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WEATHERMAN
CARL-GUSTAF ROSS

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TORNADO FUNNEL TWISTS DOWN FROM STORM CLOUD OVER NEBRASKA PLAINS

STEVE SUGANO

Man's Milieu

(See Cover)

From the missile-testing station at Cape Canaveral, Fla., a modified Viking rocket soared up 125 miles one night last week, its bright exhaust glowing briefly like a wrong-way shooting star. Its flight was a partial test of the "vehicle" that will lift the U.S. artificial satellite in 1958, and the instruments that will steer it, into its orbit around the earth. When the satellite is established there, one of its most important jobs will be to keep track of the global movements of the white clouds far below. It will then be busy at the homely old task of forecasting the weather, doing in essence what a farmer does when he looks up at the sky and holds a wetted finger to the wind.

Young Science. Between the farmer's wetted finger and the cloud-watching satellite lies the young and booming science of meteorology. A hundred years ago it hardly existed, and for another 50 years few people took it seriously. The "weatherman" was a popular joke, and his vague daily forecasts had little more prestige than the guesswork predictions in farmers' almanacs.

This attitude is slowly changing. The public still makes jokes about the weatherman from force of habit, but it relies on him too. Last year the U.S. public made more than 200 million telephone calls asking about the weather, and this year the score will be higher. Farmers called, hoping for rain. Vacationers, picnickers, soft-drink bottlers and garden-party hostesses called, hoping for clear skies. Every year more weather facts are demanded and supplied: sailing conditions for yachtsmen, rainfall on watersheds. Newspapers and TV feature weather maps. Industries, department stores, oil companies and airlines employ meteorologists. The armed services, more at the mercy of weather than in foot-slogging days, keep thousands of them busy.

One man who did as much as anyone to raise meteorology to its present high estate is a likable, high-spirited, round-faced Swede named Carl-Gustaf Arvid Rossby. Most leaders of modern meteorology are friends or past pupils of Dr. Rossby's. The "Rossby parameter" is important in up-to-date forecasting, and the grandest movements of the atmosphere are called the "Rossby waves." The history of modern meteorology is inescapably paralleled by Rossby's career.

Fractious Cyclones. Meteorology of the weather-adage type is at least as old as the Bible ("The north wind driveth away rain"; *Proverbs 25:23*), and knowledge of atmospheric behavior has accumulated slowly through the centuries. In the early 19th century, for instance, it was known that large areas of low atmospheric pressure sweep across the North Temperate Zone roughly from west to east and are apt to bring stormy weather. But this knowledge was useless for weather forecasting. The stormy "lows" or "cyclones"* move much faster than letters carried by stagecoaches, so in those days countries lying in their path could not be warned of their coming before they had come and gone.

U. S. Navy

VIKING ROCKET
Like a wetted finger in the wind.

Modern scientific meteorology was founded on the telegraph, with an assist from the Crimean War. On Nov. 14, 1854, a violent storm sank key vessels of a Franco-British fleet in Balaklava harbor. At the request of the French Minister of War, the famed Astronomer Urbain Le Verrier studied the storm and reported that it could have been tracked across Europe by the new-fangled telegraph. Soon after his report sank in, most of Europe (and later the U.S.) had a telegraphic storm-warning service.

For more than 50 years after Le Verrier, weather forecasting consisted principally of watching the cyclones as they drifted majestically, dragging the weather with them. Trouble was that the cyclones did not always behave. They were always ringed by counterclockwise winds, but the winds were sometimes gentle and sometimes violent. Sometimes the cyclones stood still, or even moved backward.

