had originally planned to visit this high mountain after completing our observations on Erongo Mountain, but the record of cloudiness made this seem useless, so after communicating with Washington by cable, we turned south to investigate Ganzberg Mountain,

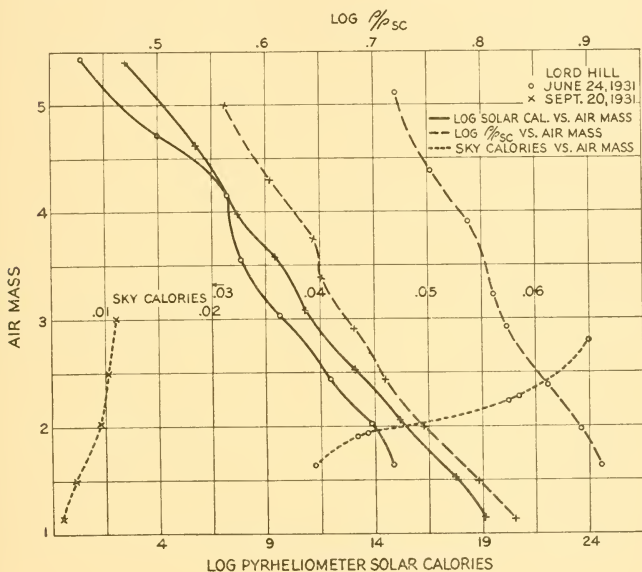


FIG. 4.

(NOTE.—June 24, sky calories measured before changing sky vestibule; September 20, after changing.)

west of Rehoboth. This mountain lies at latitude $23^{\circ} 19' S.$ and longitude $16^{\circ} 15' E.$, on the Gruendoorn farm owned by Otto Basingthwaight, and is about 7,600 feet in elevation. It is situated on the border between the nearly rainless Namib and an area in the Rehoboth section, which in some years has a rainfall as high as 16 inches. The mountain has the advantage of comparative accessibility, since its base, which can be reached by automobile, lies at nearly 6,000 feet elevation. Ganzberg consists of two separate flat-topped mountains of equal

altitude, being, in fact, the sole remnants of an extensive high plateau, the remainder of which has been cut down by erosion. We carried on our observations on the easterly and smaller of the two peaks, the westerly one being nearly 2 miles square. That very heavy rains occur at times was shown by the fact that a cloudburst had, a few months before, caused Mr. Bassingthwaight's reservoir to overflow, carrying

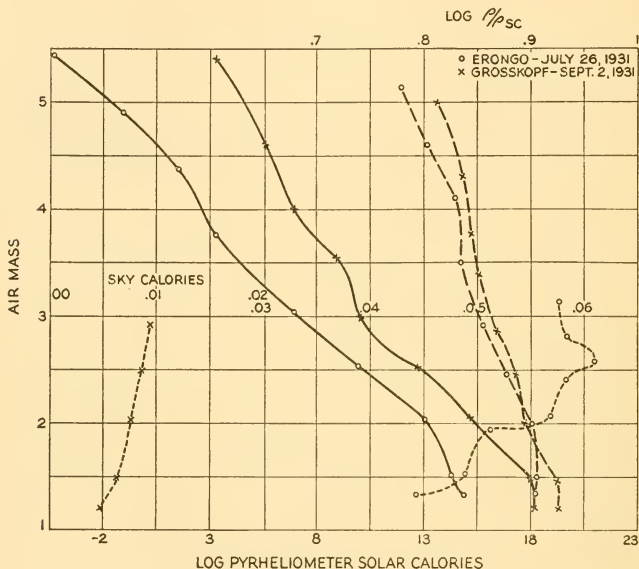


FIG. 5.

(NOTE.—Erongo sky calories measured before changing vestibule; Grosskopf after changing it.)

away the dam. He was repairing the break when we were there, and he very generously allowed us to use his native boys to carry our equipment up the mountain. He used three scrapers drawn by 12 oxen each, while repairing his dam, and the boys packed up our outfit on a day while the oxen were resting. Mr. and Mrs. Bassingthwaight were most hospitable to us, and he even accompanied the natives up the mountain each time to superintend the packing. He spoke Hottentot with all its peculiar clicks, just as well as the natives.

