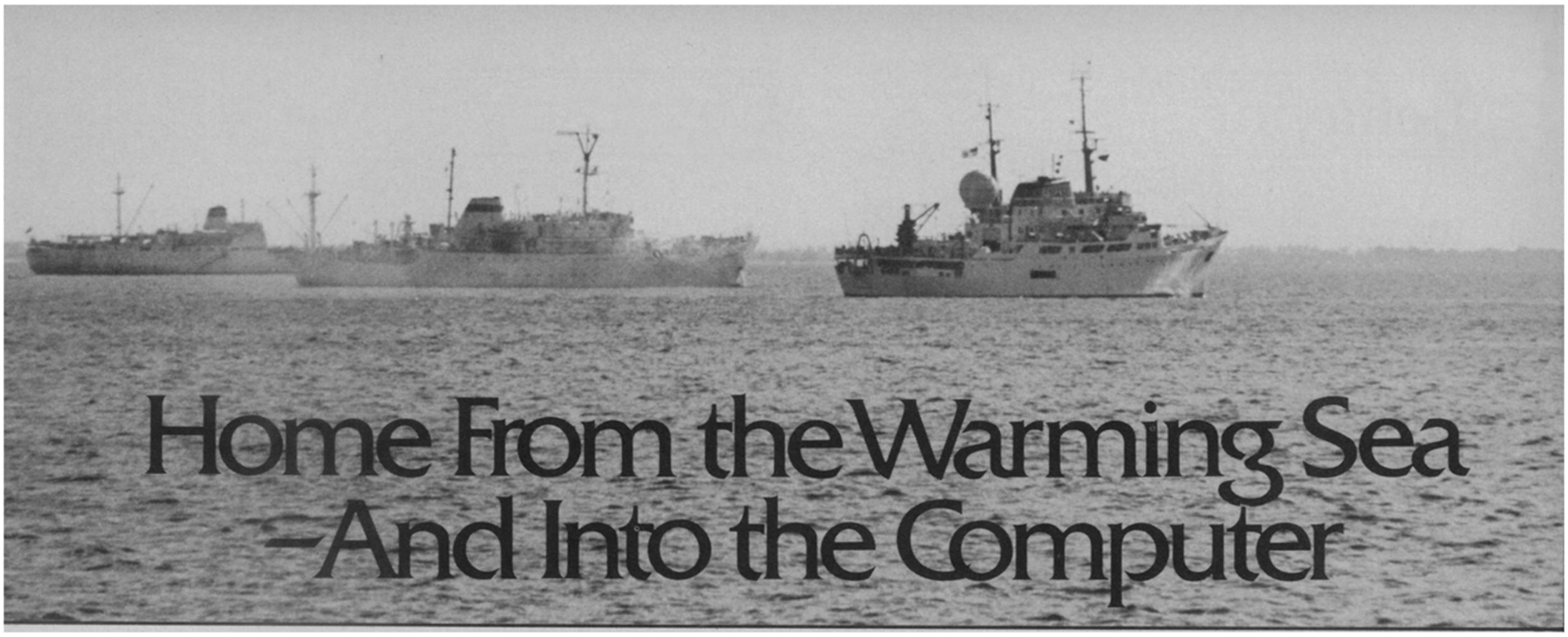


Home From the Warming Sea —And Into the Computer

The GATE researchers in the tropics obtained their data—and a new image for 'big science'

