VORTICES IN THE ATMOSPHERE

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CONTENTS

ILLUSTRATIONS

VORTICES IN THE ATMOSPHERE*

The eight TIROS weather satellites now in orbit have taken approximately 350,000 television cloud pictures. TV camera lenses of various fields of view have been used in the evaluation of the TIROS TV data, but all TIROS satellites have carried a wide-angle (104°) camera to take pictures of areas large enough for optimum cloud-coverage information. The wide-angle pictures in this report cover an area of about 750 miles on a side when looking straight down from an altitude of 450 miles. TIROS is space-oriented due to spin stabilization. It sees larger areas than would be visible from the strictly vertical, because of its constantly changing viewing angle.

Another research and development meteorological subsystem flown on four TIROS satellites is the radiation experiment which maps the visible and infrared radiation reflected and emitted from the earth. This instrument has produced data more quantitative than the descriptive and subjective identification allowed by the TV pictures.

The cloud cover of the earth portrays the dynamic conditions of the atmosphere. TV pictures of these clouds have revealed three basic types of vortices: (1) mechanically produced eddies, (2) the tropical cyclone, and (3) the extratropical cyclone. This presentation illustrates these types of vortices, in order to give some examples of what is observed, with no attempt to explain the phenomena observed.

MECHANICAL EDDIES

Figure 1 shows a "mechanically produced eddy" on the lee side of Madeira Island of the Canary Island Group off the coast of Africa. The area of picture coverage on the right is portrayed graphically on the left-hand map. The cloud structure appears white against a darker sea. The coast line of Africa shown in the left frame is not in the TIROS photograph. Note the cycloid cloud pattern which extends 150 miles SW and downwind from the island. The general area of the cycloid cloud is surrounded by relatively cloudless air in some places, suggesting that this area was sheltered by the island from the main tradewind flow. The island measures about 12 by 40 miles with mountains about 2000 feet high; the pattern is about as wide as the island. The clouds are interpreted to be stratocumulus lying beneath a strong temperature inversion which usually occurs below 1 kilometer above sea level. Hubert and Krueger of the Weather Bureau

*Paper presented by NASA/Goddard Space Flight Center to the IVTAM, Symposium on Concentrated Vortices at the University of Michigan on July 9, 1964.

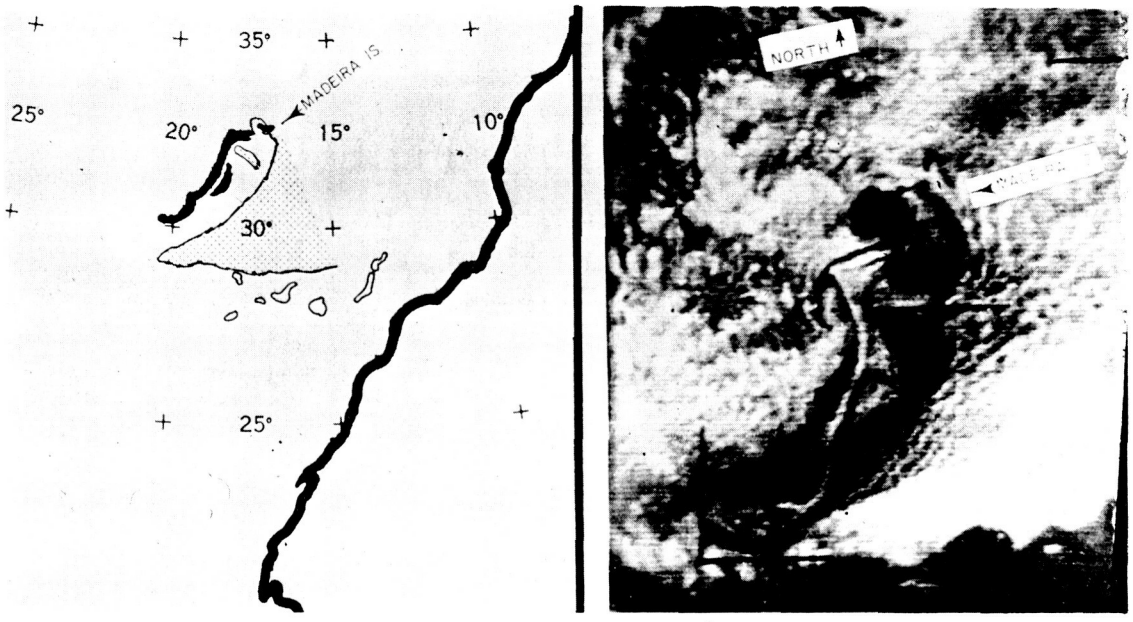

Figure 1 – Cycloidal Pattern Downstream from Madeira Island Photographed 1650 GMT, June 21, 1962. TIROS V

point out that the stability in this part of the Atlantic favors strong inertial oscillations.

The complex eddy patterns shown in Figure 2 were formed on the lee side of the main Canary Island Group, approximately 300 miles downwind. The spiral patterns are much more developed than those in the previous picture. These vortices are approximately 60 miles in diameter. Because of their great distance downstream from the island, it is believed that some energy source in addition to the mechanical motion is necessary to explain their persistence.

TROPICAL CYCLONES

Perhaps the most spectacular pictures acquired by the TIROS satellites are those of great vortices of the tropics. Tropical cyclones have a distinctive circular pattern ranging in size from approximately 100 to 1000 miles in diameter for fully developed hurricanes and typhoons.

Figure 3 is a photograph of Typhoon Ruth as she appeared on August 18, 1962, some 300 miles SSE of Tokyo. The spiral cloud structure is plainly visible, as is the nearly circular clear "eye" or center that marks the center of the storm. The diameter of Ruth is about 500 miles, the eye is about 15 miles across. Maximum winds of 125 knots were reported at the time this picture was taken.