Fronts & Masses. About the time of World War I, Professor Vilhelm Bjerknes of Norway and his son Jacob decided that the fractious cyclones, though they may be 1,000 miles across, are only minor bit-players in the weather drama. The leading players are enormous masses of cold, dry air that sweep down from the polar regions at irregular intervals. The Bjerknes theory, emphasizing fronts and air masses

* Not to be confused with tornadoes, sometimes called cyclones. They are destructive local whirlwinds connected with thunderstorms, while the meteorologists' cyclones are low-pressure areas hundreds of miles in diameter.

rather than cyclones, lit up meteorology like a new sun rising, and upgraded it into a more exact science. It is still the basis of the familiar newspaper weather maps.

None of this made much impression on young Carl-Gustaf Rossby, who in 1918 was a restless, adventurous 19-year-old student at the University of Stockholm. Son of a construction engineer, he went through *gymnasium* (secondary school) with no special interest in science. Looking around for an exciting profession, he thought at one time of astronomy. This attraction, he now recalls, came from several romantic novels about bearded astronomers sitting on mountaintops and looking at the stars, while young girls in lacy nightgowns ran uphill toward them, tearing their nightgowns on the thickets. Calm reflection convinced him that real-life astronomy does not live up to this billing.

For one year he halfheartedly studied physics at the University of Stockholm, then transferred to the Geophysical Institute in Bergen. Bergen had something special to offer: the great Professor Bjerknes, whom Rossby remembers as "a man with a bushel of hair, a remote interest in his students and a frugal way with his family." Soon Rossby was living in the professor's house and planning to take his air-mass gospel to the ends of the earth.

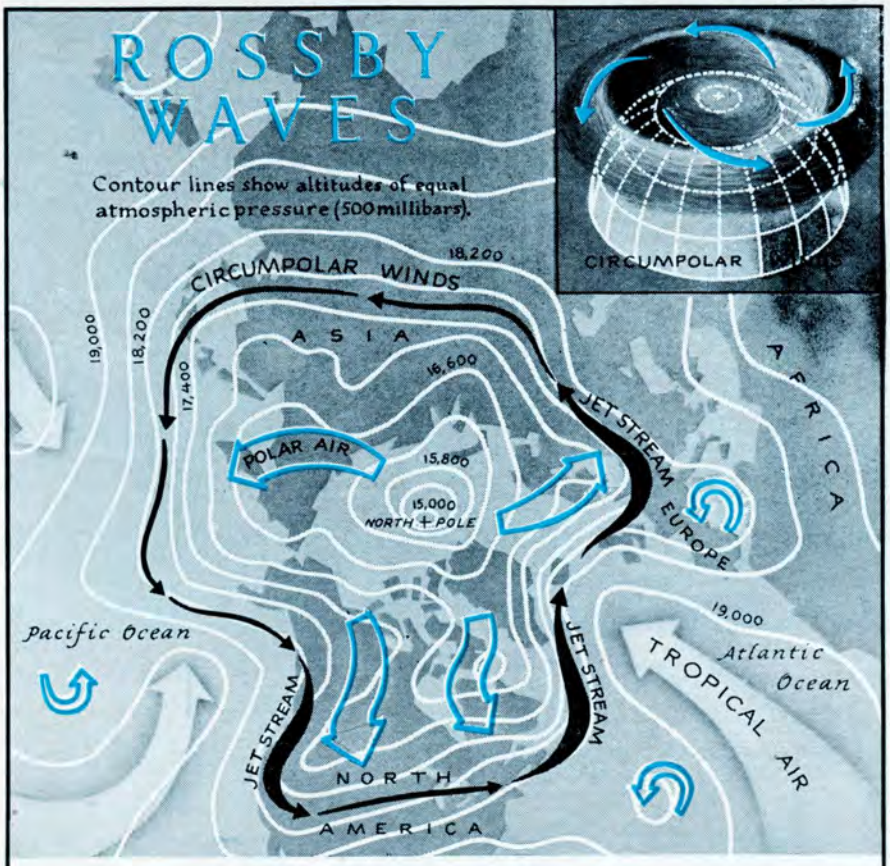
Mission to Washington. Although young Rossby was fascinated by the new meteorology, he did not stay put in Bergen. Like many European students, he wandered from university to university, stopping for a year at Leipzig, then returning to Stockholm. After winning his licentiate (graduate degree) in theoretical physics, he worked for a while for the Swedish weather bureau, where he decided "the prospects looked pretty bleak." Rescue came in 1926 from the Sweden-American Foundation, which gave him a fellowship to go to the U.S. His mission: to sell the Bjerknes doctrine to U.S. meteorology.

