Bumpas/NCAR

Riders on the Storm

BY KENDRICK FRAZIER

The most sophisticated field research project ever attempted on convective storms is probing the mysteries of High Plains thunderstorms

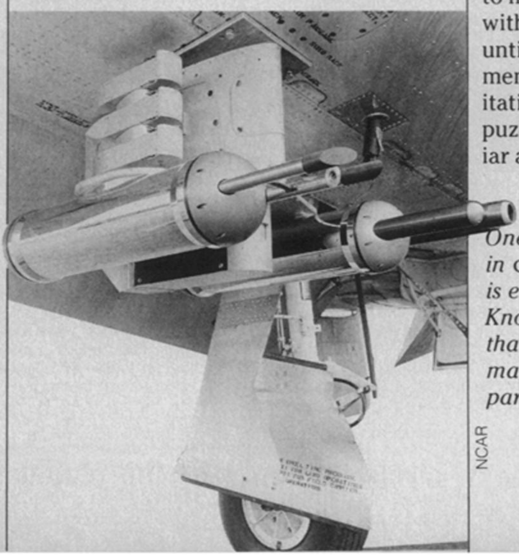
It is 2:33 p.m. on a cloud-flecked blue-sky summer day in southeastern Montana. Arlin B. Super, operations manager for today, takes another glance at the color Doppler radar screens on the master control panel before him, and speaks into his microphone. "HIPLEX 2, 10, 14 and 6, we'd like to have you launch as soon as possible. The best turrets are at 55 nautical miles 075 degrees radial out."

Over the next 20 minutes, four heavily instrumented weather research aircraft take off from the Miles City, Mont., airport 2½ miles east of the Sunday Creek control station where Super and half a dozen colleagues coordinate the day's efforts to probe the secrets of the thunderstorm. Already in the air circling what the scientists hope is a thunderstorm in the making is the National Center for Atmospheric Research/National Oceanic and Atmospheric Administration Schweizer 2-32 Sailplane. It will soon cut loose from its tow plane, enter the cloud, and attempt to catch its updraft. Spiraling upward within the fledgling storm, this craft of beauty, grace and practicality will measure everything from liquid water content to vertical air motion, precipitation-particle-size spectra and electric fields. In the hangar back at Miles City a sleek NCAR twin-jet Sabreliner and a stubby but powerful modified piston-engine T-28 wait for word that the cloud has grown into a mature thunderstorm. If so, the Sabreliner will probe the anvil of ice crystals blown across the sky by winds at the top of the storm. The T-28, heavily armored against the pounding power of hail, will fly directly into the core of the storm, monitoring all aspects of its most violent phase, including laser measurements of hailstone size. And farther east, at an air base in Rapid City, S.D., NASA's giant Convair 990 research aircraft awaits orders to fly through the thunderstorm's gust front, the fast-moving outwash of potentially destructive wind produced as the storm's downdraft reaches ground and spreads horizontally out across the landscape. All the while, the four earlier launched twin-engine research airplanes will fly preassigned routes through, under and around the cloud system.

So begins another day of the Cooperative Convective Precipitation Experiment (CCOPE, pronounced "Cope"), a major field research experiment this summer that has been studying the complex processes that create convective clouds, rain, hail and high winds over the High Plains of the United States. Jointly run by the National Center for Atmospheric Research and the U.S. Bureau of Reclamation, CCOPE is an organized high-technology assault on the mysteries of thunderstorms and the precipitation-forming processes within them. It is unprecedented in sophistication, if not in size.

NCAR calls CCOPE "the largest field research experiment ever mounted to investigate the life cycle of single convective storms, to find what regulates the severity of those storms, and to see what processes are most important to observe and understand." A dozen aircraft, 125 scientists and technicians and 29 institutions are cooperating in the project. Certainly no field study of comparable scale on convective storms has been attempted since the four-agency Thunderstorm Project of 1947. (Those were the innocent days when field projects were given simple, colorful names rather than tortured acronyms.) The Thunderstorm Project, the brainchild of University of Chicago meteorologist Horace B. Byers, brought scientists, technicians and pilots fresh from the rigors of World War II to a concentrated field study of the thunderstorm. Ten twin-fuselage, P-61 night interceptor aircraft made 1,363 penetrations of 76 separate thunderstorms in Florida and Ohio. They encountered downdrafts as fast as 79 feet per second that dropped them 2,000 feet and updrafts as fast as 84 feet per second that lifted them 5,000 feet. They were struck by lightning 21 times and battered by hail on 57 penetrations. An array of weather stations on the ground recorded the storms' outpourings. Radar tracked not only the storms but the aircraft, whose pilots strove mightily to keep them on preassigned levels and headings. Out of the Thunderstorm Project came much of the modern understanding of the thunderstorm, including the concept of the cell structure of the storms. The report of the project became, as one CCOPE scientist recalls, "the Bible" of thunderstorm researchers.