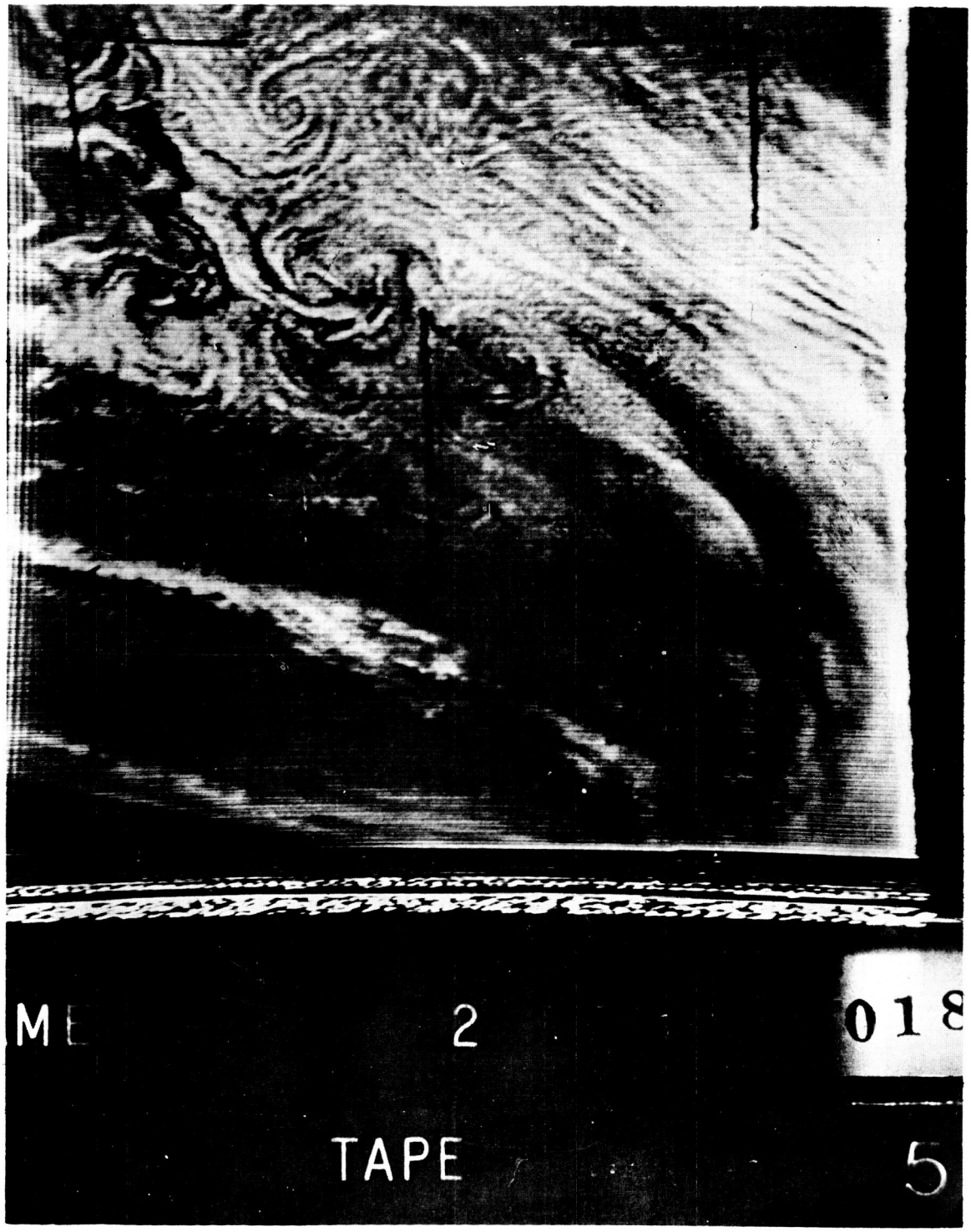

Figure 2 – Canary Island

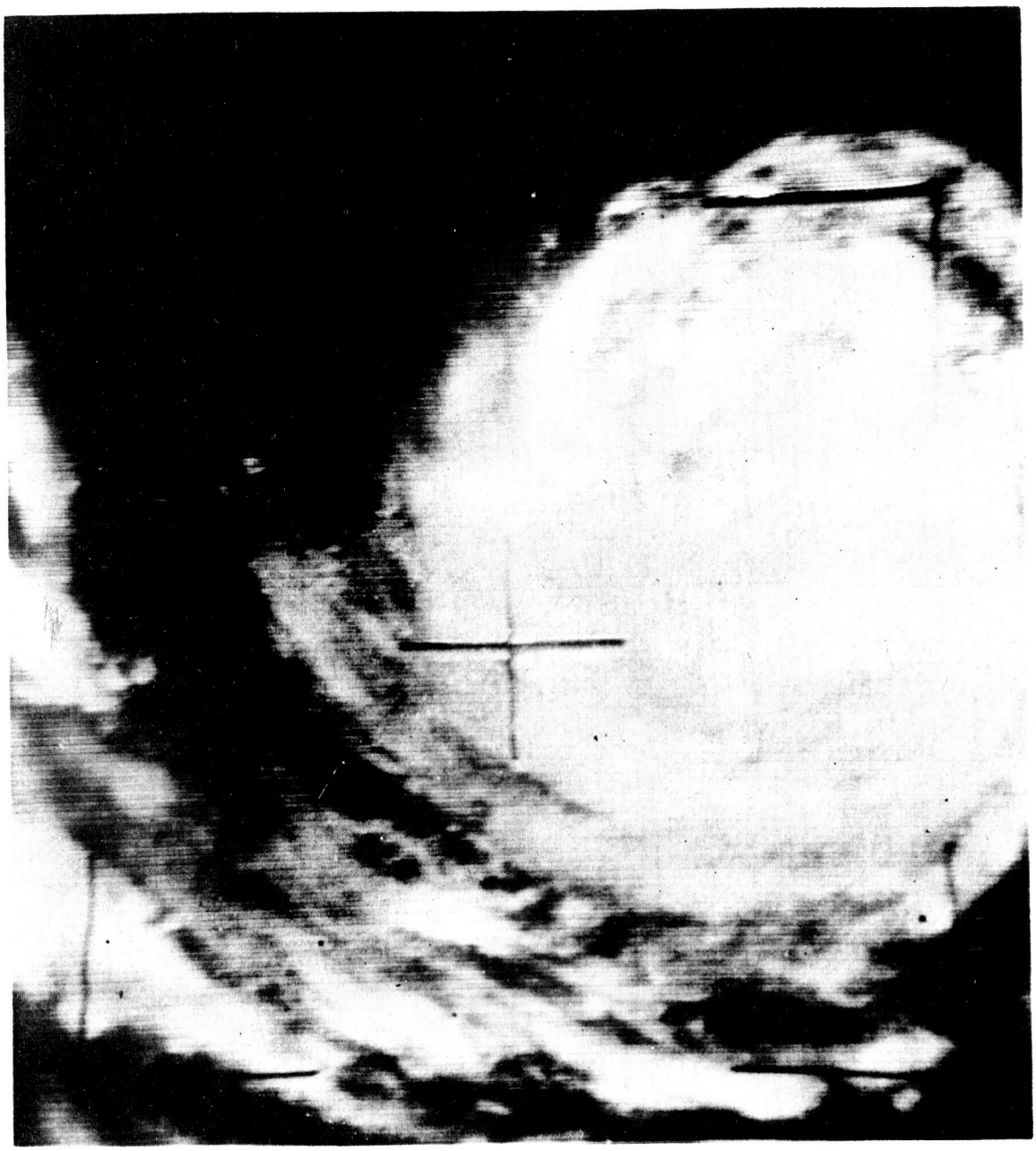

Figure 3 – Typhoon Ruth

Figure 4 shows Typhoon Gloria, comparable in size to Ruth, which also occurred in the northern hemisphere in the Pacific Ocean. Note the well-defined eye of this storm and the spiral cloud array flowing counterclockwise into the center of low-pressure areas.