First stop was the Weather Bureau in Washington, where Rossby got an unofficial job. The bureau was already an elderly outfit (founded in 1870) and valiantly impervious to new ideas, especially when presented by a young Swedish missionary so full of bounce that he could hardly stay on the floor. Rossby left the bureau hurriedly in 1927 after making an unauthorized weather forecast (a good one) for Lindbergh's Mexico flight.

Disgrace did not last long. The year 1927 was a yeasty period; the public was crazy about aviation. Almost at once the Swede rejected by the Weather Bureau was picked up by the Daniel Guggenheim Fund for the Promotion of Aeronautics and sent to California to establish the first airway weather reporting system.

Western Air Express (now Western Airlines), a pioneer airline, was flying radio-less Fokkers made of cloth and plywood between Los Angeles and San Francisco. Weather procedure before take-off was to call the next stop on the telephone and ask how the weather looked ahead. Often a field that had looked fine was socked in when the flight arrived or unexpectedly bad weather was encountered en route. "They had not considered," explains Rossby, "that weather may come from sideways."

With his assistant, an air-minded University of California student named Horace Robert Byers, Rossby combed the airline's territory for "people who had a telephone and who stayed put all day." When one of these treasures (a gas-station owner, waterworks superintendent or hotel manager) was found, they tried to persuade him to report visibility, ceiling, and rain or snow every 90 minutes. Sometimes Rossby would borrow a pilot and



THE map above shows the Northern Hemisphere with the circumpolar winds streaming west to east like a scalloped whirlpool. The lobes bulging southward are the Rossby waves, and their shifting of position can be forecast by Rossby's equation:

$$C = U - \beta\left(\frac{L}{2\pi}\right)^2$$

Where U is the speed of the circumpolar wind, Beta (β) is the Rossby parameter, a number that has to do with the rotation of the earth. L is the length of the wave. Figures for the wind speed and the wave length can be obtained from properly made high-altitude weather maps, of which the map above is a simplified example. When these figures are supplied, the equation gives C, the speed with which the waves will shift around the earth, carrying the weather with them.

Most difficult concept in the above equation is the Rossby parameter, Beta. In this case it explains the tendency of air masses to spin counterclockwise when they move toward the equator. If an air mass is over the North Pole, for instance, and is stationary in relation to the earth, it is nevertheless spinning like a wheel in space, one turn every 24 hours, because of the earth's rotation. If this air mass were to be moved to the equator, it would keep its wheel-like spin, but the earth's surface below it would not be spinning the same way. It would be moving around the earth with a motion like the surface of a wheel's tire. So the transplanted air mass from the Pole will spin counterclockwise in relation to the nonspinning surface at the equator.

Air does not move in masses from the Pole to the equator, but some increase of spin shows up whenever a mass in the Northern Hemisphere moves southward. This has an important effect on the behavior of air moving along the Rossby waves. Since the principle works in reverse also, it explains in part why tropical hurricanes lose some of their spin when they move north.

Art Shay

ROSSBY & FAMILY IN CHICAGO*
Men are still like crabs on the ocean floor.

airplane from the Army Air Corps and buzz a remote small town. When all the inhabitants were craning their necks at the glamorous flying machine, he would land in the flattest field, parade into town in an air fan's car and confer with the mayor. The result of this showmanship was usually a group of weather reporters.

