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THE HURRICANE MODIFICATION PROJECT: PAST RESULTS AND FUTURE PROSPECTS

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ABSTRACT

Modification experiments on Hurricane Debbie on 18 and 20 August 1969 were conducted by Project STORMFURY, a cooperative effort of the Departments of Defense and Commerce. The hurricane decreased in intensity following the "seedings" on each of the days. This paper summarizes the history of the Project, discusses the STORMFURY hypotheses, describes the experiment, reports the results, analyses their significance and outlines future plans of the Project.

INTRODUCTION

Results from Hurricane Debbie modification experiments on 18 and 20 August 1969 are so encouraging as to offer hope that man may one day exert a degree of control over the intensity of these devastating storms that originate over the tropical oceans. The experiments were conducted by Project STORMFURY, an interdepartmental effort of Defense (Navy) and Commerce (ESSA) (1). The Air Force has also been a very active participant and significant contributions have been made by the NSF, NASA, and FAA, as well as several university groups.

R. H. Simpson proposed in 1961 that hurricanes might be modified by introducing freezing nuclei into the massive clouds surrounding the center of a hurricane. At about the same time Pierre St. Amand and his associates at the Navy Weapons Center, China Lake, California, developed pyrotechnic generators which made it practical to introduce very large quantities of silver iodide into clouds within a few minutes. Groups from the Weather Bureau and the Navy experimented on Hurricane Esther with a single seeding on each of 2 days in September 1961. Project STORMFURY was formally organized in 1962 with R. H. Simpson as the first director. In August 1963, the experiment with a single seeding per day was repeated on each of 2 days for Hurricane Beulah. The results of these earlier experiments have been reported by Simpson and Malkus (2) and were encouraging but inconclusive. A multiple seeding experiment was designed under the leadership of Joanne Simpson, director of the project for 1965-66. During the years 1965-68 no hurricane occurred in a place suitable for experimentation. Research on hurricanes, both theoretical and experimental, continued, however, with results that led to changes in the original design of the multiple seeding experiment. Furthermore, improved pyrotechnic silver iodide generators were developed by St. Amand and his group before the 1969 hurricane season. The frustration of waiting 4 years without opportunities for experimentation may not, therefore, have been in vain. The succession of apparently minor changes to improve the design of the seeding experiment may have made the difference between success or failure for the Debbie experiments.

Two general considerations justify Project STORMFURY experiments: 1) recent improvements in our understanding of the physical processes fundamental to the maintenance of hurricanes suggest good avenues of experimentation, and 2) enormous rewards can be derived from even a slight degree of beneficial modification. The first will be elaborated in later sections; the second may be illustrated by the following rough "cost-benefit" analysis.

Hurricanes caused an average annual damage in the United States of 13 million dollars between 1915 and 1924. By the period 1960 to 1969, this figure had jumped to 432 million dollars. Even after adjusting these values for the inflated cost of construction in recent years, this represents a 650 percent increase in the average annual cost of hurricane damage in less than 50 years (3). Since Americans continue to construct valuable buildings in areas exposed to hurricanes, these damage costs should continue to increase. Hurricane Betsy of 1965 and Hurricane Camille of 1969 each caused more than 1.4 billion dollars in damage. If the United States continues supporting hurricane modification research at the present rate for the next 10 years and if by that time we modify just one severe hurricane, such as Betsy, sufficiently to reduce its damage by only 10 percent, the nation will have a 1000 percent return on its investment. The benefits in terms of prevention of human suffering are, of course, incalculable.

At least two fundamentals established in recent years by studies of hurricane structure and maintenance suggest avenues for beneficial modification: 1) an internal energy source is necessary if a hurricane is to reach or retain even moderate intensity; this source is the sensible and latent heat transferred from the sea surface to the air inside the storm, and 2) the energy for the entire synoptic-scale hurricane is released by moist convection in highly organized convective scale circulations located primarily in the eyewall and major rain bands. In the first, we find an explanation of the observations that hurricanes form only over warm tropical waters and begin dissipating soon after moving over either cool water or land; neither of which provides a flux of energy to the atmosphere sufficient to keep the storm at full intensity. In the second, we find a more rational explanation of the low percentage of tropical disturbances that become hurricanes. If a warm sea with its large reservoir of energy were the only requirements, we would have 5 to 10 times as many hurricanes as normally form. During the 1967 and 1968 hurricane seasons, 130 tropical waves were tracked in the Atlantic and adjacent areas where sea surface temperatures were warm enough for hurricane genesis, but only 13 of the areas developed storms of full hurricane intensity (4). If, however, there are only a limited number of ways in which the convective and synoptic scales of motion can interact to achieve optimum utilization of the energy flowing upward from the ocean, then it is not surprising that few tropical disturbances intensify and become hurricanes.