We made two visits to Ganzberg, viz: from August 8 to 21, and from November 3 to 14, inclusive. Although much less cirrus cloudiness was encountered than farther north, the prevalence of intense haze together with much cumulus cloudiness during the second visit militated against its suitability as an observing station site. More details will be given in later tabulations and plots.

After the first visit to Ganzberg we proceeded south to Grosskopf Mountain, located at latitude $25^{\circ} 45' S.$ and longitude $16^{\circ} 30' E.$, or about 90 miles a little north of west of Mount Brukkaros. It was the

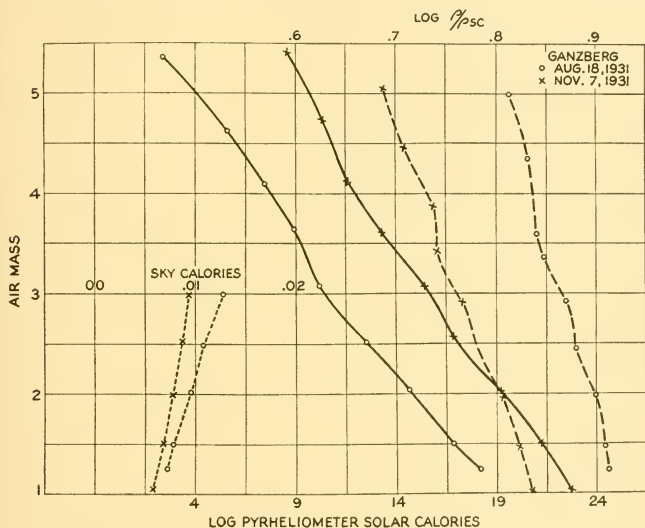


FIG. 6.

lowest peak on which we observed in Southwest Africa, being 6,400 feet above sea-level. Like Ganzberg, the mountain was flat-topped and divided into two parts. It lies in a region of slight precipitation, the annual rainfall being between 2 and 3 inches. There was scant shelter for our camp, and because we found it necessary to leave our tent at the foot of the mountain, owing to a lack of porters, we felt the cold keenly on this peak, especially since the coldest September weather in many years in Southwest Africa occurred during our stay there. We occupied the mountain from September 1 to 7, inclusive. On several occasions heavy fog blew across Grosskopf from the ocean,

and this, together with considerable cirrus cloudiness that we encountered, caused grave doubt in our minds as to its suitability for a solar station. The peak was in a very dry region as regards rainfall, but nevertheless, a good spring was found within easy access of the summit, and the climb was comparatively easy from the canyon where our car was left.

The kind hospitality that had been shown us at other places in Southwest Africa was repeated during our stay in the Grosskopf region. Especially were we indebted to John Campbell, who entertained us at his farm, and to John Buchler, the superintendent of a copper mine near Grosskopf, who greatly aided us in obtaining native boys to carry our equipment up and down the mountain.

Following our visit to Grosskopf we proceeded to Keetmanshoop, and then to Lord Hill for our second series of observations on that peak. These completed, we started north again, stopping at Mount Brukkaros for a few days to calibrate our instruments. We then began the long trip north to investigate further the possibilities of the Brandberg Mountains. We stopped at Windhoek to get the necessary government permits and then proceeded to Omaruru, where our supplies were to be purchased. The whole coastal region of Southwest Africa is a restricted area on account of the diamonds found there, and the Brandberg Mountains lie just within this area; hence the necessity of obtaining permits at Windhoek and of reporting to the commandant of the police at Omaruru.

The nearest habitation to Brandberg is the tin mine at Uis, 20 miles distant, and owned and operated by the Solar Development Company, a subsidiary of a large Canadian mining concern. The Uis mine is under the direction of Mr. McDonald, whose headquarters are in Omaruru. He had given us valuable information concerning Brandberg and the roads leading thereto, and when we arrived he directed his men to aid us in every way possible and even put a vacant mine building 5 miles toward Brandberg from Uis at our disposal during our stay there. Uis lies 80 miles nearly due west of Omaruru, and owing to the energy of the Canadian concern we found the intervening road to be one of the best over which we had driven in Southwest Africa, even though it traversed a very desolate section of the country.