Swedish Compliments. These days were wonderful fun, and Rossby's weather system worked. It became the model for use by fast-spreading U.S. airlines. When not too busy, Rossby kept up with the hard-boiled pilots in jazz-age drinking and other festivities. Most of them envied his way with women. "It was his Swedish manners," says one of his friends of those days. "He'd hold the hand of a nightclub hat-check girl for several minutes, ladling out those Swedish compliments. If it was any other guy, the girl would have called the manager."

In 1928 Rossby was invited by Massachusetts Institute of Technology to head its department of meteorology. He left Byers in charge of the weather-reporting system and said goodbye to California and its convivial pilots. "A problem solved," Rossby often remarks, "is a dead problem." In Cambridge fresh problems were waiting for him.

M.I.T.'s meteorology department, now a large and flourishing academic province, then had a faculty of two: Rossby and Hurd Willett. They roomed together in a Boston apartment, worked and played together. Soon Rossby began seriously dating Harriet Marshall Alexander, the pretty daughter of a Boston physician, who attracted him initially by her ability to identify from their songs 40 different kinds of birds. Roommate Willett dated Harriet once. When he returned late that night, Rossby was waiting up for him. "I shall kill you!" cried the passionate Swede. Willett withdrew, and Rossby married the girl. (They have three children: Stig Arvid, 25, a physics student at Illinois Institute of Technology; Hans Thomas, 19, a science student in a school near Stockholm; and Carin, 16, a student at the University of Chicago Laboratory School.)

After the romance was settled, Rossby and Willett remained friends and began plotting a major attack on the atmosphere. The Bjerknes theory was based almost entirely on ground observations, but the great air masses that it deals with go practically to the top of the atmosphere. Rossby reasoned that study of wind pressure, temperature, etc., at high altitude should show new facts about the atmosphere's large-scale circulation. This was the time of the great Dust Bowl drought of the '30s, and Rossby's project got support from the Department of Agriculture, which hoped to forecast droughts and other weather disasters.

Facts from aloft proved hard to get. So M.I.T. hired a Cessna. With Willett as pilot, he and Rossby made weather-observation flights every morning from East Boston Airport. The Government soon took over and expanded this work, but the real solution of the problem was the radiosonde. Developed in the '30s, these light, expendable radio transmitters were carried to great heights by small balloons. All the way up they reported pressure, temperature and humidity by radio, and their drift measured the winds aloft.

Grand Pattern. At first the upper-air weather looked as confused and chaotic as weather on the ground. Then a grand pattern began to appear of gigantic horizontal waves in the eastward drift of air that circles around the earth in north temperate latitudes. These are the Rossby waves, also called "long waves." There are generally four or five of them festooned around the polar region. As they shift their positions, they steer the movements of cold and warm air masses that control the weather in the North Temperate Zone.* If the tip of a wave reaches too far south, a great mass of polar air is apt to get broken off. Revolving counterclockwise, it drifts far into the tropics.

By means of elaborate mathematical reasoning, Rossby evolved an equation that could be used to predict the shifting of the waves (*see box*). Since large-scale weather phenomena depend on this shifting, Rossby's equation made it possible, at least theoretically, to forecast well in advance most of the world's weather patterns. His first paper on the subject, published in 1939, is looked on by meteorologists as a major breakthrough.

The date 1939, however, has another significance: it was the start of World War II, during which meteorology suddenly came of age. It was quickly apparent that the war would be fought largely in the air, with weather often the controlling factor. Storms would put whole air forces out of action. For surface forces, clouds and fogs would be all-important shelter.

Rossby did a part-time hitch as head of research with the Weather Bureau, which had a new chief and was trying hard to bring itself up to date. But in 1941, with the war spreading fast, the University of Chicago asked him to head its new department of meteorology. He accepted partly because one of his basic beliefs is that after about ten years a group of associates have nothing new to tell each other. They should break it up, he thinks, and look for fresh stimulation.

