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PRESENT STATUS OF CLOUD VELOCITY COMPUTATIONS FROM THE ATS I AND ATS III SATELLITES

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Abstract: Latest developments in spin-scan cloud photography from the ATS geosynchronous satellite permits us to produce images of the global disc at certain time intervals which are about 23 min for ATS I and 31 min for ATS III when the entire disc is scanned. Experiments performed with ATS III in April 1968 revealed that a series of one-half scans, extending from the north pole to the equator, at 14 min intervals is capable of depicting not only the motion of neph systems at various levels but also the explosive development of severe thunderstorms over the United States. Presented in this paper are the effects of slight movement of subsatellite longitude and latitude, apparent velocities of clouds as viewed from geosynchronous satellites, loop projection methods of cloud-velocity computation, and actual examples of computation. Included in the presentation is a time-lapse motion picture of clouds in motion filmed from special half-scan picture sequences obtained in April 1968 under the project "Tornado Watch" conducted jointly by NASA, ESSA and the University of Chicago, by using Professor Suomi's spin-scan camera on board the ATS III satellite. It will be revealed in this presentation that clouds not only move but also undergo development and dissipation. Some severe storm producing clouds are characterized by explosive development; meanwhile, they modify their environment thus resulting in a dissipation of nearby clouds as storms grow rapidly. The most difficult problem is the estimation of cloud heights from current ATS pictures. The relationship between cloud and air motions must be studied from theoretical and analytical points of view. It should be pointed out also that there are various neph systems associated with the wave motions in the atmosphere. In such cases the estimation of wave velocities and humidity distribution are of vital importance.

Резюме: Последнее усовершенствование метода фотографирования облаков при помощи вращающихся сканирующих устройств с геостационарного спутника ATS позволяет получать глобальные изображения диска в определенные интервалы времени, которые составляют около 23 мин. для ATS-I и 31 мин. для ATS-III,(время сканирования всего диска). Эксперимент, выполненный на ATS-III в апреле 1968г., показал, что серия сканирований половины диска, охватывающих область от северного полюса до экватора с 14-минутными интервалами, способна отразить не только движение неф-системы на различных уровнях, но также внезапное развитие сильных гроз над Соединенными Штатами. В докладе приведены эффекты слабого движения подспутниковой точки, видимые скорости облаков, наблюдаемые геостационарными спутниками расчеты скорости облаков методом петлеобразной проекции и примеры вычисления. Представлены кадры замедленной съемки облаков в движении, заснятых специальными рядами при сканировании половины диска, полученные в апреле 1968г. в рамках " Project Tornado Watch ", управляемой совместно NASA, ESSA и Чикагским университетом, при использовании камеры проф.Суоми со сканирующим устройством на борту спутника ATS-III. Обнаружено, что облака не только движутся, но подвержены также развитию и рассеиванию. Некоторые облака, образующиеся в результате сильной грозы, характеризуются внезапным развитием; между тем, они изменяют окружающую их среду, что выражается в конечном счете диссипацией близлежащих облаков по мере быстрого нарастания бурь.

1. Effects of subpoint movement

Although an image of the global disc appears to be a photograph taken from the geosynchronous altitude 22300 miles above the equator, it consists of numerous scan lines obtained by intersecting the Earth with scan cones having their vertices at the satellite. Fig. 1 gives the basic geometry of scan by a cloud camera. Equations of gridding under the assumption of an ellipsoidal Earth were solved and a series of tables at 0.1 deg longitude and 1.0 deg latitude intervals has been computed at the University of Chicago. From these tables, it is now feasible to construct grid lines on any ATS picture as long as the satellite is located above the Earth's equator.

Slight deviation from the nominal equatorial orbit results in a small figure-of-eight motion of the subsatellite point. When the subsatellite point moves, by even a very small distance from its nominal position, geographic grid points as well as cloud elements displace slightly. These displacement vectors are a function of the grid-point location on the disc. They also depend upon the mode of the subpoint movement. Presented in figs. 2 and 3 are the vector shifts of the grid points at the intersections of longitudes and latitudes drawn at 10° intervals. In computing vector shifts the subpoint was displaced southward (fig. 2) and westward by 1° geocentric angle, respectively. The numbers next to each vector represent the amount of the shift when the image radius is normalized to 1000 units. It is evident that the direction of the grid shift is approximately parallel to the subpoint motion. The amount of the grid shift, G, however, decreases from the subpoint to the horizon. Expressing the subsatellite distance, λ, in %, grid shifts are plotted in fig. 4 as a function of λ. Despite the fact that G was computed under the assumption of an ellipsoidal Earth, the decrease in G can be expressed as a very simple function appearing in the figure. It is, therefore, evident that the loci of the grid shift are conformal to the subpoint track.

2. Apparent and true cloud velocities

The velocity vectors of cloud motion determined on an ATS picture represent apparent motion of clouds. It is, therefore, necessary to convert an apparent velocity into a true velocity.

