Western Region Technical Memorandum No. 4, March 1966

USE OF METEOROLOGICAL SATELLITE DATA

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1. NEPHANALYSIS LEGEND

1. CLOUD TYPES

 Cumuliform

 Apparent CUCG or CB

 Strato-cumuliform

 Cirriform

Stratiform

2. CLOUD AMOUNT (COVERAGE)

O	Open	≤20%
MOP	Mostly Open	20% - 50%
MCO	Mostly Covered	50% - 80%
C	Covered	>80%

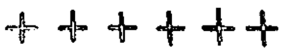
3. SIZE OF FEATURES

Cloud	Size (Nautical Miles)	Open Spaces
1	0 - 30	6
2	30 - 60	7
3	60 - 90	8
4	90 - 120	9

4. BOUNDARIES

 Major cloud system

Definite

 Limit of snow or ice

Indefinite

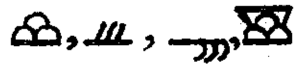
5. PATTERNS AND SYNOPTIC INTERPRETATIONS

 Point toward which cloud band(s) tend to spiral

 Point in a generally open field of cumuliform clouds toward which cloud elements tend to spiral

 Distinct comma shaped cloud mass

5. PATTERNS AND SYNOPTIC INTERPRETATIONS (Continued)

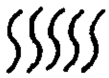
 Cloud line (form may be )

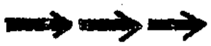
 Cloud line, tenuous

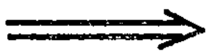
 Change of element size along cloud line as indicated

 Striations

 Striations, tenuous

 Wave clouds (mountain or transverse)

 Estimated location of the jet

 Direction of streakiness in cirrus clouds

 Bright (highly reflective cloud mass)

— Thin

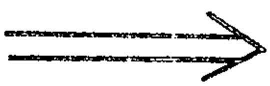
6. TERMS

Cellular	-	Pattern of cumuliform cloud elements which form polygons with either open or closed centers
Eddy	-	Mesoscale spiral cloud
Hazy	-	Condition when known terrain features are not seen with usual clarity
Probable	-	Used when only part of cloud system or pattern is visible in satellite picture and there is a high degree of confidence in the interpretation
Possible	-	Used when observed cloud pattern is not a clear-cut example of its type or when other available synoptic data and analysis does not clearly support interpretation

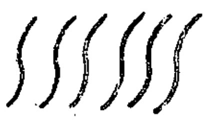
Cloud Line - The cloud elements visible in the satellite picture fall in a line and are nearly all interconnected. In general, the line is only one element wide, but many elements long. The line may be straight or curved.
Cloud form denoted by

Cloud line, tenuous

Cloud line. Elements change size along the line as indicated.



Cirrus Shear Direction - The vector arrow is aligned parallel to the streakiness in cirrus cloud and points from an area of dense cloud toward the point where the cloud thins and becomes no longer visible in the satellite picture.



Wave clouds (mountain or transverse)

Snow line or Ice line - This symbol indicates the boundary between apparent snow covered terrain and mostly snow-free terrain. A snow line analysis appears only where clouds are absent or thin and the edge of a snow covered area can definitely be determined from a satellite picture. This line, as entered on the nephanalysis, is discontinuous over areas where clouds obscure the edge of a snow field. The word snow also appears on the neph to indicate which side of the line the snow lies. When used over water, this symbol indicates the edge of the gross ice field in the polar oceans. The same criteria are used in entering the ice line on nephanalysis as are used in entering the snow line.

Bright - Highly reflective cloud mass.

Thin - A cloud area where other clouds or terrain features can be detected beneath it is indicated as thin.

1. General Terminology

Element - The smallest distinguishable unit in a cloud mass or pattern in a satellite picture.

Cloud Mass - An identifiable patch of cloud elements. A cloud mass is generally equal or greater in size than an area two degrees latitude square. The cloud amount within the patch is usually greater than 80%.

Cloud Pattern - An arrangement or distribution of cloud elements, distinct groups of cloud elements, or cloud masses which show a distinctive organization. Patterns of all scales appear in the satellite views of clouds. The distinctive cloud pattern produced by mountain waves is a mesoscale pattern. A cloud vortex is a macroscale pattern.

Cloud System - The cloudiness produced by or associated with the dynamics of any atmospheric system. Examples of atmospheric systems are an occluding storm, a cold upper low, a tropical storm, a high pressure cell, etc. The cloud systems associated with a particular type of atmospheric system usually have a distinctive pattern.

Cloud Band - A cloud formation with a distinct long axis where the ratio of length to width is at least four to one. This formation is usually covered (C) or mostly covered (MCO). Bands can be both straight and curved.

2. Symbols Used in Nephanalysis

Cumuliform Cloud

Cirriform Cloud

Stratiform Cloud

Apparent CUCG or CB

2. <u>Symbols Used in Nephanalysis</u> (Continued)

Strato-cumuliform

Boundary of major cloud systems. Fronts, vortices, or other system dominating the scene viewed by the satellite.

Definite boundaries of more or less unorganized cloud masses.

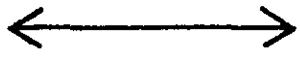
Indefinite cloud boundaries.

A cloud pattern of one or more cloud bands which appears to spiral inward toward a central point. This pattern is usually associated with a vortex in the atmosphere.

The center of an area of brighter appearing cloud elements in a field of open cellular cumuliform cloudiness. The brighter appearing elements may or may not be organized into cloud lines or bands which form a spiral pattern. This formation is most frequently observed to occur between a long wave ridge and the trough immediately down stream. It is often associated with a center of positive vorticity.

A distinct crescent or comma-shaped cloud mass equal to or greater than two degrees latitude in length. This pattern is often associated with the area of positive vorticity advection (PVA) which precedes short wave troughs in the upper air flow.

Estimated location of the jet. This symbol appears on a nephanalysis parallel to a cloud formation which has the appearance and configuration of clouds associated with the jet stream. The arrows are entered along the cold side of the cloud edge.

 Striations - Narrow, approximately parallel streaks seen in the clouds.

 Striations, tenuous

3. <u>Words Used in Nephanalysis</u>

<u>Cellular</u> - A cellular pattern of small contiguous polygonal cloud elements. This pattern may be either <u>open</u> or <u>closed</u> in appearance. In the first case the cells are hollow with apparent cloud-free centers; in the second case they are closed with the centers of the cloud polygons completely cloud covered. The clouds forming an open cellular pattern are usually cumulus. The open cellular pattern accompanies a more unstable condition in the lower troposphere than exists when a closed cellular pattern is observed. Clouds forming the closed cellular pattern are predominately strato-cumulus.

<u>Eddy</u> - Mesoscale spiral cloud pattern. This pattern is often produced by perturbations in the flow caused by islands or similar terrain barriers.

<u>Hazy</u> - May be used when a terrain feature which was clearly seen on a previous orbit is no longer seen with the same clarity. (This condition may indicate the presence of very thin cirrus.)

<u>Probable</u> - (1) Used when only part of a cloud system or pattern is visible within the area viewed by the satellite and when there is a high degree of confidence in the interpretation. (2) Used when the cloud system or pattern is near the horizon in the satellite view. Interpretation is supported in both cases from views of the area on previous orbits or from NMC analysis.

<u>Possible</u> - (1) Used when observed cloud pattern is not a clear-cut example of its type.
(2) Used when available synoptic analysis and data does not support interpretation.

2. PICTURE INTERPRETATION

Weather satellites have given meteorologists a new view of the earths' atmosphere. Views from satellite altitude now make it possible to observe the cloud system of an entire storm in one picture. Circulations exist in the atmosphere on many scales and produce a variety of cloud types and forms. The appearance and distribution of clouds as observed by a satellite reveal considerable information on the structure and motions of the air below. To obtain this information the meteorologist must learn to identify and interpret the many different cloud forms seen in the pictures.

This section briefly describes how to identify some of the different types of clouds and how to recognize some of the more important synoptic scale[1] cloud formations which appear in the pictures. A selected bibliography on the problems of cloud interpretation and the relationship of clouds to synoptic patterns appears at the end of this section.

2.1 Appearance of Clouds in Satellite Pictures

In operational interpretation of satellite pictures, it has been found useful to classify cloud forms into three broad catagories: cumuliform, stratiform and cirriform. Clouds viewed from satellite altitude vary in pattern, texture, structure and brightness. The variations of these cloud characteristics make it possible to identify the different cloud forms[2]. It is also possible to identify a few of the specific cloud types which are reported by ground observers. Cumulonimbus and some forms of stratocumulus and cirrus can be identified by their unique appearance. Recognizing different cloud forms and cloud types provides indirect information on vertical cloud distribution, and also makes possible inferences about horizontal and vertical motions and the stability of the atmosphere.

2.1.1 Cumuliform Cloud

Cumuliform cloud areas may be organized into cellular patterns, have banded structure, or be composed of randomly distributed cloud elements of varying size. Cumuliform clouds in completely overcast areas often can be identified by the shadows they cast on the lower portions of the top of the overcast photographed from the satellite (See figure 17).

Figure 14 shows an example of one type of cellular pattern observed in cumuliform cloud areas. A large area of cumuliform clouds appears to the west and south of a vortex centered near 50°N, 135°W. In the area where the cumuliform clouds appear, cold air is being heated from below as it moves over

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[1]Synoptic scale: Characteristic dimension 300-1500 miles (500-2500 Km)

[2]The meteorologist using satellite pictures for the first time should be aware at all times that he is seeing the cloud patterns from above the clouds.

warmer water. Here, the cumulus cloud elements form a pattern of irregular polygons with less cloudy or "open" centers. This type of pattern is referred to as "open cellular." The convection cells producing the cloud pattern are mesoscale[1] in size. This type of pattern is observed mainly over the oceans where large amounts of water vapor are available in the lower levels of the atmosphere. Where open cellular patterns are observed the air is unstable through a relatively deep layer above the surface and the clouds are largely cumulus and cumulus congestus.

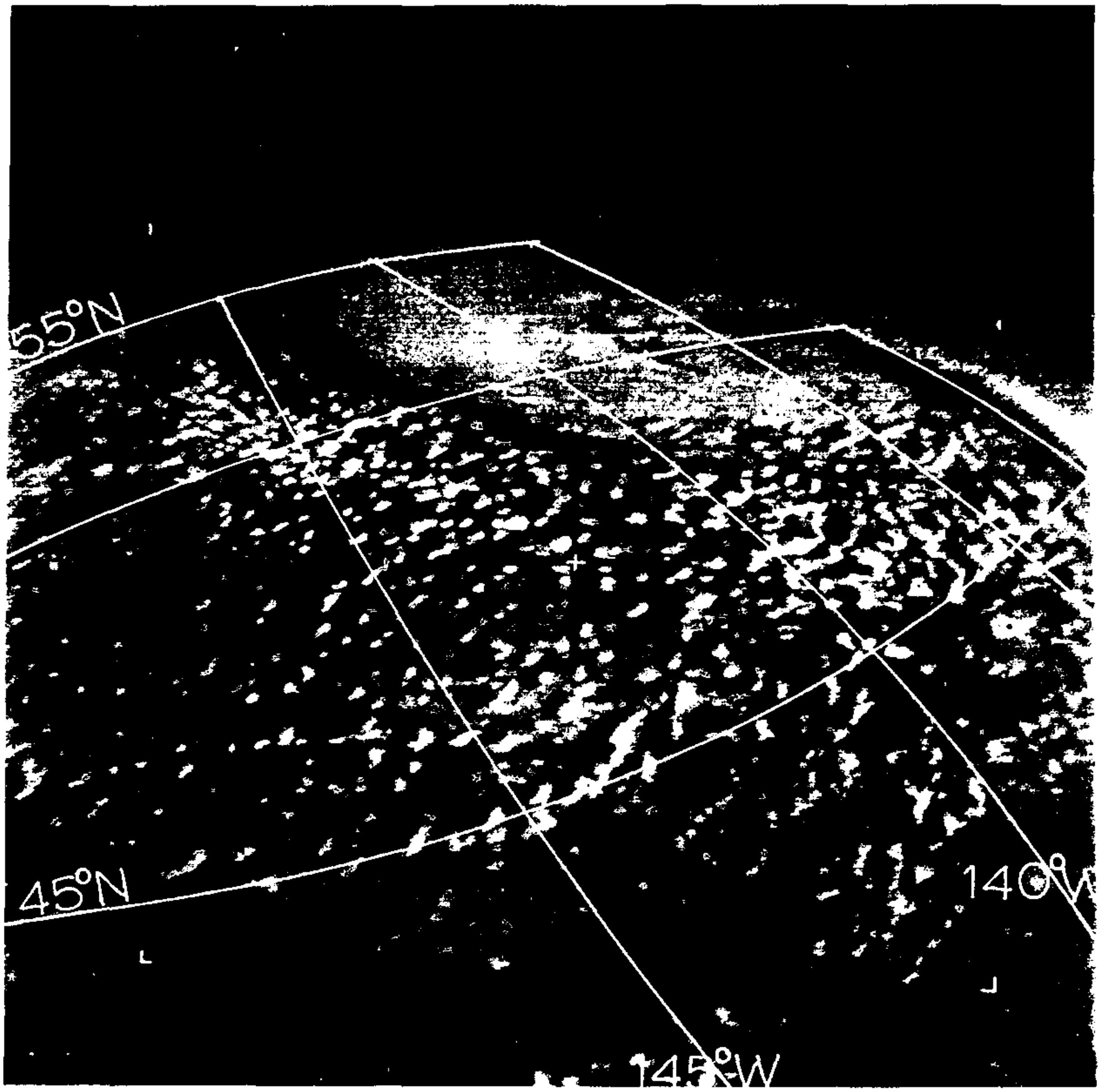

Fig.14 Open cellular pattern, cumuliform clouds--North Pacific--2302 GMT, Jan.9, 1964 TIROS 7 Pass 3010T. (Pass number is that of the orbital pass on which data was acquired from the satellite. T indicates stored data; D would indicate pictures taken directly.)

A cellular pattern of different appearance is shown in figure 15. This is a satellite view of clouds in the southeast quadrant of a polar high. In this picture the mesoscale convection cells appear to have cloud covered centers, hence the pattern is referred to as a "closed cellular" pattern. This pattern is observed in areas where subsiding air aloft produces a stable layer, or inversion. The clouds forming this pattern are predominately stratocumulus. Closed cellular patterns are observed most of the year in the eastern portion of the subtropical oceans.

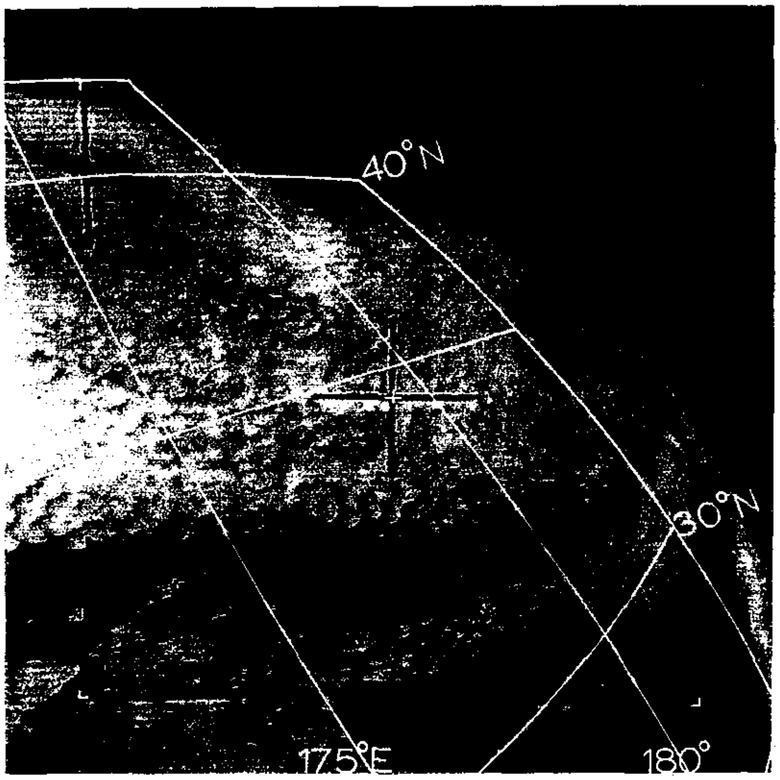

Fig.15 Closed cellular pattern, cumuliform clouds--North Pacific--2243 GMT Oct.30, 1963 TIROS 7 Pass 1974T

Banded structure in cumuliform clouds is seen in figure 16. This picture shows cumulus forming immediately off the eastern shore of North America in cold continental air as it moves offshore over warmer water. Research has indicated that the orientation of convective cloud bands is frequently coincident with the direction of the shear through the layer in which the convection is occurring. In this example, the bands appear smallest in the area offshore where the clouds first form (G, fig. 16). Since there is little vertical development in these small cloud lines their orientation closely approximates that of the surface wind direction. Downstream, as the clouds increase in height (H, fig.16), the bands grow in width and are more closely oriented in the direction of the shear through the convection layer. Further to the east (I, fig.16) the banded structure breaks down into an open cellular pattern. A frontal band can be observed in the picture near the horizon (J, fig.16).

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[1]Mesoscale: Characteristic dimensions: 30-300 mi (50-500 Km)

Fig.16 Banded structure, cumuliform clouds--North Atlantic--1713 GMT April 12, 1963 TIROS 6 Pass 3010D

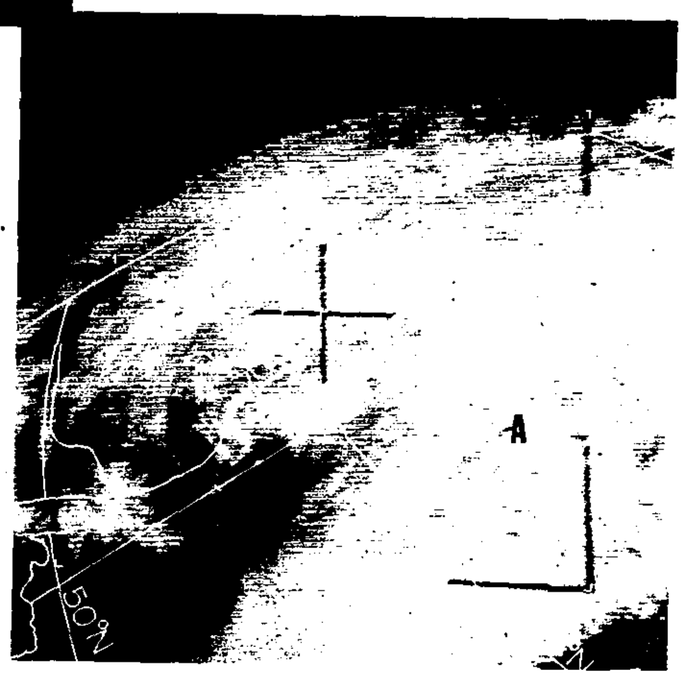


Fig.17 Shadows and highlights, cumuliform clouds--North Atlantic--1316 GMT, Sept. 19, 1962--TIROS 6 Pass 0018T

Figure 17 shows an example of the appearance of cumuliform clouds in a completely cloud covered area. This "pebbled" or "bumpy" appearance (A, fig.17) results from shadows cast by cumuliform cloud elements protruding above the general level of cloud tops. Where sun angles are low, protruding cumuliform cloud elements are highlighted on the side toward the sun, and cast a shadow on lower clouds on the side farthest from the sun.