by Jonathan Eberhart

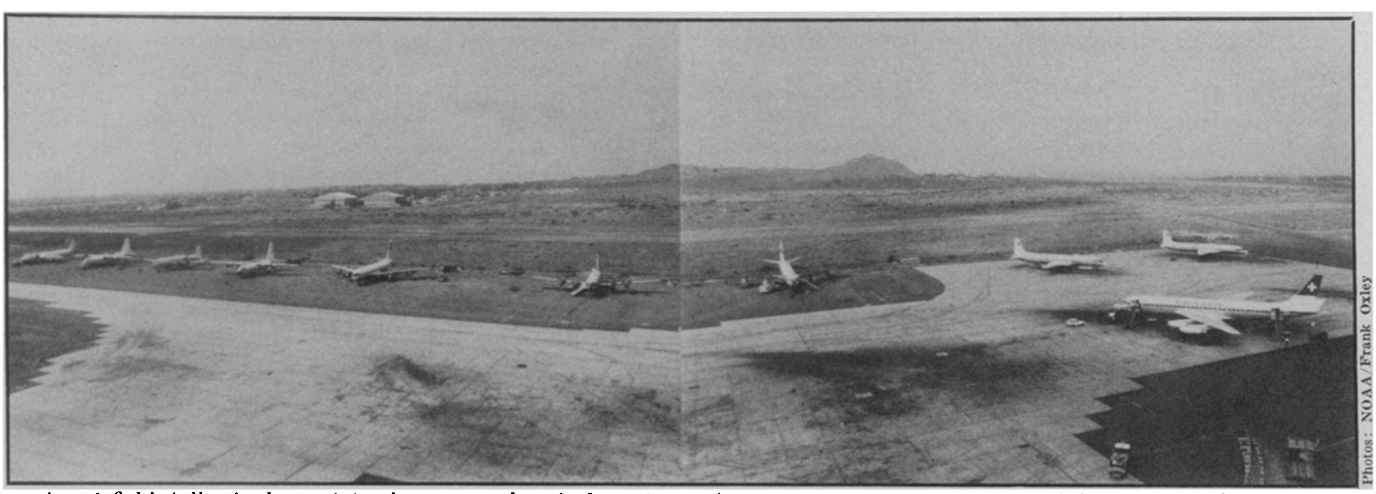
They nursed it, rehearsed it—and it worked. Thousands of people together with scores of ships, planes, balloons, buoys and instruments could easily have been a recipe for chaos. But in their 14 weeks in the field, the participants in the GARP (Global Atmospheric Research Program) Atlantic Tropical Experiment, less cumbersomely known as GATE, have managed to prepare what should be a fruitful result from one of the largest, most complex scientific missions in history. Yet the real proof of the pudding remains.

The goal of GATE (SN: 6/1/74, p. 354) is to learn how the tropics affect the world's weather, an effect that is disproportionate to its size because it is the only part of the globe that takes in more heat from the sun than it gives off to space. The answer, however, involves much more than simply recruiting an army of scientists to go out and measure everything in sight. The planning required to keep such a vast program from producing a mere useless, uncoordinated pile of numbers is at least as important as the data-gathering itself or the difficult analysis that follows.

For the data-gathering portion of GATE, planners were faced with coordinating an exercise as complicated as any ever faced by a field commander at war, made increasingly difficult by a basic GATE rule that no day's activities would be finalized until the day before.

This demanding dictum was a response to one of the harsh lessons learned from the Barbados Oceanographic and Meteorological Experiment (BOMEX), a 1969 project that was far smaller than GATE, but which was nonetheless large enough to reveal (by unfortunate hindsight) the need for exhaustive planning. In BOMEX, points out Joshua Holland of the National Oceanic and Atmospheric Administration's Center for Experiment Design and Data Analysis, a relatively small number of aircraft flight plans were laid out well in advance and during most of the mission were simply flown over and over. Though expedient for the state of large-scale meteorological planning at the time, this relative inflexibility went directly against one of the basic characteristics of weather: It changes.

For GATE, therefore, a large repertoire of possible missions was designed to allow for a wide range of weather developments, and the program's planners set up a Mission Selection Team, an international group of scientists who would pick options for each day's activities the previous afternoon, using constantly updated information from



An airfield full of planes joined an armada of ships (top of page) to compare upper- and lower-level phenomena.

the very people and instruments who were conducting GATE itself.

It sounds almost fatuous to make a point of such a seemingly obvious system, but so fast changing are conditions in the tropical Atlantic and so vast were the resources that had to be deployed that its success as a method has to be one of GATE's major accomplishments.