To Chicago Rossby brought his old friend Horace Byers of California days, and made him executive assistant and backstop. This move was a lifesaver, for success had made Rossby increasingly individualistic. He was a wonderfully stimulating teacher, an inspiring leader, and he produced ideas at a fantastic rate, but he was also a poor manager. He hardly ever answered mail. Instead, he stacked unopened letters in a pile to ripen. When they were so old that their writers no longer hoped for an answer, he felt it would do no harm to throw them away. He cut classes, was usually stony broke, ignored university budget restrictions. Sometimes he would ring furiously for his secretary when he was already dictating to her.

Onrushing Crisis. These peculiarities might have got Rossby into serious trouble, in spite of his recognized genius, but the onrushing war was a crisis, and he thrived on crises. The U.S. was building the world's biggest air force, and soon it would need the world's biggest corps of meteorologists. There were only a few in the country, many of them hopelessly behind the times. The Government's solution was to put Rossby in charge of a monstrous, high-pressure training program. He crisscrossed the country, setting up branch units at New York University, U.C.L.A., Caltech and M.I.T. At the University of

* From left: Son Stig and wife, Daughter Carin, Wife Harriet. Son Hans is at school in Sweden.

* Similar waves, less well-known, are found in the South Temperate Zone.

Chicago, Rossby lectured with a slight, but attractive, Swedish accent to classes of 400 students, force-feeding them with the Bjerknes doctrine.

The students got a crash-grounding in the sort of meteorology that would be most useful in war. They learned how to predict whether the sky over a German city would be clear enough at a certain hour for high-altitude, visual bombing. Similar methods predicted days when dirty weather would protect ground troops from enemy air.

Forecast on D-Day. The biggest moment for military weathermen was critical D-day, when General Eisenhower's forces crossed the Channel to land on the Normandy coast. Everything depended on the weather, which could have broken up the invasion fleet as it had the Spanish Armada, sailing in the opposite direction, 356 years before. As June 1944 approached, the weather over the Channel remained impossibly bad. Each service demanded several different kinds of weather. The airborne infantry wanted cloud-cover to shelter it from enemy fighters; the bombers wanted clear skies. Ground forces wanted cloud-cover and fairly dry soil in Normandy to support their vehicles.

Selecting the kind of weather that would be best for all concerned, the High Command asked the weathermen to pick the date when the chances would be highest for getting it. June 4 or 5 was chosen tentatively, but on June 3 the weathermen said no; the weather would not be good enough. On June 4 General Eisenhower postponed the invasion. Late that night he got better news from the weathermen. A storm, they said, would pass over the Channel on June 5, leaving fairly good conditions on Tuesday, June 6.

Eisenhower followed the weathermen's advice and made his decision for a June 6 landing. June 5 was stormy, but on June 6 weather conditions were reasonably good. The invasion forces crossed the Channel, finding the Germans unprepared. Their airplanes were grounded; their naval vessels absent. Deceived by the storm which had just passed, they thought Eisenhower would wait at least another day.

The Generals Asked Too Much. During the war, Rossby visited most of the theaters where his meteorologists were sweating out their decisions. Some of the generals and admirals, he noted, alternated between cursing the weathermen and demanding forecasting accuracy that was impossible to supply. Many of their bitterest complaints were not about the forecasting but about the weather. General Patton, despairing of meteorology, once turned to his chaplain: "Goddam it," he shouted, "get me some good weather!"

After the war was over, most of the military meteorologists shifted to other fields. The Weather Bureau was the only large employer, and although, under Francis W. Reichelderfer, it was considerably modernized, it still had few jobs. Hating to see his beloved science slump to its prewar level, Rossby tried to persuade private industry to hire meteorologists or to contract for special meteorological

services. For a while he put his heart into this promotion effort, writing and even answering quite a lot of letters. An important step was to persuade the Weather Bureau to make its Teletype weather data available to qualified persons to interpret as they saw fit.