2.1.2 Stratiform Cloud

Stratiform cloud areas normally lack organized pattern or structure (A, fig.20). The cloud types which have this appearance in satellite pictures, are thick stratus cloud or fog (A, fig.42), thick altostratus and nimbostratus. Cirrostratus when it occurs above layered altostratus can also have this appearance.

2.1.3 Cirriform Cloud

The term cirriform is applied to clouds which have a fibrous appearance. Cirriform clouds have been identified in satellite pictures in association with such identifiable cirrus producing atmospheric systems as cumulonimbus clusters and the jet stream.

Clouds of fibrous appearance are visible in figure 18 south of the 5°S latitude line. This picture shows an extensive area of cirriform cloud over Northern Brazil. Examples of cirriform cloud associated with the jet stream are also shown in figures 19, 21 and 22. The cirrus produced by cumulonimbus is shown in figures 38 and 39. Over highly reflective land, thin cirrus may not be detectable in satellite pictures.

2.2 Extratropical Cloud Systems

2.2.1 Jet Stream

Under certain circumstances, cirrus clouds associated with the jet stream are visible in satellite pictures. Looking downstream along a jet core, an extensive cirrus cloud shield often forms to the right of the core (left in the southern hemisphere) in areas where the jet is turning anti-cyclonically. The edge of this cirrus shield nearest to the core of strongest winds is relatively straight and lies parallel to the core. This cirrus edge is visible in satellite pictures and can be used as a guide in locating the jet stream.

A jet associated cirrus cloud shield is shown in figure 19. The edge of the cirrus cloud can be seen extending from point A to point B. The cirrus cloud area can be identified by its relative translucence; the lower clouds can be seen through this cirrus deck. Cumuliform clouds (C, fig.19) which can be seen to the north of the cirrus formation extend to the southeast under the cirriform cloud (D, fig.19). Around point C, the cumuliform cloud elements are bright and have sharp well defined edges. The cloud-free areas appear dark. Around point D, where the cumuliform clouds are visible through the cirrus, each cloud element has an indistinct edge and the areas between elements appear grey. This appearance is typical of lower clouds when viewed through a layer of thin higher cloud. A relatively translucent cloud area, such as the one above, with an extensive straight edge identifies a formation as jet associated cirrus cloud.

Fig.18 Fibrous appearance, cirriform clouds--Northern Brazil--1626 GMT, Feb. 12, 1964--TIROS 7 Pass 3523T

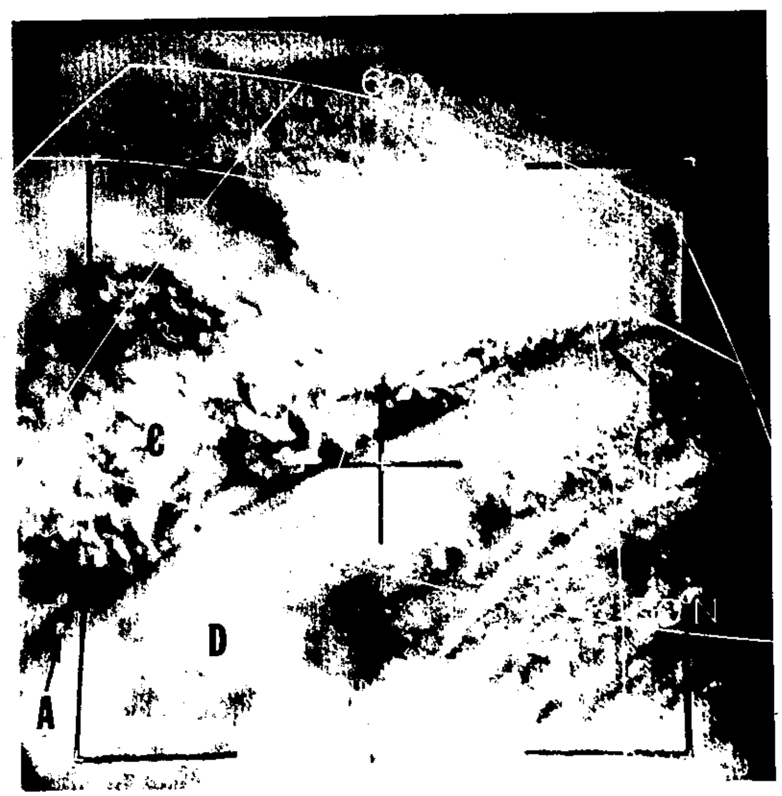


Fig.19 Jet Stream cirriform cloud formation, cumuliform clouds detectable beneath--North Atlantic--1511 GMT, Jan. 31, 1964 TIROS 7 Pass 3346T

Many times the cirrus shield associated with a jet occurs above an area totally covered with lower clouds. Under these circumstances, it is often difficult to identify the straight edge of this cirrus unless the shadow cast by this cloud edge is detectable in the picture. This shadow is most apparent when the difference in height between the top of the cirrus and the top of the lower undercast is large and the sun angle is low. The shadow effect is most pronounced at higher latitudes.

An example of this shadow effect is shown in figure 20. The cirrus cloud edge extends from J to K across the picture. The shadow appears as a thin dark line, without which it would be impossible to detect the presence of the cirriform cloud shield.

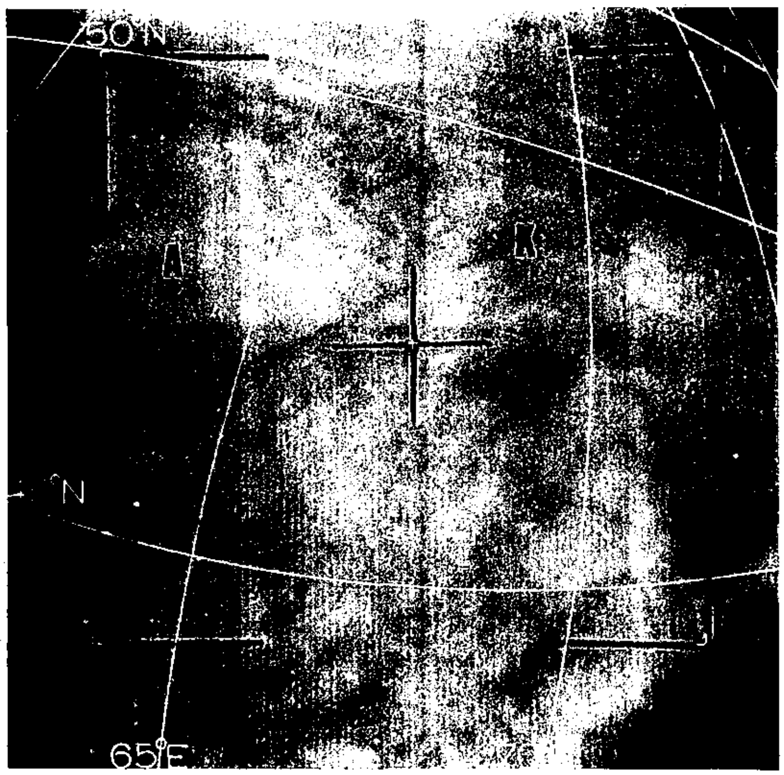


Fig.20 Shadow effect, jet stream cirriform cloud layer. Kazakh Republic, USSR--0741 GMT, Mar. 29, 1964 T-5 Pass 4202T

A banded structure is often seen in satellite pictures of middle and high clouds. An example of this is the streaky cirrus over northern Florida and southeastern Georgia in figure 21 (A, Fig.21). A jet stream core was located just to the north of these clouds. Small cloud bands or streaky cloud formations similar to the one in this picture often are observed where the upper winds are strong. In situations where there is little horizontal shear in the wind direction aloft, the orientation of the bands and streaks in high clouds is a good indication of the direction of upper level flow. Figure 21 is a good example of banded cloud structure parallel to the upper level wind flow.

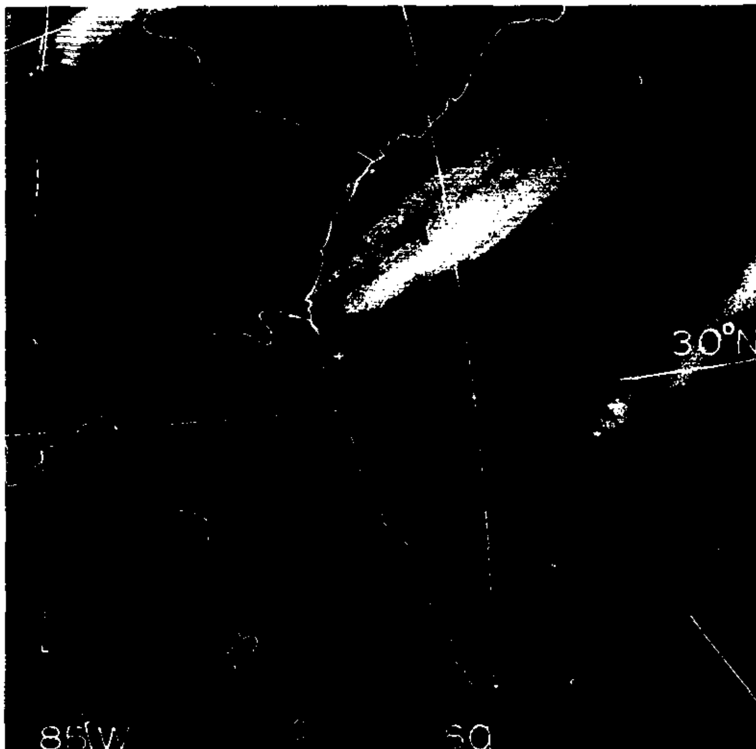


Fig.21 Banded structure, streaky cirriform clouds near the jet stream-- Southeastern United States--1650 GMT Feb.9, 1964 TIROS 7 Pass 3479T

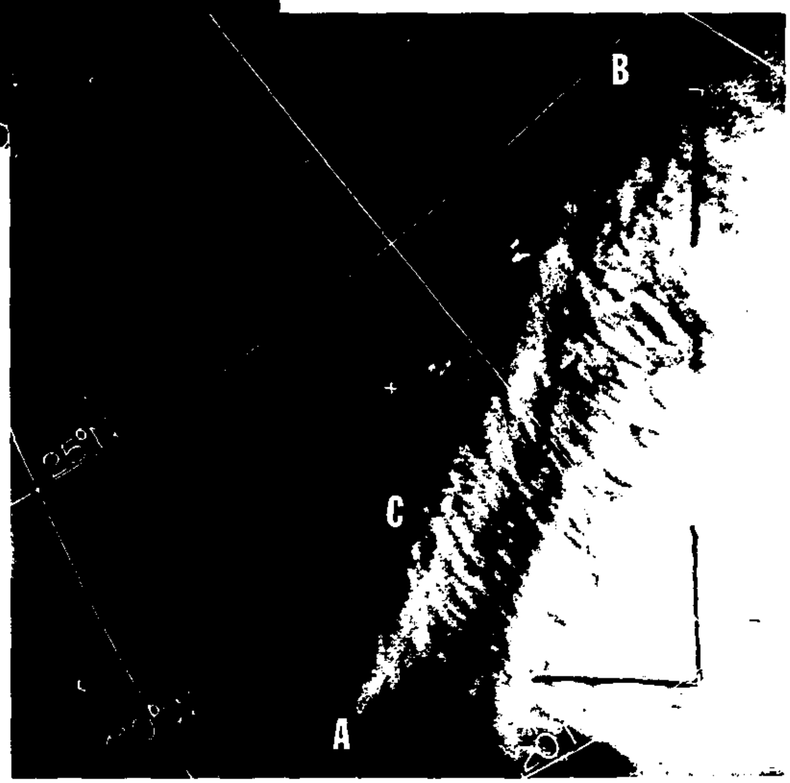


Fig.22 Transverse bands, cirriform cloud formation along the jet stream-- Western Mexico--1919 GMT Jan. 7, 1964 TIROS 7 Pass 2992T

Cirrus clouds along a jet on occasion exhibit banding which is nearly perpendicular to the upper flow. This transverse banding often turns anti-cyclonically along the cloud edge . Figure 22 shows transverse banding in the clouds associated with a subtropical jet located over the west coast of Mexico. Here, the northern edge of the jet-associated cloud band extends from point A northeastward to point B. The transverse banding is most pronounced immediately to the southeast of point C. This type of transverse banding in cirrus is observed over both land and water and helps to identify the cloud formation as jet-associated.

2.2.2 Fronts and Frontal Waves

Frontal cloud bands are quite easily recognized in satellite pictures. The frontal cloud system of a fully occluded storm is shown in figure 23. In this picture, a continuous cloud band spirals from point A, southwest of the storm, inward to the storm center at point B. This cloud band corresponds to the cold and occluded portion of the frontal system. To the east of the storm there is no clearly identifiable cloud formation representing the warm front. Clearly identifiable frontal cloud bands are observed in satellite pictures only in zones of strong baroclinicity. Where baroclinicity is relatively weak, as is the case with many warm fronts, no organized cloud band will be in evidence. The clouds to the rear of the cold front around point C are cellular cumulus. This is the typical cloud pattern observed to the rear of cold fronts over ocean areas.

Frontal cloud bands in advance of upper trough lines have a distinctly different appearance than those which lie to the rear of upper trough lines. This change in appearance is illustrated in figure 24. This picture shows a 500mb trough line intersecting a frontal cloud band in the vicinity of point A. The portion of the front to the north of point A is in advance of the upper level trough line. Upward vertical motion in this area is at a maximum and the frontal cloud band is relatively wide with no breaks apparent in the clouds. Southwest of point A the frontal band has different characteristics. It is much narrower and appears ragged and full of breaks. This portion of the front is to the rear of the upper trough line and is in an area where the air aloft is descending. The frontal band in this area is composed mostly of cumuliform clouds. East of the trough line where the front broadens the clouds are multilayered and the cloud tops have a smooth appearance. In figure 25 the 500mb trough line does not cross the front and the frontal band maintains the same relative width along its entire length. The knowledge that the appearance of frontal cloud bands is associated with the relative positions of the front and its associated upper trough line can be used to position trough lines in sparse data areas.

The formation of a wave on a frontal cloud band is indicated in satellite pictures by a widening of the band where the wave is forming. The middle and high clouds which accompany an active front become thicker and more extensive near a developing wave. Where the frontal band is widest the edge of the cloud along the cold side of the band has a convex curvature toward the cold air. This edge is almost always curved concavely toward the cold air except when a frontal wave is present. There is no recognizable circulation center visible in frontal clouds during the early stages of wave development.

An example of a developing wave is shown in figure 25. In this picture, a front associated with a strong baroclinic zone extends northeastward across the Gulf of Mexico and along the east coast of the United States. The 500 millibar trough approaching from the west is inducing the formation of a wave on the front at point A. Here the frontal cloud band has become wider and shows convex curvature toward the cold air.

Two days later, this wave developed into the fully occluded storm shown in figure 23.