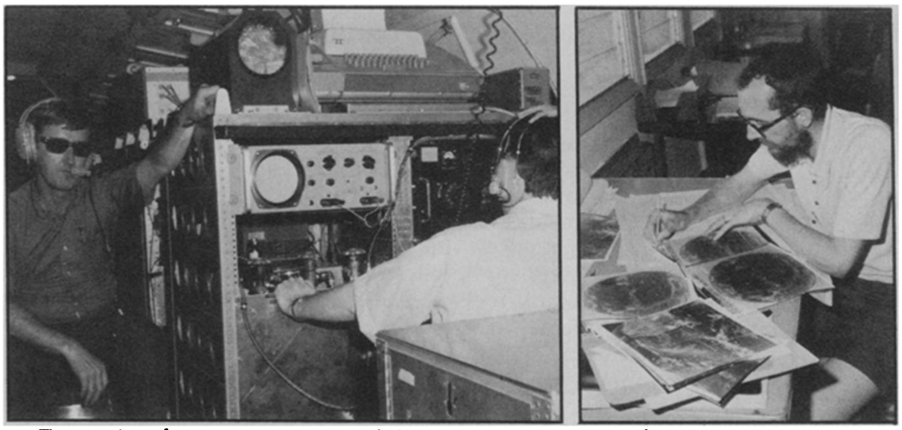
Consider Aug. 5, a typical mission day. On the afternoon of Aug. 4, the Mission Selection Team assembled in a briefing room in the specially constructed control center at Dakar, Senegal. Reviewing weather reports, satellite photos, radar imagery and other data, the group issued a report that would be the chief guiding document for constantly changing numbers and types of ships, planes and personnel. On that representative day, this was the operations plan sent out by teleprinter to receivers on ships and distributed by hand to scientists and aircrews in Dakar:

> "Coordinated ship-air mission. All ships on accelerated schedules. Operation is a convection cloud structure mission. The pattern is a line through either side of the chosen convective system [the final choice could be updated even on the mission day itself]. Aircraft are DC-6 (U.S.) 500 ft., C-130 (U.S.), 5,000 ft., IL-18C (USSR) 16,000 ft., CV-990 (U.S.) 20-30,000 ft. Mission scientists James (UK) assisted by Zhalev (USSR). Airborne mission scientist Cox (U.S.) assisted by Zhalev (USSR). Other air operations are: a radiation divergence and intercomparison with the [ship] Korolov (USSR). Aircraft are the IL-18M (USSR) between 100 and 21,000 ft. and the Sabreliner (U.S.) between 50 and 45,000 ft. A dropwindsonde mission by the KC-135 along the African coast. Airborne mission scientist R. Simpson (U.S.)."

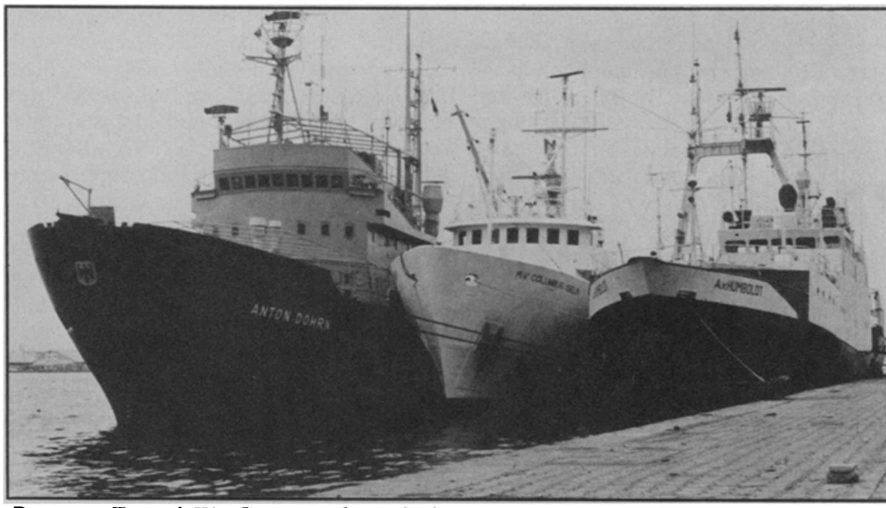
One of the most important aids in the day-to-day planning, as well as in the research itself, was the Synchronous Meteorological Satellite. In fact, by numerous accounts, it was the star of the whole GATE operation. Launched on May 17, the NOAA weather-watcher went into operation only one day before GATE's fieldwork began, providing cloud-cover photographs every 30 minutes that showed the entire GATE region with up to half-mile resolution. "It was an incredible help," says one scientist who worked with its images. "We could have done without it—if the launch had been held up another month we might have had to—but after seeing the pictures I wouldn't want to try."