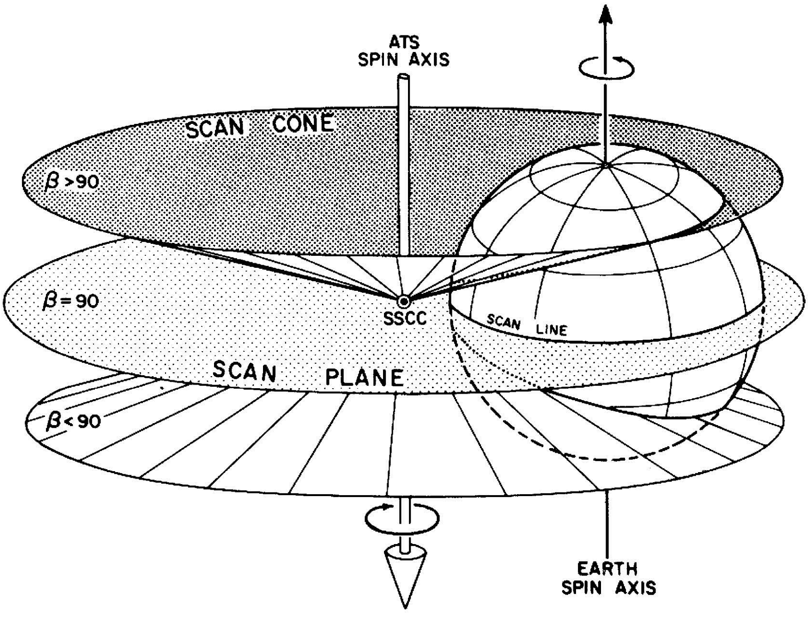

Fig. 1. Geometry showing the intersections of scan cones of the ATS spin-scan cloud camera (SSCC) with the Earth. β denotes the inclination of the camera's optical axis measured from the spin axis of the ATS satellite.

A correction factor which is to be multiplied by the apparent speed in order to obtain the true cloud speed was computed. With a high degree of approximation, the correction factor can be expressed as a factor of λ, the relative radius, and the image crossing angle defined as the direction of a vector measured from that of the tangent to the concentric circle around the subpoint. In computing the correction factor in fig. 5, it was assumed that the factor is 1.00 when applied to the cloud velocity at the subpoint. It would be necessary, therefore, to compute the cloud velocity at the subpoint from the picture size and the satellite altitude, taking, of course, the satellite picture intervals into consideration. Fig. 5 shows that the correction factor increases with the crossing angle when the subsatellite distances of clouds are assumed identical. Inside the stippled domain in the figure, the correction factor is less than 1.1, suggesting that no correction is necessary unless an accuracy better than 10% cloud speed is desired.

The directions of the apparent cloud motion must also be corrected in order to convert them into true directions. Such corrections in degrees are contoured in fig. 6 as a function of relative radius and image crossing angle. The correction is always made by rotating the apparent velocity toward the radial through the cloud. No such correction is required when a cloud velocity orients toward either the radial

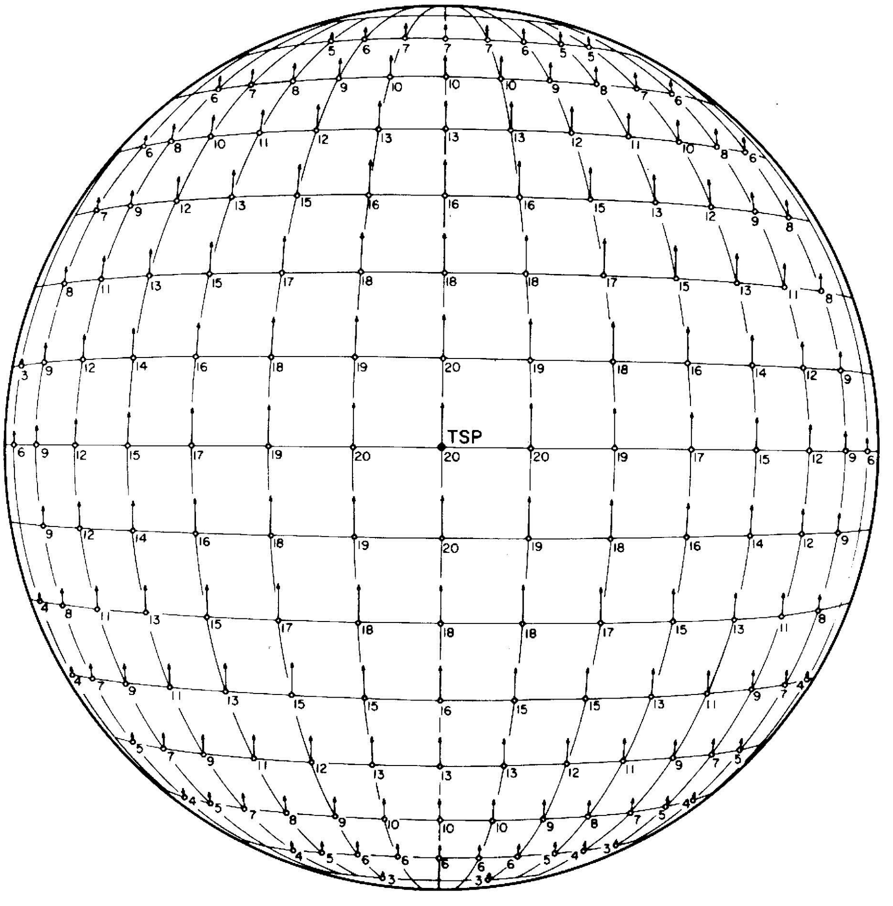

Fig. 2. The vector shifts of geographic grid points when the ATS subpoint is moved southward by 1° from the equator. Numbers at each grid point denote the amount of the grid shift when the disc radius is assumed to be 1000 units.

or the tangent line through the cloud. Less than a 2° correction is required inside the stippled area in the figure. If one desires to determine the cloud directions from the local north line, we have to correct the north line directions also.