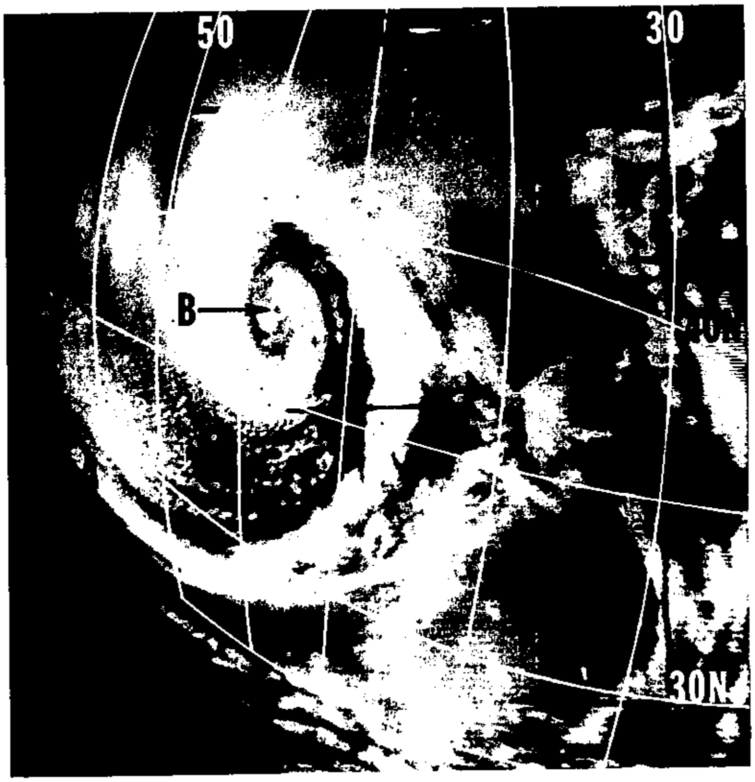


Fig.23 Vortex and frontal band, occluded storm--Atlantic Ocean--1707GMT Feb.16, 1965 TIROS 9 Pass 307

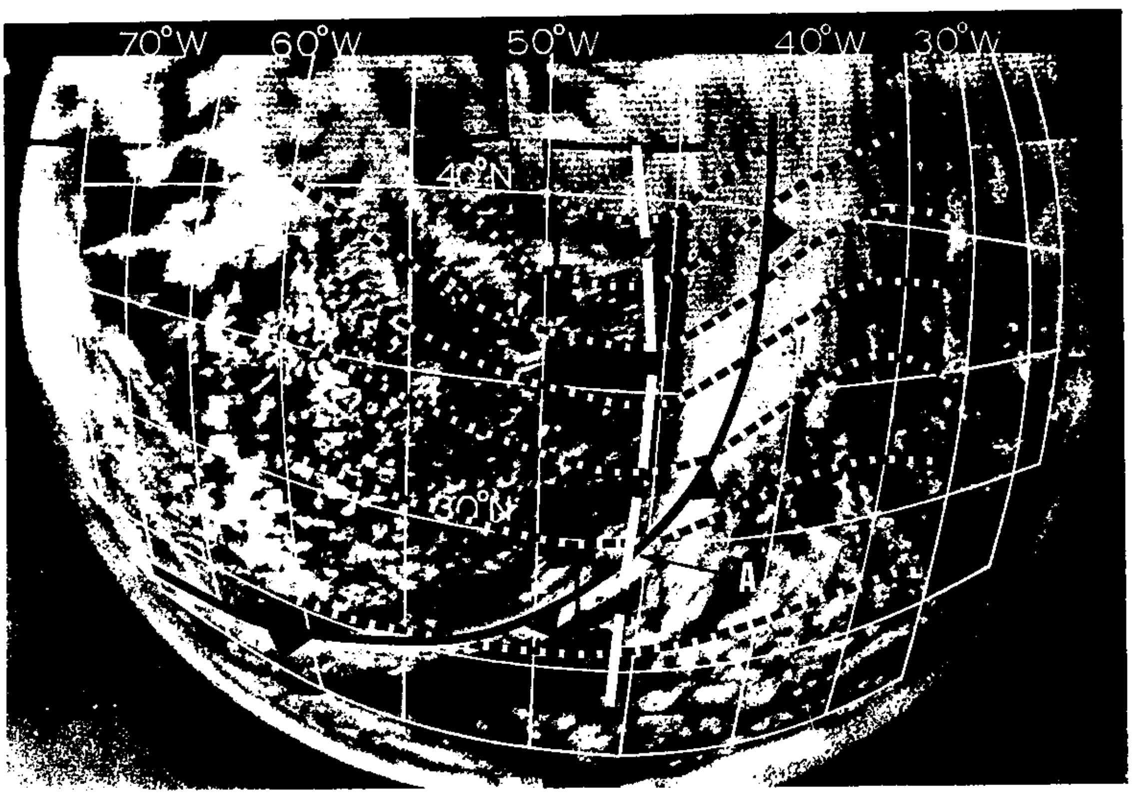


Fig.24 Change in character of a frontal cloud band where an upper air trough line crosses the front. 500mb contour pattern indicated by dashed line--North Atlantic--1641 GMT Feb 6, 1965 TIROS 9 Pass 186

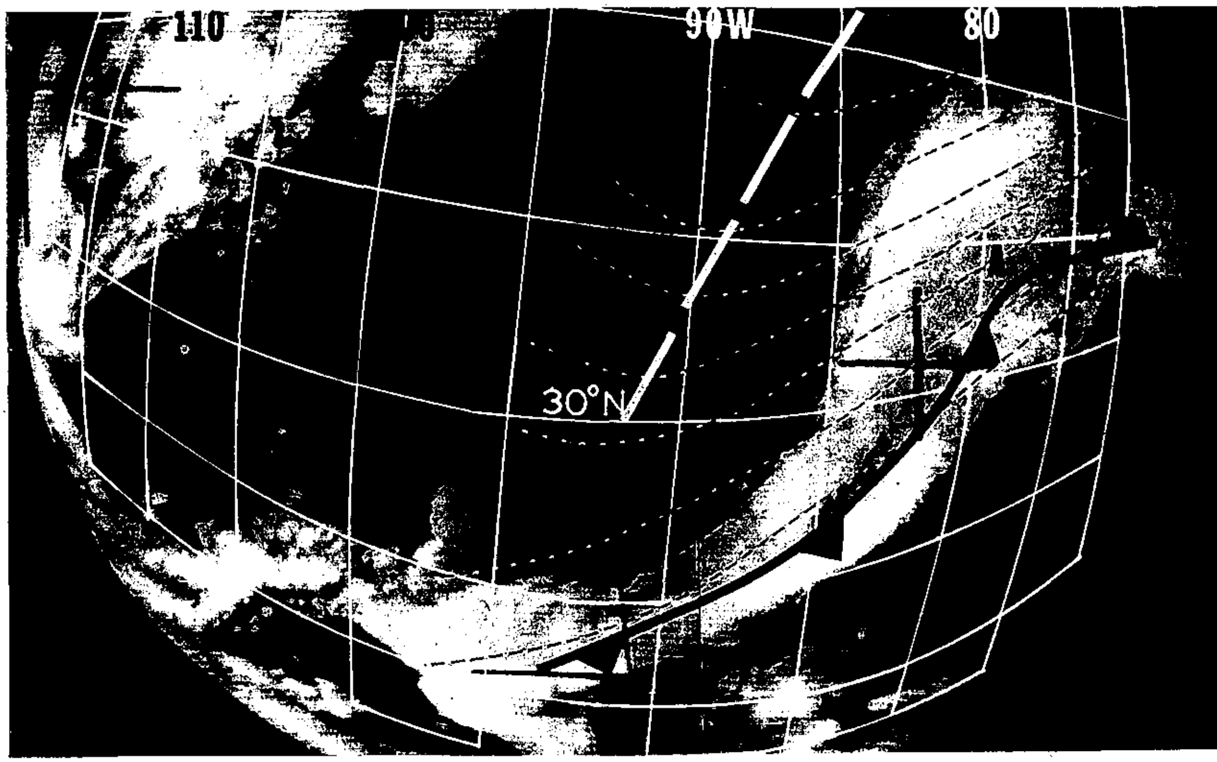


Fig.25 Wave forming on a frontal cloud band. 500mb contour pattern indicated by dashed line--North America--1924 GMT Feb.14,1965 TIROS 9 Pass 284

2.2.3 Centers of maximum positive vorticity

In the cold air some distance behind a cold front there is often evidence in the clouds of the presence of a maximum of positive vorticity. The presence of a vorticity maximum is evidenced in the pictures by an area of more active cumulus convection in the open cellular cumulus of the cold air. This area of enhanced cumulus frequently has a clearly detectable vortical pattern suggestive of a rotation center. Figure 27 shows an example of this pattern at point A. The increased cumulus activity in this area is a result of the steep lapse rate and upward motion found in and in advance of a maximum of positive vorticity associated with an upper level shortwave trough. Figure 26 shows a more developed cloud system (A, Fig.26) associated with a maximum of positive vorticity. The cloud formation in figure 26 is more developed than that in figure 27 and appears crescent, or comma shaped. The area where the cloud cover in this formation is most extensive (A, fig.26), corresponds closely with the area of maximum mid-tropospheric vorticity advection. The cloud formations just described are observed mainly in the cellular cumulus patterns in the cold air over the oceans. Over land, where the air in cold outbreaks is quite dry at low levels, little or no cold air cumulus is found behind the front. This is the case in figure 25; there are no clouds associated with the positive vorticity maximum in the trough line to the rear of the front. The cloud formations of vorticity maxima represent significant weather systems in themselves, and are also an aid in identifying and locating vorticity centers to the rear of fronts. Such vorticity maxima are significant in that they can be instrumental in producing or reinforcing wave development.

2.2.4 Vortices

The spiral cloud patterns produced by a vortex have many variations, most of which are readily recognizable in satellite pictures. The more spectacular patterns are those associated with storms with a closed wind circulation extending from the surface through at least the 500mb level. When deep storms of this type are quasi-stationary or moving slowly, the major cloud band of the vortex may make more than one complete revolution inward toward the storm center. Examples of this type of vortex are shown in figures 23 and 28. Such fully developed storms have little tilt with height and the center of the cloud spiral corresponds closely to the center of the three dimensional wind circulation.

Storm systems with an open trough aloft and a closed circulation only in the lower levels, have a somewhat different appearance. These storms which usually are moving with the speed of the upper air shortwave trough, have a more crescent shaped cloud formation. The band of clear air behind the major cloud band does not spiral completely into the center of the system as it does in the storms with deep closed circulations.

2.2.5 Satellite Data Applied to Weather Analysis

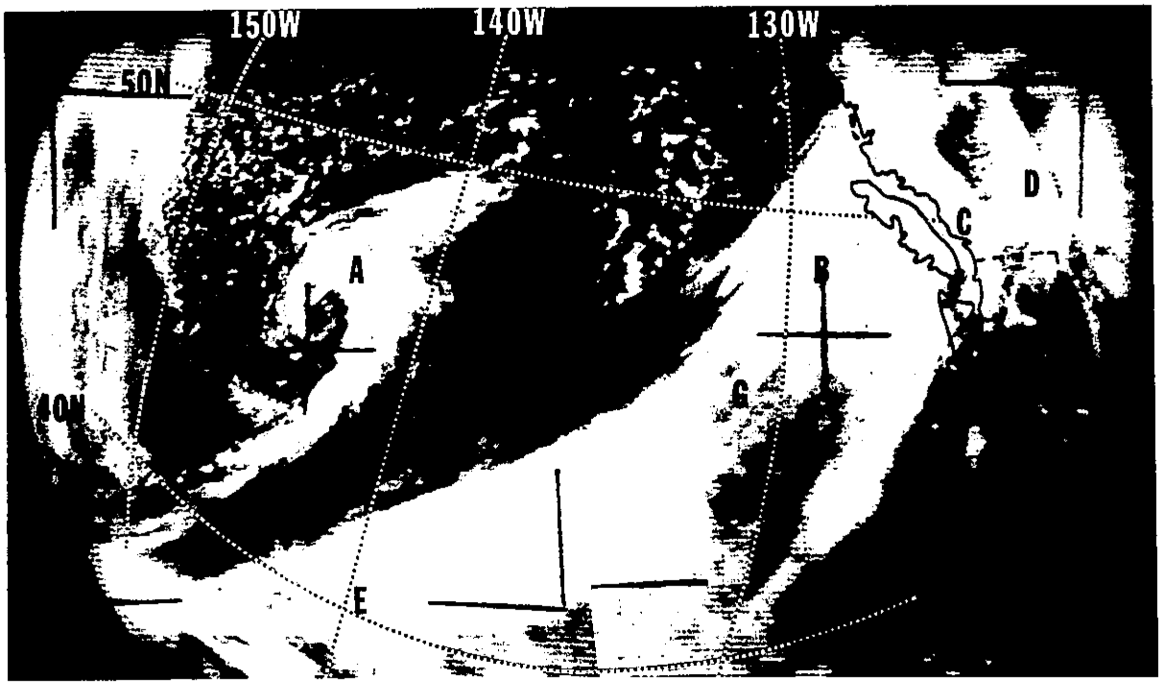
The cloud formations produced by fronts, vorticity maxima, and vortices have a definite relationship to the flow patterns appearing on surface and upper air weather charts. Some examples of these relationships are shown in figures 26, 27 and 28. In these three examples the 1000mb and the 500mb analysis for the areas of the satellite pictures have been rectified to the same perspective as the satellite views. The analyses represent the best fit of the surface and 500mb contours to the satellite cloud formations, and are based on the latest findings regarding these relationships. The analyses are compatible with all the conventional data available at the synoptic reporting times nearest to the time of the pictures, and are adjusted slightly toward the times of the satellite pictures.

EXAMPLE 1.

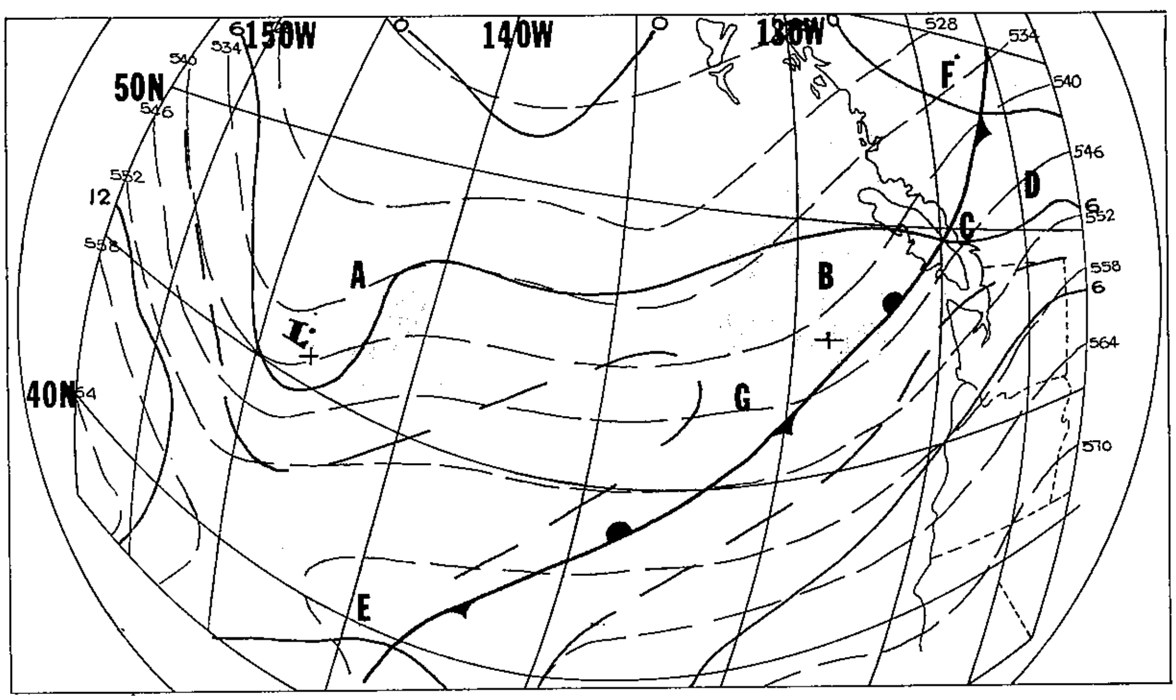
The relatively broad frontal band in figure 26A extends from point E northeastward to point F. The cloud formation produced by a vorticity maximum is seen at point A in the cold air to the rear of the front. A weak 500mb trough line crosses the frontal zone at point B. At point G, to the rear of this trough, the frontal band is thinner, and breaks appear in the clouds. The two bright cloud bands at C and D are orographic clouds on the windward side of the Coast Range and the Rocky Mountains of British Columbia.

Fig. 26A Example 1: Satellite Data Applied to Weather Analysis. Cloud formation produced by a maximum of vorticity-- North Pacific. 2155 GMT, Feb. 25, 1965 TIROS 9 Pass 418

Fig. 26B Example 1: Satellite Data Applied to Weather Analysis Surface and 500mb analyses for the same time as the satellite picture shown in figure 26A. Shaded areas correspond to significant cloud areas in the picture. Dashed lines are 500mb contour lines labeled in tens of meters. Continuous lines are 1000mb contour lines labeled in tens of meters. The analysis shown on figures 27B and 28B is depicted similarly.



150W
140W
130W
50N
40N
A
B
C
D
E
G



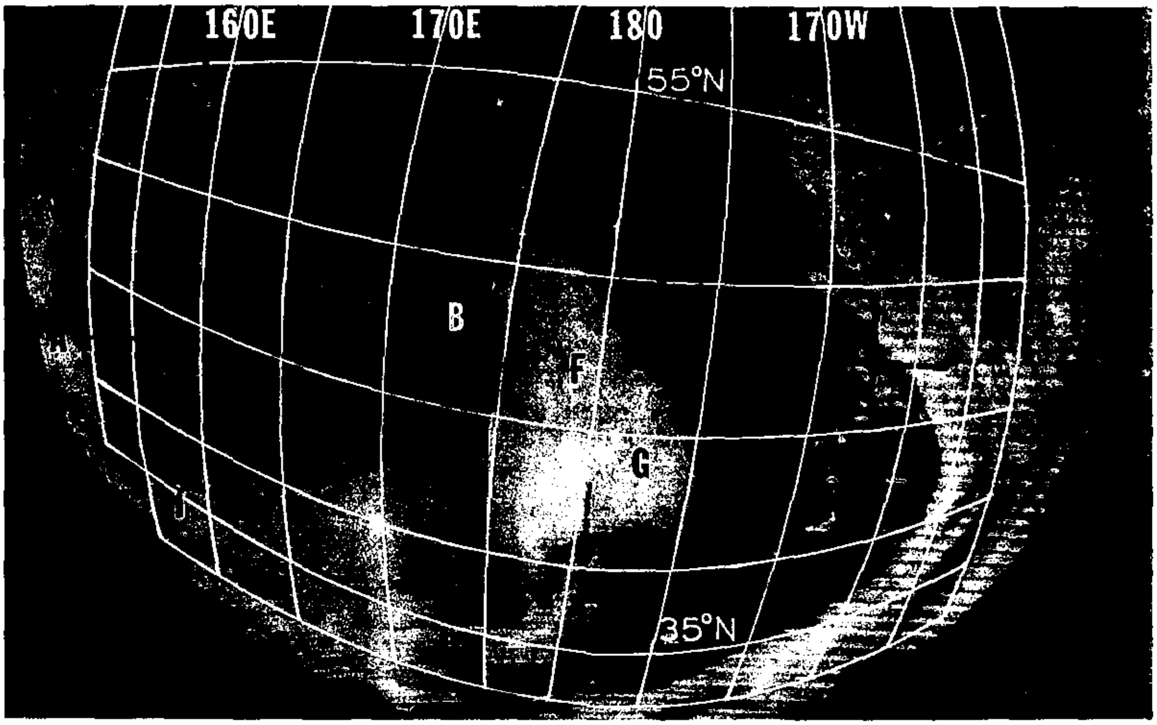
150W
140W
130W
50N
40N
A
B
C
D
E
F
G
L
528
534
540
546
552
558
564
570

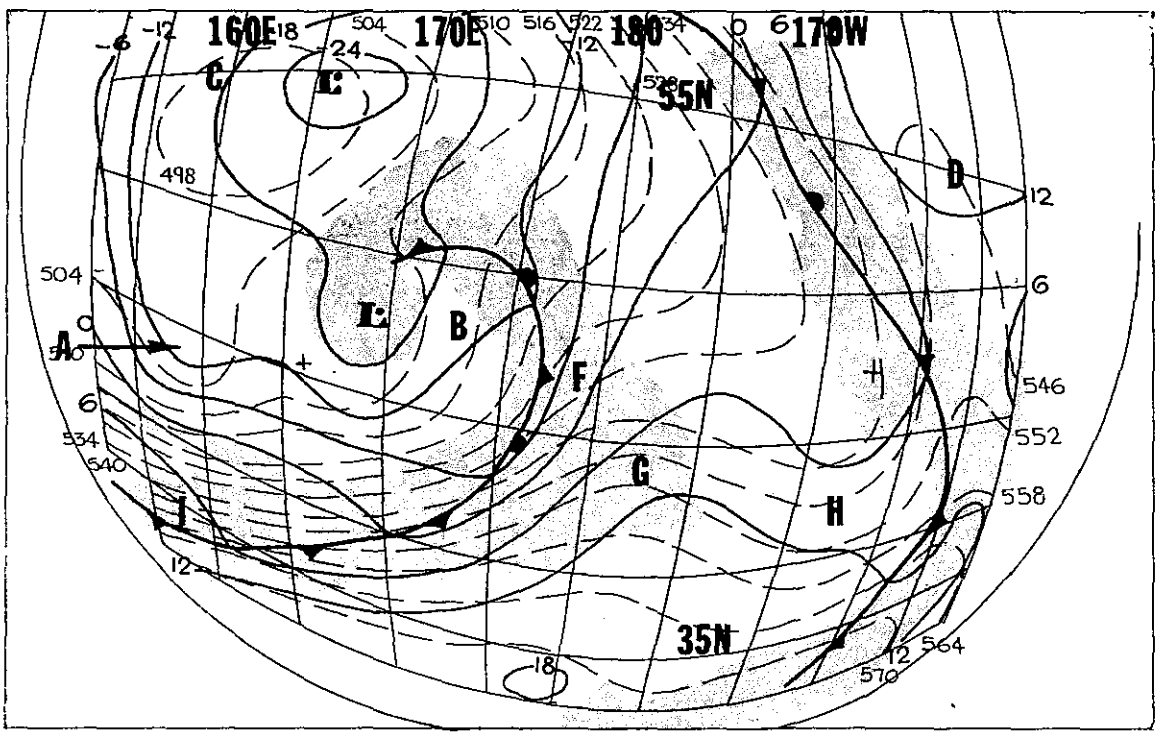
EXAMPLE 2.