THEORY OF MODIFICATION

Both of the above findings suggest possible field experiments which may beneficially modify a hurricane. On the basis of the first, we may attempt to reduce the flux of energy from the sea surface to the atmosphere, probably through attempts to inhibit evaporation. On the basis of the second, we may try to modify the release of latent heat in the small portion (1 to 5 percent) of the total storm occupied by the organized active convective-scale motions in a manner that redistributes heating to produce a weakening of the storm.

We do not know of any practical means of reducing the flux of energy from the sea surface to the atmosphere in the area of gale and hurricane force winds.

We do have a means of modifying the rate of release of latent heat in the clouds of the hurricane. This we can do by introducing freezing nuclei into the clouds containing supercooled water drops. By causing them to freeze, we could add heat to the air in the storm. The question to be answered is where in the storm could addition of heat result in a reduction in the maximum winds. This is particularly pertinent because the hurricane is a heat engine. It derives its enormous energy by converting latent and sensible heat extracted from the ocean and the warm moist tropical air into potential and then partially into kinetic energy. We have sought the answer to this question by theoretical investigations and numerical modelling work.

The life cycle of hurricanes can now be simulated by theoretical mathematical models. Researchers in ESSA and at a number of universities have been developing these models for a number of years (5, 6). Current models are capable of simulating only an axially-symmetric cyclone with rather limited vertical resolution and they parameterize in a relatively simple fashion the effect of air-sea interaction and the transfer of energy by cumulus convection. They cannot predict the effects on storm motion of artificial intervention. They do, however, simulate many features of a hurricane quite well.

We have used the model developed by S. L. Rosenthal (6) to get indications of where to release the heat by seeding the supercooled clouds with freezing nuclei (silver iodide). We also asked what effect the seeding might have on the intensity of the hurricane. The answer of the first question is to release the heat just outside the mass of relatively warm air concentrated in and around the core of the hurricane. Specifically, the best chances for reducing the maximum intensity of the hurricane is to seed from the core of the belt of maximum winds outwards along a radius. The model suggests that this can result in a reduction of maximum winds in the hurricane by about 15 percent.

THE MODIFICATION EXPERIMENT

The modification experiment, therefore, seeks to exploit energy sources within the hurricane. Hurricane clouds contain large quantities of water substance still in the liquid state at temperatures lower than -4°C (fig. 1). Introduction of silver iodide nuclei at these and lower temperatures should cause the water droplets to change to ice crystals and release the latent heat of fusion, thus providing a possible mechanism for adding heat to the hurricane. One objective of the STORMFURY experiments is to verify the indications from the numerical model that heat should be released at the outer edge of the mass of warm air occupying the central portion of the hurricane in order to cause a reduction in the storm's intensity. The experiments on Hurricane Debbie were designed to determine if addition of heat in this area would result in diminishing the maximum horizontal temperature gradients in the storm and, eventually, in weakening the maximum winds of the storm.

HURRICANE DEBBIE EXPERIMENT

Hurricane Debbie was a mature storm with winds stronger than 100 knots on 18 August. It was about 650 n mi east-northeast of Roosevelt Roads, Puerto Rico, the primary operating base of Project STORMFURY (fig. 2). This was an extreme range for the experiment, but other conditions were favorable and the storm was moving west-northwestward so that its course would bring it closer to the base as the day progressed. Thirteen aircraft were available--9 from the Navy, 2 from ESSA, and 2 from the Air Force. With these 13 aircraft, 15 flights were made on 18 August and again on 20 August. Considering the many things that can go wrong with heavily instrumented aircraft, this was a major accomplishment. Of these flights, 5 carried the pyrotechnics for seeding the hurricane with silver iodide, and the other 10 monitored the storm for changes in structure and intensity beginning about 6 hours prior to the first seeding and continuing until 6 hours after the fifth and last seeding.