Before the war, most private meteorologists were rural quacks who went by the phases of the moon or the furriness of caterpillars. The postwar crop is generally more responsible and far more effective. Most of them do not try "to beat the Weather Bureau." Instead, they take Weather Bureau information and extract from it facts of special importance to their customers. They coach oil companies on whether they should evacuate their offshore drilling rigs in the path of a hurricane. Knowledge that evacuation is not necessary may save many thousands of dollars. Small business for the private weathermen is advising whether to call off outdoor fairs and parties. Big business is coaching insurance companies that issue policies against losses caused by the weather.

Jet Stream. Promoting private meteorology was for Rossby a kind of decompression period after the war. It was not real science, and he had not forgotten the Rossby waves. Indeed, a startling feature of them had been forcibly impressed upon him during the war.

Everyone who has glanced aloft at the high, feathery cirrus clouds knows that they often move at impressive speed, but until the U.S. B-29s began bombing Japan, no one realized just how hard the high winds could blow. Sometimes the bombers were even blown backwards by head winds approaching 200 m.p.h.

When Rossby heard about these winds, he saw at once that they must be associated with the long, high-altitude waves that he had discovered. He named them the "jet stream." After the war he worked out a highly mathematical theory to account for the wind. Now the jet stream is used in the flight-planning of both civil and military airplanes. Its behavior can be predicted to a considerable extent by Rossby's theories.

Numbers Game. The most exciting postwar news for Rossby was the appearance of high-speed electronic computing machines. Meteorologists had often dreamed of "numerical forecasting," *i.e.*, predicting the future actions of the atmosphere by applying mathematical equations to its current pattern, but they were stopped at once by two difficulties: 1) they did not know the proper equations, and 2) they would have to do so much figuring that they could not keep up with the weather, let alone forecast it. British Meteorologist L. F. Richardson described in 1922 a forecasting center built like a gigantic theater, with 64,000 mathematicians frantically busy with desk computers. A modern computing machine can figure as fast as 100,000 men.

Other men than Rossby noted this startling fact. Dr. Vladimir Zworykin, inventor of the iconoscope, the first effective television-camera tube, sold the idea to

PROFESSOR VILHELM BJERKNES
Bit part for a cyclone.

his Princeton neighbor, the great Mathematician John von Neumann. Teaming up with Rossby, who provided the meteorological knowledge, Von Neumann and his brilliant assistant Dr. Jule Charney devised ingenious mathematical tricks to shoehorn weather observations into computing machines.

Rossby's main contribution to numerical forecasting, besides his discovery of the long waves, is his simplified equations, which treat the atmosphere as if it were as two-dimensional as a sheet of paper. Looked at in the large, this is not far from true. The part of the atmosphere that concerns the weather is only some seven miles deep, and it covers the surface of a globe 8,000 miles in diameter. Proportionately, it is much thinner than the skin of an apple.

Fran Byrne

PROFESSOR HORACE BYERS
Backstop for a genius.

Electronic Editor. Electronic weather forecasting is now being done with steadily increasing success by the Joint Numerical Weather Prediction Unit at Suitland, Md., where the Air Force, Navy and Weather Bureau have pooled their forces. Weather information flows into the machines from both ground stations and upper-air probes. Some 1,400 punched cards cover North America. Other information equally important comes from the rest of the Northern Hemisphere, including Soviet Russia and Communist China. The machine even "edits" the raw data, selecting from masses of figures the special ones wanted, such as air pressure at 18,000 ft. over the Aleutian Islands.

The machine's forecasts do not pinpoint ground-level weather for any locality. They concern the behavior of the high-altitude waves, which have broad control over local ground weather. At present, says Dr. G. R. Cressman, head of the unit, the machine makes fine forecasts of upper-air weather for high-flying aircraft. For ground-level weather, it is not yet very good.