The thermal structure of tropical cyclones, and their formation process, are much more complex than the simple chimney theory.

Figure 4 – Typhoon Gloria

Generally, tropical cyclones require several conditions for formation:

1. They form over the subtropical ocean.
2. Water and air temperatures are close together at about 26°C.
3. There is a perturbation in the pressure system, associated with low-pressure troughs moving eastward.
4. There is rapid exit flow aloft.

Essentially, the tropical cyclone is a heat engine. The warm moist air at the core is the heat source. Air flows into the storm at lower levels, ascending from near the surface of the ocean to the upper atmosphere, where it is rapidly removed from the cyclone.

Figure 5 is a photomosaic of Hurricanes Debbie and Esther, which were seen by TIROS III on September 11, 1961, in the tropical mid-north Atlantic. Each of these hurricanes was about 500 miles in diameter. They are roughly 1000 miles apart on centers as shown.

The graphical presentation below the mosaic is a nephanalysis or cloud interpretation. The eventual paths that these hurricanes took were contrary to the theory of interaction between vortices cited in the works of S. Fujiwhara: "Vortices either attract or repel each other; they rotate about a center of gravity located on the straight line between them." Debbie proceeded north, and Esther eastward, on their individual divergent courses.

Figure 6 is an infrared-radiation map of Hurricane Anna in its early stages. The radiation data add significantly to the TV data, because the radiometer provides measurements of energy which may be interpreted in terms of temperature of cloudtops; these temperatures in turn may be interpreted in terms of heights of cloudtops.

This photograph was taken off the north coast of Venezuela in July 1961. Radiation data taken at the same time are shown as a radiation-analysis overlay superimposed on the photograph. The white areas are heavy multilayered cumulus cloud formations. The isolines depict the equivalent blackbody temperatures in degrees centigrade, and can be equated to height contours, giving a third dimension to the cloud model. Note the peaks as indicated by the cold temperatures; observe the slope at the edge of the formation, and the warm center denoted by the letter W. The analysis shown was carried out by Prof. T. Fujita at the University of Chicago. In areas of scattered or broken clouds, these radiometric temperatures are not readily interpretable as cloudtop or ground temperatures, because they represent an integrated average of the two.