After reaching Uis we got in touch with Mr. Donnett, a German employed by the mine, who had made several trips to the Brandberg Mountains. He stated that there were two possibilities for attacking the ascent, viz: via the Zizab Canyon on the northeast side of the range, or via the Hungarob water-hole on the south. He advised the former route, for the reasons that there was more water and a more

gradual ascent, although it was considerably farther. We realized, in conversing with Mr. Donnett, that we had a very hard climb ahead of us, especially for the native boys who would carry our supplies and equipment. The lack of water in this extremely dry region, coupled with the fact that there was a climb of about 6,600 feet, with practically no trail, made the prospect rather forbidding. The base of the mountain, accessible by automobile, is less than 2,000 feet above sea-level, as compared with nearly 6,000 feet at Ganzberg, and the summit is over 8,500 feet, or 900 feet higher than Ganzberg. Brandberg lies at latitude $21^{\circ} 7' S.$ and longitude $14^{\circ} 33' E.$

But having come thus far, we decided to make the attempt, to learn first-hand of the actual conditions. Mr. Donnett could not arrange to accompany us up the mountain, although he did guide us to the Zizab Canyon, a considerable part of the route having no road. We arranged to have as a guide an old Klip Kafir who had accompanied Mr. Donnett on two trips to Brandberg. The Zizab water-hole is visited by much game, including lions, so we slept in our car while the boys had a camp-fire all night to keep the wild animals at a safe distance. Early the next morning, leaving the car in the canyon, we got under way afoot. The farther we proceeded the rougher the canyon became. Near the upper end of the water-hole we found huge boulders as large as good-sized houses, and under some of them our guide showed us some of the ancient Bushman paintings on the rocks. These paintings represented men and various animals, and the pigments were remarkable in maintaining their colors.

After leaving the water-hole we soon came upon an old Kafir and a youngster of about 6 years. Their garb, or lack of garb, was quite in keeping with the rugged surroundings. The old man said that he lived in the Brandberg Mountains and that we could expect no more water before the next day about noon. I had the boys return to the water-hole and fill all the water cans. After lunch we resumed the climb and we found the whole bottom of the canyon filled with enormous boulders, so that it became very difficult for the boys to make progress with their packs. Discontent could plainly be discerned in their demeanor, so about mid-afternoon, while they were resting, I climbed to a high point from which I could see up the canyon, and found that for several miles ahead there could not be much hope of improvement. The aneroid showed a rise of only about 1,000 feet for the day. With over 5,000 feet yet to climb and the morale of the boys none too good, no choice seemed to be left but to abandon the attempt. The boys did not think that they could return to the car

that night, but by a promise of double rations of tea and sugar, the impossible became possible and the car was reached just after dark.

The general cirrus cloudiness and the observations that we had made from the Erongo Mountain three months before did not offer much encouragement for continuing the attempt. However, after discharging most of the boys we took two boys and drove around to the Hungarob entrance to Brandberg. But we found the climbing conditions there similar to the Zizab Canyon, so abandoned Brandberg altogether. By the bad record of cloudiness in July in the Erongo Mountains and in October in the Brandberg region it became apparent that most likely the northern part of Southwest Africa did not warrant further consideration.

Hence, on our return to Omaruru, realizing that we probably would not be so far north again, we decided to make a trip of a few days to the Etosha Pan, the wild game reserve of the country. We proceeded via Grootfontein, visiting the 50-ton meteorite on the Hoba West farm near that town; then to Tsumeb, a copper mining town; then to Namutoni, a police post located in an old German fort on the edge of the Etosha Pan. We remained overnight in the fort, as it was not safe to sleep out-of-doors on account of the lions. We saw considerable game including zebra, wildebeeste (gnu), kudü, springbok, etc., but not as many varieties as we had hoped.

