Controlling Hurricanes

Can hurricanes and other severe tropical storms be moderated or deflected?

By Ross N. Hoffman
Every year huge rotating storms packing winds greater than 74 miles per hour sweep across tropical seas and onto shorelines—often devastating large swaths of territory. When these roiling tempests—called hurricanes in the Atlantic and the eastern Pacific oceans, typhoons in the western Pacific and cyclones in the Indian Ocean—strike heavily populated areas, they can kill thousands and cause billions of dollars of property damage. And nothing, absolutely nothing, stands in their way.

But must these fearful forces of nature be forever beyond our control? My research colleagues and I think not. Our team is investigating how we might learn to nudge hurricanes onto more benign paths or otherwise defuse them. Although this bold goal probably lies decades in the future, we think our results show that it is not too early to study the possibilities.

To even consider controlling hurricanes, researchers will need to be able to predict a storm’s course extremely accurately, to identify the physical changes (such as alterations in air temperature) that would influence its behavior, and to find ways to effect those changes. This work is in its infancy, but successful computer simulations of hurricanes carried out during the past few years suggest that modification could one day be feasible. What is more, it turns out the very thing that makes forecasting any weather difficult—the atmosphere’s extreme sensitivity to small stimuli—may well be the key to achieving the control we seek. Our first attempt at influencing the course of a simulated hurricane by making minor changes to the storm’s initial state, for example, proved remarkably successful, and the subsequent results have continued to look favorable, too.

To see why hurricanes and other severe tropical storms may be susceptible to human intervention, one must understand their nature and origins [see box on next two pages]. Hurricanes grow as clusters of thunderstorms over the tropical oceans. Low-latitude seas continuously provide heat and moisture to the atmosphere, producing warm, humid air above the sea surface. When this air rises, the water vapor in it condenses to form clouds and precipitation. Condensation releases heat—the solar heat it took to evaporate the water at the ocean surface. This so-called latent heat of condensation makes the air more buoy-
Some scientists believe that they may be able to weaken or move hurricanes onto less dangerous tracks by altering the initial physical conditions (the air temperature or humidity, for example) in the center of the storm or even in the surrounding areas. To succeed, they need to make accurate and detailed forecasts of hurricanes. Here are the outlines of how these powerful storms arise.

**ANATOMY OF A HURRICANE**

Hurricanes start to form when tropical oceans release heat and water into the atmosphere, producing large amounts of warm, humid air above the surface. Warm air rises, and as it does so, the water vapor in it condenses to form clouds and rain. This condensation produces heat, causing air in the developing thunderclouds to climb still farther.

The release of heat above the tropical seas creates a surface low-pressure zone, where additional warm, moist air from the outer perimeter converges. This continuous movement into the burgeoning thunderstorm shifts huge amounts of heat, air and water skyward. This upward transfer and release of heat further enhance the convergence of surrounding air toward the growing storm center, which starts to circulate under the influence of the earth’s rotation. The process continues apace, strengthening and organizing the storm.

**Dreams of Control**

Because a hurricane draws much of its energy from heat released when water vapor over the ocean condenses into clouds and rain, the first researchers to dream of taming these unruly giants focused on trying to alter the condensation process using cloud-seeding techniques—then the only practical way to try to affect weather. In the early 1960s a U.S. government-appointed scientific advisory panel named Project Stormfury performed a series of courageous (or perhaps foolhardy) experiments to determine whether that approach might work.

Project Stormfury aimed to slow the development of a hurricane by augmenting precipitation in the first rain band outside the eye wall—the ring of clouds and high winds that encircle the eye. They attempted to accomplish this goal by seeding the clouds there with silver iodide particles dispersed by aircraft, which would serve as nuclei for the formation of ice from water vapor that had been supercooled after rising to the highest, coldest reaches of the storm. If all went as envisioned, the clouds would grow more quickly, consuming the supplies of warm, moist air near the ocean surface, thus replacing the old eye wall. This process...