A small plastic cloud-velocity computer was designed by the author in cooperation with Mr. K. Watanabe of the Meteorological Research Institute in Tokyo, and Mr. L. Whitney of the Meteorological Satellite Laboratory, Suitland, Maryland. The computer is placed on a sheet with apparent cloud velocities to convert them into time velocities.

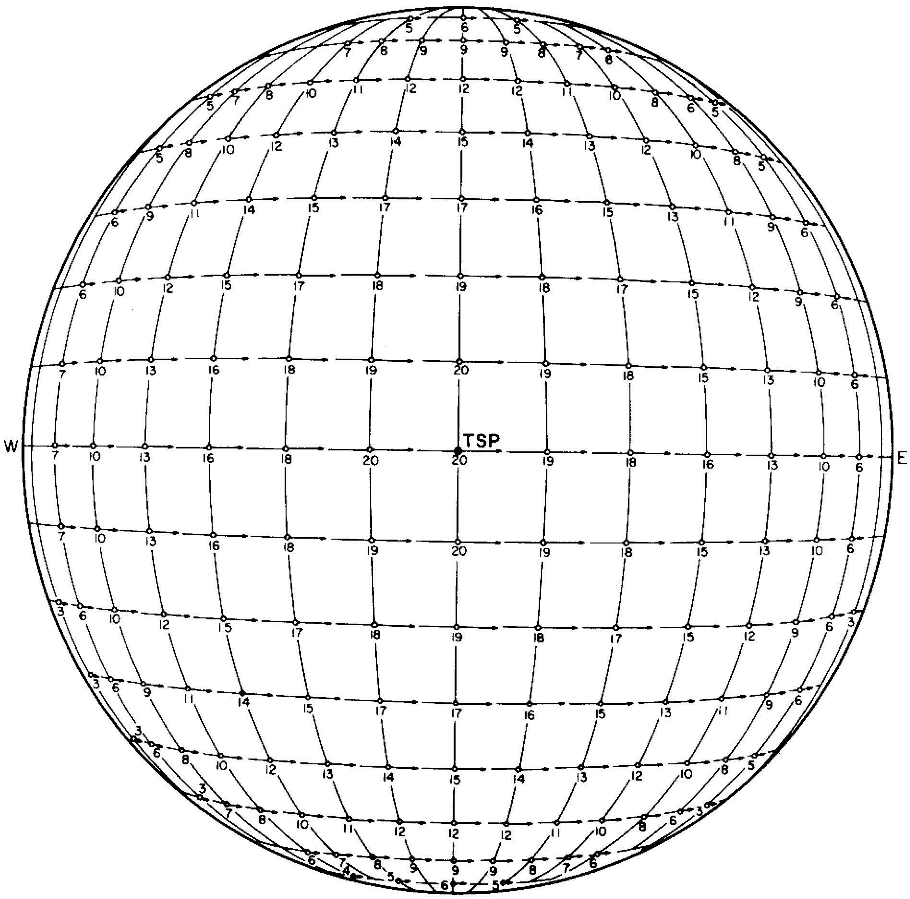

Fig. 3. The vector shifts of geographic grid points when the subpoint is moved westward by 1°. The disc radius is assumed to be 1000 units.

3. Loop projector method of cloud-motion computation

After viewing a large number of time-lapse movies of ATS I and ATS III pictures, the author became convinced that they are extremely useful in gaining knowledge of the development and motion of clouds. In many cases, the difference in the direction of cloud motions permits us to distinguish those clouds located at different levels. Three different directions of cloud motion were observed within a small area, suggesting that they could be used in determining the vertical distribution of winds if we could relate cloud and wind velocities.