The journey northward from Omaruru convinced us as to the unsuitability of the northern part of the country for solar work, for the cloudiness and poor skies increased as we approached the tropics. And the long journey from the Etosha Pan to Ganzberg showed the reverse, viz: that better skies were to be found toward the south. However, summer conditions were approaching, and our second stay at Ganzberg did not prove as favorable as the visit in August. After Ganzberg we proceeded south to Maltahöhe, intending to go, if possible, to Grosskopf for a second visit. The uncertainty was caused by heavy rains having fallen in scattered places, and the huge salt-pan between Maltahöhe and Grosskopf would have been impassable when wet.

However, at Maltahöhe we received instructions from Washington to go to Mount Brukkaros, help dismantle the apparatus there, and proceed to Mount St. Katherine on the Sinai Peninsula, unless, in our judgment, Ganzberg or Brandberg had proven enough better than Mount Brukkaros to warrant further observations. With Brandberg definitely out of consideration and with Ganzberg, the best of the peaks that we had visited in Southwest Africa, not much better than Mount Brukkaros, it seemed best to move our operations to the Sinai Penin-

sula. About a month was required to pack the Brukkaros apparatus for shipment to Washington, and the day after Christmas we left Keetmanshoop en route to the east coast of Africa via Johannesburg. We made a short side trip to Victoria Falls on the Zambezi River, and sailed from Durban on January 20, arriving at Port Said on February 19.

Nearly two weeks were required to make arrangements for proceeding to Mount St. Katherine. We learned from Maj. D. J. Wallace Bey, in charge of the Frontiers Department of the Egyptian Government, that it would be perfectly safe for Mrs. Moore to accompany the expedition, and he gave us the necessary permit to proceed across the Sinai desert. Mrs. Moore had kindly assisted with the observing during the whole sojourn in Southwest Africa, and it was good news indeed when we learned that she would not have to remain in Cairo during the expedition's stay in Sinai.

By a strict government rule, not less than two cars may undertake the desert journey across the Sinai Peninsula. We had only the car that we had used in Southwest Africa, so it became necessary for us to rent an additional car. Three natives had to be engaged: a dragoman or guide to act as interpreter and arrange the details of our trip; a chauffeur for the rented car; and owing to the sort of caste system prevailing in the country, a third man for water carrier and guard.

Three trips were made to Mount St. Katherine, and in each instance Cairo served as the base of supplies, although the actual start across the desert was made from Suez. The road led north from Suez to Kubri, where we were ferried across the Canal, then south along the east bank of the canal to a point opposite Suez, thence it turned inland, in a few miles passing the Springs of Moses, a beautiful oasis where, tradition states, the Israelites first camped after leaving Egypt. The road then traversed a most barren and desolate region a short distance inland, but again returned to the coast at the little port of Abu Zenima, belonging to an English manganese mining company. On the first two trips we entered the mountains at Wadi Sidri, about 20 miles south of Abu Zenima, but on the third trip we continued on to the mouth of Wadi Feiran, and remained in this wadi (or canyon) until we had passed the Feiran oasis and convent. The route via Wadi Sidri is shorter but much more sandy. There is no well-established road, for the most part, in any of these canyons, a person just picking his way as best he can. The Feiran oasis, about 7 miles long, is the largest and most beautiful in the Sinai Peninsula. The stately palms, set off against the very rugged mountains, present a striking picture. Feiran is the site of the ancient Paran of early Bible history. The monk

at the little convent always served us with coffee and presented us with vegetables and fruit from his garden.

Soon after passing the oasis the road left Wadi Feiran and entered Wadi Sheikh, which brought us nearly to the St. Katherine Monastery. This is the oldest monastery now in existence and has been in continuous operation for over 15 centuries. It is under the Greek Orthodox Church, with headquarters in Cairo, in which city the Archbishop resides. At present there are about 20 monks living at the monastery, and without exception, they proved most hospitable and friendly toward us. The Archbishop spent several weeks at the monastery, and he with five of the monks visited us on Mount St. Katherine during our second sojourn there. The Archbishop and monks made it clear that they would gladly welcome the establishment of a solar-radiation station on or near Mount St. Katherine, and would do all in their power to aid in its construction and operation. Since it is entirely due to the presence of the monastery that this wild region is safe from Bedouin brigands, and since the monastery virtually controls all the native labor in the vicinity, we were indeed glad to find those in charge so kindly disposed toward our venture.

