WEATHER IN MOTION

A commentary on the
series of pictures taken by the ATS-III satellite.

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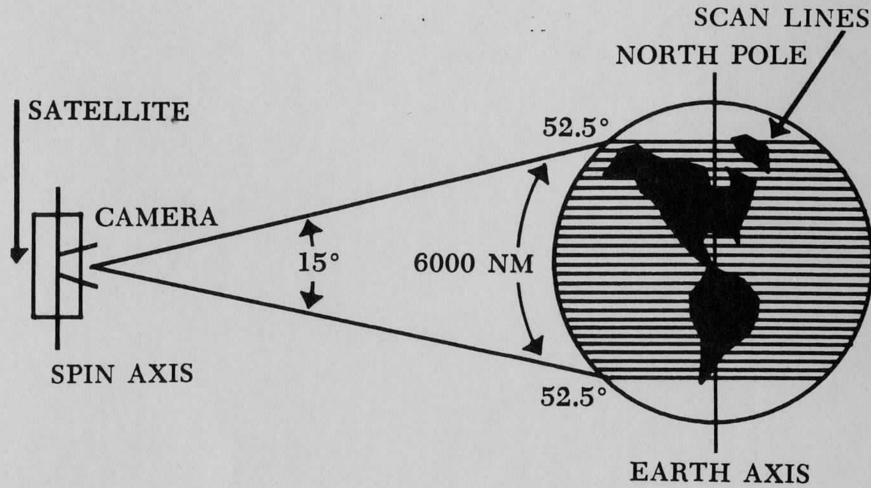
SCAN LINES
NORTH POLE
SATELLITE
52.5°
CAMERA
15°
6000 NM
SPIN AXIS
52.5°
EARTH AXIS

WEATHER IN MOTION

This film consists of a series of pictures taken by the ATS-III satellite. ATS-III is in geosynchronous orbit; that is to say, because its orbital period is the same as the rotational period of the earth (24 hours), the satellite remains stationary over a point on the equator. To some extent this position can be controlled from the ground. At the time of this picture sequence, ATS-III was over the mouth of the Amazon River. Its altitude was 22,250 miles (38,500 km).

The spin-scan camera on ATS-III has three sensors which look at the earth in the red, green and blue parts of the visible region of the electromagnetic wave spectrum. Signals from these sensors are separately transmitted and received, then combined on the ground into a single color picture.

Each sensor sees through the same narrow angle telescope. This telescope views an area which directly below the satellite is 2.2 miles (3.5 km) in diameter and increases outward toward the edge of the earth. Therefore nothing smaller than 2 miles can be resolved in the satellite images.

The full earth picture is a mosaic of millions of individual views. As the satellite spins, the telescope scans across the face of the earth. After each revolution of the satellite the telescope is tilted down, just enough that the next scan leaves no gap in coverage. (Individual scans leave the east-west lines visible in enlarged parts of ATS pictures.) This scan cycle is repeated until the full earth disk is covered; the telescope then returns to its original position, ready to make a new picture. The total time (interval between successive pictures) for a full earth image is about 25 minutes.

When viewing these pictures, remember that the satellite sees only clouds and the features of the earth's surface. We cannot directly see the motions of the atmosphere, yet clouds offer possibilities for inferring much about how the atmosphere behaves. Clouds in the first place tell us the air there is or has recently been moving upward. Horizontal motion dominates in the atmosphere; therefore the cloud, once formed, will tend to move with the wind. Those that don't are controlled by obstacles like mountain ranges and large islands (and are called orographic clouds) or extend through very deep layers of the atmosphere (convective clouds, of which thunderstorms are an example). We can distinguish passive, "wind tracing" clouds from others by their appearance, their behavior and their proximity to ground obstacles. Likewise, the appearance of a cloud provides clues as to its height above the ground, and therefore the height of the winds that we infer from cloud motions. Bright, distinct clouds generally are composed of liquid water drops and are found in the warmer lower atmosphere. Thin, fuzzy-edged clouds generally are composed of ice crystals and are found in the colder upper atmosphere. They often occur along "jet streams," long narrow currents of high-speed winds usually found in the upper atmosphere. Thunderstorms combine these two types in a single cloud which usually is identifiable by its extreme brightness and rapid growth; only in the thunderstorm is the upward airspeed comparable to horizontal windspeed.

Changes in the clouds are greatest over land. Sunshine warms a land surface much more than it does a water surface. This heating is conducted to the air above. Continued heating of the air from the bottom leads to instability, overturning of the air, and the production of clouds.

All of the 35 ATS pictures in this film were taken on a single day. They are presented first as full earth images, then as enlargements showing various parts of the earth's disk. The time-lapse presentation enables us to see small changes in clouds from picture-to-picture as movement—*Weather in Motion.*

1. NOVEMBER 18, 1967

Preceding the ATS pictures, an illuminated globe is viewed from the perspective of the ATS-III satellite, and provides an orientation for the ATS pictures which follow.