In order to determine the cloud velocities on a movie screen it is necessary to

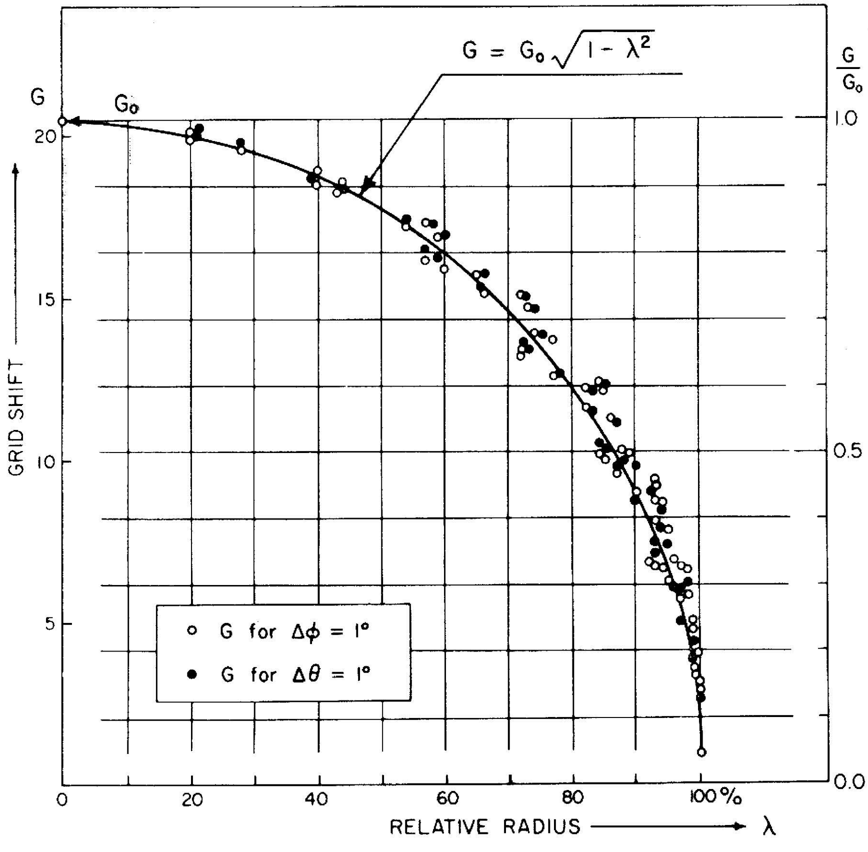

Fig. 4. The amount of the grid shift, G, when the subsatellite point is moved by 1° latitude and 1° longitude, respectively. G_0 represents the grid shift at the subsatellite point and λ, the relative radius of grid point, which is defined as the subsatellite distance divided by the disc radius.

follow a specific cloud element or cloud mass as it travels for a short distance during its lifetime or for the period of the daylight hours, whichever is the shorter. Usually the cloud life is much shorter than 12 hr, the average daylight period at lower latitudes. By filming two frames of every picture taken at 23 min intervals, changes in cloud during a 10 hr period, for instance, will be shown in about 60 frames and appear on a movie screen for about three seconds. A cloud with a one- or two-hour lifetime would appear on only about 8 to 14 frames, which would not exceed one second of projection time.

In an attempt to prolong the projection time of specific cloud elements with about a one-hour lifetime, a cyclic filming technique was explored. This involves selecting a series of about five pictures and then filming them according to the schedule described in table 1.

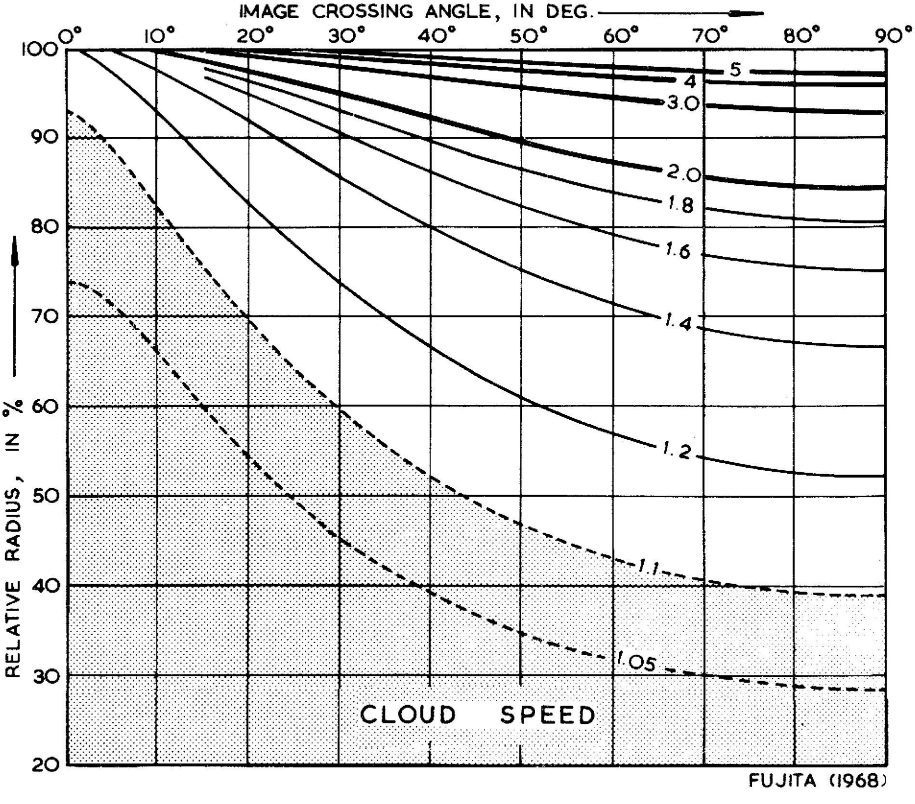

Fig. 5. The cloud-speed correction factor given as a function of relative radius and the image crossing angle, the direction of the cloud velocity measured from the tangent of a circle centered at the subpoint and passing through the cloud. The stippled domain requires less than 10% correction to the speed.