All authorities insist that computer forecasting should not be judged by its present performance but by its capacity to improve. Old-style forecasting is partly a subjective art, but the computing machine is objective. It will always come to the same conclusion about the same set of figures, and as the figures improve, its forecasts will improve also.

The Rossby Limit. Rossby still watches numerical forecasting, but in 1950 he began to get restless in Chicago. He had been there about ten years—the Rossby limit. Gradually, he transferred his interest to Sweden, where he hoped to find fresh contacts to keep his brain turning over.

Since the war, U.S. meteorology had continued to expand explosively. All the armed services were demanding better forecasting and better knowledge of the atmosphere. Radars had proved fine weather-observing tools, showing up rain or snow 300 miles away. Rockets could photograph from above hundreds of thousands of square miles of weather, even entire hurricanes. Weather ships were stationed at sea; weather airplanes were flying into hurricanes.

Rossby felt that the vigorous, hard-shelled U.S. type of meteorology was in good hands. It might be better for him to start at a new level, studying neglected properties of the atmosphere. With the help of the Swedish government, Rossby set up in Stockholm the International Meteorological Institute, which soon became a place of pilgrimage for meteorologists, both European and American.

Aside from continued study of atmospheric circulation, Rossby's favorite program at Stockholm has been "atmospheric chemistry." The atmosphere, he and his researchers have found, is anything but uniform chemically. Parts of it, for instance, are full of sea-salt particles which are responsible for a common kind of

rainfall. Not much is known about them, although they may be one of the factors controlling the world's climates. The chemicals in the airborne salt, for instance, are not in the same proportion as they are in the sea. No one knows why, and Rossby wants to find out.

CO_2 Menace. Another atmospheric variable is carbon dioxide. CO_2 is comparatively plentiful downwind from industrial areas such as the Ruhr, and there is a good possibility that man's fires and engines are adding so much of it to the atmosphere that the world's climate may be changed drastically by the solar heat that it traps. Rossby wants to find out about this little matter too.

He is not too hopeful about human efforts to change the weather. He admits that cloud seeding with dry ice or silver iodide particles can coax rain out of a susceptible cloud, but he is not convinced that it can be done often enough to be valuable. Rossby believes that better long-range forecasting would probably be more valuable than attainable extra rain. A long-range forecast of a disastrous drought (*see* NATIONAL AFFAIRS), such as the one that is affecting much of the U.S. at present, could prevent much suffering.

Long a naturalized U.S. citizen, Rossby now splits his time between the U.S. and Sweden. In Stockholm he lives in an apartment full of books, pictures, orchids (which he cultivates) and Swedish antiquities. His headquarters in the U.S. is Cape Cod, where he works at the Woods Hole Oceanographic Institution.

Respect the Planet. Rossby's next project, which may make him spend more time in the U.S., is to bring meteorology into close relationship with the other earth sciences, especially oceanography. The atmosphere affects both the sea and the land, and is affected by them, so meteorologists ought to work closely with oceanographers, geographers and geologists. "The atmosphere," says Rossby, "is man's milieu. Everything that affects it affects man." Long-range study of the milieu, he hopes, may show up the causes of recurrent droughts and wet periods, and of recurrent ice ages. "It would be nice to know," says Rossby, "when the ice will cover our countries again."

A grand era in meteorology will begin when artificial satellites can watch the atmosphere from above. "Right now," says Rossby, "we are like crabs on the ocean floor. What we need is a view from a satellite. Only from a satellite could we see the planetary waves."

But Rossby is not entirely happy about man's fast-increasing powers. Each year the atmosphere is more polluted by man's airborne refuse. Man's atomic operations have already increased the earth's radioactivity. Rossby watches all this with growing misgivings. He feels that the meteorologists and their allies must hurry to understand the atmosphere before some bungler, well-meaning or otherwise, turns it against man. "Tampering can be dangerous," he says. "Nature can be vengeful. We should have a great deal of respect for the planet on which we live."