The Navy seeder aircraft approached the storm from the south-southwest at 33,000 feet, penetrated and crossed the eye, and entered the wall cloud on the north-northeast side. Shortly after entering the wall cloud and at a spot where past experience suggests one should cross the radius of maximum winds as well as the most intense temperature gradients, the crew started dropping the pyrotechnic generators which produced the silver iodide*. Each aircraft carried 208 of these and dropped them along a line leading radially away from the center (fig. 3). Each generator contained slightly more than 120 grams of silver iodide and each gram should produce in excess of 10^{12} freezing nuclei. There is some evidence that each gram might produce more than 10^{14} nuclei active at temperatures found in the hurricane clouds (7).

Each seeding run lasted 2 to 3 minutes or between 14 and 20 n mi. The 5 seeding runs came at intervals of approximately 2 hours on each of the 2 days.

DATA FOR EVALUATING THE EXPERIMENTS

Many data were collected by personnel in the 10 monitoring flights and some by the 5 seeder aircraft. The ESSA National Hurricane Research Laboratory at Miami is still busy processing these data, but we can draw tentative conclusions from those processed thus far. A few of the data are shown in Figures 4 and 5.

The two DC-6 aircraft of ESSA's Research Flight Facility have similar instrumentation systems which have been cross calibrated and have crews trained in using the same techniques. Data from the two aircraft are as nearly comparable as planning and testing can make them. These aircraft were assigned to relieve each other in making repetitive passes across the storm, in order to provide almost continuous coverage of the hurricane by one of them from 3 hours before the first seeding until 5 or 6 hours after the fifth seeding. This was essentially accomplished, except for some time gaps on August 18 when the storm was at such great range the first aircraft could not make the round trip to base for refueling during the time the second aircraft could remain on station. The aircraft flew at 12,000 feet. In previous mature hurricanes such as Debbie where we have had measurements at several levels, the 12,000-ft winds have been about 95 percent as strong as those near the surface (8).

The flight patterns called for each aircraft to make a round trip across the storm from a point about 50 n mi west-northwest of the hurricane center to 50 n mi east-southeast of it or, to a point beyond the belt of strongest winds. Each aircraft then flew similar traverses from the south-southwest quadrant to the north-northeast quadrant until fuel shortage dictated departure from the storm. Since we have more data on the later passes, they are the ones presented in Figures 4 and 5. In most cases with a storm moving towards the west-northwest the strongest winds are found a short distance north-northeast of the center.

RESULTS AND DISCUSSION

Between successive passes on both the 18th and 20th, the winds sometimes increased and sometimes decreased. In the mean, however, the wind speeds decreased from shortly after the second seeding until at least 5 or 6 hours after the fifth seeding. This decrease was most marked on the 18th (fig. 4).

Before the first seeding on 18 August, maximum winds at 12,000 feet were 98 knots. By 5 hours after the fifth seeding they had decreased to 68 knots, or by 31 percent. The storm reintensified on 19 August, starting about 8 hours after the last seeding on the 18th. On 20 August the maximum wind speed before the first seeding was 99 knots. Within 6 hours after the final seeding the maximum had dropped to 84 knots, or a decrease of 15 percent.

The response of the winds to the seeding on 20 August was more impressive than this summary suggests. Debbie had a double wall cloud structure on this day. That is, there were 2 concentric walls with radii of approximately 10 and 20 n mi, respectively. Each was associated with a maximum of wind speed at corresponding radii. The hypothesis for the experiment calls for the nuclei to be introduced into clouds at greater radial distance than that of the maximum winds. All of the seedings were so conducted relative to the inner maximum, but only the fifth seeding was performed beyond the outer maximum. The wind speeds of the inner maximum started decreasing after the second seeding, but the outer maximum did not show a net decline until after the last seeding.

Variations in the force of the wind are closely related to variations of the square of the wind speed or the kinetic energy of the air particles. These decreases in maximum winds represent a reduction in kinetic energy in the belt of maximum winds of 52 and 28 percent, respectively, on 18 and 20 August.