Table 1
An example of cyclic filming to produce various modes of reciprocal motion of a cloud. In this case, a series of five pictures, identified as numbers 1 through 5, were filmed in three filming modes according to the number of frames shown

Picture number	1	2	3	4	5	4	3	2
Oscillation Mode	16	3	3	3	16	3	3	3
Quick-return Mode	16	3	3	3	16	1	1	1
Instant-return Mode	16	3	3	3	16	0	0	0

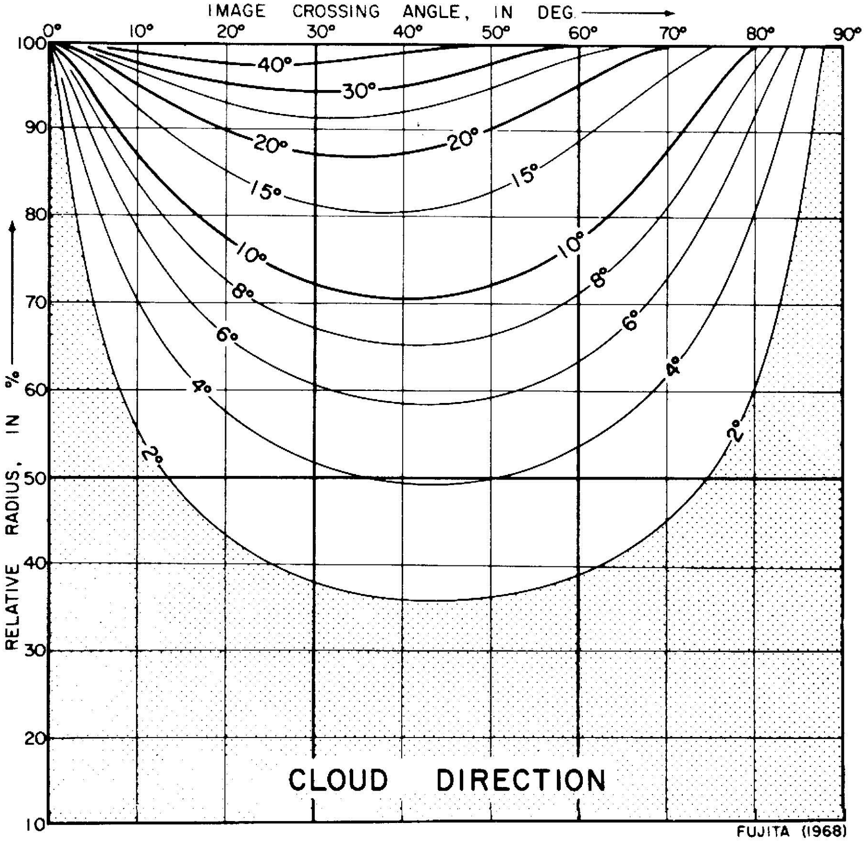

Fig. 6. The cloud-direction correction in degrees. The correction angle should be added to the image crossing angle. Less than a 2° correction is required within the stippled domain.

Cyclic filming in the oscillation mode is done by exposing picture no. 1 sixteen times, picture nos. 2, 3 and 4 three times each, picture no. 5 sixteen times; then by making three exposures each of nos. 4, 3 and 2 the first cycle consisting of 50 frames is completed. In order to produce a 250-frame endless loop, for instance, five such cycles should be completed. When such a loop is projected at 16 frames sec^{-1}, the clouds on the first frame remain on the screen for one second; then they move very fast, taking only a fraction of a second, toward their positions on the fifth picture which is shown for one second. Thereafter all clouds return to their positions on the first frame, taking only about half a second.