A newly occluded cyclone is shown in figure 27. The Kamchatka Peninsula is seen at point C and the Aleutian Islands are visible extending westward from point D. The 500mb flow is divergent near 180°. The jet stream passes over the frontal clouds and turns southeastward near point G. North of the jet, around point F, shadows from cumuliform cloud elements protrude above the general cloud tops causing this area to appear uneven or "bumpy." South of the jet the clouds have a much smoother appearance. The frayed appearance of the clouds east of point G is typical of dissipating cirriform cloudiness found along a jet on the east side of a ridge line. To the north of the jet position, the frontal cloudiness ends abruptly at about the position of the 500mb ridge line.

Fig. 27A Example 2: Satellite Data Applied to Weather Analysis. Vortex and frontal cloud bands. Central-North Pacific- 0124 GMT, Feb. 2, 1965 TIROS 9 Pass 130

Fig. 27B Example 2: Satellite Data Applied to Weather Analysis. Surface and 500mb analysis for the same time as the satellite picture shown in figure 27A.


160E
170E
180
170W
55°N
B
F
G
J
35°N

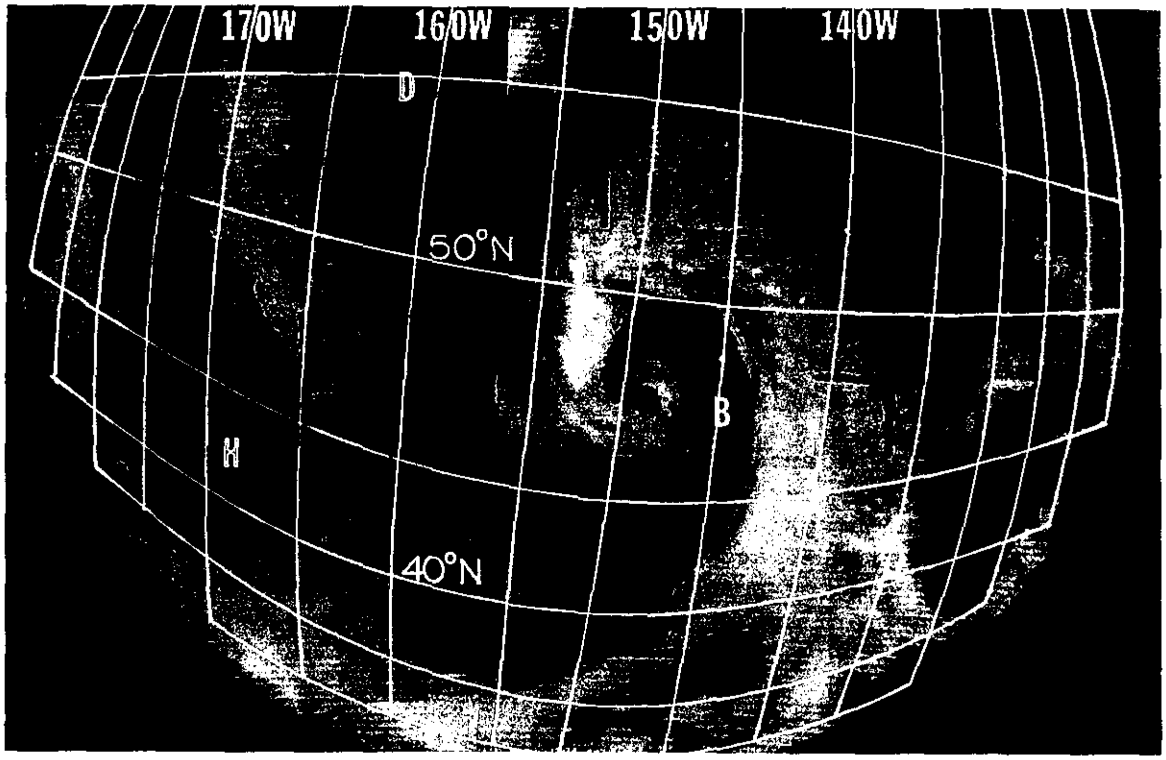

160E
170E
180
170W
55N
35N
A
B
C
D
F
G
H
J
L
498
504
546
552
558
564
570

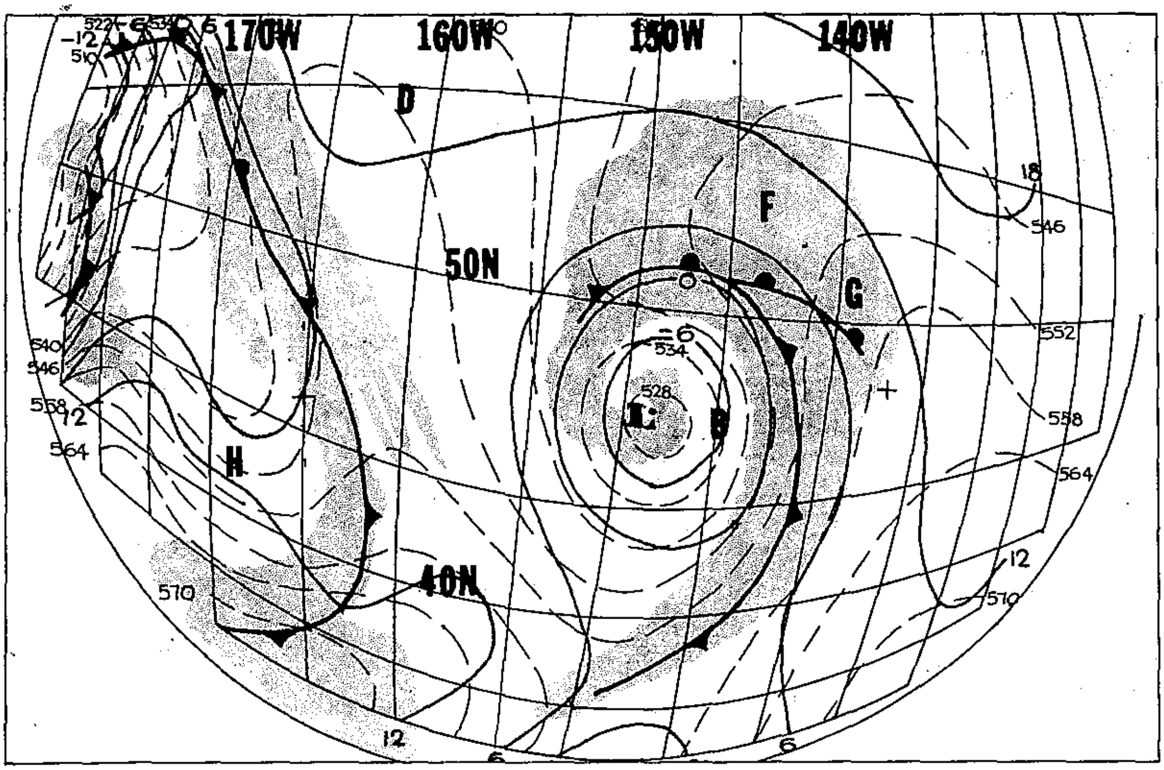
EXAMPLE 3.

Another occluded storm is shown in figure 28. This photograph was taken two hours earlier than that in figure 27. The Aleutians are again seen extending westward from point D. The storm in this picture has more of a cut-off circulation at 500mb than the one shown in example 2. The band of clear air spiraling into the vortex center (B, Fig.28) is more developed in this slow moving, cut-off type storm. The same change in cloud texture observed between points F and G in figure 27 can be seen also in figure 28 in the area where the jet stream crosses the frontal clouds. On the cold side of the jet (F, Fig.28) the clouds have a bumpy appearance. On the warm side, around point G, the clouds have a much smoother appearance.

Fig. 28A Example 3: Satellite Data Applied to Weather Analysis
Spiral cloud pattern associated with a cut-off 500mb low--
North Pacific--2325 GMT, Feb. 1, 1965 TIROS 9 Pass 129

Fig. 28B Example 3: Satellite Data Applied to Weather Analysis
Surface and 500mb analysis for the same time as the satellite picture shown in figure 28A.


170W
160W
150W
140W
D
50°N
B
H
40°N


170W
160W
150W
140W
D
18
546
F
50N
G
552
-6
534
528
L
B
540
546
558
12
564
H
558
564
12
570
40N
570
12
6
6

2.3 Tropical Cloud Systems

2.3.1 Zone of Intertropical Convection

Near the equator there is a zone of convective activity, generally about five degrees of latitude in width. The north and south boundaries of the zone are sharp and easily recognized in satellite pictures. Variations in convective activity along the zone produce a series of distinct cloud systems. These active cloud systems are interspersed with relatively inactive areas of much less cloudiness. There are seasonal variations in the position and extent of the zone, and in the cloud activity. Conditions within the zone also vary significantly from region to region.

Figure 29 shows the appearance of this zone in the equitorial Atlantic in February. An area of increased cumulus activity along the zone is centered at point A; the areas around points B and D show a minimum cumulus activity and a maximum area of activity is centered near point C. At the northern border, just south of point E the character of the cloud changes abruptly from the cumuliform and cirriform cloud within the zone, to closed cellular stratocumulus north of the zone. The region south of the zone is relatively free of clouds.

The satellite pictures make it possible to identify areas of greater cumulus activity, to observe changes in their intensity, and to track their movement.

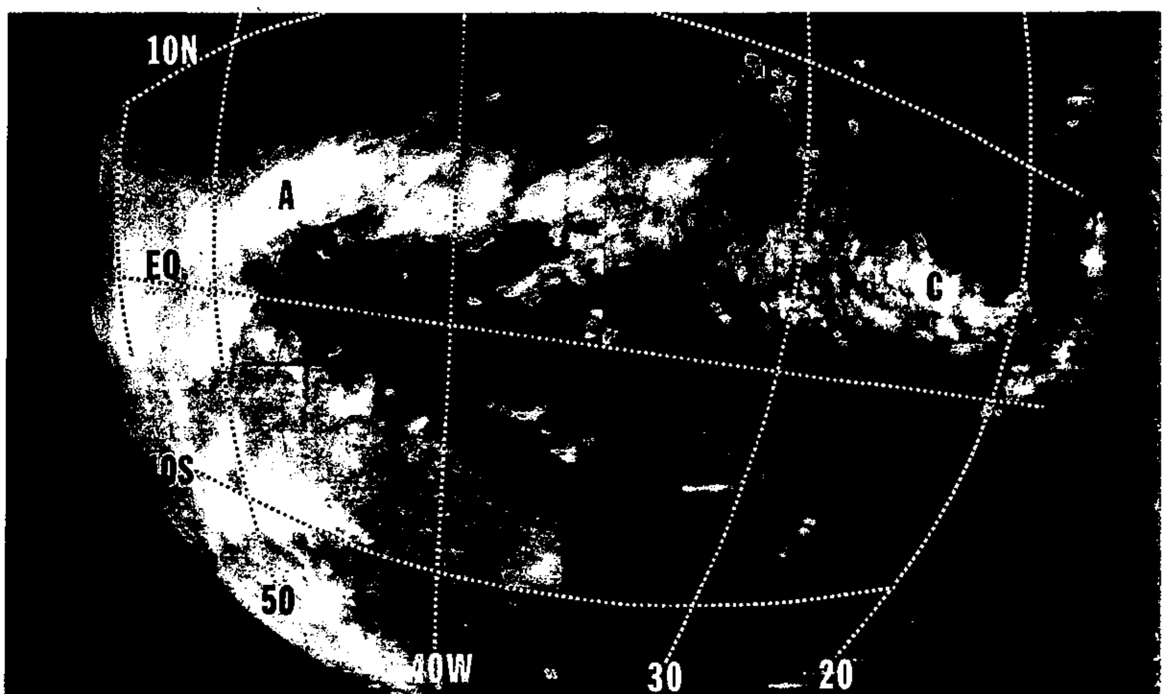
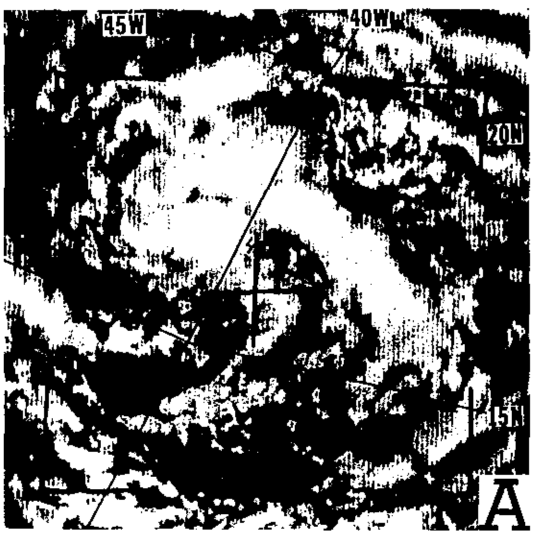


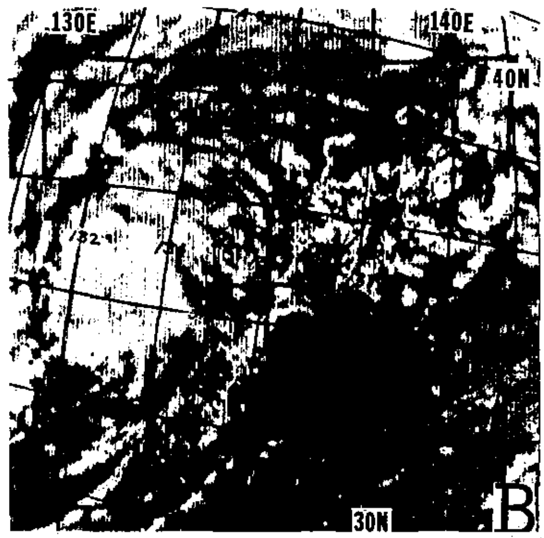
Fig. 29 Convective clouds, zone of intertropical convergence--Equitorial Atlantic 1544 GMT. Feb. 25, 1965 TIROS 9 Pass 416

2.3.2 Tropical Vortices

Good estimates of the stage of development and of the intensity of tropical storms can be obtained directly from satellite pictures. As tropical storms intensify, they undergo recognizable changes in appearance in satellite pictures. The maximum speed of the wind in mature storms is related to the size of the dense cloud shield over the storm and to the character of the striations, bands and breaks in the total cloud system.

A series of pictures showing tropical vortexes appears in figures 30 and 31. The wind speeds in these storms vary from less than 30 knots to 140 knots. The wind speeds are maximum values obtained from post storm summaries. All of the pictures in figure 30 except the one of post typhoon Sarah represent storms in the formative stages. The last four storms pictured in figure 31 are fully developed hurricanes or typhoons. These storms are arranged in order of increasing diameter of the cloud shield and concentricity of internal striations within the shield. Eyes are visible in all of these storms.