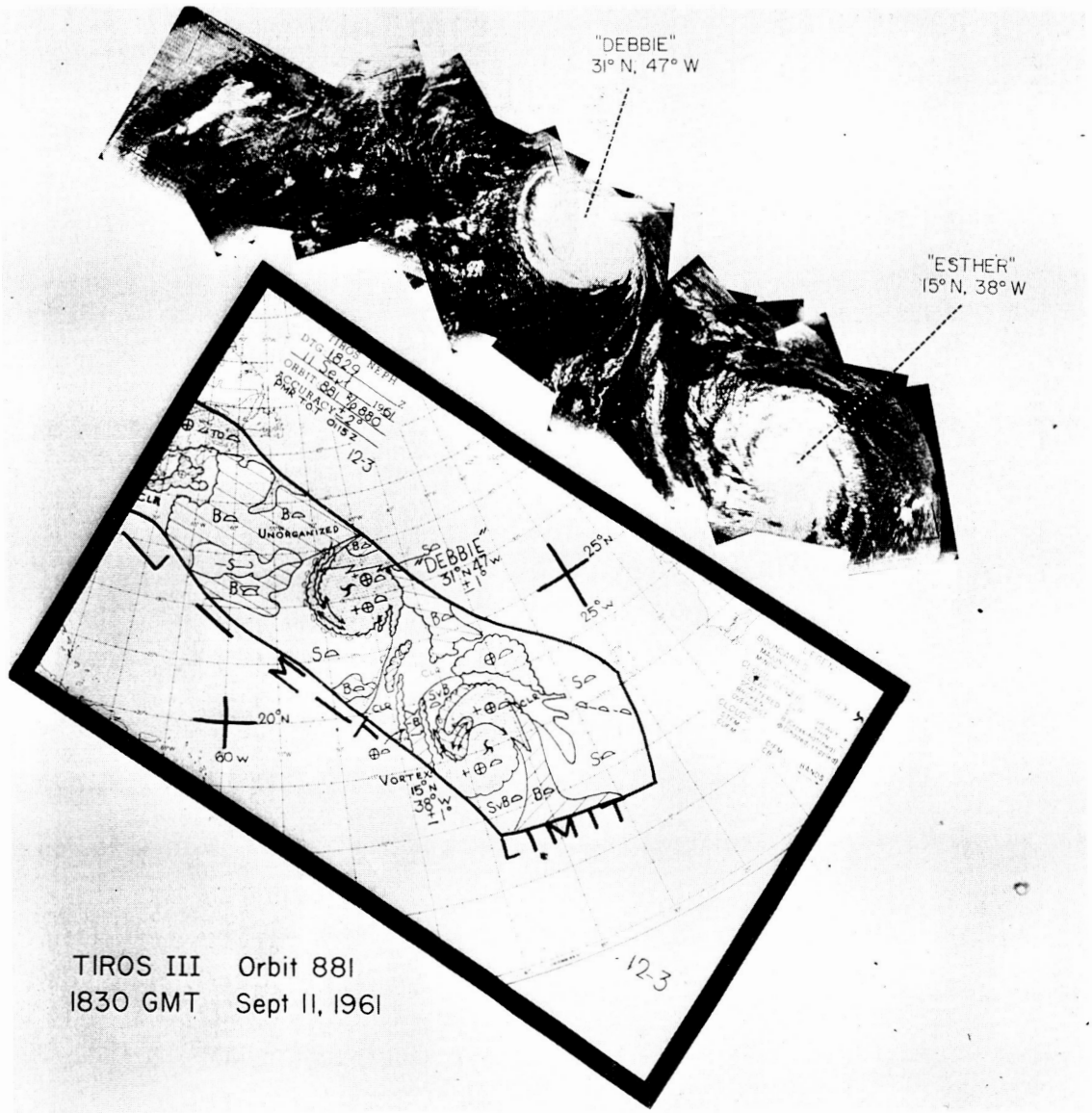

Figure 5 – Hurricanes Debbie and Esther

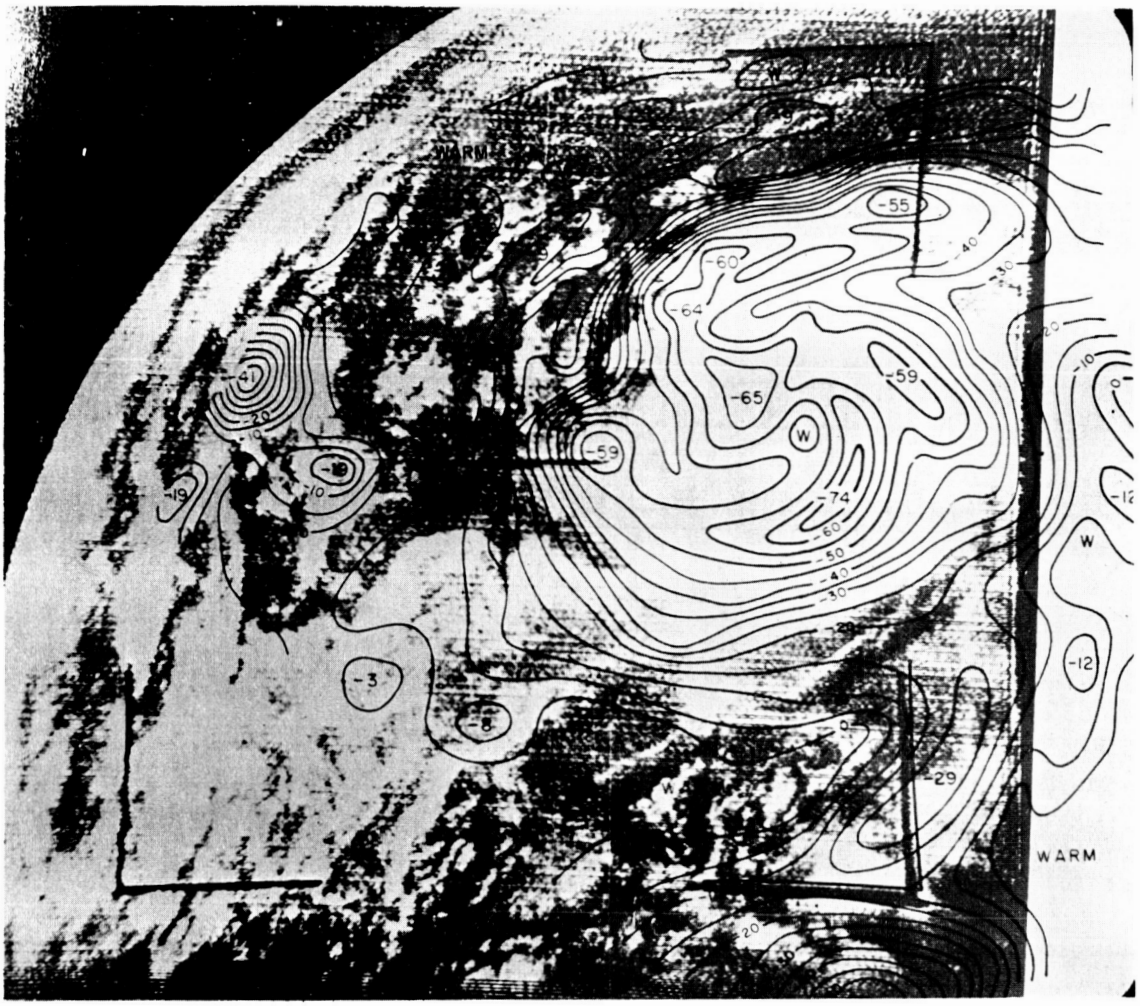

Figure 6 – Hurricane Anna

During the period October 21 through October 28, 1963, TIROS VII obtained a series of TV pictures of Hurricane Ginny shown in Figure 7. A tropical disturbance formed over the southeastern Bahamas on October 17 and reached hurricane intensity southeast of Cape Hatteras on October 20.

On October 22, under the influence of a large cold high-pressure area which moved southward, the hurricane was forced southward; there it turned west and looped around to the north.

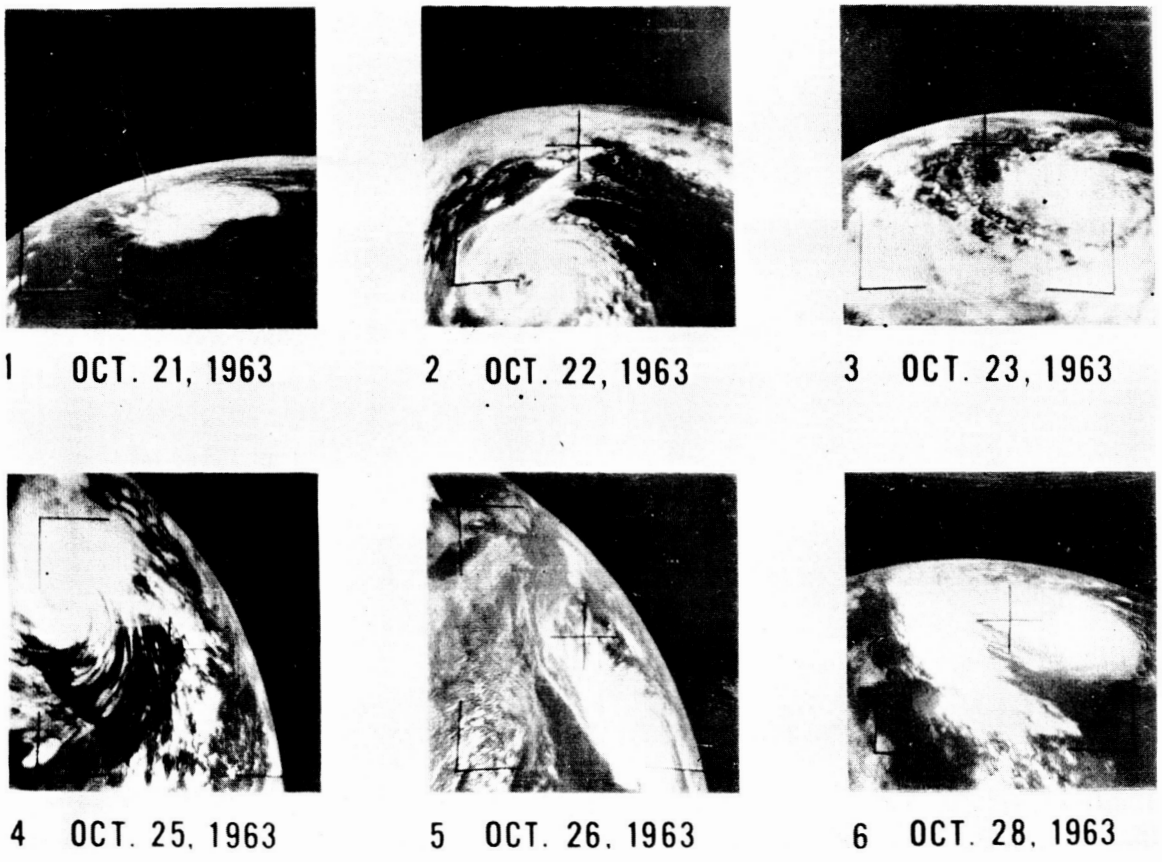

Figure 7 – Hurricane Ginny

Figure 8, a series of eight pictures taken by TIROS V and VI, shows the growth and development of Typhoon Karen from a tropical storm to a fully developed typhoon. Karen passed over Guam on November 11, 1962.