When a film loop is made in the quick-return mode, clouds stay in their posi-

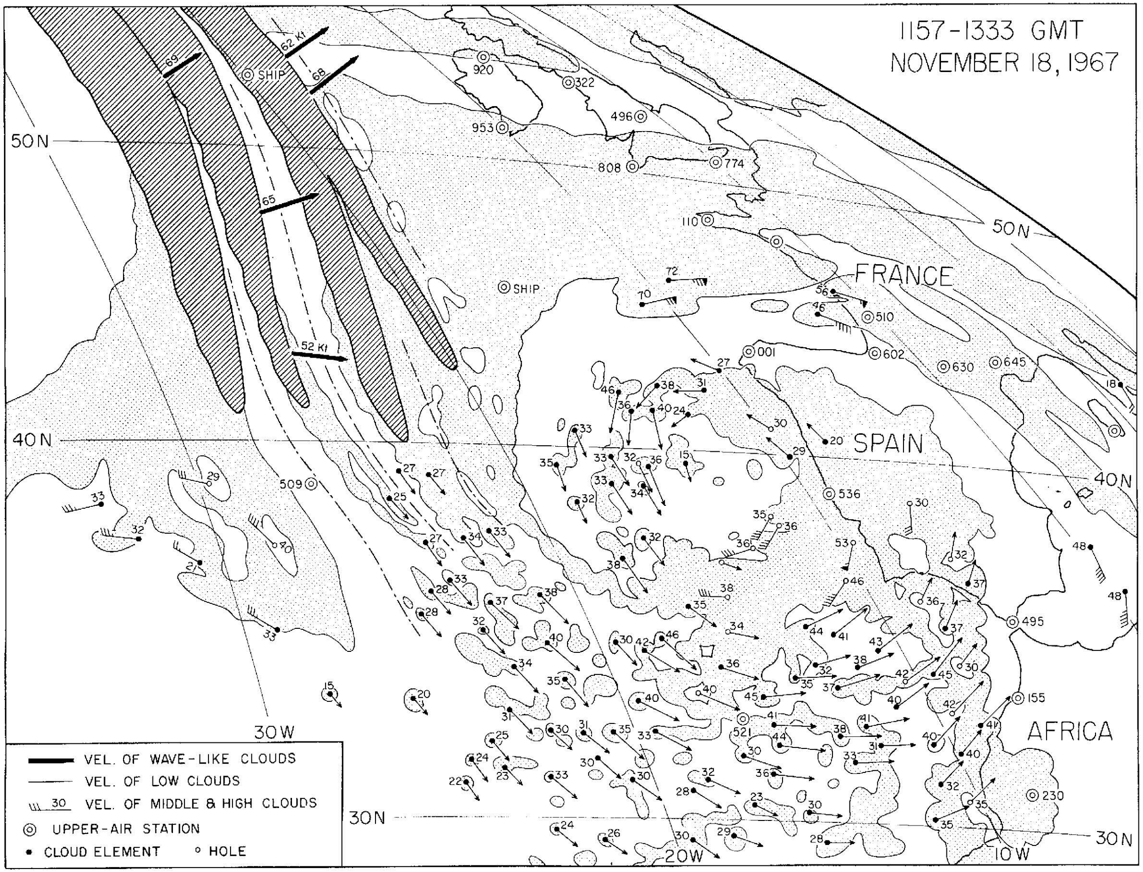

Fig. 7. Velocities of clouds over the north Atlantic computed from four color pictures taken by the ATS III satellite on 18 November 1967. Both cloud elements and holes were followed in order to compute velocities.

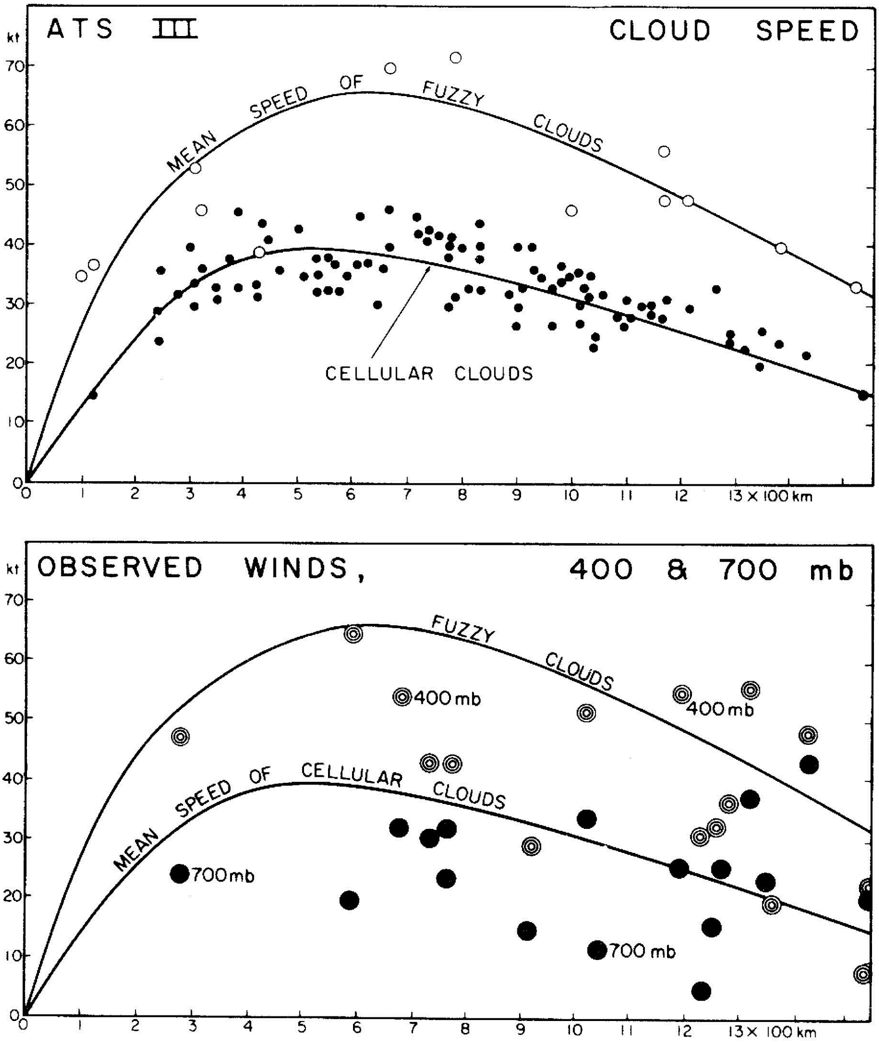

Fig. 8. Velocities of clouds plotted against the distance from the center of the cut-off low centered at 39°N and 12°W at 1200 UT on 18 November 1967 (upper diagram). Comparison of mean speeds of cellular and fuzzy clouds with observed 400 and 700 mb winds (lower diagram).

tions on the first and fifth pictures for one second each. Unlike the oscillation-mode case, clouds move slowly from the first to the fifth picture, then they quickly return to their initial positions. In this mode, therefore, an analyst can tell immediately the direction of the cloud movement more readily than in the oscillation mode.