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**Overview/Taming Hurricanes**

- Meteorological researchers are simulating past hurricanes using sophisticated weather-forecasting models that closely reproduce the complex internal processes crucial to the development and evolution of severe tropical storms.
- The work confirms that these massive, chaotic systems are susceptible to minor changes in their initial conditions—for instance, the air temperature and humidity near the center of the storm and in the surrounding regions.
- Using complex mathematical optimization techniques, the researchers are learning what modifications to a hurricane could weaken its winds or divert it from populated areas.
- If these theoretical studies are ultimately successful, they should point the way toward practical methods for intervening in the life cycle of hurricanes to protect life and property.
would then expand the radius of the eye, lessening the hurricane's intensity in a manner akin to a spinning skater who extends her arms to slow down.

The Stormfury results were ambiguous at best. Meteorologists today do not expect this particular application of cloud seeding to be effective in hurricanes because, contrary to the early beliefs, the storms contain little supercooled water vapor.

Chaotic Weather

Our current studies grew out of an intuition I had 30 years ago when I was a graduate student learning about chaos theory. A chaotic system is one that appears to behave randomly but is, in fact, governed by rules. It is also highly sensitive to initial conditions, so that seemingly insignificant, arbitrary inputs can have profound effects that lead quickly to unpredictable consequences. In the case of hurricanes, small changes in such features as the ocean’s temperature, the location of the large-scale wind currents (which drive the storms’ movements), or even the shape of the rain clouds spinning around the eye can strongly influence a hurricane’s potential path and power.

The atmosphere’s great sensitivity to tiny influences—and the rapid compounding of small errors in weather-forecasting models—is what makes long-range forecasting (more than five days in advance) so difficult. But this sensitivity also made me wonder whether slight, purposely applied inputs to a hurricane might generate powerful effects that could influence the storms, whether by steering them away from population centers or by reducing their wind speeds.

I was not able to pursue those ideas back then, but in the past decade computer simulation and remote-sensing technologies have advanced enough to renew my interest in large-scale weather control. With funding support from the NASA Institute for Advanced Concepts, my co-workers and I at Atmospheric and Environmental Research (AER), an R&D consulting firm, are employing detailed computer models of hurricanes to try to identify the kinds of actions that might eventually be attempted in the real world. In particular, we use weather-forecasting technology to simulate the behavior of past hurricanes and then test the effects of various interventions by observing changes in the modeled storms.

Modeling Chaos

Even today’s best weather prediction computer models leave much to be desired when it comes to forecasting, but with effort they can be useful for modeling these storms. The models depend on numerical methods that simulate a storm’s complex development process by computing the estimated atmospheric conditions in brief, successive time steps. Numerical weather prediction calculations are based on the assumption that within the atmosphere there can be no creation or destruction of mass, energy, momentum and moisture. In a fluid sys-
The altered version of Hurricane Iniki veered off, so that Kauai escaped the storm’s most damaging winds.
six-hour period then supplies the first guess for the next six-hour interval.

After simulating a hurricane that occurred in the past, we can then change one or more of its characteristics at any given time and examine the effects of these perturbations. It turns out that most such alterations simply die out. Only interventions with special characteristics—a particular pattern or structure that induces self-reinforcement—will develop sufficiently to have a major effect on a storm. To get an idea of what this means, think of a pair of tuning forks, one vibrating, the other stationary. If the forks are tuned to different frequencies, the second fork does not move, despite being struck repeatedly by sound waves emitted by the first. But if the devices share the same frequency, the second fork will respond in a resonant manner and vibrate sympathetically. In an analogous fashion, our challenge is to find just the right stimuli—changes to the hurricane—that will yield a robust response that leads to the desired results.

**Calming the Tempest**

To explore whether the sensitivity of the atmospheric system could be exploited to modify atmospheric phenomena as powerful as hurricanes, our research group at AER conducted computer simulation experiments for two hurricanes that occurred in 1992. When Hurricane Iniki passed over the Hawaiian island of Kauai in September of that year, several people died, property damage was enormous and entire forests were leveled. Hurricane Andrew, which struck Florida just south of Miami the month before, left the region devastated.