The main monastery is located near the base of Mount Sinai, but there are also other smaller convents and shrines under the control of the monks, among which may be mentioned the shrine on the summit of Mount St. Katherine, "El Arbain," or the Convent of the Forty Martyrs, and "Rabba," or the convent rest-house near the Plain of the Law. Through the kindness and generosity of the monks we were permitted to occupy guest rooms in the shrine on Mount St. Katherine during our entire 15 weeks' stay on that mountain. Archimandrite Joakim, the Head Monk at the large monastery, did all in his power to add to our comfort and instructed all the monks under him to do likewise. Father Moissi, in charge of the El Arbain convent also had the shrine on Mount St. Katherine under his care. He even went so far as to send up fruit and vegetables from his garden, and they were a happy change from our menus from tin cans. On our second and third departures from Mount St. Katherine, Archimandrite Joakim and one of his assistants met us personally at the Rabba rest-house, had a wonderful luncheon prepared for us, and rooms ready so that we might rest after the tiring journey down the mountain.

The trail that the monks have constructed up Mount St. Katherine is truly a marvel, of even gradient, well constructed, and the equal of our best mountain trails. On it camels can proceed to a point only 150 feet lower than the summit, and excellent stone steps complete the trail to the top. A strong spring was found about 800 feet below the

summit and in a small canyon to the northeast of the shrine. Unfortunately, some Bedouin goat-herders polluted this spring near the close of our second visit, so that during the third visit it was necessary to have our water packed up on camels from the large monastery. In order to insure its coming from the monastery and not from some water-hole as bad or worse than the polluted spring, we arranged that the water boy should carry a paper from me each trip, which would have to be stamped with the monastery seal in the Head Monk's office and returned to me when he brought the water.

Mount St. Katherine or rather Gebel Zebir, adjacent to it, is the highest mountain in the Sinai Peninsula and in all of Egypt, being about 8,600 feet above sea-level. The mountains of crystalline formation, in which this peak is located, are among the most rugged to be found in the world, and make of this desert a wilderness in every sense of the word. The mountain lies at latitude $28^{\circ} 31' N.$ and longitude $33^{\circ} 58' E.$ It is nearly in the center of the triangular mountainous region forming the southern end of the Sinai Peninsula. To the north of this triangle sandy table-lands slope toward the Mediterranean.

The view from Mount St. Katherine is grand indeed. It towers above the varicolored mountains and chasms to be found on all sides. Particularly do Mount Sinai (Gebel Musa), Gebel El Shomer, and Gebel Serbal stand out in the north, south, and west, respectively. Beyond the Sinai mountains toward the west lies the Gulf of Suez, where, although it is over 30 miles distant, one can count the ships on a clear day. To the south the Red Sea appears, and to the east are seen stretches of the Gulf of Akaba, separating the Sinai Peninsula from Arabia. On most days the mountains of the Egyptian and Arabian mainlands could distinctly be seen.

On our first visit we occupied the mountain top from March 9 until April 18, inclusive. During this period we experienced some most excellent skies, some moderately good, and others very hazy. The clearness of the excellent skies was remarkable, equalling, if not excelling, the very best that northern Chile and Table Mountain, Calif., have afforded. The absolute absence of haze near the sun persisted until sunset, a most unusual thing. On two or three such days there was a very thick, sharply defined layer of haze extending perhaps a half degree above the horizon in the west at sunset. When the last vestige of the solar disk buried itself in this sharp layer of haze a distinct green ray was seen; and strangely enough, we saw another flash of green as the sun disappeared behind the distant Egyptian mainland. On the other hand, during the first visit, there were nearly half of the days with very hazy skies, but with only three days lost by

clouds in the six weeks' period. Cloudiness was nearly negligible. The most remarkable feature of the weather, particularly for March and early April, was the lack of wind. Nearly half of the days were entirely calm, and another fourth had only a light breeze. On less than three per cent of the days was there a brisk wind.