By returning from the fifth to the first picture instantaneously, we produce a film

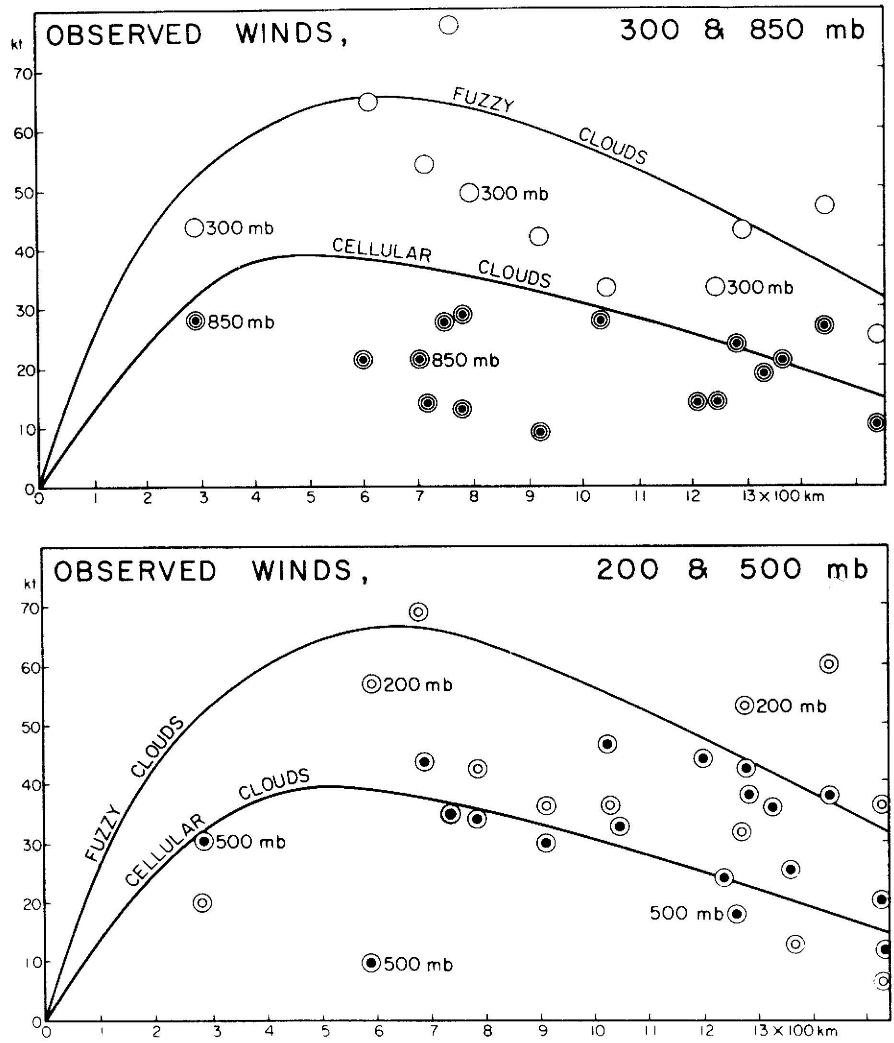

Fig. 9. Comparison of mean speeds of cellular and fuzzy clouds with observed 300 and 850 mb winds (upper diagram) and 200 and 500 mb winds (lower diagram).

in the instant-return mode. The projected image shows that all clouds simply move from the first to the fifth picture positions in repeated fashion. It was found that a film in this mode is also very useful in obtaining a field of cloud velocities quickly.

There are a large number of other filming modes that can be used for various purposes. We have also tested a three-color mode in which the first and fifth pictures are tinted in red and blue respecitvely, while the second, third and fourth