EXTRATROPICAL CYCLONES

Figure 9 is a mosaic of an extratropical cyclone. The general circulation of the atmosphere (characterized in the mid-latitudes by the convergence of dissimilar air masses having different temperature and humidity properties) form sloping boundaries called "fronts." Between adjacent currents moving at different speeds, waves are formed along a front. The resulting convergence and rising air are accompanied by low pressure. As the wave develops, the pressure gradient is focused toward the center and the pattern of air flow becomes cyclonic. Extratropical cyclones vary in size from 100 to 2000 miles; average size for the United States is 1000 miles.

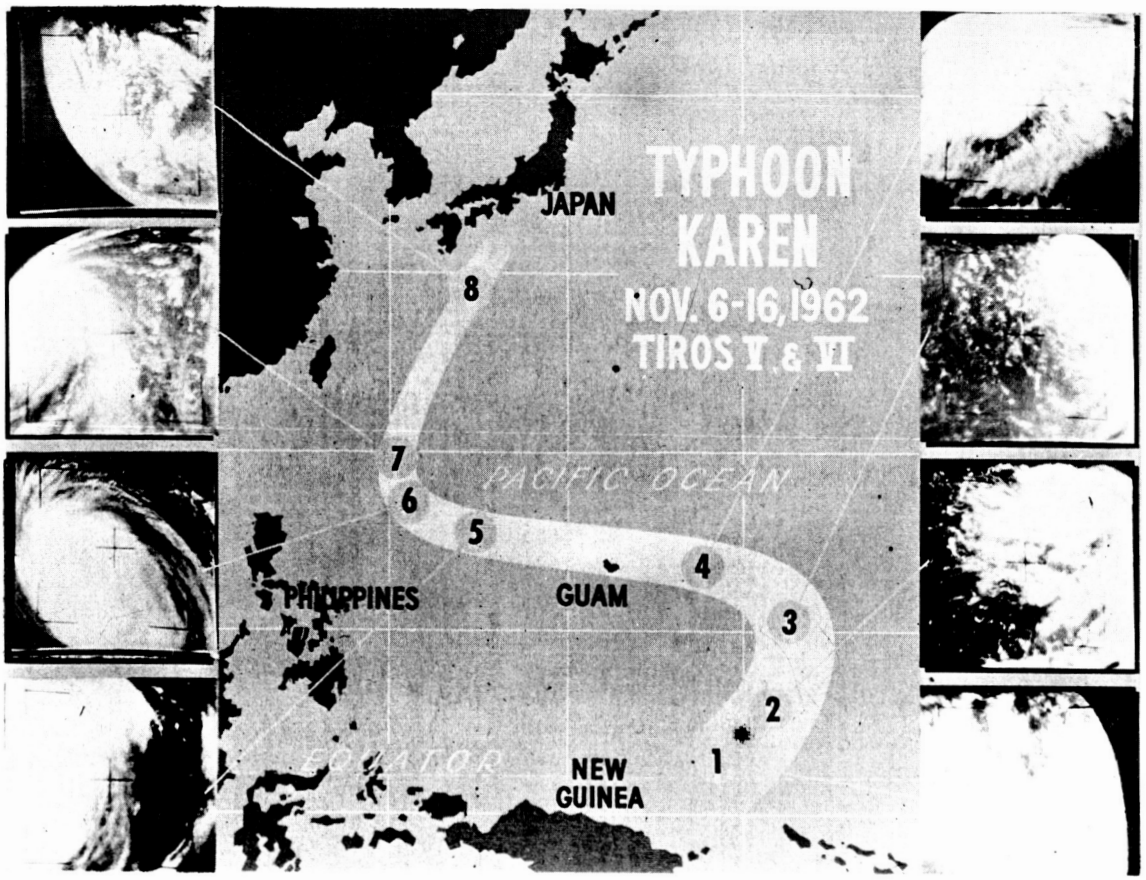

Figure 8 – Typhoon Karen

The lower half of this picture is a photomosaic of TIROS I pictures taken over the north Pacific on May 20, 1960. Above is a rectified cloud interpretation of this mosaic. The area enclosed by the dotted line is that depicted by the mosaic. Superimposed on the cloud-rectification illustration is a surface analysis of pressure field and frontal structure. On the left is a mature occluded cyclone; in the center, an open wavefront on the verge of becoming cyclonic; and to the right, a dissipating cyclone. The area of coverage of these combined frontal systems is about 4500 miles. The cyclone on the left is approximately 1200 miles in diameter; and the length of the open wavefront is approximately 2400 miles.

Figure 10 illustrates a frontal cloud structure over the North Pacific. Note the line of cumulus clouds associated with this cold-front activity. The cellular