Surprisingly, given the imperfections of existing forecasting technologies, our first simulation experiment was an im-
mediate success. To alter the path of Iniki, we first chose where we wanted the storm to end up after six hours—about 60 miles west of the expected track. Then we used this target to create artificial observations and fed these into 4DVAR. We set the computer to calculate the smallest change to the initial set of the hurricane’s key defining properties that would yield a track leading to the target location. In this early experiment we permitted any kind of possible artificial alteration to the storm system to take place.

The most significant modifications proved to be in the starting temperatures and winds. Typical temperature adjustments across the grid were mere tenths of a degree, but the most notable change—an increase of nearly two degrees Celsius—occurred in the lowest model layer west of the storm center. The calculations yielded wind-speed alterations of two or three miles per hour. In a few locations, though, the velocities changed by as much as 20 mph because of minor redirections of the winds near the storm’s center.

Although the original and altered versions of Hurricane Iniki looked nearly identical in structure, the changes in the key variables were large enough that the latter veered off to the west for the first six hours of the simulation and then traveled due north, so that Kauai escaped the storm’s most damaging winds. The relatively small, artificial alterations to the storm’s initial conditions had propagated through the complex set of nonlinear equations that simulated the storm to result in the desired relocation after six hours. This run gave us confidence that we were on the right path to determining the changes needed to modify real hurricanes.

For the subsequent hurricane simulation trials, our team used higher grid resolutions to model the hurricane and set 4DVAR to the goal of minimizing property damage.

In one experiment using the modified code, we calculated the temperature increments needed to limit the surface wind damage caused by Hurricane Andrew as it hit the Florida coast. Our goal was to keep the initial temperature perturbation to a minimum (to make it as easy to accomplish as possible in real life) and to curtail the most destructive winds over the last two hours of the first six-hour interval. In this trial, 4DVAR determined that the best way to limit wind damage would be to make the greatest modifications to the beginning temperature near the storm’s eye. Here the simulation produced changes as large as two or three degrees C at a few locations. Smaller temperature alterations (less than 0.5 degree C) extended out 500 to 600 miles from the eye. These perturbations feature a wavelike pattern of alternating rings of heating and cooling centered on the hurricane. Although only temperature had been changed at the start, all key variables were
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The original, but to compensate for making no initial temperature changes in the storm center the remaining temperature changes had to be larger. Notably, temperature changes developed rapidly near the storm center during the simulation.

Another potential method to modify severe tropical storms would be to directly limit the availability of energy by coating the ocean surface with a thin film of a biodegradable oil that slows evaporation. Hurricanes might also be influenced by introducing gradual modifications days in advance of their approach and thousands of miles away from their eventual targets. By altering air pressure, these efforts might stimulate changes in the large-scale wind patterns at the jet-stream level, which can have major effects on a hurricane’s intensity and track. Further, it is possible that relatively minor alterations to our normal activities—such as directing aircraft flight plans to precisely position contrails and thus increase cloud cover or varying crop irrigation practices to enhance or decrease evaporation—might generate the appropriate starting alterations.

What if Control Works?

If meteorological control does turn out to work at some point in the future, it would raise serious political problems. What if intervention causes a hurricane to damage another country’s territory? And, although the use of weather modification as a weapon was banned by a United Nations Convention in the late 1970s, some countries might be tempted.

Before those kinds of concerns arise, however, our methods would need to be proved on atmospheric phenomena other than hurricanes. In fact, we believe our techniques should first be tried out in an effort to enhance rainfall. This approach could then serve as a test bed for our concepts in a relatively small region that could be instrumented densely with sensors. For such reduced size scales, perturbations could be introduced from aircraft or from the ground. If our understanding of cloud physics, computer simulation of clouds and data assimilation techniques advance as quickly as we hope, these modest trials could be instituted in perhaps 10 to 20 years. With success there, larger-scale weather control using space-based heating may become a reasonable goal that nations around the globe could agree to pursue.

more to explore


NOAA’s Hurricane Research Division: www.aoml.noaa.gov/hrd/tcfaq

Ross N. Hoffman’s technical presentations on weather modification can be found at www.niac.usra.edu/studies/