On our second visit to Mount St. Katherine, our records covered the period from April 30 to May 30. During this interval the number of excellent and satisfactory days increased quite materially,

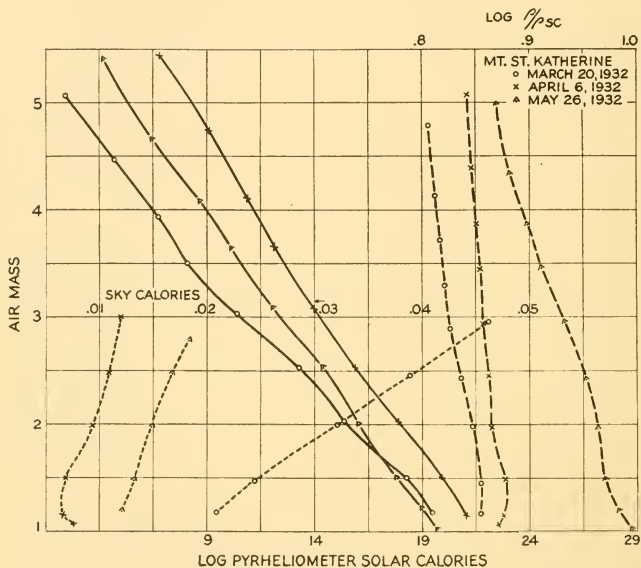


FIG. 7.

owing to less haze. Ten per cent of the days were lost by clouds, and the windiness increased somewhat, although nearly two-thirds of the days were calm or with light wind.

Our third visit extended from June 12 to July 19, and from a standpoint of weather should be divided into two separate groups, the June days and the July days, for there was a marked change for the better between June 30 and July 1. This change seemed to be permanent, for it lasted during the nearly three weeks of July in which we were on the mountain. During this period the excellent

and satisfactory days totaled nearly 95 per cent, while there were 84 per cent of days of calm or light wind. During June, however, the wind was rated as moderate or brisk on over half of the days. No days were lost by clouds in either June or July.

From the above it is seen that during the four months of March, April, May, and June, the chief drawback in the weather conditions on Mount St. Katherine was the haziness. Only six days out of a total of 106 were lost by clouds, which is a very admirable record,

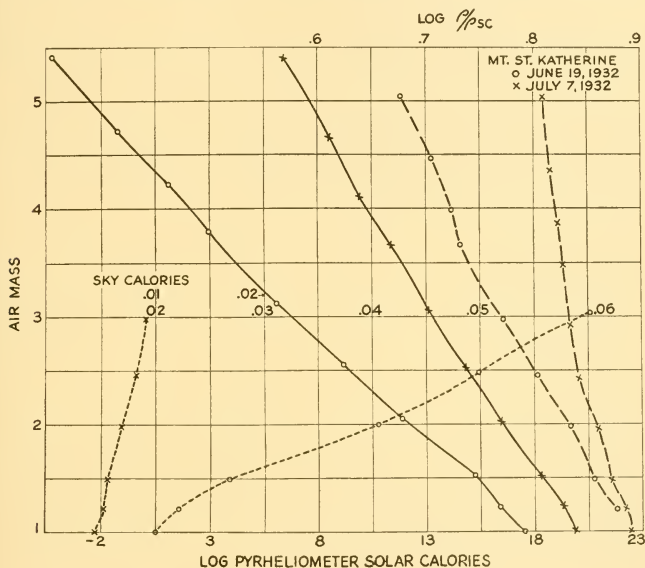


FIG. 8.

particularly for spring months. And the prevailing calmness is a strong point in favor of the place, especially as compared with Southwest Africa, where the wind was found to be a very serious handicap to accurate observations. We made inquiry regarding summer thunderstorms and from all sources learned that they are exceedingly rare. Lightning does occasionally accompany winter storms, but the absence of marks made by lightning on the rocks of the high peaks in Sinai is in great contrast to such peaks in Southwest Africa, where the rocks are literally covered with the markings.