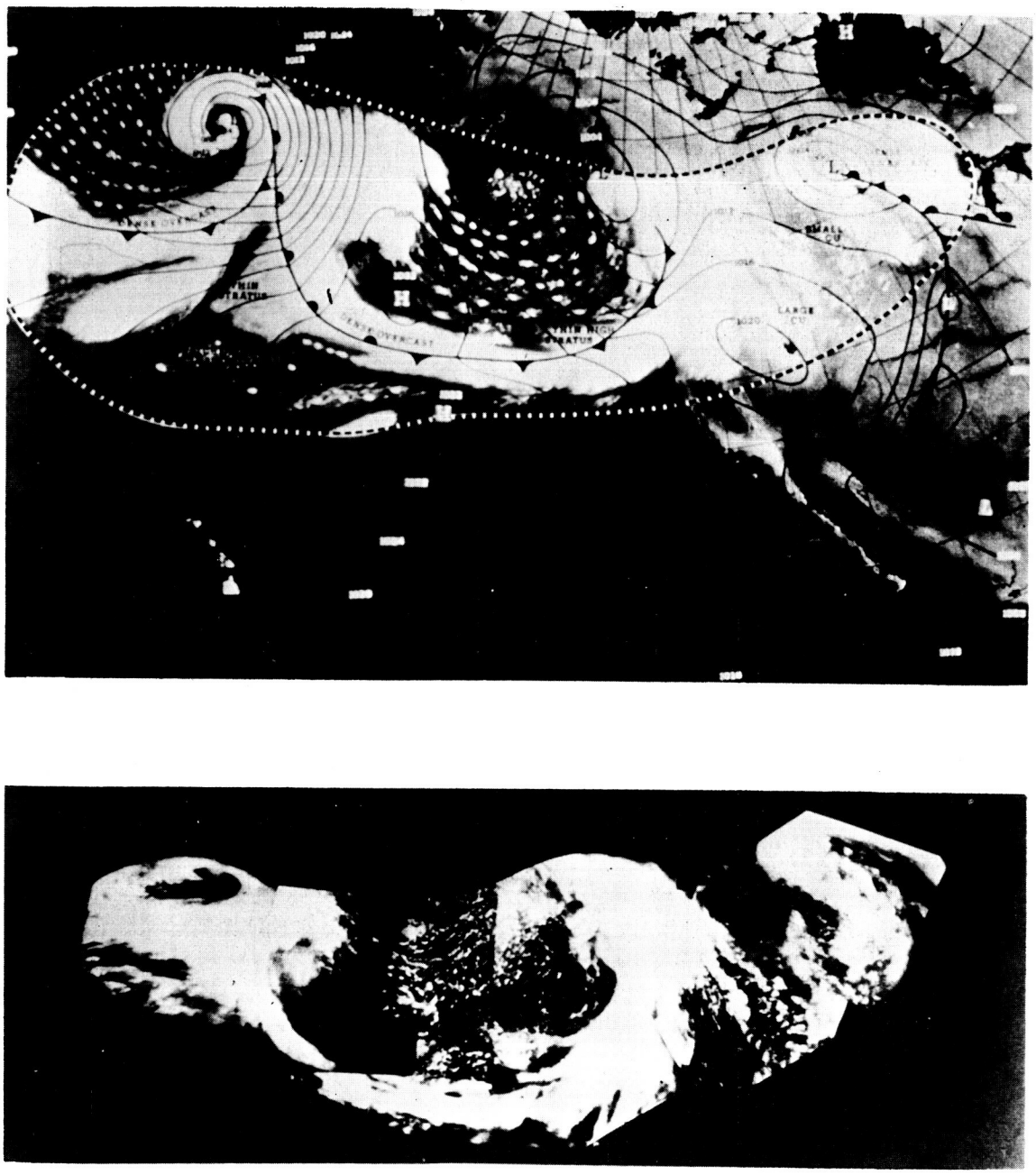

Figure 9 – Mosaic of an Extratropical Cyclone

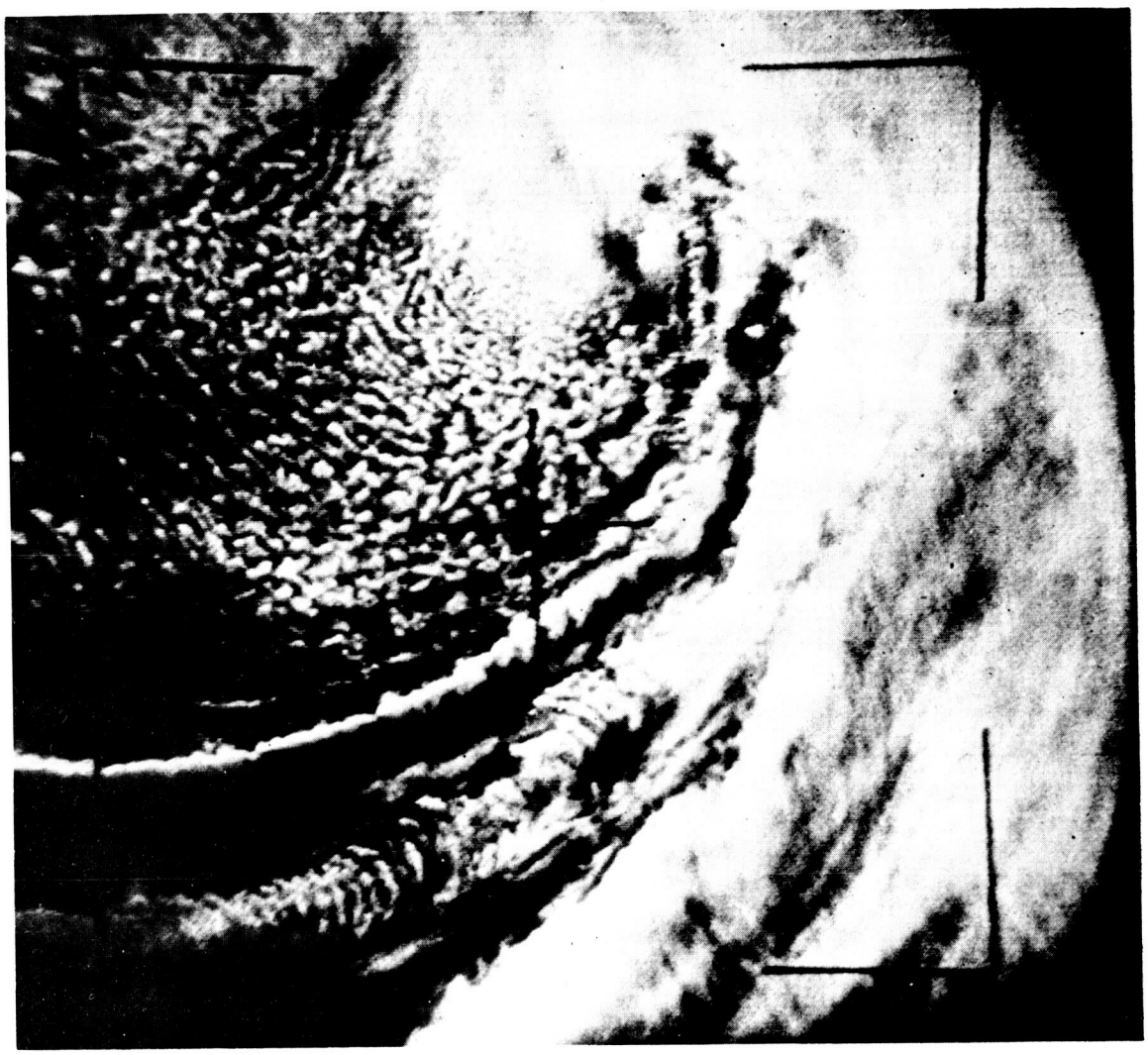

Figure 10 – Frontal Banding over North Central Pacific

clouds in the cold air mass behind the front are in the order of 10-20 miles in diameter. Investigations have shown these patterns to be similar to those observed by Benard in unstable fluids.

Figure 11 is a deep occluded cyclone which was photographed over the North Atlantic west of the British Isles on May 21, 1964. The cold air (the clear band) is broad and maintains its identity well into the cyclone.

Figure 11 – Vortex West of British Isles

Figure 12 is a mature occluded cyclone off New Zealand taken March 3, 1964. By contrast with the previous picture, note the clockwise rotation about a low-pressure system for this southern hemisphere vortex.