The full earth sequence shows the larger scale behavior of the atmosphere—the general circulation. In the northern and southern polar portions of the earth disk, clouds are moving generally towards the east. In the equatorial region between, cloud motion is substantially slower and generally towards the west. This reflects the dominant features of the general circulation: strong polar westerlies in middle and high latitudes; trade easterlies near the equator.

Looking more carefully at particular parts of the globe, we see individual vortices in the cloud field. These vortices rotate in a counterclockwise direction in the northern hemisphere and in a clockwise direction in the southern hemisphere. They are associated with areas of low surface pressure and are the major weather-producing systems of temperate and polar latitudes.

In the equatorial region there is a prominent cloud band extending from Africa westward just north of the equator to South America. This is the Inter-Tropical Convergence Zone (ITCZ). It is in and along the ITCZ that most tropical disturbances occur, disturbances which in certain seasons sometimes intensify into hurricanes. These disturbances generally move from east to west along or just north of the ITCZ. The ITCZ generally appears as a broken band of clouds but may change substantially from day to day or week to week. It also migrates seasonally, reaching a northern position in the late summer and retreating southwards toward the equator in the northern winter season. The ITCZ is where the action is; rainfall is copious. We can see the effect of the ITCZ on the African vegetative cover. Its seasonal migration spreads the rain over equatorial parts of Africa, but the cut-off on the north is sharp. The northernmost position of the ITCZ over Africa is apparent in the division of northern Africa into two zones: a brownish-colored northern region of bare rock and desert sand, and a darker, heavily vegetated zone to the south consisting of grasslands, crops and forest.

For reasons which are not clear, the Atlantic south of the equator has no ITCZ.

2. *CYCLONE OVER THE EAST COAST OF THE U.S. AND CANADA*

Large cloud vortices are associated with cyclonic storms which typically form along the boundary between cold and warm air. This cyclone shows by the motion of its clouds the characteristic poleward movement of warm air to the east and south of the vortex and the equatorward movement of cold air to the west and north. The enormous mixing of contrasting air masses which is implied by these motions is the primary role of extratropical cyclones in the atmosphere.

The major cloud band lying across Florida in the SW corner of the frame and arcing northeastward and northwestward into the center of the vortex is associated with the cold front separating warm air from cold air. Just west of the cold frontal band is a tongue of relatively clear air that projects into the center of the vortex from the southwest. This clear air intrusion is a characteristic feature of extratropical cyclones. Typically, thunderstorms and showers occur along and ahead of the cold front, with steady rains, drizzle and fog more typical within the northern parts of the vortex. These different types of precipitation are reflected in the different types and textures of clouds. In advance of the frontal band the clouds are generally broken, some of them very bright and cellular in appearance. In the northern portions of the vortex the clouds have a much smoother, more homogeneous form and texture.

3. *GULF OF MEXICO AND CARIBBEAN AREA*

The Florida peninsula in this view lies at center-right. The southern states of the US extend across the top of the picture with Mexico along the left margin; the long brownish mass at the bottom is Cuba.

Most prominent in this series are intense convective storms over Florida with clouds being drawn off the top of the storms towards the NE. In the left two-thirds of the picture there is a general clockwise movement of the clouds, representing an anticyclonic (high pressure) flow near the surface. The clouds moving rapidly from west to east across the top left are very high ice clouds called cirrus which are associated with the subtropical jet stream.

Next is a view of the Caribbean Sea with South America along the southern border, Cuba in the NW corner, and the other islands of the Caribbean extending eastward from the tip of Cuba: Haiti/Dominican Republic, Puerto Rico, and the Windward and Leeward Islands (Lesser Antilles) arcing southward along the extreme eastern edge of the picture. Most of the large cloud masses are associated with the larger land masses — a result of the solar heating effect described previously. Over the open sea, especially in the Caribbean, clouds are generally small and move with the speed and direction of the low level winds. The circulation that is apparent through the motion of these small clouds is typical of northeasterly trade winds.

4. *CYCLONE OVER NORTHEAST ATLANTIC*

A counterclockwise rotating cyclonic vortex is the dominant feature of this series. The cyclone lies just off the west coast of Africa. High velocity cirrus clouds move eastward in a clockwise arc across Africa. These clouds mark the position of another part of the subtropical jet stream. This configuration of subtropical jet stream and cyclone is typical of strong extratropical cyclones in middle latitudes. In higher latitudes there is usually a polar jet stream partially encircling the vortex on western, southern and eastern sides. When these jet streams occur together, there may be overlap in the vicinity of the frontal band.

Along the coast of Africa there are two types of clouds: sheets and patches of low clouds which lie within a few thousand feet of the surface, and filaments and wisps of high clouds which may be as much as 30 to 50 thousand feet above the surface. The low clouds appear only over the ocean. Any air flow that might take them across the African coast would bring them into a region so warm and dry the clouds would quickly evaporate. However, the upper clouds, because of their height, are insulated from the drying effect of the desert and undergo no changes as they cross the coast.