Returning to the subject of cloudiness, our record covered 106 days in the period from March 10 to July 19, and during this interval only six days were lost by clouds while we were on the mountain. Possibly 10 days would be an outside estimate for cloudy days during the entire 131 days between the above dates. Dr. W. F. Hume, the Government geologist of Egypt, was very much interested in our work, and being familiar with the Sinai region, gave us much valuable information and data concerning it. In 1898-99 he made an extended geological survey of southeastern Sinai, and a meteorological record was kept by the late H. G. Skill. Doctor Hume kindly presented us with a copy of this publication. The weather record covered whatever location the geological party happened to be occupying, hence it probably shows more cloudiness than would have been encountered on the summit of Mount St. Katherine, and quite likely some observing could have been done on days that Mr. Skill listed as cloudy. In any event their record shows the following for morning hours from October 15 until March 10, when our record begins:

Month	Days observed	Clouds in a. m.
October	15	1
November	30	6
December	31	6
January	31	5
February	28	6
March	10	1
	—	—
Total	145	25

It appears that 25 days lost by reason of clouds from October 15 to March 10 would be a very fair estimate. There are no records available from July 19 to October 15, but from our record of July and Doctor Hume's record of the last half of October, it would appear that six days would be an outside estimate of days lost by clouds during this interval. Hence if 1932 and 1898-99 were average years, it would seem that approximately 40 days per year would thus be lost on Mount St. Katherine. From several conversations that we had with Mr. Smith, the superintendent of the British manganese mine at Abu Zenima, where he has been stationed for four years, it would appear that 1932 was more cloudy and hazy than normal. Unfortunately, the monks at the monastery have kept no weather records during the long period of the monastery's existence.

The above figures would indicate that about 89 per cent of the days throughout the year could be used for observations as far as actual clouds are concerned. Doctor Hume's record of windiness would not

be of much worth to us, since most of his observations were made in canyons, along the Gulf of Akaba, a very windy region, and in other places not at all comparable with Mount St. Katherine. But a quotation from his book may be of interest. It states: "With regard

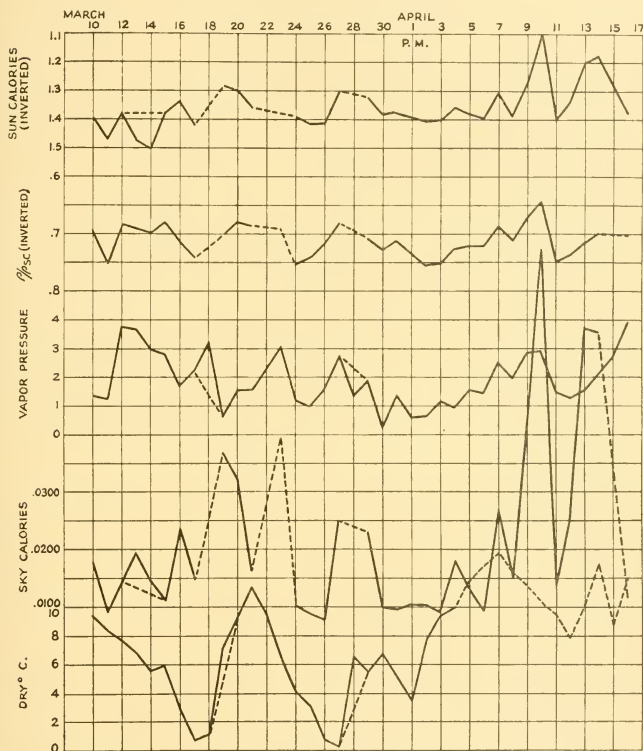


FIG. 9.—Mount St. Katherine daily means versus days.

to wind effects, as different districts were passed over, it is difficult to give definite conclusions, but in general the stillness of the air is a marked feature in the mountain regions, especially at night or in the morning. In the afternoon, especially in spring, a light breeze prevails, but probably rarely exceeds a velocity of 15 miles per hour."