Figure 13, taken over the Northern Pacific on March 7, 1964, shows a weakening occluded cyclone. Of particular interest are the well-defined convection cells in the form of rings or crescents. The larger cells in the center of the picture are about 50 miles in diameter. Sigmund Fritz of the Weather Bureau, among others, has made studies of these phenomena. The significant fact is that, although they

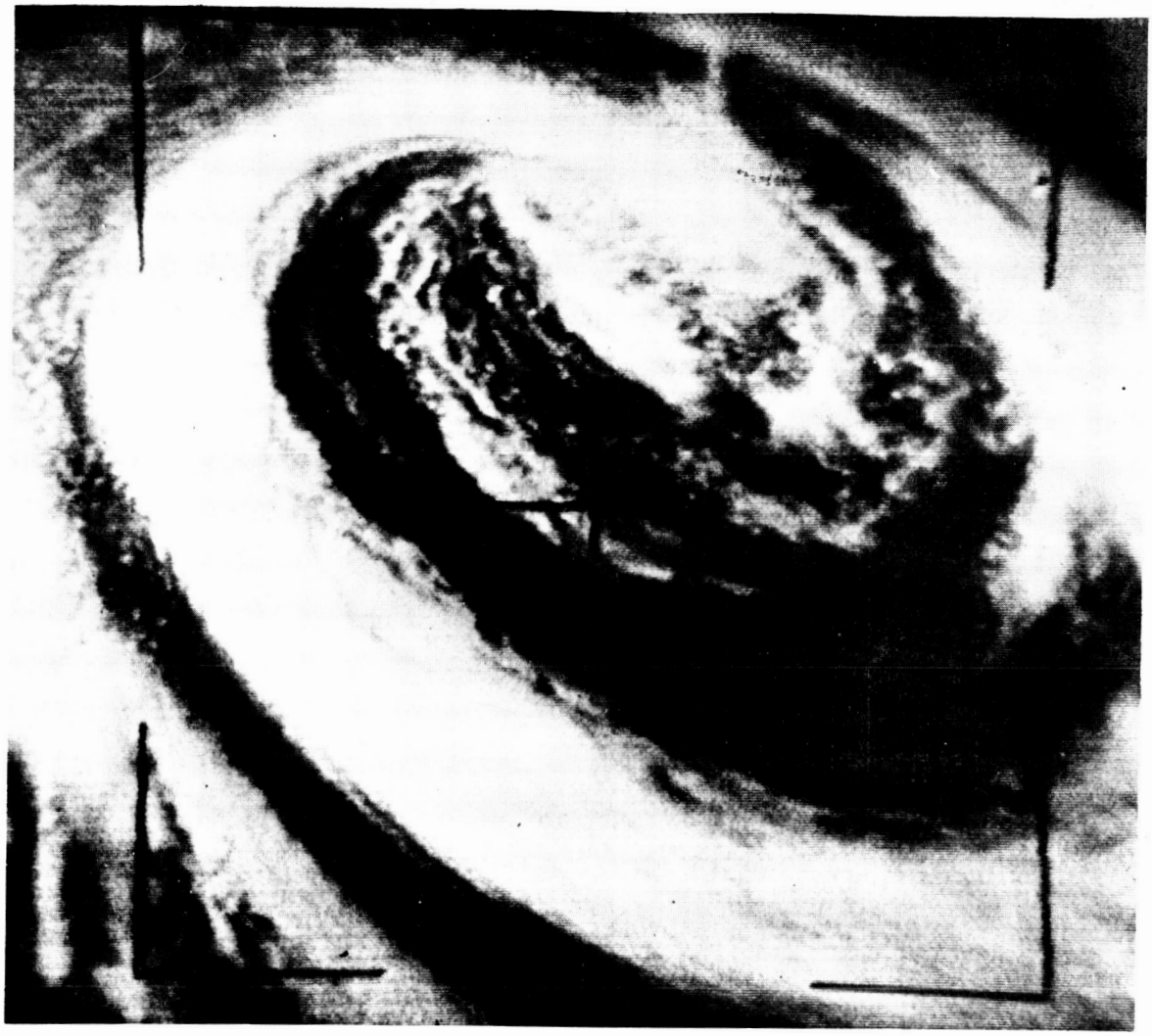

Figure 12 – Storm off New Zealand

resemble Benard cells, they do not have the classical dimensions of the latter. The fluid is extremely shallow in the atmosphere.

The unusually bright and isolated cloud in Figure 14 is associated with heavy thunderstorm and tornado activity. This picture was taken at 2000 hours GMT on May 19, 1960. A rectified cloud schematic of the photograph appears in the upper-right-hand corner. The lower right-hand corner is a surface chart of the weather conditions of the same area compiled 2 hours after this picture was taken. Notice that the main disturbance has moved slightly to the ENE