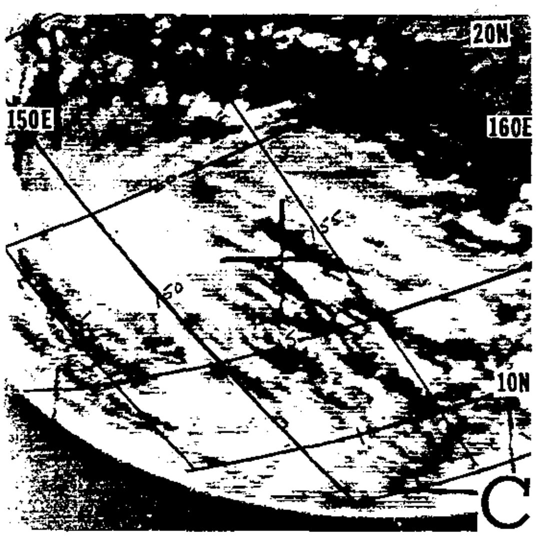
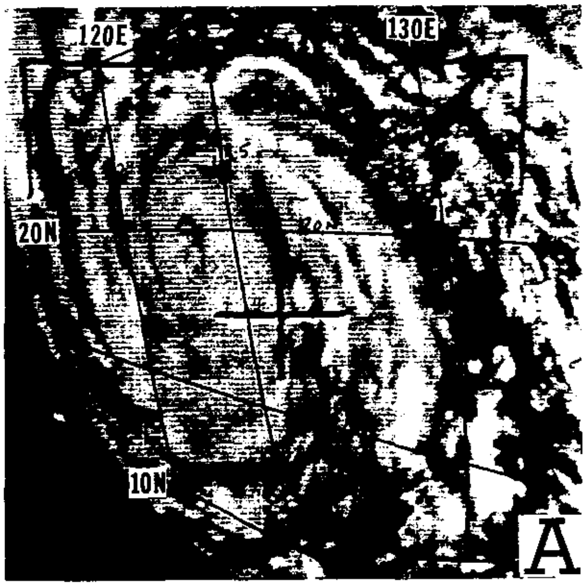
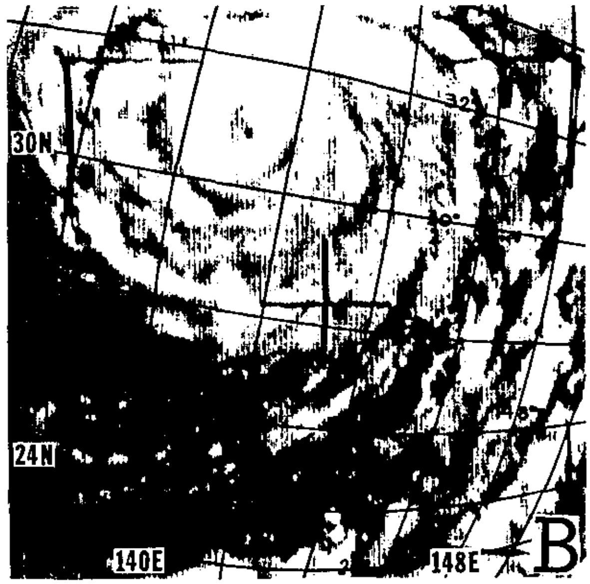


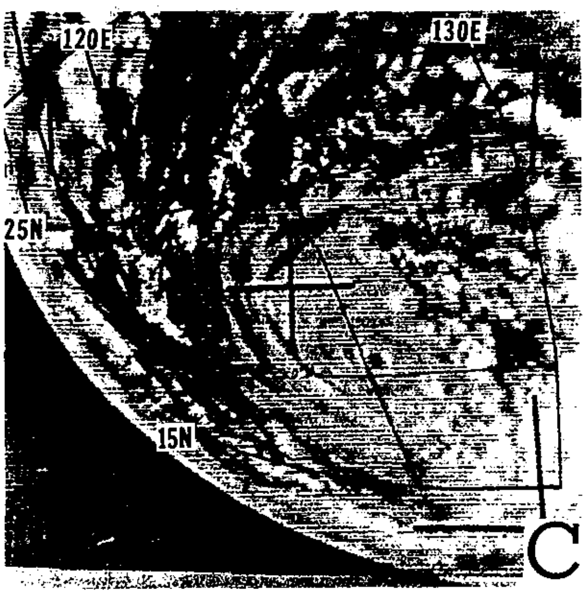
Fig.30 Tropical Vortices
A. Tropical Depression
Maximum wind 27 kts.
1205 GMT; Sept.19, 1963
TIROS 7, Pass 1362T
B. Post Typhoon Sarah
Maximum wind 30 kts.
0319 GMT; Aug.22, 1962
TIROS 5 Pass 912T
C. Tropical Storm Amy
Maximum wind 45 kts.
2250 GMT; Aug. 29, 1962
TIROS 5, Pass 1024T



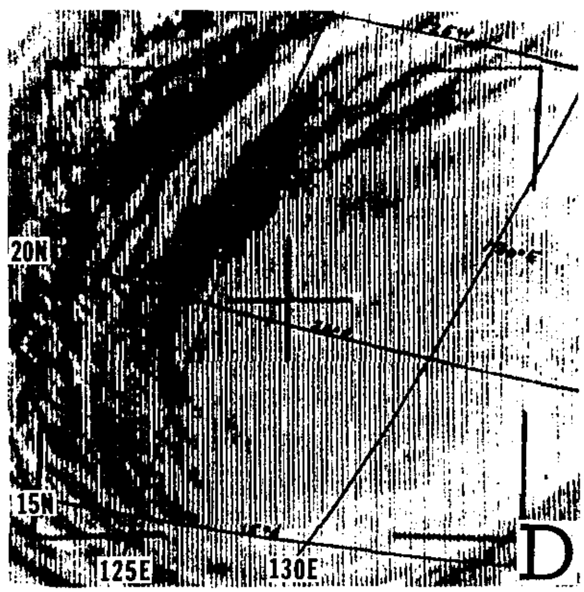
A. Typhoon Wanda
Maximum wind 80 kts.
0031 GMT; Aug. 30, 1962
TIROS 5, Pass 1034T



B. Typhoon Ruth
Maximum wind 95 kts.
0351 GMT; Aug. 18, 1962
TIROS 5, Pass 855T



C. Typhoon Amy
Maximum wind 130 kts.
2326 GMT; Sept. 3, 1962
TIROS 5, Pass 1096T



D. Typhoon Karen
Maximum wind 140 kts.
0138 GMT; Nov. 14, 1962
TIROS 6, Pass 827T

Fig. 31 Tropical Vortices

2.4 Terrain Effects and Mesoscale Cloud Systems

2.4.1 Wave Clouds

Wave clouds that form in the lee of mountain barriers produce a pattern easily recognizable in satellite pictures. This pattern shows the small parallel bands of clouds that form where a deep layer of winds is blowing perpendicular to a terrain barrier. The wave clouds formed are parallel to the barrier and perpendicular to the wind flow. Studies have shown that the wave length of lee waves, or the distance between the cloud lines, varies directly with the speed of the mean wind through the layer where the waves are occurring.

Wave clouds in a formation of altocumulus are shown in figure 32. This wave cloud pattern, east of point A, was produced by winds blowing over the Sierra Madre (altitude, 6000 ft.) in Northern Mexico. The strong winds aloft in this area were in advance of an eastward moving upper level trough. The lee waves are transverse to the upper wind direction.

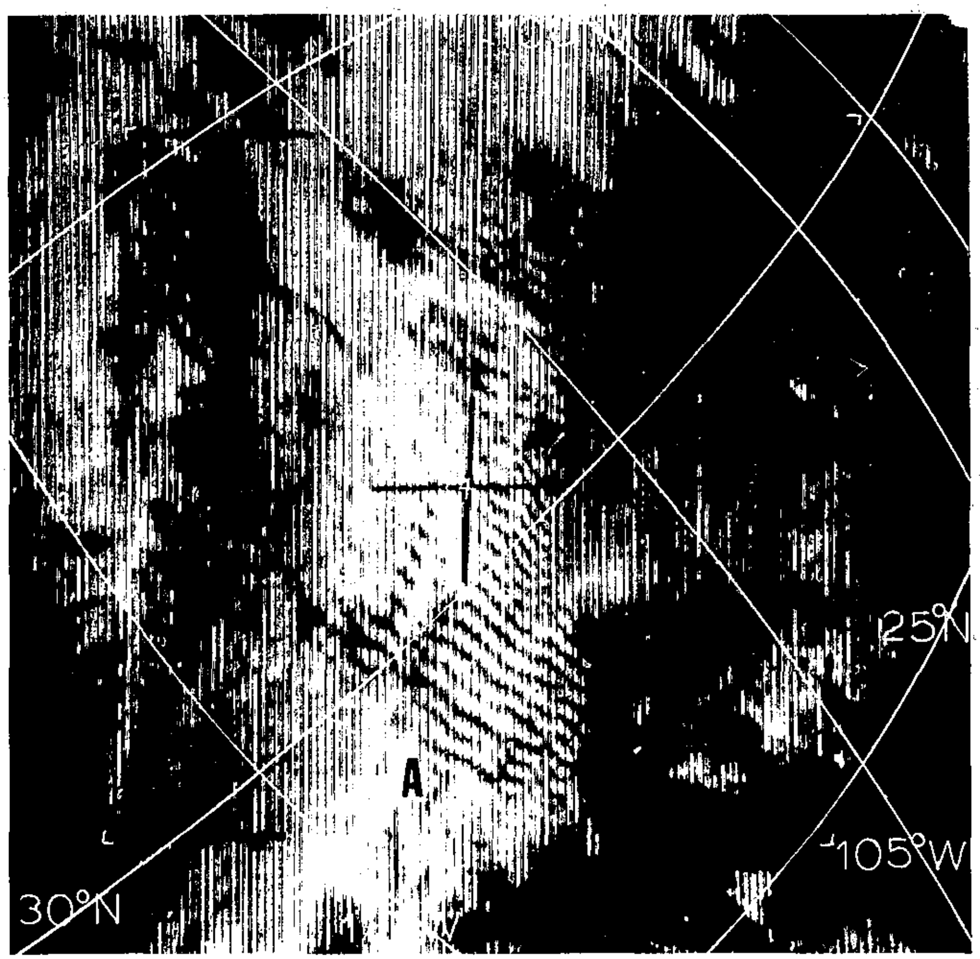


Fig.32 Wave clouds, east of the Sierra Madre--Mexico--1706 GMT, Nov. 16, 1962 TIROS 6 Pass 0851D

Wave clouds in an area of cumulus clouds are shown in figure 33. Here cloud bands transverse to the wind flow have formed to the lee of the southern Kurile Islands. The wave cloud pattern seen in the picture extends northeastward from Hokkaido Island (A, fig.33) to point B. Northwest surface winds at 40 knots were reported in the area of these lee wave clouds.

Banded structure parallel to the wind flow is also evident in this picture. The cumulus clouds in this area were formed in cold continental air heated from below as it passed over warmer water offshore (see Fig.16).

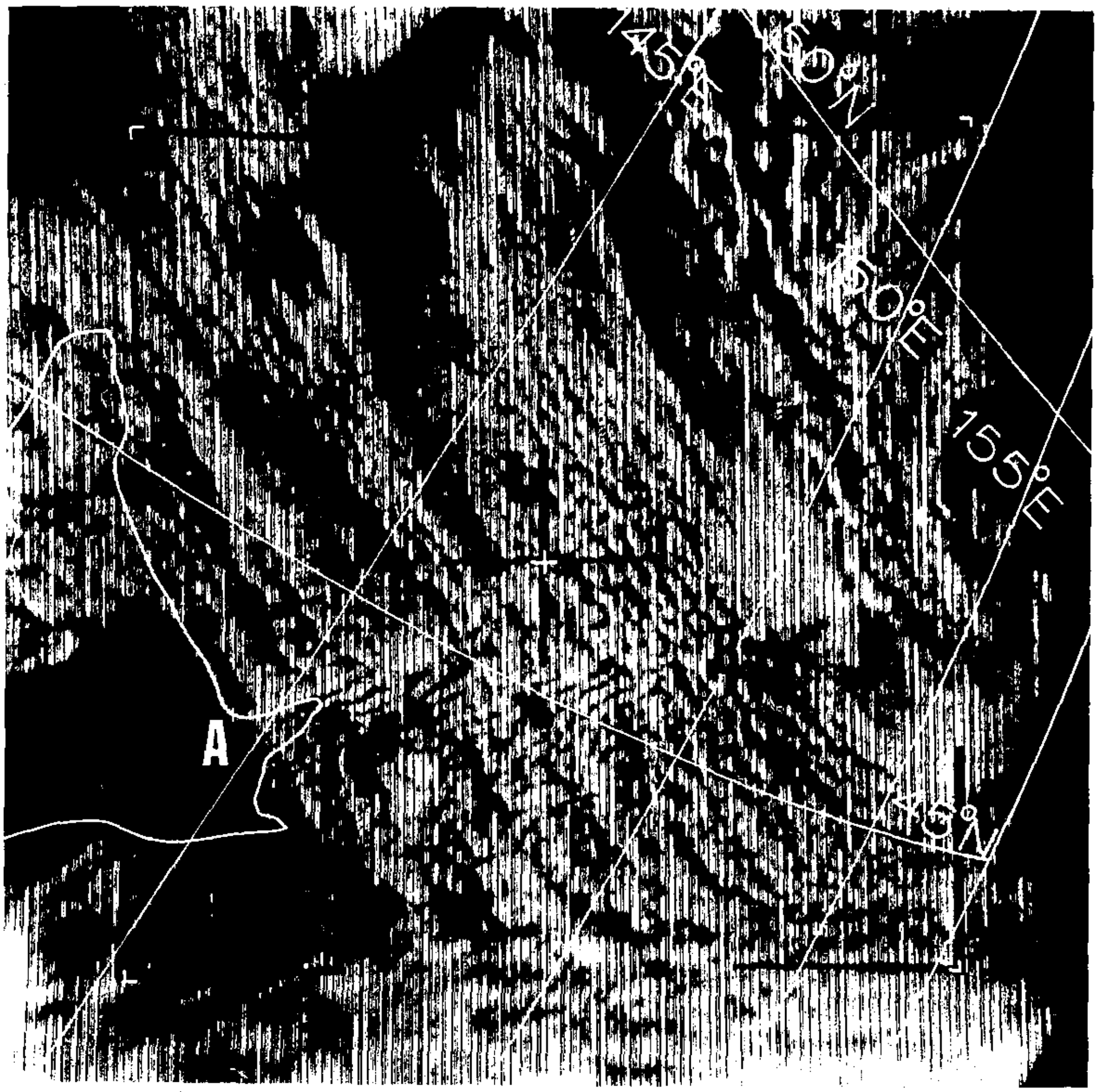


Fig.33 Wave clouds, southeast of the Kurile Islands--Western Pacific--0126 GMT Nov. 16, 1962 TIROS 6 Pass 0856T

Small cumulus cloud lines over land may appear similar to wave clouds and be mistaken for them. An example of this phenomenon is shown in figure 34. The cloud lines in this case are cumuliform clouds over southern Quebec Province, Canada. All the cumulus clouds over the relatively flat terrain in the vicinity of point A, figure 34, are arranged in small lines. In this area, the vertical development of the clouds is small and the direction of the shear through the convective layer approximates the surface wind direction. The small cloud line orientation therefore gives an indication of the surface wind direction. Only the very narrowest cloud lines appearing in satellite pictures--those just above camera resolution--are likely to be low level cumulus and have this relationship with the surface wind direction.

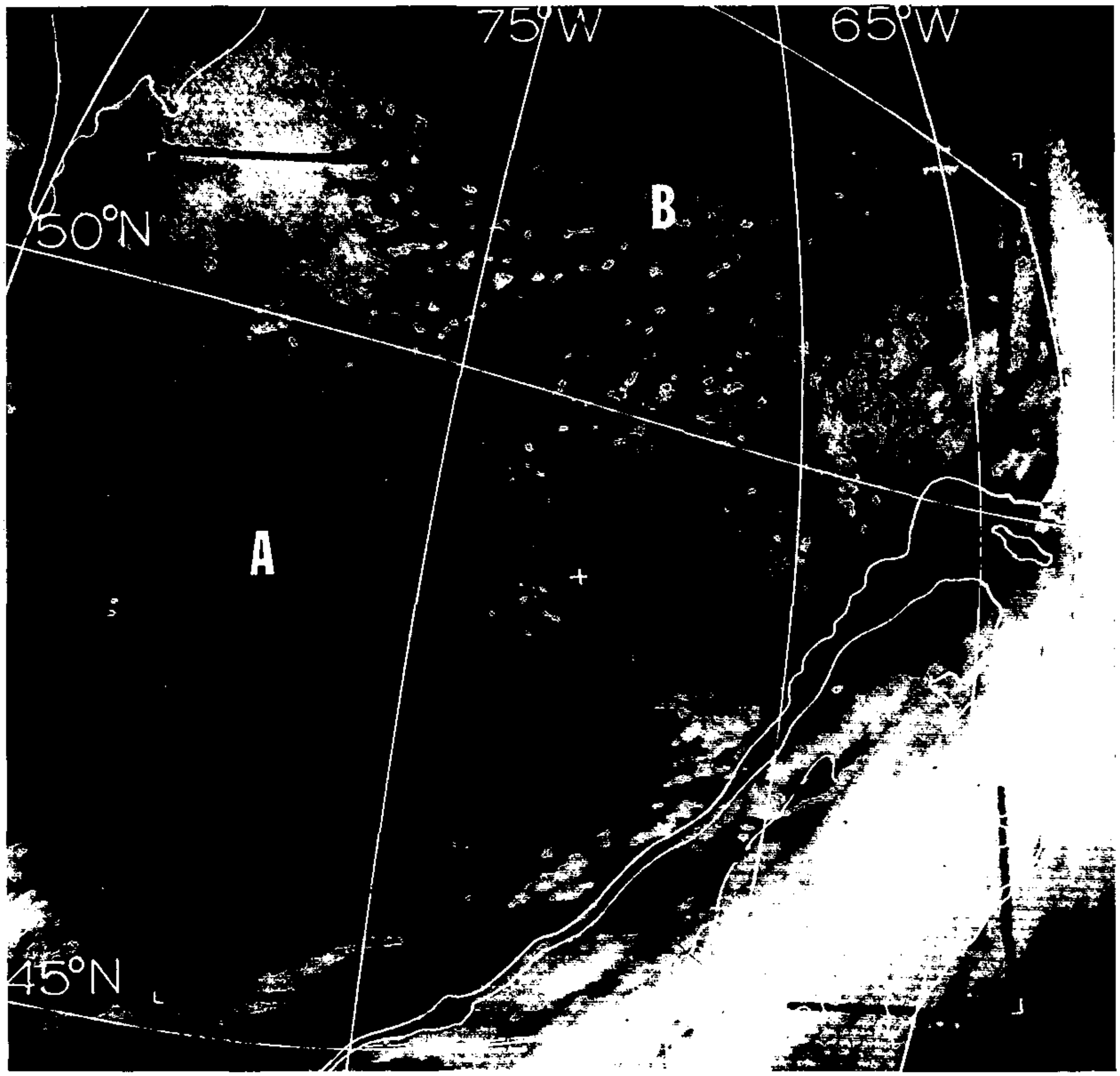
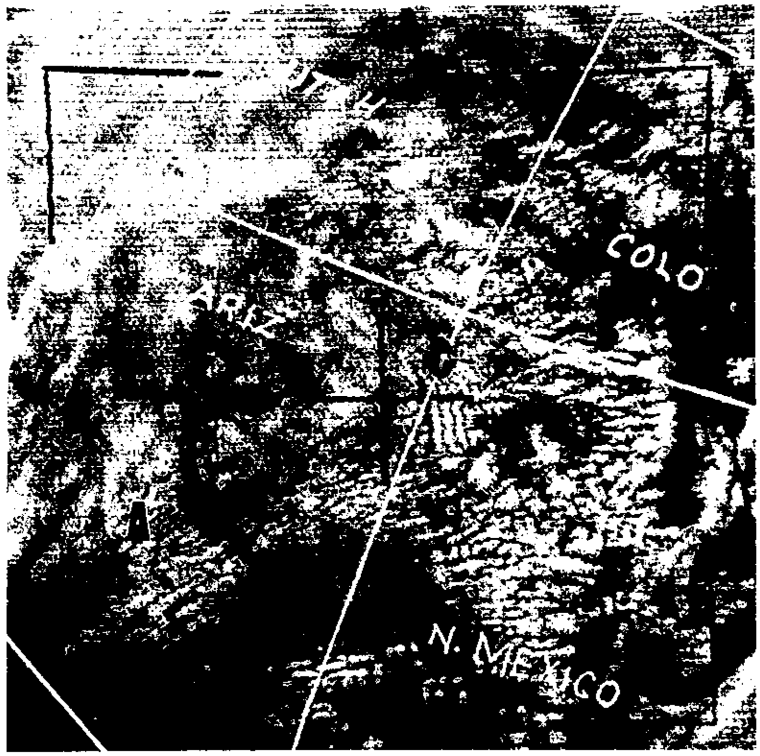
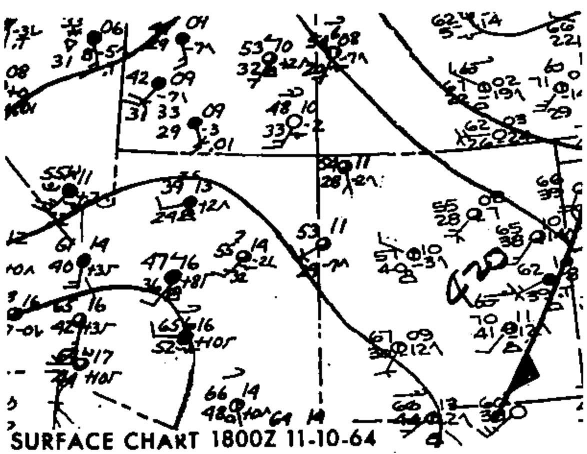
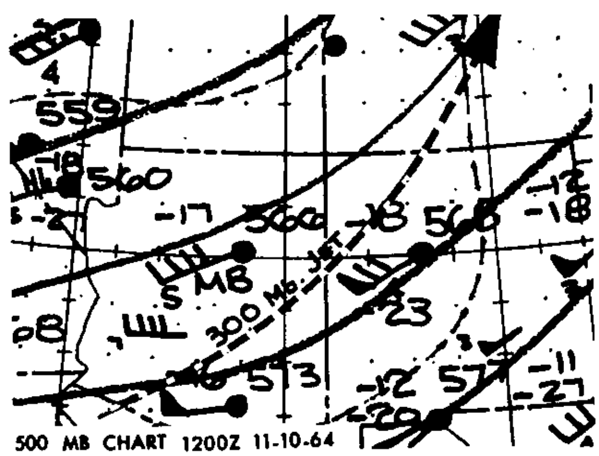