That Hurricane Debbie decreased in intensity following multiple seedings on 18 and 20 August is well established. What we do not know is whether the decrease was caused by the seeding, or whether it represents only natural changes in the hurricane.

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*These were developed by the Navy Weapons Center, China Lake, California, under the leadership of Pierre St. Amand. The massive seedings which introduced more than 10^{17} active freezing nuclei into the hurricane clouds within 10 minutes were not possible until Dr. St. Amand's team developed the generators.

From analyses of past storms, we can, however, make some statements as to the probability that the changes observed might have occurred naturally. The rate of rise in central pressure in Debbie which accompanied the reduction in wind speed on 18 August has occurred in only 9 percent of 502 similar length periods we have studied in other tropical cyclones. Our measurements of winds in previous hurricanes are less complete than are those of the pressure changes, but it is believed that the rate of decrease in wind speeds on 18 August is also a relatively rare event.

Although the decrease in wind speeds on 20 August was smaller than on 18 August, this rate of decrease occurs in considerably less than one-half of the hurricane days. Furthermore, on each of the days, the reduction in wind speed occurred at a time when it could reasonably have been caused by the seeding experiment.

We are still studying satellite pictures taken by the ATS-III satellite; radar pictures taken aboard the project aircraft; and measurements of the pressure, temperature and liquid water taken by the project aircraft. A motion picture of the hurricane clouds prepared from time lapse pictures taken by the ATS-III satellite will be shown at the meeting.

FUTURE PLANS

The thing that seems obvious is that since results of the 1969 modification attempts suggest so strongly that modification was accomplished, the experiment must be repeated on one or more additional storms as soon as practical to seek further confirmation. We must also continue searching for clues from the data still to be analyzed, and from results of our theoretical investigations in order to better identify probable cause and effect relationships and to improve design of our seeding experiments.

The various groups supporting STORMFURY are proceeding with preparations that will make it practical to do the multiple seeding experiment on 4 different hurricane days during the 1970 season if nature provides the opportunities. In addition, other experiments are planned for use when a hurricane is not satisfactory for the big experiment. These involve seeding the bands of clouds spiraling around the hurricane, and seeding them at distances greater than 50 n mi from the center of the hurricane. At these radii the thermal structure and lapse rates in clouds are much different than in those nearer the center of the hurricane. The objective of seeding these outer clouds would be to make them become more active and offer competition to those nearer the center. It is believed that in this manner the energy of the storm could be distributed over a larger area and not be as intense in the area of principal concentration.

A dry run training exercise will be performed in July to check-out new procedures suggested by the Debbie experiments and to train the new crews which will be participating in the modification experiment for the first time. This will be followed by some experimental seedings of clouds arranged in lines but in circulations not related to a tropical cyclone. This will provide opportunity to study not only the effect of seeding on individual clouds but also the interaction between adjacent clouds when both are seeded. Knowledge thus gained should have application to the design of modification experiments on the tropical storms and hurricanes to be seeded later in the summer.

ACKNOWLEDGMENT

I wish to express deep appreciation and pay tribute to all of those who have contributed to the success of STORMFURY. These include the Navy, Air Force, and ESSA crews who made the field experiments on Hurricane Debbie a success; members of the National Hurricane Research Laboratory and other agencies who have assisted in the research; and the STORMFURY Advisory Panel. The work herein reported has indeed been the result of a team effort.

REFERENCES

(1) Gentry, R. Cecil, "Project STORMFURY," Bull. Amer. Meteorol. Soc., Vol. 50, No. 6, June 1969, p. 404.

(2) Simpson, R. H. and J. S. Malkus, "Experiments in Hurricane Modification," Sci. Amer., Vol. 211, No. 1, Jan. 1964, p. 27.

(3) Gentry, R. Cecil, "Nature and Scope of Hurricane Damage," Hurricane Symposium, October 10-11, American Society for Oceanography, Houston, Tex., 1966, p. 229.

(4) Simpson, R. H., Neil Frank, David Shideler, and H. M. Johnson, "Atlantic Tropical Disturbances, 1968," Mon. Wea. Rev., Vol. 97, No. 3, March 1969, p. 240.

(5) Ooyama, K., "Numerical Simulation of the Life Cycle of Tropical Cyclones," J. Atmos. Sci., Vol. 26, No. 1, Jan. 1969, p. 3.

