Reply

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We appreciate Dr. Howell's comments and the opportunity which they offer to clarify the discussion presented in our paper. In doing this, it is necessary to restate clearly the manner in which we are proposing to utilize asphalt coatings for producing convective rainfall since this seems to have been misunderstood. We are proposing to apply asphalt strips, aligned parallel to the most prevalent direction of the onshore sea breeze, to arid coastal regions. Both experimental data and theoretical considerations indicate that such strips should become hotter than the surrounding uncoated ground and that this heat will be transferred to the air immediately above the strips, causing this air to become hotter than the air above the uncoated ground on either side. The resulting local instability should lead to a helical circulation producing convective clouds which would extend in a street downwind from the strip. This cloud-forming process should be assisted by the ability of the strips to act as a focus for convective activity in that area. On days when convection of sufficient intensity could be stimulated in this manner, it might be expected that some precipitation would occur on the downwind portions of the asphalt and that even greater amounts of rainfall would occur over the uncoated territory downwind of the strips.

We, therefore, agree with Howell's comment that a conical mountain might be a better model for this rain-making process. In the area of North Africa where our analysis was performed, this requirement is met for the Benghazi Peninsula where the land rises to 2000 feet about 15 miles from the coast and goes back to almost sea level behind the Peninsula and along the seacoast on either side. This area is treated in Figs. 3a and 4 of our paper and in Table 1 where the asphalt strip needed to reproduce this type of lifting is estimated to be 19 miles in length. It can be seen from Fig 5 of our paper that the 2 points plotted for the 19-mile coating lie near the maximum of our correlation curve and would indicate 1.5 to 3 acres of arable land per acre of asphalt rather than the 2 to 3 acres per acre which we concluded from the overall curve. The restriction of our analysis to this single conical mountain would not, therefore, have resulted in any significant change in our estimates of the amount of rainfall which a coating might produce.

We tried to point out at several locations in the paper that the major purpose of these calculations was to determine whether the concept discussed previously in Black (1963) deserved further investigation. To answer this question would require more than an estimate of "what the approximate cost of the rainfall might be." We wanted some idea of (1) how large a coating would be needed to show that this concept could produce at least some rainfall, and (2) what coating size might produce optimum effects. This information could not be obtained from analysis of a single situation but required examination of several mountains of differing heights and differing rain-making efficiencies in the same climatological area. It would have been preferable that these all be isolated conical peaks. We did not find a region where an ideal situation of this type exists. The best area for our analysis appeared to be North Africa where we were forced to include mountains which lay athwart the wind. While recognizing that this type of relief would affect the location of the rainfall, we assumed that the *total amount* of precipitation would be a useful data point within the accuracy needed for our objectives.

Howell questions the effectiveness with which we might collect water falling on our coating. While we anticipate that most of the rain will fall behind the coating rather than on it, his objection is not trivial since (1) we must drain the coating effectively to maintain its effectiveness as a hot surface and (2) we would plan to utilize the rainfall collected from the coating to augment the water supplies in the downwind areas. Experiments by ourselves and others have indicated that satisfactory water collection efficiencies can be expected from low-cost, waterproofed soil surfaces. It has been reported by Myers (1961) that asphalt coatings similar to those we propose for weather modification will give run-off efficiencies varying from 80 per cent for a 0.1-inch rain to 98 per cent for a 1.0-inch rain. This Spring we have installed a 10-acre experimental watershed at the White Sands Missile Range in cooperation with the local military authorities and the U. S. Geological Survey, who will follow the results. Since this watershed uses a coating of the type we propose for weather modification, it should produce data directly applicable to our weather control concept.

We feel that our citation of Riehl (1949) to the effect that general disturbances tend to produce general and heavy precipitation is applicable to our analysis since the type of disturbance asphalt coatings might produce should be analogous to that produced by the conical mountains of Hawaii. The isolated mountain of moderate height on the Benghazi Peninsula appears equally appropriate for the application of Riehl's observations. The fact that the rainfall all along the Libyan and Egyptian coasts is only 2–3 inches per year, except for the short interval at Benghazi, still persuades us that strong distrubances appear unlikely to be important sources of rainfall for this area. This conclusion is supported by a U. S. Weather Bureau (1954) report which states "While the axis of the Mediterranean Sea is a locus of weak frontogenesis and a path of lows and fronts, North Africa is at too low a latitude for very frequent or strong frontal activity."

The rainfall, of course, must come from overcast skies. If our coatings prove effective, the clouds which they produce would start at some point downwind from the windward edge of the coating, as is the case with the convective cloud streets produced by islands. We naturally need sunshine over the windward portion of the coating to maintain the convective activity. What it is necessary to determine is whether rain over the Benghazi Peninsula can normally be associated with clear skies over the neighboring desert sectors of the coastline. We are attempting to set up channels for obtaining data of this type from a refinery at Marsa Brega which is located on the Gulf of Sirte just west of the Benghazi Peninsula.

The suggestion of using energy to add vapor and heat to the air along the coastline by boiling sea water is interesting. However, it is doubtful that this could be accomplished over a long section of coastline without incurring rather high investment costs for piping, insulation and heat transfer surfaces. In any case, there is no lack of moisture in the air over this area. The British Meteorological Office (1936) reports the relative humidity at Benghazi to be 70 per cent or higher on 11 months of the year and 80 per cent or more in July and August.

As indicated in the last section of our paper we are proceeding with the development of improved mathematical models of convective circulation to provide us with a better understanding of the effects which large asphalt coatings might produce. These models will be evaluated by observation of the convection and precipitation associated with mountains and with natural heat sources such as islands. We will continue to welcome any suggestions as to where such data might be available and where we might best conduct field observations to obtain new information of this type.

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