Despite that intensive effort and all other studies since then, convective storms like thunderstorms have managed to maintain much of their mystery. Hidden within their boiling gray-black clouds and until recently immune from most instrument probing, many aspects of the precipitation-forming process have remained a puzzle. It seems paradoxical that so familiar and so economically important a natu-



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One of 14 research aircraft participating in CCOPE, the T-28 military trainer at left is equipped with special devices, such as Knollenberg probes beneath the wings, that allow special measurements to be made of mature thunderstorms, particularly hailstorms.

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Twin-engine planes (left) are instrumented to fly for more than 3 hours at altitudes up to 7 km. Barrel-shaped boom attached to the nose places wind sensors ahead of disturbances and, via an interior inertial navigation unit or "black box"—subtracts the aircraft's motion from the wind. The single-engine T-28 (above) is designed for shorter-endurance (about two hours) observations.

ral phenomenon as a thunderstorm has kept so many of its essential characteristics from cloud-physics researchers.

"That we don't understand so much about rainfall processes is remarkable," says NCAR atmospheric physicist Charles Knight. He, the Bureau of Reclamation's Arlin Super and NCAR's Brant Foote are on-site co-scientific directors of CCOPE. "Rainstorms are so familiar. It's very ironic." Yet nobody ever said the atmosphere is simple.

The Thunderstorm Project came about because the World War II experience dramatically revealed to weather scientists and aviation officials how little they knew about thunderstorms. CCOPE similarly had its origin in an antecedent event of the mid-1970s, the National Hail Research Experiment. Scientists had gone into NHRE, carried out in northeastern Colorado in the midst of the nation's "Hail Alley," confident they would learn enough to use weather modification technology to slightly but significantly reduce the damaging effects of hailstorms. Soviet scientists had made dramatic claims of advances in this area, and the NHRE was a field test of some of those ideas. It didn't work out. The project did provide a detailed picture of the structure of an evolving hailstorm. Daughter cloud cells serve as an aerial "womb" for small embryo hailstones, then merge in sequence into the main cloud mass. There they become mature storm cells with large updrafts conducive to growth of heavier hailstones. But NHRE scientists found no significant effect — either hail suppression or enhancement — attributable to the randomized cloud seeding they carried out. They concluded that they had to have more detailed knowledge of the physical processes of severe convective storms before further progress was possible.

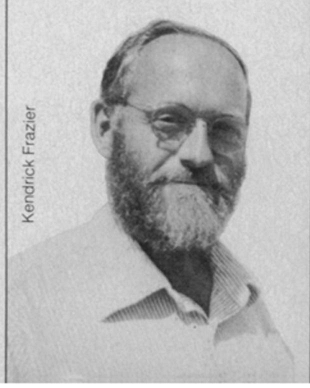
NCAR organized a Convective Storms Division to tackle the problem. CCOPE is its first major field study. In joining forces with the Bureau of Reclamation, the project draws on the experience and logistical apparatus the Bureau has amassed over the past three years in carrying out still another project. This is the High Plains Cooperative Program, or HIPLEX, a randomized weather modification (rain enhancement) experiment on summer clouds over the Montana High Plains. Knight considers HIPLEX one of the best-designed weather modification experiments ever organized and laments its premature demise at the hands of buget cutters.

CCOPE may not use military interceptor aircraft in piercing the storms it is studying, but all the scientists agree it is leaps ahead of the Thunderstorm Project in sophistication. Radar is much more advanced than in the postwar years, and of course Doppler radar, which tracks the motion of precipitation particles within storm cells, hadn't even been thought of then. Radio interferometry, monitoring beepers on each aircraft, tracks each aircraft precisely, and its exact position and recent path is automatically plotted and color coded on the ground controllers' video consoles. Aircraft data are telemetered continuously to ground stations and available as a thick sheaf of computer printouts almost immediately. The sophisticated network of about 100 solar-powered ground meteorological stations spaced over a grid several hundred kilometers on a side similarly telemeters its readings to the central station at one-minute intervals (some of the stations relay their data by satellite, transmitting every hour). These data can be plotted and displayed on the scientists' consoles in innovative ways, so movement of a thunderstorm gust front or a wave of air pressure, for example, can be tracked instantaneously. And the research aircraft are laden with instruments that just didn't exist 20 or 30 years ago.

"For the first time, in CCOPE, we are getting the sign of the electric field and the magnitude of the charge on the precipitation-size particles within the cloud at the same time," says Knight. This is an important datum in better understanding the role of electric charge in precipitation formation. As he notes, "Almost all agree that electric charge is separated [within a cloud] by sedimentation of particles with charges on them. But how the particles get the charge on them, there are dozens of theories on that. This kind of data will rule out some theories and strengthen others."