We now come to the matter of the haziness encountered during our observations on Mount St. Katherine, and by far the most serious meteorological handicap found there. It is not remarkable that haziness should have occurred during the months from March to June, but one would not expect to find it so intense at nearly 9,000 feet elevation. Before visiting the mountain it was supposed that the prevailing northwest and north winds sweeping down from the Mediterranean would carry all haze due to sand storms and other disturbances having their origin in the great Sahara Desert, to the south and southwest of Mount St. Katherine. But from observations during the spring months the above assumption was found to be incorrect. The cirrus clouds nearly always moved from west toward east or from southwest toward northeast. Such clouds probably lay from 10 to 20 kilometers above sea-level and hence showed that the prevailing winds at such high elevations were moving from over the Sahara Desert toward the Sinai Peninsula. Our observations showed that about 80 per cent of the haze storms moved in from the west or southwest, and also that the haziness was usually fairly closely correlated to the water-vapor content of the atmosphere, as indicated by the p/p_{sc} instrument. At times, however, it was apparently due more to dust particles and molecular scattering. It seems quite likely that fine dust particles are carried to great altitudes during sand storms in the vast area of the Sahara Desert, and being carried eastward or northeastward by the prevailing winds at such high altitudes, finally, by force of gravity, tend to settle, and in doing so, come in contact with the moisture-laden north and northwest winds from the Mediterranean. These particles act as nuclei for condensation, and the result is a haze particle of considerable water-vapor content. This condensation occurs at times at a much higher elevation than any mountains in Sinai or Egypt, and hence no hope is had at such times to get above the haze.

The one redeeming feature concerning the haziness is that our observations showed much more uniformity of conditions during observing hours, particularly in the morning, than prevail at either the peaks of Southwest Africa or at Table Mountain in California. The accompanying graphs, which are taken from observations on average days in all cases, clearly show the superiority of Sinai over Southwest Africa. Hence, with such uniformity prevailing, even on very hazy days, there is much hope that the solar transmission coefficients over Mount St. Katherine can be quite accurately determined, in which case the haze would not be fatal to good observations of the solar constant.

In conclusion, in addition to the acknowledgments already cited, may I express the thanks of the expedition to the following: to the

native officials of the Egyptian Government; to Dr. John Ball, in charge of the Desert Survey of Egypt, for valuable advice and furnishing us with an excellent map of the Sinai Peninsula; to Dr. Robert McClenahan, Dean of the American University, on whom we often called for advice and help, and who recommended a reliable dragoman to us; to the ever-helpful missionaries of the American Mission; to Mr. Davidson in charge of the Near East Foundation work in Cairo; and to Mr. Salameh, of Cook's Agency, for their generous part in making our stay in Egypt a pleasant one.

Summary.—Observations for determining the suitability of various high mountains in the Eastern Hemisphere for sites for solar-radiation stations were carried on in the island of Fogo, in the Cape Verde group; in Southwest Africa; and on Mount St. Katherine in the Sinai Peninsula. About two months were spent in the Cape Verde Islands, seven months in Southwest Africa, and five months in the Sinai Peninsula and Egypt. Owing to freedom from clouds and wind, Mount St. Katherine proved to be considerably better than the Cape Verde Islands and Southwest Africa. The haziness which sometimes enshrouds Mount St. Katherine during the spring months probably causes it to fall short of northern Chile as regards suitability, but doubtless it will prove considerably superior to Mount Brukkaros and Table Mountain for solar-constant work.



1. North side of volcano, Fogo, with rough lava flow in foreground.



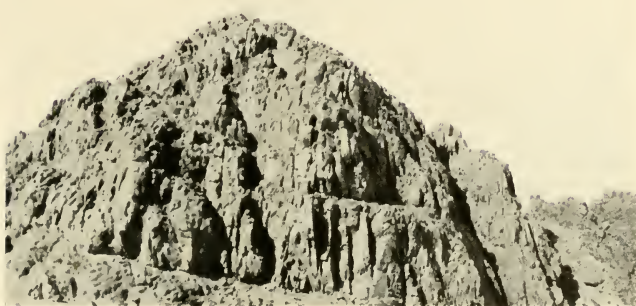
2. Packing equipment up the Erongo Mountains, Southwest Africa.



1. Boulders in Zizab Canyon, Brandberg.



2. Rugged mountains near Mount Sinai and Mount St. Katherine.



1. Shrine on the summit of Mount St. Katherine.



2. Closer view of shrine on the summit of Mount St. Katherine.



1. Observing on summit of Mount St. Katherine.



2. The St. Katherine Monastery.