5. *EQUATORIAL ATLANTIC*

Africa lies in the east in this sequence, South America to the west. As is implied by its name, the

ITCZ (here shown in detail) represents a zone where air masses of different origin come together. To the north the motion of the clouds imply that the air near the surface is moving from the east and northeast with a component slightly convergent on the ITCZ. Convergent motion to the south is less apparent. Typically this air moves from the SE across the equator, then turns northward as it approaches the ITCZ. This convergence of air masses implies lifting of the air within the ITCZ. Most of this lifting occurs in a small number of thunderstorms scattered in groups along the ITCZ. These groups appear along the ITCZ as cloud clusters. At least three are apparent from the east to west across this field of view. Within clusters, active thunderstorms are located where the clouds are brightest.

Looking carefully at the bright regions, especially in the center clusters, we see thin fibers of cloud being carried rapidly northeastward off the thunderstorm tops. These are cirrus clouds caught in an upper level airflow. They are to the individual thunderstorms what smoke plumes are to smoke stacks.

The flow pattern which emerges from these deductions consists of two horizontally moving air streams converging on the ITCZ in the lower atmosphere with a third air stream crossing the ITCZ above. Vertical coupling of these lower and upper streams occurs along the ITCZ in clusters of thunderstorms.

The next series covering the western Atlantic just south of the equator clearly shows the difference in effects of sunlight being absorbed by land and sea surfaces.

A similar series is repeated for the eastern Atlantic just south of the West African bulge. In early morning coastal parts of Africa are covered by low clouds and fog as the result of nighttime radiational cooling of the moist vegetated surface. As the sun gets higher in the sky, the heating produced by solar radiation absorbed at the surface evaporates the fog and low clouds, producing temporary clearing. This is almost immediately followed by the generation of small convective clouds, some of which amalgamate to produce the isolated, very bright clouds of thunderstorms. Again, cloud systems over the ocean are essentially unaffected by the cycle of solar radiation.

6. *SOUTH AMERICA*

(a) The diurnal change of cloud patterns over land is pronounced in the northern two-thirds of South America. To the south there is a series of vortices moving rapidly eastward in the belt of strong westerly winds that surround Antarctica. In between the regions of diurnal convection and westerly circulation there is a belt of inactivity, most apparent in the central part of South America and adjacent parts of the Pacific Ocean. Clouds there are somewhat dimmer and more static than elsewhere. The large cloud mass over the Pacific just west of South America is composed of low level stratiform clouds that produce little or no precipitation.

These cloud patterns are reflected in average rainfalls over South America. Heaviest amounts occur over the Amazon basin where convective clouds dominate. There is a second maximum produced by travelling vortices in the extreme south. Lesser amounts fall in between, especially along the west coast.

The effects of topography and solar heating are combined in the clouds which form over the peaks of the Andes Mountains towards the end of the day. The dark area a little to the left and below center in this series is Lake Titacaca. Titacaca, the highest large lake in the world, is so cold convective clouds almost never form over it.

(b) Stratus leaving coast of Chile—The Pacific stratus clouds mentioned above dissipate in a narrow strip along the coast during the day. The bright area moving westward from the coast towards the end of the sequence is the sun's reflection. Its size and brightness are a measure of the sea's roughness.

The Andes Mountains provide a substantial obstacle to weather systems moving eastward in southern polar latitudes. The vortex approaching from the west is deflected southward as it nears South America. Clouds associated with the vortex are seen to pile up just west of the crest of the Andes. A few clouds which cross the Andes are high level cirrus. This cloud distribution implies heavy precipitation on the windward slopes. Patterns like this are repeated whenever a large mountain range lies across a strong, low level atmospheric current.

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To observe a most striking display of weather in motion on a typical day, hold the color picture between the index finger and thumb of each hand along the sides and midway down from the top of the picture. In the display, Africa is the bright orange area in the upper right, the United States is faintly visible in the upper left, the Greenland ice cap appears in the upper center, and South America stands out prominently in the lower central area. Tilt the top of the picture slowly towards you and then away through a small arc (about 20°). Each time the top moves toward you, cloud motions over the entire picture area are authentic and, alternatively, are reversed when the top of the picture is tilted away.

Note the spectacular spiral cloud band off the northwest coast of Africa. The cloud system is associated with a storm center (center of the spiral cloud bands) and the counterclockwise rotation of the clouds indicates that it is a cyclonic disturbance. The display also presents many other weather phenomena as revealed by cloud type, distribution, pattern, and evolution.

The display is a composite of 9 individual pictures taken at approximately 60 minute intervals by the NASA Multicolor Spin-Scan Cloud Camera on the Applications Technology Satellite, ATS - III. The total time interval presented in the display is about an 8-hour period. Thus, from weather satellite pictures taken at frequent intervals clouds and cloud motions can reveal useful information on weather systems on a global scale.

The weather in motion display was conceived and developed under a NASA sponsored contract by Walter A. Bohan.

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