The project's contribution in this area is unique, says Knight. "What we're trying to do in CCOPE really hasn't been done before. We're getting to the point where we can

Schweizer 2-32 sailplane (right), upon its release by a tow plane, studies early storm activity. This should shed light on rainfall processes, which, says Charles Knight of NCAR (below), are familiar yet little-understood.



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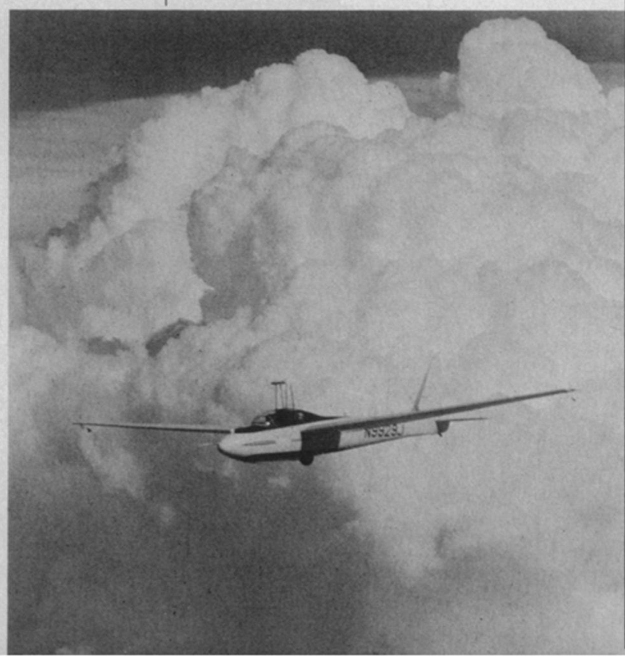

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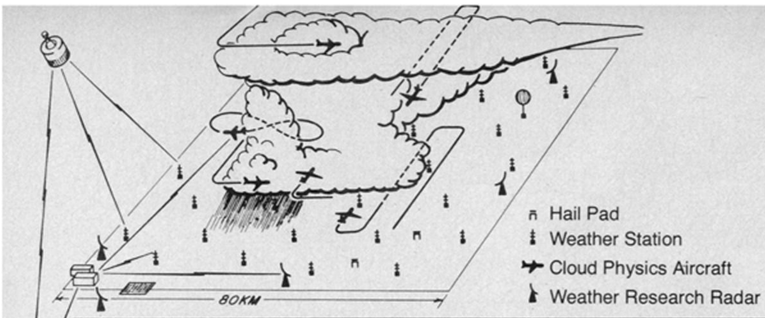


Research aircraft fly through developing thunderstorms over a grid of automated ground weather stations east of Miles City, Mont., while an array of six Doppler radars chart wind velocities and precipitation densities throughout the cloud system. CCOPE *should vastly improve knowledge of rain- and hail-forming processes in convective storms.*

really check some of these ideas, and it is getting quite exciting."

Convective storms form precipitation by one of two general processes, liquid coalescence (typical especially of tropical storms) or the ice process (typical of storms on the High Plains). The latter involves the nucleation of ice, followed by growth of ice crystals from the water vapor. "We know the mechanism here is the ice process," notes Knight in briefing a visitor to his field office in a trailer at the CCOPE field headquarters facilities at the Miles City airport. "But we need to understand that process in detail."

It will probably not be possible to understand the origin of ice in many convective clouds without, for example, understanding the process known as entrainment, the mixing of air from outside the area of upward-flowing convection with the air inside the cloud's updraft. This environmental air surrounding the parcel of convection is quite dry.

"So a fundamental question," says Knight, "is what is it that determines the amount of mixing of the dry air with the cloud? The amount of mixing will determine the cloud's lifetime and the height to which it will grow."

The modern idea, he says, is that most of the mixing is from the top of the cloud, with very little from the sides. This mixing of dry air results in a lot of evaporation at the cloud tops, which causes the air in the updraft to cool. It eventually attains negative buoyancy and begins to drop. The effect of this downdraft can vary according to the maturity of the cloud.

"For smaller cumulus clouds, it's a force tending to destroy the cloud," notes Knight. The downdraft and the updraft mingle, canceling each other out, and cloud growth stops. "For big storms, however, an organized downdraft can keep a storm growing. If a storm is organized properly, the downdraft will come from a different location than the updraft. So they are not fighting each other." The gust front formed along the ground by the cool air from the downdraft can then serve to deflect more warm, moist surface air up into the cloud, re-energizing the storm and causing it to grow even bigger and stronger.