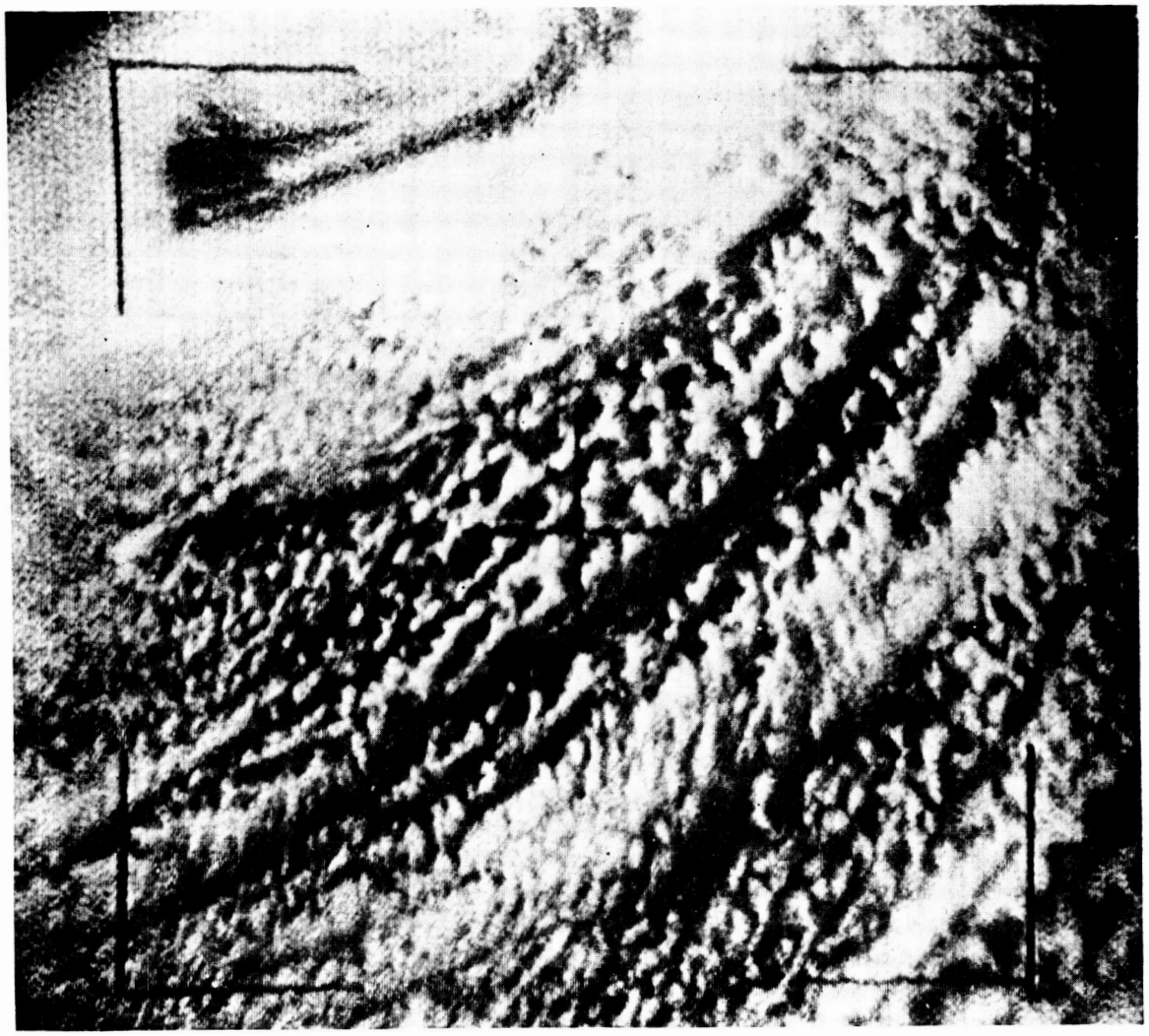

Figure 13 – Vortex over Northern Pacific

in the 2-hour timeframe. Tornadoes were associated with this cumulonimbus activity in central Oklahoma. Most tornadoes are a few hundred yards in diameter at the ground, and are formed in the warm section of cyclonic systems just ahead of a cold front and where there is cold-air flow aloft.

The tornadoes are not shown because the resolution of the cameras - about 2 miles - is much too poor. However, the brightness of the cloud and the regularity of boundaries are indicative of the intensity of the atmospheric activity.

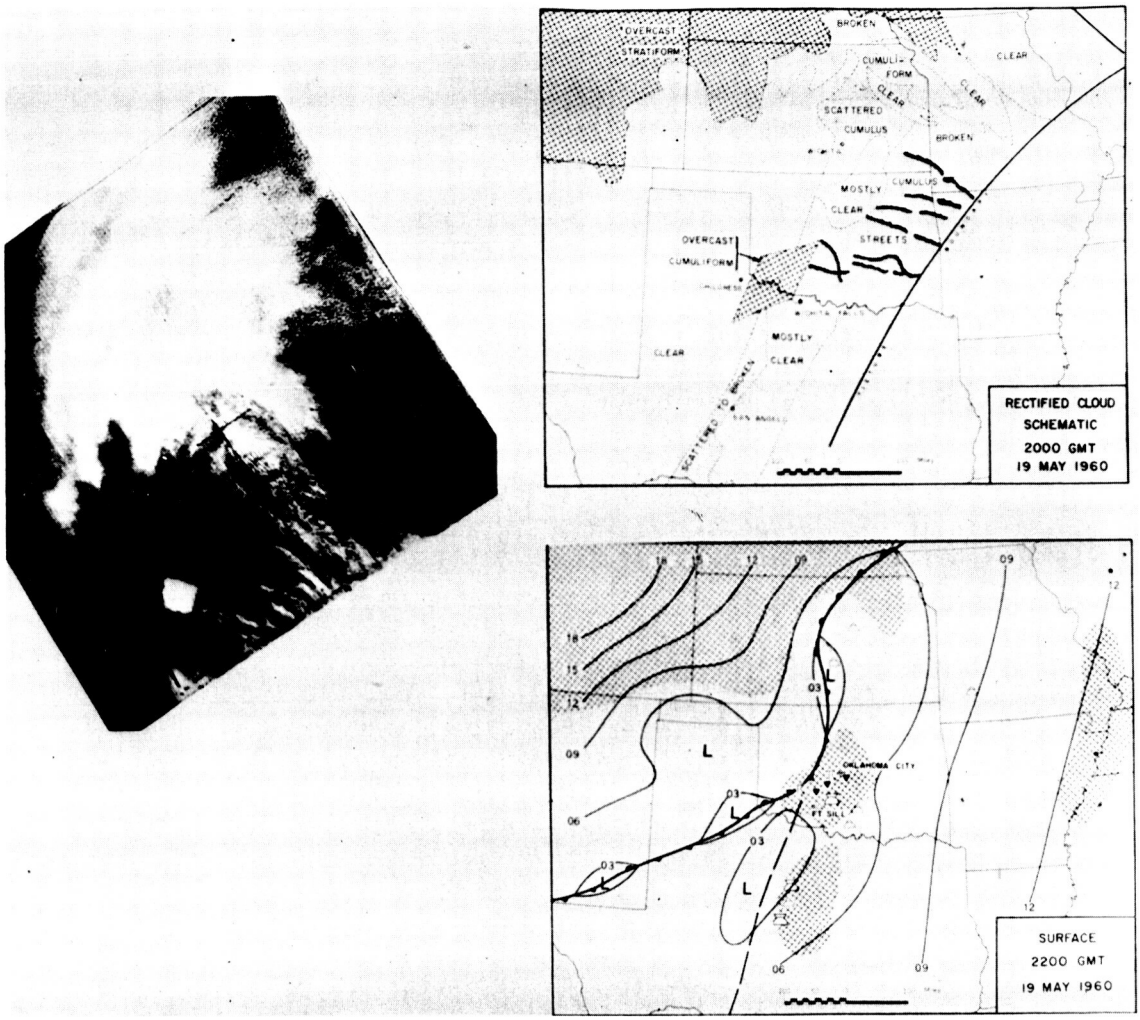

Figure 14 – Square Cloud Tornado

Figure 15, a small vortex approximately 200 miles in diameter, was photographed on November 20, 1963, centered over the Caspian Sea. North direction is to the left. Note the darker water and lighter land mass. The white streak below the storm is possibly snow on the Caucasus mountains. It is not certain how this vortex was formed; possibilities are that it was thermally induced by surface heating from a relatively warm sea, or mechanically induced by flow across the mountains to the west or association with the remnants of a trailing cold front extending across the sea.

Dr. W. Nordberg, a senior scientist at Goddard Space Flight Center, has pointed out that the cloud photographs can be interpreted as images of a giant

Figure 15 – Small Storm over Caspian Sea

laboratory experiment staged by nature itself. The validity of conclusions drawn from actual laboratory experiments carried out under the usual limiting conditions, or from theories constrained by questionable assumptions, can thus be tested. At the very least, the conditions for, and the extent to which the laboratory and theoretical results may be applied to the free atmosphere, are demonstrated by the satellite results.