Fig.34 Cloud lines--Southern Canada 1907 GMT, Sept. 11, 1964
TIROS 7 Pass 6659T

Figure 35 shows a picture of wave clouds and cumulus cloud lines occurring together, and also shows the surface winds for the time of the picture, and the 500mb winds and jet stream postion for six hours prior to the picture. These data indicate little directional shear between the surface and the upper air wind reports in the area of the picture. The banded structure of the cumulus clouds is aligned approximately parallel to the wind direction southeast of points A and B. Southeast of point C, transverse wave clouds can be seen. These are formed in the lee of the Chuska Mountains (9500 ft.). East of point D, the amounts of parallel and transverse mode banding appear equal. Southeast of point B the clouds end abruptly at the Sangre de Christo Mountain Range (14,000 ft.). A thorough knowledge of terrain is essential for identification of wave clouds appearing in satellite pictures.







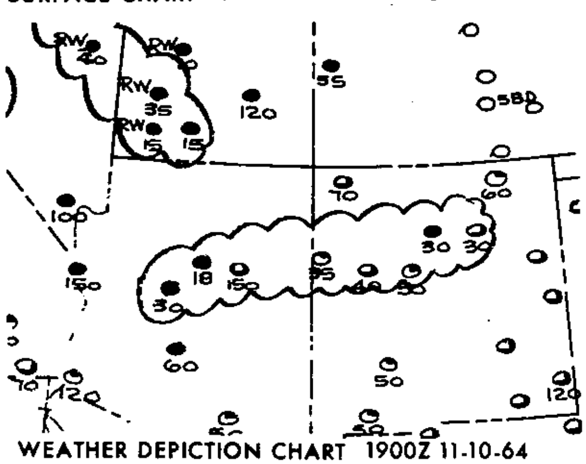
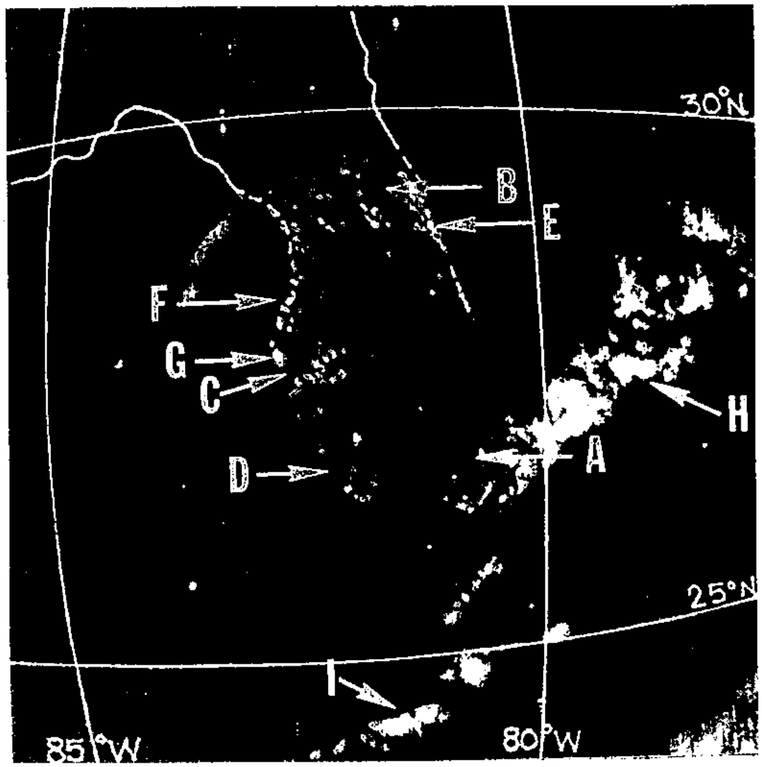


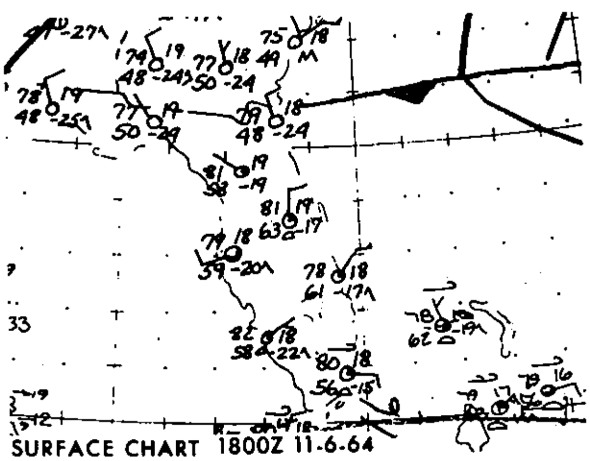
Fig. 35 Transverse and parallel mode cloud bands--Southwestern United States--1745 GMT, Nov. 10, 1964 TIROS 8 Pass 4717T

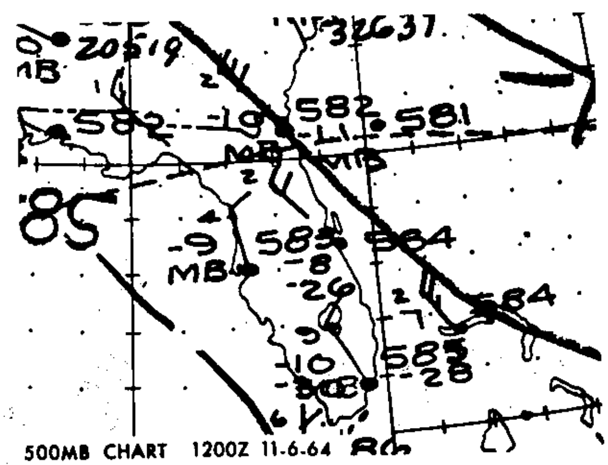
2.4.2 Fair Weather Cumulus

Although individual cloud elements in a field of fair weather cumulus are usually too small to be resolved by the satellite camera system, mesoscale variations in the amount of this cumulus cloudiness are detectable. These variations are caused by terrain and surface differences of the area over which the cumulus are observed.

Figure 36 of the Florida peninsula shows an example of these effects. Most of the clouds in the interior of the peninsula are below camera resolution, thus giving the area a mottled grey appearance. The effects of coastlines and interior lakes on the cumulus cloud distribution can be seen in this picture. Over Lake Okeechobee (A, fig.36) and the lakes in Northern Florida (B, fig.36), where land induced convection is absent, the skies appear relatively cloud-free. Tampa Bay, east of point C, and Charlotte Harbor, east of point D, are also free of cloud. Local convergence has caused a concentration of cloudiness along the coastlines near points E and F. On the St. Petersburg Peninsula (G, fig.36) to the west of Tampa Bay convergence has produced a single cloud which appears larger than the rest. The clouds over the Atlantic and south of the Florida Keys, at points H and I, are cumulonimbus. The effects of local terrain on the development and distribution of cumulus cloud are often quite evident in satellite pictures.







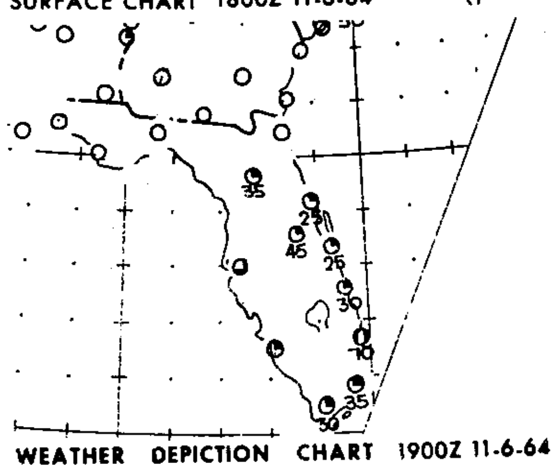


Fig.36 Fair weather cumulus--Florida peninsula, United States-- 1747 GMT, Nov. 6, 1964 TIROS 8 Pass 4659T

2.4.3 Cumulonimbus Clouds

Cumulonimbus clouds are often the brightest clouds observed in satellite pictures. An area of cumulonimbus activity over Texas is shown in figure 37. The major cloud formation in the center of the picture is a cluster of cumulonimbi whose tops have merged together to form a cirrus shield. The cirrus is very smooth and very bright in appearance. Since the winds aloft are very light, no cirrus plumes have been produced and the clouds appear fairly symmetrical. Symmetry is particularly evident in smaller cloud elements (A, B, C, fig.37) which appear nearly round in the picture. Where shear is present cumulonimbus have a sharp cloud edge on one side of the formation and a fuzzy edge on the other. The fuzzy edge is produced by the cirrus plume which extends downwind in the direction of the shear. There is no evidence of shear in this picture.

The row of tropical cumulonimbus in figure 38 has pronounced cirrus plumes toward the northwest (A, fig.38). The cloud elements in the formation have a sharp edge at point B, on the side of the clouds opposite from the cirrus plumes. The plumes are aligned with the direction of the shear through the convective layer. Evidence of cirrus shear can be a useful aid in the analysis of the upper air wind field in the tropics.

An example of shear in cumulonimbus at high latitudes is shown in figure 39. Two of the large cloud elements at the right hand side of the picture have sharp edges at E and indistinct edges at F. This spiral cloud formation is the result of a decaying vortex which extended from the surface through 500mb at picture time. The cloud bands of cellular cumulus appear to spiral cyclonically toward the vortex center; the shear, as indicated by the cirrus plumes is in the opposite direction or anticyclonic. This indicates that the winds around the low are stronger at the surface than aloft.

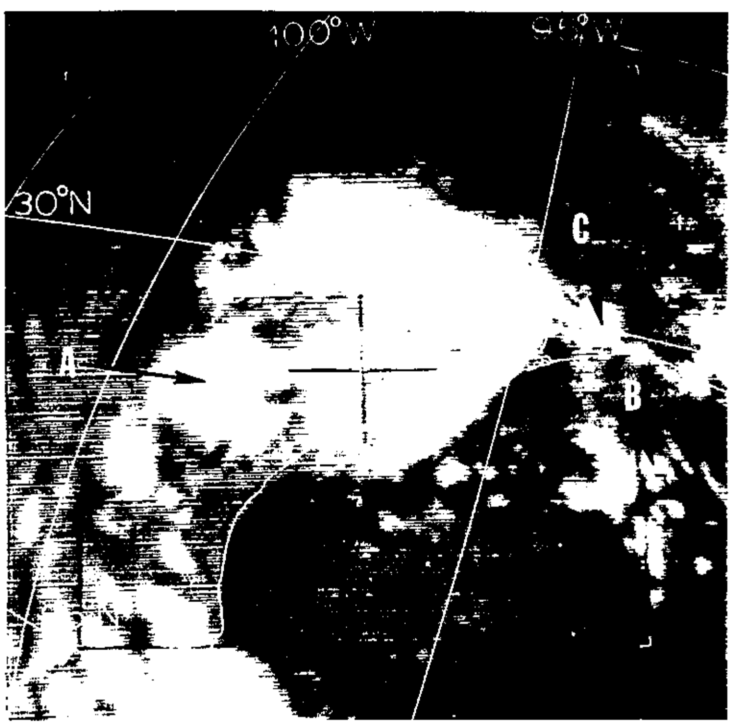


Fig.37 Cumulonimbus cluster--
Gulf Coast, United States-
1841 GMT, June 24, 1963
TIROS 7 Pass 0080T
No cirrus shearing.

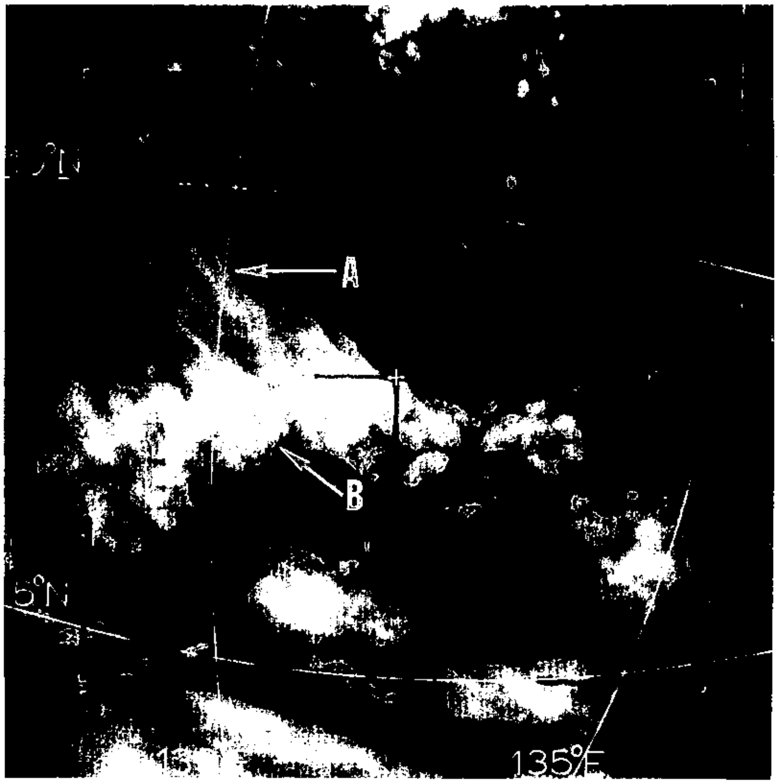


Fig.38 Cumulonimbus clouds and associated cirrus plumes; indication of upper level shear--Southern Philippine Sea--0324 GMT Mar. 22, 1964 TIROS 7 Pass 4091T

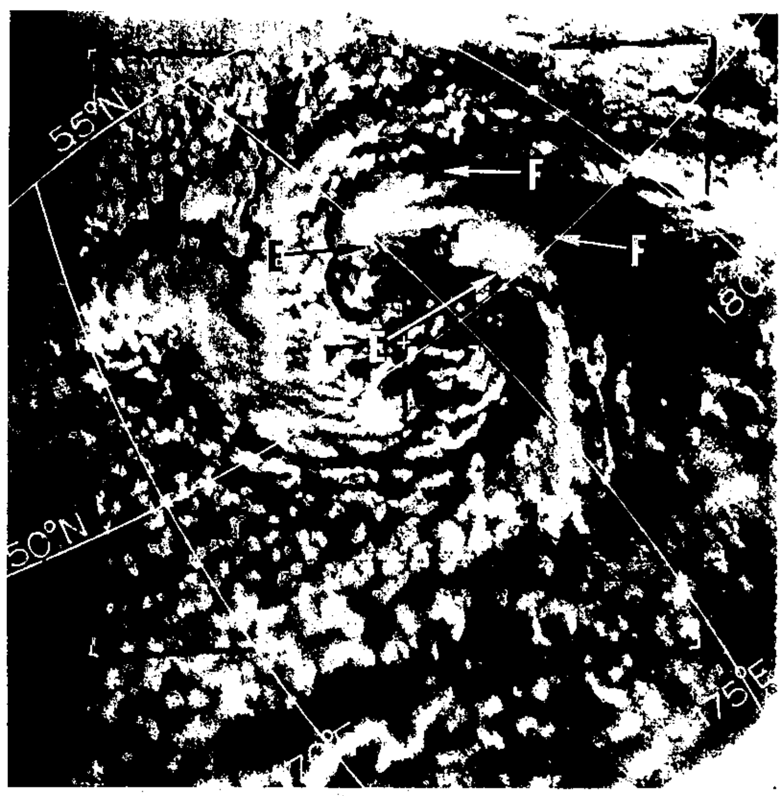


Fig.39 Cumulonimbus clouds and associated cirrus. Bering Sea, North Pacific. 0151 GMT, Jan.30, 1964 TIROS 7 Pass 3326T

Cumulonimbus often occurs in an area where extensive low cloud is also present, so that it becomes impossible to observe cumulonimbus from the ground except by radar. In the satellite picture of figure 40 a cold front lies through north central Texas with an extensive area of clouds to the north of the front. The winds aloft are from the southwest and strong warm air overrunning is taking place. The radar summary chart of figure 40 outlines the areas of observed scattered radar echo returns one hour before the satellite picture. The areas of cumulonimbus in the satellite picture (B, C, fig.40) can be separated from the lower clouds by their brighter appearance toward the southeast and by the shadows which they cast on the tops of the lower clouds toward the northwest. The rather well defined shadow at point D is evidence that the cloud element which produced it reached a considerable height above the general cloud level and so is probably cumulonimbus. The cloud layer at point A is stratiform; the top of the layer is smooth in appearance. In contrast the upper cloud surface to the east and northeast where the cumulonimbus are present exhibits the typical "bumpy" appearance of cumuliform clouds.