Another effect mixing can have in generating severe storms is to moderate the initial updraft enough so that the cloud can grow. Often the early updrafts are so strong—vertical winds of 20 to 40 meters per second or 50 to 100 miles per hour—that there is not enough time for precipitation particles to grow in them before the air goes right out the top of the updraft shaft. "It takes tens of minutes to form precipitation," says Knight. Without some intervening influence, there's often not enough time available. "You can get a big storm with little precipitation," Knight says. "But other times you can get a big storm with lots of precipitation." Questions about such discrepancies abound. To what degree, for example, do the initial processes affecting cloud growth happen outside the main updraft? We know that frequently occurs with the small daughter cells that merge to form hailstorms.

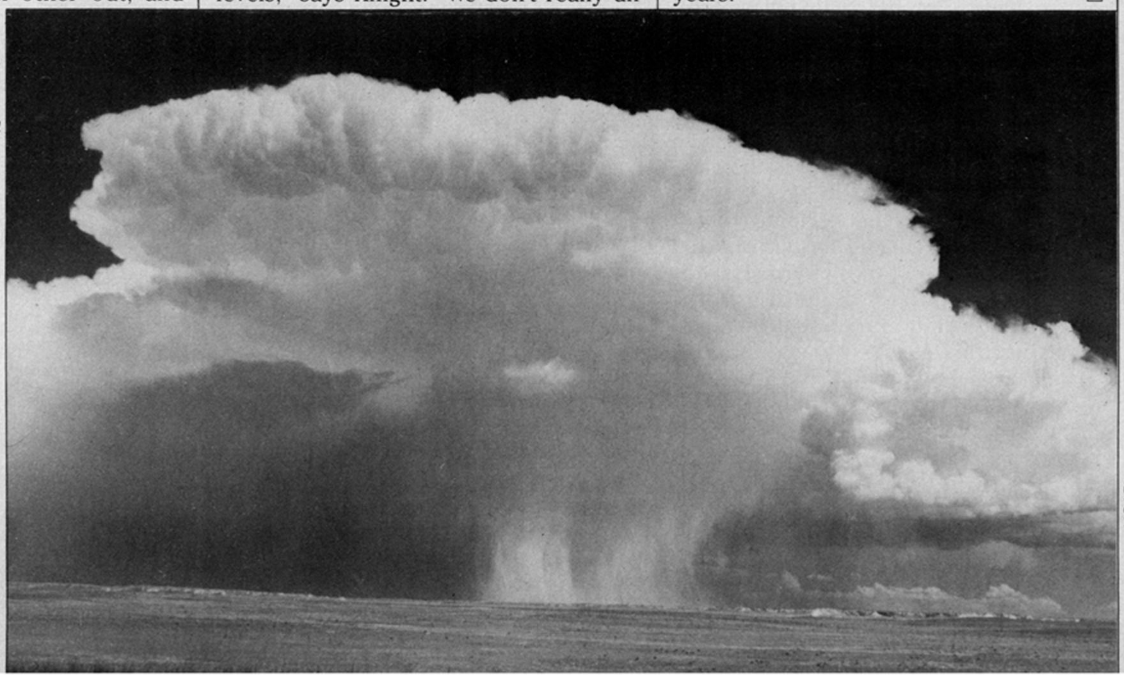
Still another factor is the effect on a storm of wind shear at various altitudes. The wind can cause the storm to lean, allowing the precipitation to fall off to the side and not down the downdraft. This again can keep the storm going. "Yet the wind shear can be three-dimensional, blowing in different directions at different levels," says Knight. "We don't really understand that all very well." CCOPE's array of six Doppler radars can give a whole three-dimensional picture of the wind-shear structure, while the aircraft flying in and under the storm and the ground weather network can combine to show where the precipitation is falling. "The whole thing has been poorly understood because until now we've had almost no data at hand with which to understand it," Knight says.

The research this summer by CCOPE's scientists, technicians and pilots will no doubt rectify that situation, not just for the wind-shear question but for many of the mysteries about precipitation processes within thunderstorms that, depending on subtle variations in conditions, bring life-giving rain or crop-damaging hail.

The combined assault on the secrets of nature's brief but abundant convective storms—scientists estimate 2,000 to 3,000 thunderstorms are in progress on the planet at any given moment—has already brought in more data than can ever be analyzed in detail. "We've got more storms now worthy of case studies than anybody is going to look at," says Knight.

Co-director Foote echoes that appraisal. "It has gone spectacularly well, as far as our general goals go," he said with three weeks left to go in the project. "We haven't been having as many mature storms as we might like, but we have quite a good data set. If we get a couple more organized thunderstorms through here I think people will be satisfied."

Then will come the long process of putting it all together, analyzing, synthesizing, generalizing and preparing scientific articles for the journals. "All the real learning," says Foote, "will take place in the coming years." □



Studies of mature storm clouds, such as this cumulonimbus cloud, will provide information about entrainment, the mixing of dry environmental air with the air inside the cloud's updraft.