An Experiment in Hurricane Modification: Preliminary Results

A series of two cloud seeding experiments was performed in hurricane Beulah on 23 and 24 August 1963 by Project Stormfury, a joint program (*1*) of the U.S. Weather Bureau and Navy. The purpose was to test a hypothesis relating storm and cloud processes, to compare results with a similar seeding of hurricane Esther in 1961 (*2*), and to develop a foundation for improved hurricane experiments.

Since measurements from ten aircraft were made, months will be required for complete analysis. However, because of the potential importance of the experiments and widespread interest aroused, preliminary results are presented here. This program represents a first attempt to experiment upon an atmospheric circulation phenomenon larger than a cumulus cloud. It is hoped that such experiments may become the background for future amelioration of severe storms.

The hypothesis, beginning with observations that supercooled water abounds in hurricane cloud towers proposes that silver iodide seeding can release heat of fusion in the eye wall, the site of maximum pressure gradient. The additional heating of the tropospheric column would be expected to lower the pressure there, reducing and displacing outward the maximum radial pressure gradient. Our physical reasoning is that this, by upsetting a marginal balance of forces, could induce an outward migration of the wall cloud and thus increase the radius at which the ascent of the inflowing air occurs.

Since the difference between a "hurricane" and a mere "tropical storm" lies not in the energy released but in the momentum production of the last few miles penetrated by the inflow (*3*), we hypothesize that this increase in radius of ascent should lead to a decrease in maximum windspeed.

The aircraft measured the cloud structures and circulation features of the storm core for 5 hours, centered on the seeding time. A unique feature of the operation was the use of pyrotechnic silver iodide generators, developed by Pierre St. Amand of the Naval Ordnance Test Station, China Lake, California. These generators were dropped from 35,000 feet (10,700 meters) along a radial path extending from 15 to 35 miles (25 to 55 kilometers) from the storm center, to produce a vertical "sheet" of silver iodide more than 20,000 feet in depth which would then be swept around by the strong winds.

On 23 August hurricane Beulah was immature and unsteady. The wall cloud was incomplete, consisting of a crescent which shifted abruptly from the west to the southeast side of the center before seeding, but it changed very little subsequently. Cloud maps made from the height-finder (RHI) radar show that the seeding material missed the tall clouds altogether during the monitoring period. The timing of the changes and the location of the seeding indicate that these observations depict only the natural development of the deepening storm.

The observations made before seeding on the 24th show that the storm had steadied down. The central pressure fall and wind increase had leveled off (see Table 1). The cloud maps showed much smaller changes in the 16 hours after the post-seeding period on the 23rd than occurred during the pre-seeding monitoring on the 23rd. Furthermore, the wall cloud maintained both orientation and radius during the entire pre-seeding monitoring period on the 24th. The cloud maps for the 24th demonstrate conclusively that the seeding material entered the active eye wall.

The radar showed pronounced changes in the clouds after the seeding, changes which were different from those on the 23rd. While on the 23rd radii of all cloud bands were conserved, despite a shift in the sector of wall activity, on the 24th the eye wall appeared to degenerate and reform at an increased radius. Clouds in the next outer rain band underwent very rapid development and some outward migration also. Thus the mean radius of ascending air on the 24th was larger after seeding than before.

That the cloud changes were a consequence of seeding, however, cannot yet be established definitely. A handicap is our sparse knowledge of natural cloud fluctuations in hurricanes.

The changes in wind profiles, thermal structure, and circulation dynamics of the storm will require much further analysis. Nevertheless, some preliminary results are worthy of note. Table 1 shows the trend in central pressure and maximum wind at 12-hour intervals. The deepening process continued through the seeding period on the 23rd. On the 24th, a sudden drop in maximum wind followed the seeding. Furthermore, the radius of maximum wind was about 5 to 20 miles greater after seeding than before.

The clearest evidence of the predicted dynamic consequences of the seeding was the weakening of the inward pressure gradient in all quadrants. This weakening averaged 16 percent in the radial interval from 10 to 40 miles, in agreement with the warming due to freezing of a reasonable amount of water. Also, preliminary calculations suggest that such warming could have changed the balance of forces on the inner ring of air in such a way as to initiate a net outward acceleration in the expected sector. Finally, Table 1 shows a 15-millibar rise in central pressure about 12 hours after the seeding. If verifiable and connectable to the experiment, this rise could be a logical but indirect consequence of the other changes described.

Thus, on first quantitative inspection, the results of the Beulah seeding are consistent with the hypothesis upon which the experiments were based. Nevertheless, uncertainties remain in the data and analyses. The hypothesis involves many crucial, yet unestablished, links in a long chain. Many hurricanes do undergo naturally the dynamic changes observed in Beulah, without human interference. This experiment must be repeated, fluctuations in unmodified hurricanes must be measured, and both theories and experiments must be developed at each link in the reasoning chain.

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Table 1. Central pressure and maximum wind, hurricane Beulah, 1963. Arrows mark the time of seeding.

Date (Aug.)	21		22		23		24		25		26	
Time (GMT)	00	12	00	12	00	12	↓00	12↓	00	12	00	12
Central pressure (mb)	1006	1005	1002	995	990	969	963	964	965	978	977	982
Maximum wind (knots)	35	45	55	67	80	90	100	104	79	63	75	80

References

1. Project Stormfury is partially supported by the National Science Foundation.
2. R. H. Simpson, M. A. Ahrens, R. D. Decker, *Natl. Hurricane Res. Project Rept. 60* (1963).
3. H. Riehl and R. C. Gentry, ibid., *Rept. 17* (1958).

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