Cirrus spissatus often has the appearance of cumulus in satellite pictures. The globular clouds along the Gulf Coast shown in figure 41 are cirrus spissatus. No cumulus clouds were reported by ground observers. The shadows which are visible to the north of each cloud element identify these clouds as high clouds rather than low cumulus. While the cloud shadows suggest cumulonimbus the appearance of the cloud area is not typical of cumulonimbus. Where cumulonimbus are forming, other cumuliform cloud elements of various sizes are usually also present. The tops of such cloud elements extend to various altitudes, not all of which are high enough to cast shadows. In figure 41 all the cloud elements are observed to have shadows suggesting that they are a formation of high altitude clouds such as cirrus spissatus rather than cumulonimbus. Globular cirrus, such as that shown in this example, can easily be mistaken for cumulus in satellite pictures.

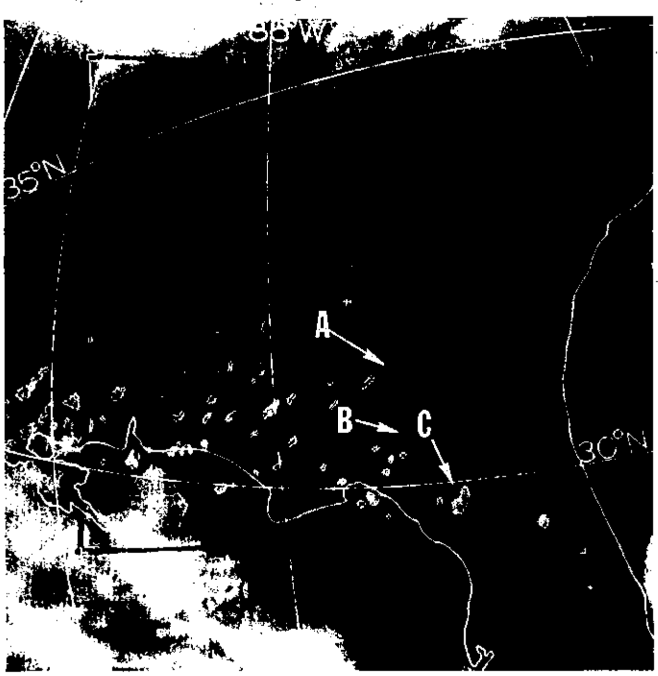
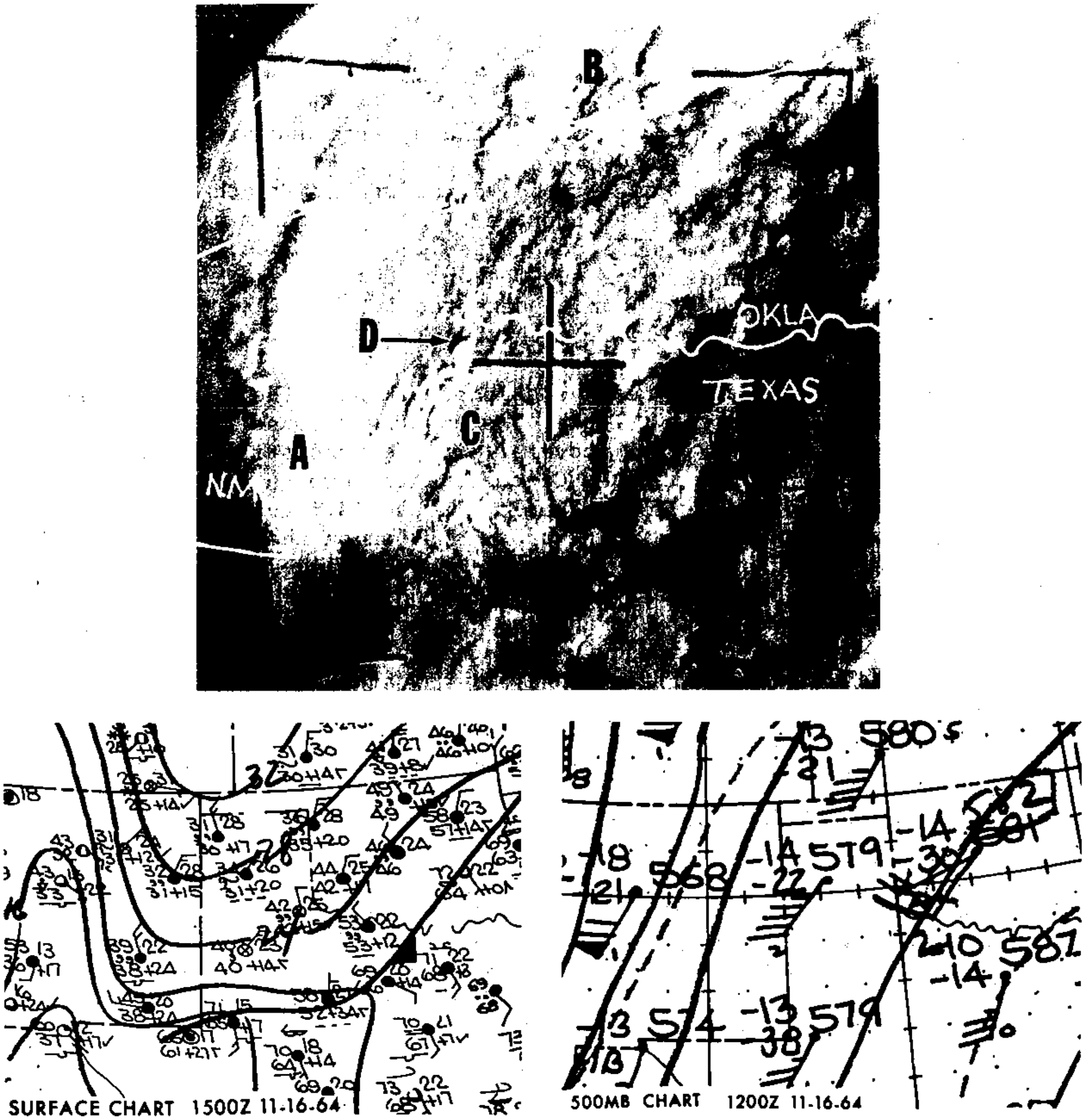


Fig.41 Cirrus Spissatus: Similar in appearance to cumuliform clouds in satellite pictures--Southeastern United States--1541 GMT, Jan.15, 1964 TIROS 7 Pass 3108D.



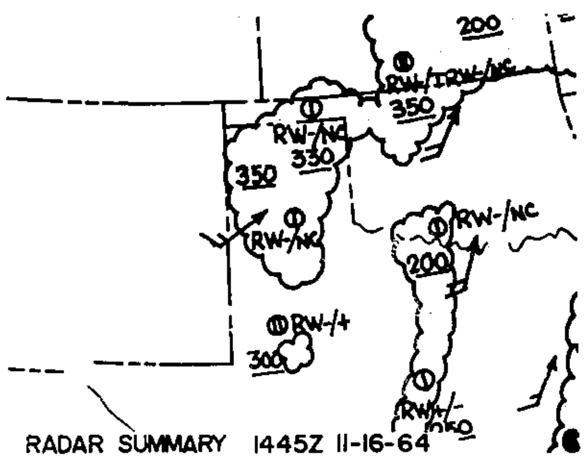


Fig.40 Cumulonimbus and stratiform cloud--Central United States--1555 GMT, Nov. 16, 1964 TIROS 7 Pass 7633T

2.4.4 Fog and Stratus

Thick ground fog or low stratus which has formed over land has a distinct appearance. The top of a fog or stratus area appears very smooth and flat as at point A in figure 42. In northern Illinois (south of point A) the fog area in this satellite picture has a relatively smooth edge; this is typical of an area of fog over flat terrain. The cumuliform clouds in Missouri (B, fig.42) are much more irregular and ragged in appearance. High cumuliform clouds are visible above the top of the fog and stratus layer in eastern Iowa (C, fig.42). These upper clouds can be detected in the picture by the shadows they cast on the cloud surface beneath them.

Satellite pictures can be an aid in determining the exact boundary of an area of fog or low stratus. Figure 43 shows Puget Sound (A,fig.43) and the Willamette River Valley (E,Fig.43) covered with fog and stratus. The Coast Range between points B and C and the Cascade Range between points D and F are cloud-free. Low clouds cover the Columbia Plateau (G,fig.43). Most of the weather stations reporting fog and stratus as shown on the Weather Depiction Chart (fig.43) are located in the lowlands. The continuous smooth line shown in the Weather Depiction Analysis attempts to enclose the areas where cloud bases are less than 1000 feet. The analysis, which is based on available surface reports only, has erroneously included the cloud-free Cascades in the cloud covered area. The satellite pictures show at a glance those areas where the terrain is above the low clouds.

Snow covered mountain peaks can also be seen in the picture. Immediately south of point D, Mount Rainier (14,410 feet) shows as a small bright area. Also visible are Mount St. Helens (9,671 feet) and Mount Adams (12,307 feet).

Much sea fog and stratus occurs at high latitudes over ocean areas during the summer. This extensive cloudiness makes difficult the identification of more significant cloud formations such as frontal bands which appear to be surrounded by areas of fog and stratus. These areas of fog and stratus have the mottled and streaky appearance characteristic of most of the cloud visible in figure 44. In this satellite view over the Aleutian Islands, a frontal cloud band extends between points A and B in the upper left part of the picture. The thicker clouds in the frontal band appear brighter in the satellite picture than do the areas of fog and stratus on either side of the front (C, D,fig.44). Since fog and stratus decks are usually close to the earths' surface, islands can cause variations in their appearance. At points E, F and G the southerly winds in advance of the front have caused orographic thickening of the clouds along the windward side of three of the Aleutian Islands. Just to the north and downwind from the islands, three breaks in the general cloud cover can be seen. Islands of any appreciable height act as barriers to the wind flow so that small open areas or even eddys in low level clouds can be produced in the lee of an island. If relatively low islands produce these effects, one can deduce that the disturbed cloud deck is a low one.

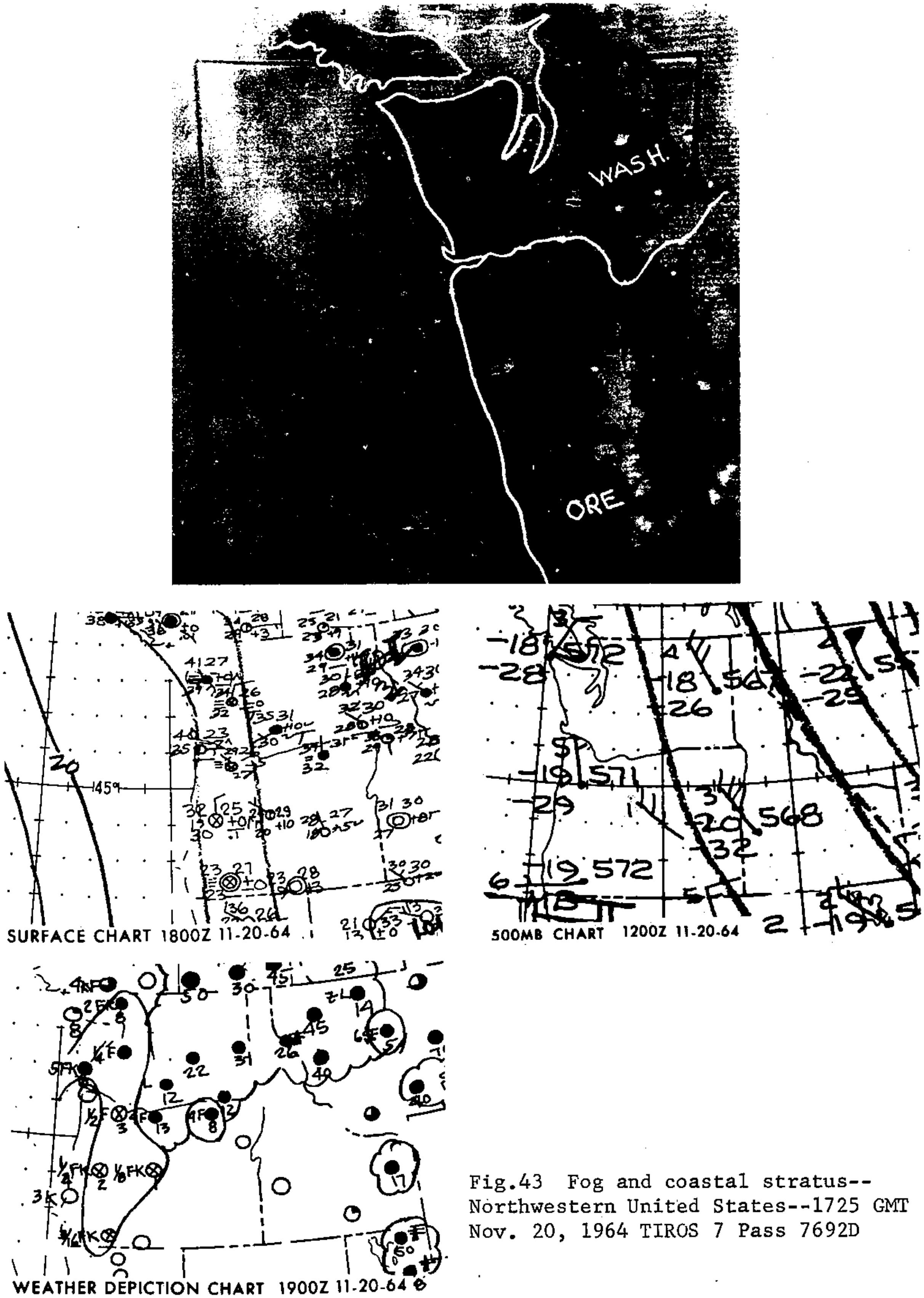
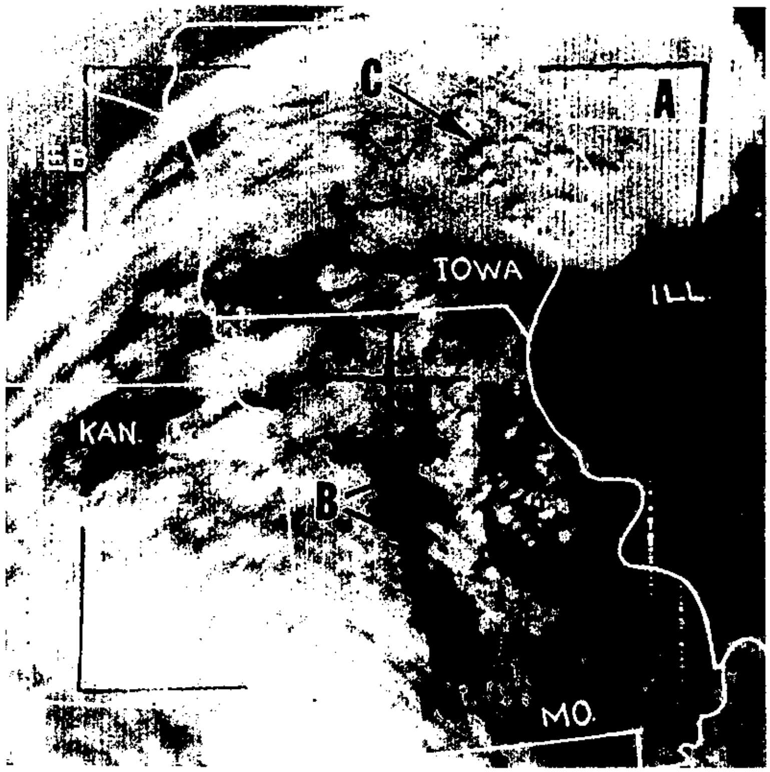
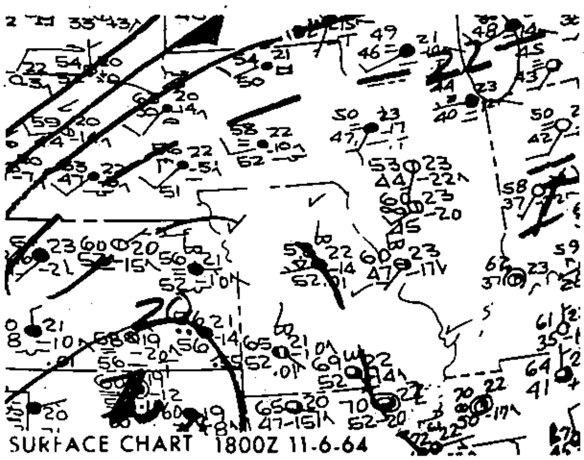
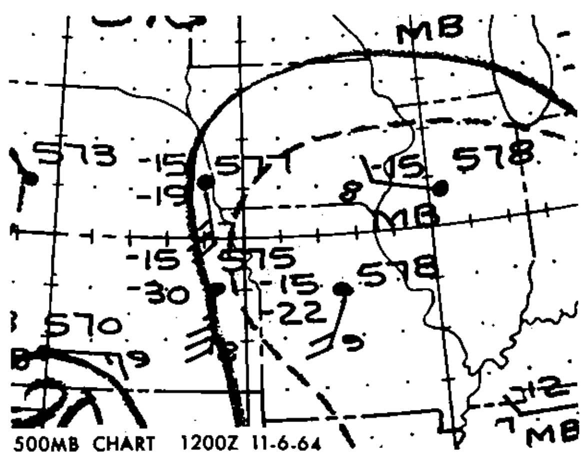