(6) Rosenthal, "Experiments with a Numerical Model of Tropical Cyclone Development. Some Effects of Radial Resolution," ESSA Technical Memorandum ERLTM-NHRL 88, Environmental Science Services Administration, Washington, D. C., 1970.

(7) Elliott, S. D., Jr., R. Steele, and W. D. Mallinger, "STORMFURY Pyrotechnics," Project STORMFURY Annual Report 1968, U. S. Department of the Navy and U. S Department of Commerce, 1969, Appendix B., p. 1.

(8) Hawkins, H. F., "Vertical Wind Profiles in Hurricanes," National Hurricane Research Project Report No. 55, U. S. Weather Bureau, Washington, 1962.

ILLUSTRATIONS

Figure 1. Schematic cross section of a hurricane.
Figure 2. Track of Hurricane Debbie, August 1969. Seeding areas on 18 and 20 August are indicated on the track.
Figure 3. Track of seeder aircraft.
Figure 4. Changes with time of wind speeds at 12,000 feet in Hurricane Debbie on 18 August 1969. The winds were measured by aircraft flying across the storm from south-southwest to north-northeast or the reciprocal track. Profiles are given which show the wind speeds before the first seeding, after the third seeding, and after the fifth seeding.
Figure 5. Same as Figure 4, except that the wind speed profiles are for 20 August 1969 and are for the periods before and after the seedings.

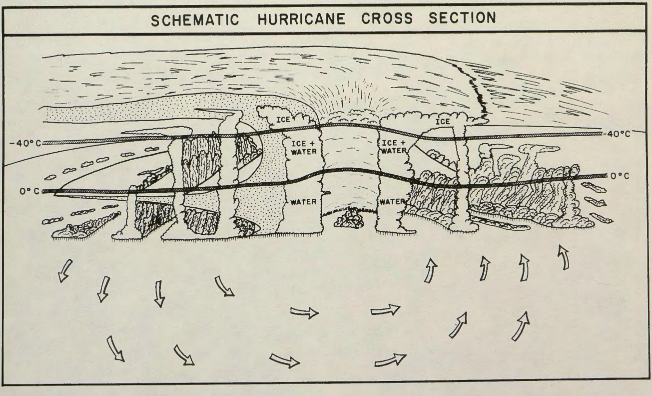
SCHEMATIC HURRICANE CROSS SECTION
ICE
ICE
-40°C
-40°C
ICE + WATER
ICE + WATER
0°C
0°C
WATER
WATER

Figure 1.

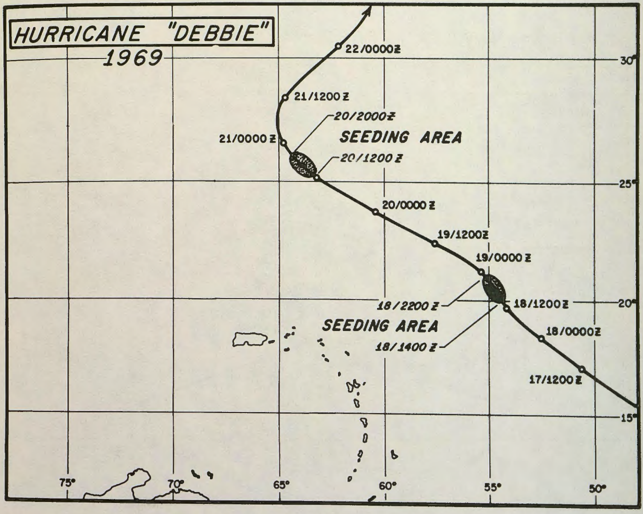
HURRICANE "DEBBIE"
1969
22/0000Z
21/1200 Z
20/2000Z
SEEDING AREA
21/0000 Z
20/1200 Z
20/0000 Z
19/1200Z
19/0000 Z
18/2200 Z
18/1200 Z
SEEDING AREA
18/1400 Z
18/0000Z
17/1200 Z
30°
25°
20°
15°
75°
70°
65°
60°
55°
50°

Figure 2.