Besides helping the mission selection team do its work, sequences of its photos were often assembled into "loops," in effect motion pictures, by which scientists could actually watch cloud features move. Playing the loops backwards made the satellite into a virtual time machine, showing how the features developed.

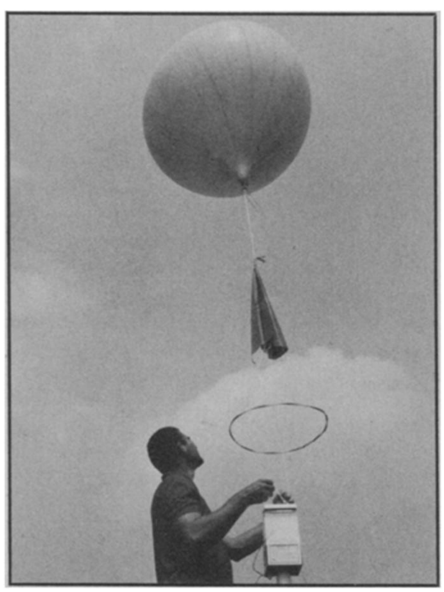
Various GATE researchers labeled it "fabulous," "essential," and "really spectacular." Yet even SMS could not see everything—a realization which



Tons of airborne instruments (left) were guided by updated satellite photos.



Between E. and W. German ships, Iselin (U.S.) was dubbed Checkpoint Charlie.



Land stations added radiosonde data.

Communications center was in Dakar.

Photos: NOAA/Frank Oxley

proved to be useful in its own right. "Even the half-mile resolution," says Joanne Simpson of the University of Virginia, "failed to identify most active oceanic meso-scale [nominally 10 to 100 kilometers] cloud lines in their growing phases. Many convective systems were not recognized until the dying stages, when cirrus anvils predominated."

The satellite photos also revealed that there seem to be many occasions in the tropics when visible spiral or ring-shaped cloud formations are either unrelated to or far removed from the wind circulation patterns that would be expected to accompany them. "On numerous occasions," says Simpson, "satellite stills and/or loops showed cloud features suggesting a closed circulation, which either did not exist in the wind field or existed at a remote distance from the cloud 'center' in a place where it never could have been located by any type of cloud imagery, from satellite, through radar, visual photography or eyeball."

This realization, however, was turned from an operational problem into a positive discovery when airborne scientists such as Edward Zipser of the National Center for Atmospheric Research were able to spot low-level vortices from aircraft, then use the oft-renewed satellite photos to locate the upper-level ones—which were sometimes displaced by as much as 200 miles.

Fortunately, it was part of GATE's original conception that where one kind of sensor proved inapplicable, another type would be available to take its place. For this reason among others, Simpson, who was the ranking airborne scientist on four of her thirteen flight missions, relied on radar (and eyeball) for selecting flight patterns. "On each of the occasions that we had a good, lively convective day," she says, "my mission scientist radioed from [the control center in Dakar] that his satellite imagery told him that we were boxing around nothing, while I was seeing a beautiful line of building 'cb's' [cumulonimbus] from my aircraft."

GATE was not without its problems, of course. Instruments malfunctioned, transmitter frequencies drifted, some data were lost when communications difficulties caused instrumented, tethered ballons to be lowered prematurely. One of the more serious difficulties occurred early in the program, when several ships assigned to collect data for future numerical "models" of tropical weather systems failed for various reasons to arrive at their stations, or missed gathering their data because of instrument problems. Numerical modeling—a computer technique for analyzing a phenomenon based on comparing a theory with observations—is one of GATE's two main goals. The other is to study in a more general way how small-scale meteorological factors affect large-scale ones. The early ship difficulty is likely to leave some holes in the data available for the largest scale modeling (GATE measurements were coordinated into four basic size ranges, or scales: individual clouds, convective cells, cloud clusters and atmospheric waves), but for research other than large-scale modeling, most of the gaps were closed during the latter stages of the program.

But GATE's raw data would be virtually useless without an effective way of studying them later. Again thanks to BOMEX, the GATE planners knew that analysis would be inseparable from gathering, and designed their program to keep ahead of the game.