Fig.43 Fog and coastal stratus--Northwestern United States--1725 GMT Nov. 20, 1964 TIROS 7 Pass 7692D







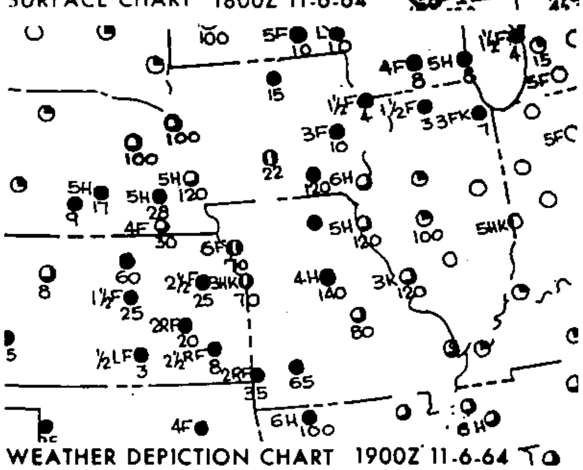


Fig.42 Fog, stratus and cumuliform clouds--Central United States--
1746 GMT, Nov. 6, 1964 TIROS 8 Pass 4659T

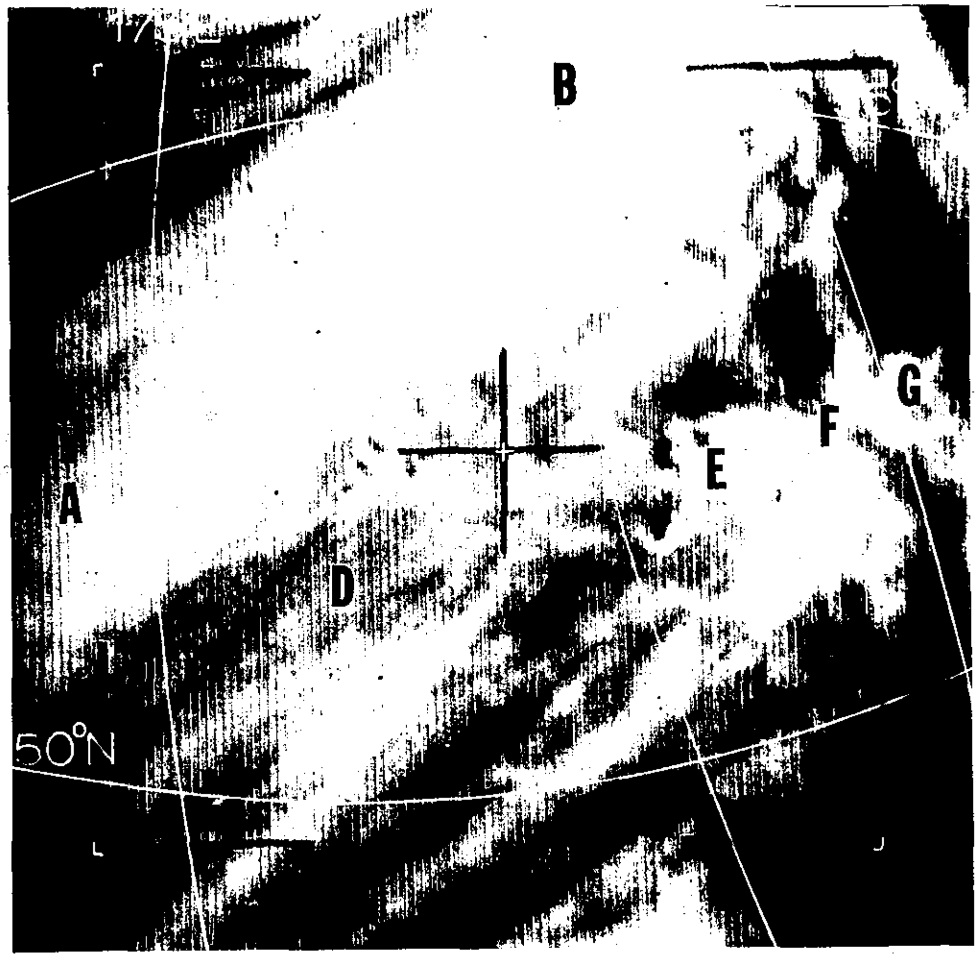


Fig.44 Frontal cloud band surrounded by fog and stratus--
North Pacific--0106 GMT, Aug. 15, 1963 TIROS 7 Pass 0837T

2.5 Snow and Ice

2.5.1 Snow Covered Land

Clouds or snow covered ground can appear equally white in satellite pictures. This similarity in appearance presents a problem in interpretation when both snow covered land and bright clouds appear together in a picture. Where snow is restricted to a relatively small area, such as the top of a mountain ridge, it can easily be mistaken for clouds. Where the area of snow cover is extensive, it is often difficult to differentiate between the snow and overlaying clouds.

The appearance of snow covered terrain in satellite pictures depends on the topography and vegetation of the region being viewed. Every region of the world which is normally snow covered has its own unique appearance. A picture analyst should become familiar with the appearance of snow covered terrain in his own area of interest, so he will be able to recognize anomalies that indicate the presence of clouds.

The mountainous snow covered terrain of southern Norway is shown in figure 45. Here southwest Norway is mostly cloud-free. The dendritic pattern of Sognefjord (east of point C) can be plainly seen in the picture, as can the valleys to the east of the main mountain range (D, fig.45). The brightest areas are along the mountain ridges, where vegetation is sparse. The darker areas outline the shape of the valleys; the darker appearance results from the snow covered ground being obscured by forests in the valleys, or from shadowing of the valley by the surrounding ridges. This dendritic pattern is typical of mountainous snow covered terrain.

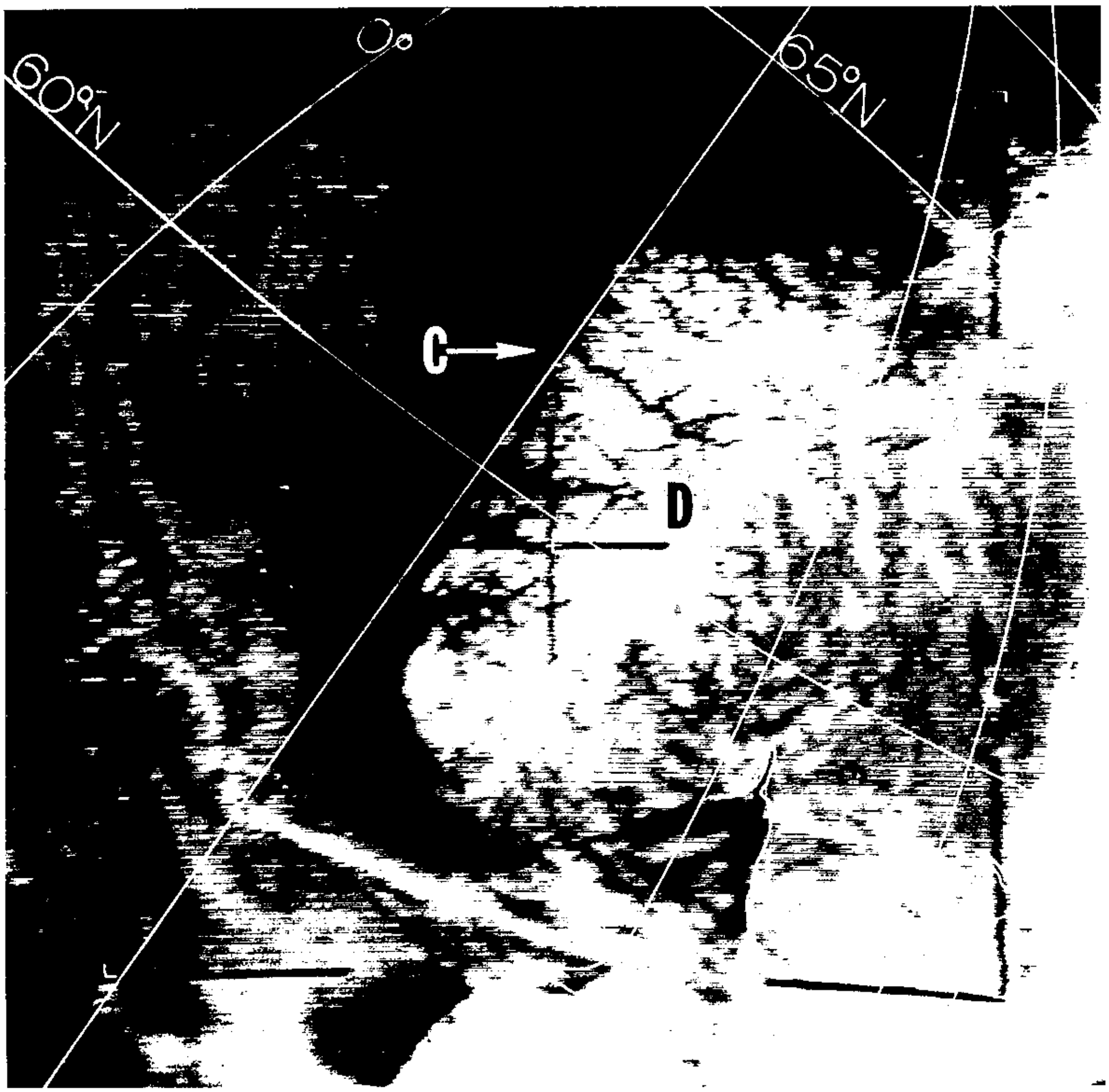


Fig.45 Dendritic snow pattern produced by mountainous terrain--Southern Norway--1125 GMT, Feb. 15, 1963 TIROS 5 Pass 3455T

The relatively flat terrain of the central plains in North America is shown in figure 46. The area is cloud-free and completely snow covered. The whitest areas in the picture are ice covered lakes. Lake Winnepeg, the largest, is visible at point A. The many small white spots indicated by point B are also ice covered lakes. The area surrounding point B is forested with evergreen trees and thus appears dark. The four dark areas east of point D are forested mountains. The light grey area around point C is snow cover on the wheat and grain farms of southwestern Manitoba. The variations in whiteness produced by topography and vegetation change appreciably with the seasons but vary little from day to day. One is able to differentiate clouds from snow by learning the characteristic appearance of a snow covered region. When clouds are present they obscure all the landmarks which can be identified when the area is cloud-free. To identify cloud areas over regions with which one is unfamiliar, satellite pictures for successive days can be compared. Snow patterns will appear the same from day to day; clouds seldom have the same appearance on successive days.

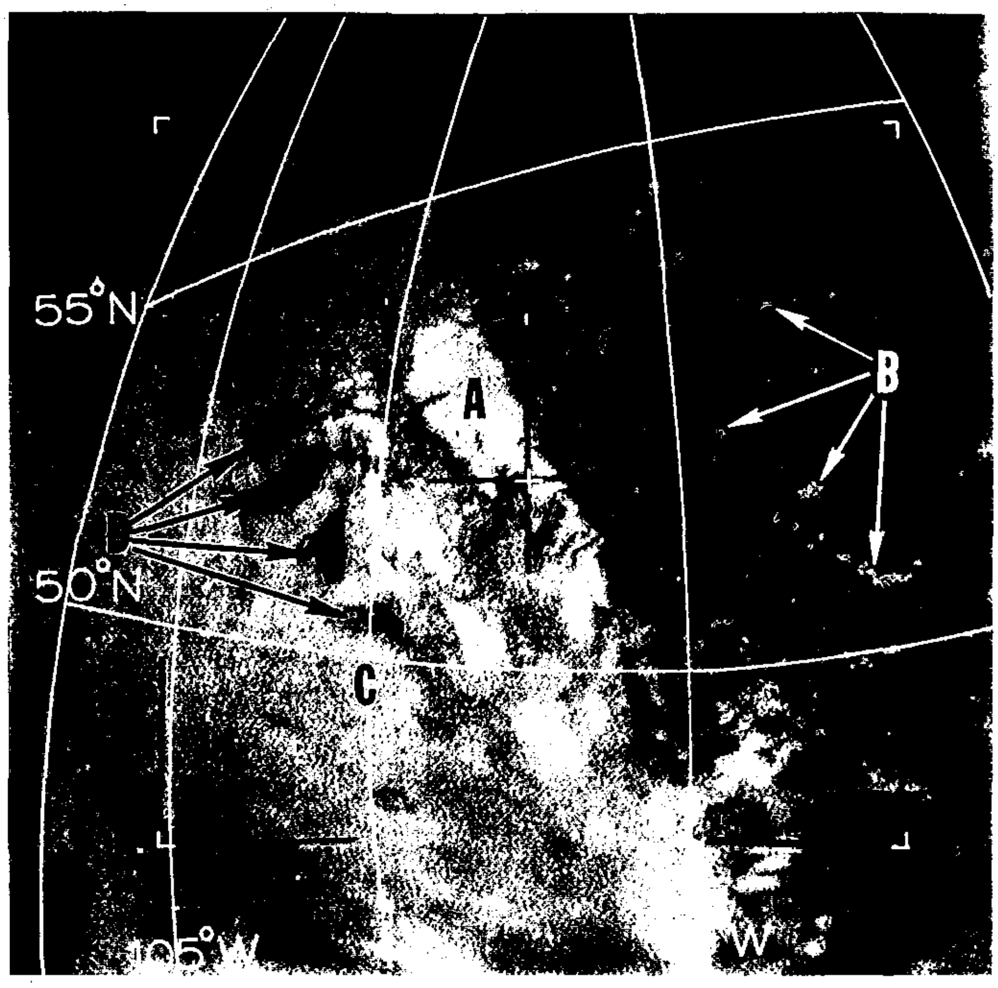


Fig.46 Snow covered terrain and frozen lakes--
Southern Canada--1555 GMT, Feb.26,1964 TIROS 8 Pass 0976T

2.5.2 Sea Ice

The edge of Arctic pack ice can be seen quite clearly in satellite pictures. Pack ice in the Davis Straits is shown in figure 47. The edge of the ice extends northward from point K. The western shore of Greenland can be seen on the right side of the picture, and cloud-free offshore waters appear west of point L. The low level winds from the west-northwest at the time of this picture produced cloud lines over the water at point M. The dark areas to the east of points N and O are shore leads in the pack ice which formed by the action of offshore winds. Many of the large scale and some of the small scale changes in ice boundaries can be observed in satellite pictures.

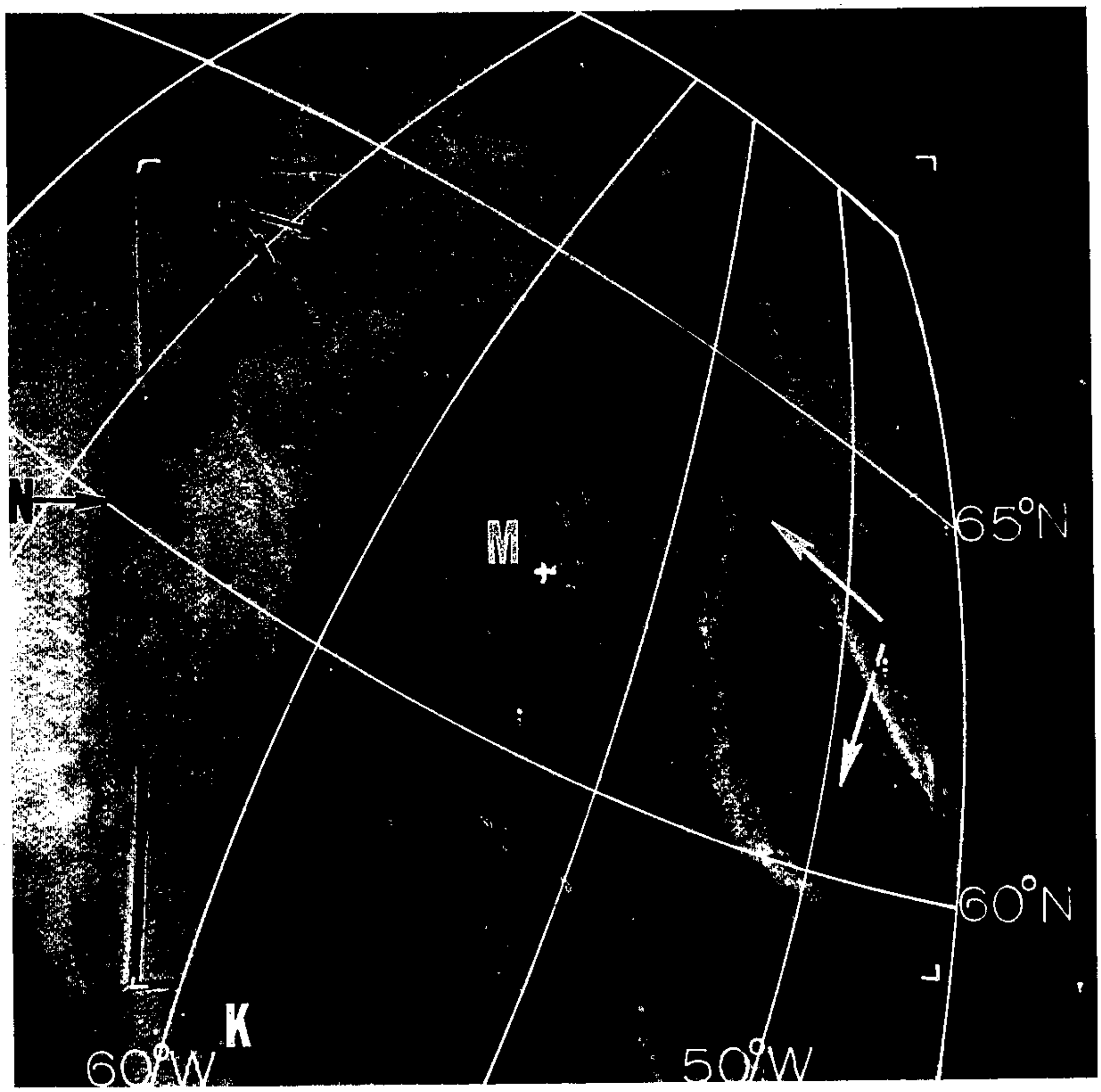


Fig.47 Sea ice boundary--Davis Straits, North Atlantic--
1601 GMT, Feb. 26, 1964 TIROS 8 Pass 0976T