FLIGHT TRACK FOR SEEDING AIRCRAFT

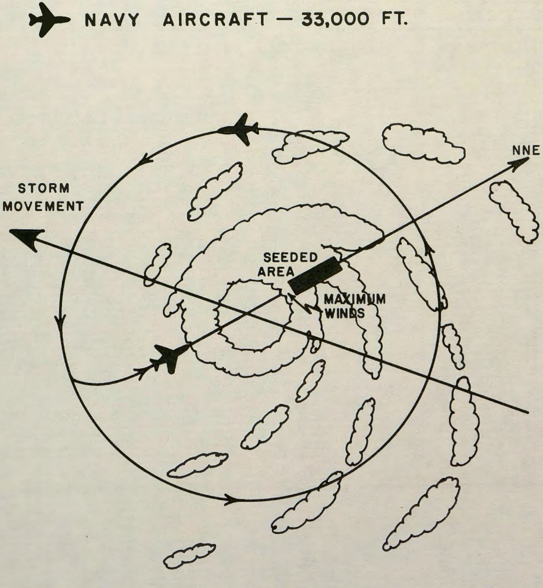

Figure 3.

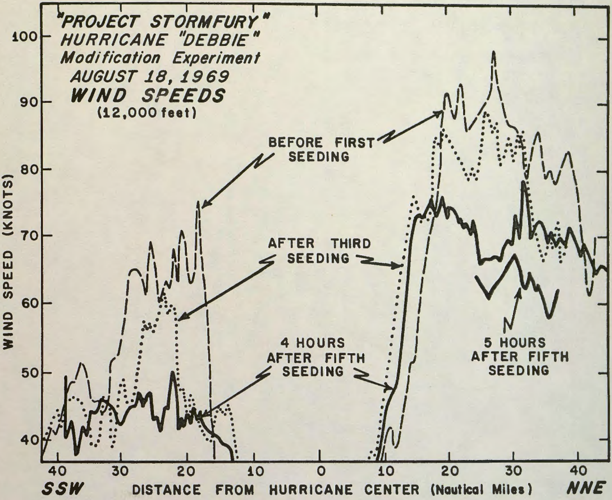
"PROJECT STORMFURY"
HURRICANE "DEBBIE"
Modification Experiment
AUGUST 18, 1969
WIND SPEEDS
(12,000 feet)
BEFORE FIRST SEEDING
AFTER THIRD SEEDING
4 HOURS AFTER FIFTH SEEDING
5 HOURS AFTER FIFTH SEEDING
WIND SPEED (KNOTS)
100
90
80
70
60
50
40
40
30
20
10
0
10
20
30
40
SSW
DISTANCE FROM HURRICANE CENTER (Nautical Miles)
NNE

Figure 4.

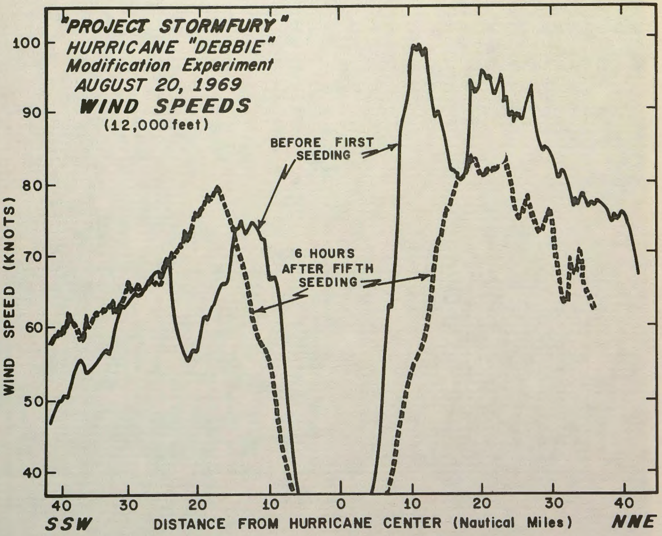
"PROJECT STORMFURY"
HURRICANE "DEBBIE"
Modification Experiment
AUGUST 20, 1969
WIND SPEEDS
(12,000 feet)
BEFORE FIRST SEEDING
6 HOURS AFTER FIFTH SEEDING
WIND SPEED (KNOTS)
100
90
80
70
60
50
40
40
30
20
10
0
10
20
30
40
SSW
DISTANCE FROM HURRICANE CENTER (Nautical Miles)
NNE

Figure 5.