Five years ago during BOMEX, many of the data from ships were recorded without including the ship's positions, which were to be maintained by sea anchors. When some of the sea anchors failed, the data lost much of their value, since there was no precise way to correct for the ships' speed. Computer analysts solved the problem, but, Holland says, the answers were "crude and uncertain at best," and at a penalty of three-and-a-half-years' delay.

The GATE remedy was to plant firmly fixed buoys at known locations before the ships took their measurements. Every 15 minutes, the ships would take positional fixes on the buoys, and report them right along with the data. Net saving: the entire three and a half years.

Another BOMEX difficulty was that the process of "digitizing," in which raw measurements are converted into a form that can be handled by a computer, had to be done ashore, after the ships got back to port. The digital conversion was still going on a year after the data had been collected.

For GATE, the conversion equipment was right on ship, often enabling the operators to complete their work while they were still at sea.

Besides speeding up the general processing work load, this bit of forethought sometimes even enabled scientists to look at one another's data while their own experiments were still going on. One of GATE's unanticipated discoveries was the finding, by a team of oceanographers coordinated by Walter Düing of the University of Miami, that the subsurface equatorial current, a west-to-east flow previously thought merely to meander between the Northern and Southern Hemispheres, also moves in short, rapid "pulses." Like the similar pulsations found in the winds of the jet stream, the quick movements are both horizontal and vertical. They may be important to oceanographers because the pulses affect the size of the currents' larger-scale motions, as well as to meteorologists because of the solar heat carried by the water. In mid-ocean, Düing's ships transferred their data tapes to the computer-equipped vessel Columbus Iselin and went on about their business. The Iselin was thus able to have the data converted and waiting at Dakar by the time Düing arrived.

One of the major questions now facing GATE scientists is whether the knowledge they are gaining of the eastern tropical Atlantic can be extrapolated to the rest of the tropical oceans, since repeating such a huge program elsewhere could be prohibitively expensive. Many of the reseachers feel that since the data are just beginning to be analyzed (in England, France, West Germany, the Soviet Union and the United States), the answer must wait. Joanne Simpson, however, is already warning that widespread generalization be approached with caution. "My pre-GATE contention that the GATE area is almost a 'freak' region of the tropics," she says, "is stronger than ever as a result of my participation." In the GATE region, for example, she points out, the ocean temperature drops and atmospheric stability increases more rapidly with increasing distance from the equator than they do in the tropics of the central and western Atlantic and the Pacific. The nearby continent of Africa contributed an unexpectedly large load of dust to the atmosphere, and the change from land to sea surface meant that many of the weather systems being studied were rapidly changing at the time, and had not yet reached stable forms that might more broadly typify the tropics.

There may, in fact, be as many as four or five different types of tropical regions, Simpson believes, "and hence it is hard to imagine that any one simple parameterization scheme [fitting the scale of the data to the scale of the weather phenomena being studied] will catch the essential energy transactions and large-scale impacts of all of them." Possibly, suggests Alan Betts of Colorado State University, the answer may lie in figuring out what makes the GATE region atypical and borrowing data on the differences from smaller programs in other areas of the tropics. Such data have been accumulating for more than a quarter-century, Simpson points out, such as those from the Woods Hole Oceanographic Institution's expeditions to the Caribbean, which began in the 1940's, and the Project Redwing meteorological studies in connection with nuclear tests in the Marshall Islands of the Pacific.

Beyond its research results GATE was something else as well: a significant example of "big science." This phrase for scientific superprograms requiring great cooperation has occasionally been rather a dirty word in the past, because of administrative and diplomatic factors that have sometimes gotten in the way of the work at hand.

GATE had the potential to go either way—it was only at the threat of Soviet nonparticipation that it was moved from the western to the eastern Atlantic—but the years of preparation paid off in a remarkable show of international togetherness. "I can hardly put enough glowing adjectives to it," says Eugene Bierly of the National Science Foundation.

Even Simpson, a 30-year opponent of huge efforts that structure out all chance for individual creativity to help, rated the management "excellent." "If all 'big science' went like the field phase of GATE," she says, "most of us would find our reservations about it greatly allayed." □