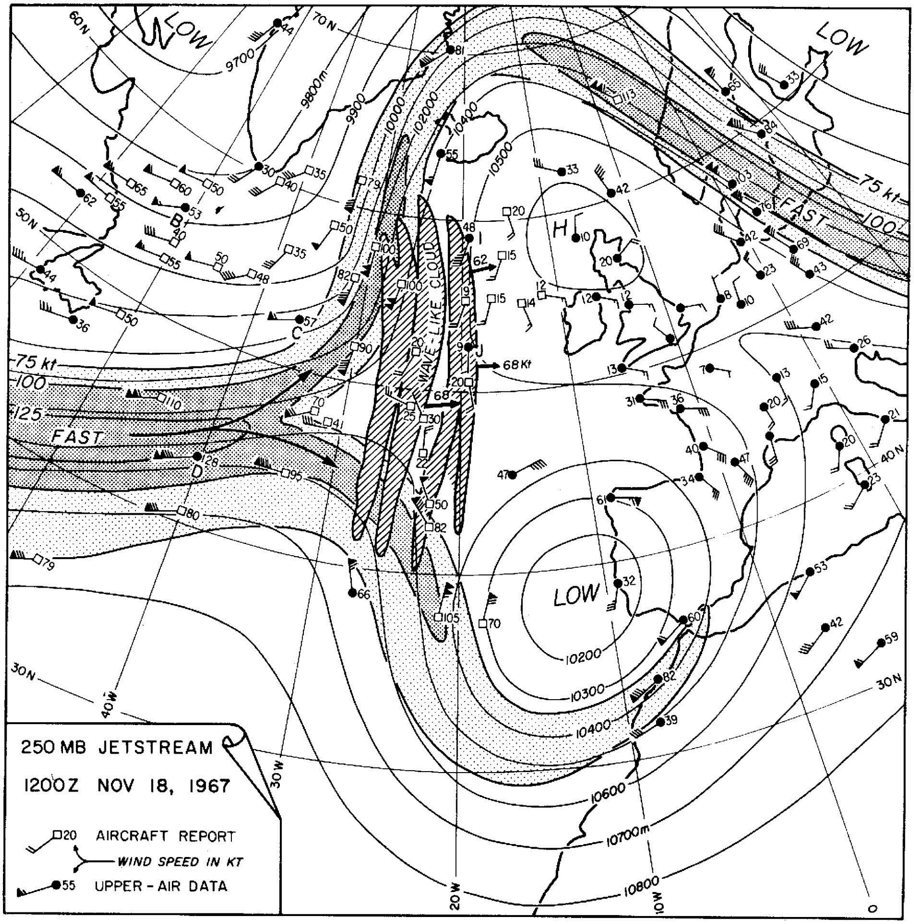

Fig. 10. The wave-like clouds seen on ATS III pictures for 18 November 1967 which were placed on the 250 mb chart for 1200 UT, 18 November 1967. These clouds were located where a jet-stream splits into two, and diverges north and south. The picture sequence projected in movie form revealed that these waves originate near the split point and propagate eastward at 62 to 68 knots.

pictures remain black. It was found, however, that a rapid change in color within a short time does not create a comfortable feeling for our eyes. The use of identical color for all frames and the adoption of various filming modes seem to satisfy most of the necessities for the computation of cloud velocities with our loop projector.

4. An example of cloud-velocity computation

In order to give the pattern of cloud velocities determined from several ATS pic-

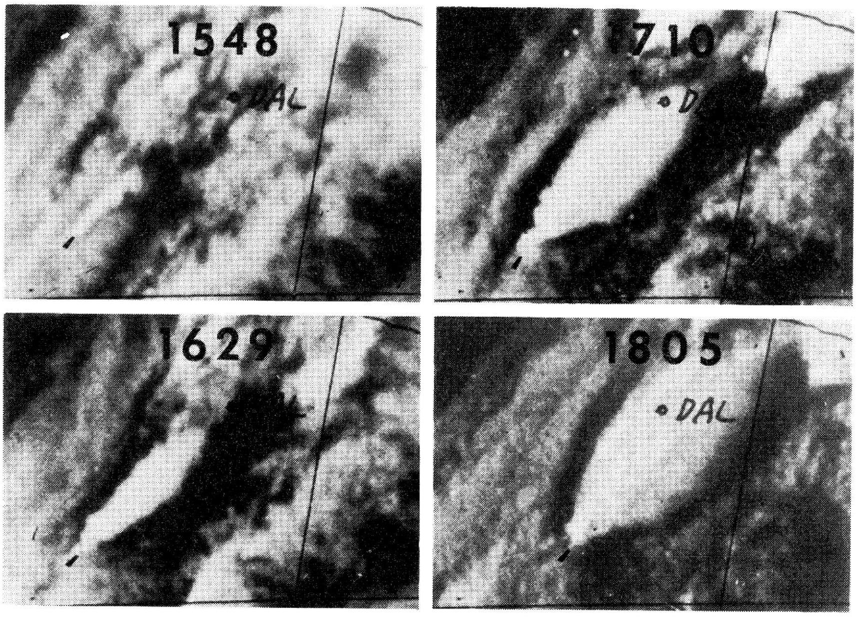

Fig. 11. The stages of growth of a diamond shaped cloud near Dallas, Texas on 19 April 1968, starting at 2148 UT.

tures, a series of four colour pictures taken between 1157 and 1333 by ATS III was filmed in a combination of oscillation and instant-return modes. The result of the computation is presented in fig. 7. The area of analysis covers the northeast Atlantic and western Europe under the influence of a deep cut-off low.

Both cellular clouds and holes were tracked for the velocity determination. Computed velocities were separated into three categories, velocities of low clouds, those of middle and high clouds, and those of wave-like clouds near the northwest corner of the analysis area. There are, of course, no ways of determining the cloud heights. However, cellular clouds with distinct boundaries were classified as low clouds and fuzzy faint clouds were assumed to be middle and high clouds.

When the velocities of these clouds were plotted against the distance from the center of the cut-off low, it was found that two groups of scattered points were located along two separate curves shown in fig. 8. The mean velocities of these cloud motions were then compared with measured wind speeds reported from upper-air stations in and near the cut-off low. Three diagrams in figs. 8 and 9 reveal that cellular clouds were moving faster than the 700 mb wind but probably slower than the 500 mb winds. Fuzzy clouds showed speeds of about 300 mb winds suggesting that they consisted of high cirriform clouds.

Of interest are the orientation and the velocity of wave-like clouds near the northwest corner of fig. 7. When these clouds were placed on a 250 mb chart (see fig. 10) reanalyzed by the author after adding a number of aircraft reports, it became evident that the waves in question were located over the region when a jetstream, extending east-northeast from the eastern coast of the United States, split into north and south branches and the stream was stopped by a blocking high centered over England. Despite the fact that the wave-like clouds propagated at 60-68 knots eastward, no winds aloft were reported by weather ships in the area characterized by an east component in excess of 30 knots. It would, therefore, be reasonable to conclude that the clouds in question were closely related to the waves.

5. Rapid growth of severe storm clouds

While small or fuzzy clouds are likely to travel with environmental winds, large thunderstorms do not move with winds. In fact, there would be no chance to observe a unique wind inside the entire depth of a large storm.

During the period of the project "Tornado Watch" in 1968, a complete history of the growth of a huge thunderstorm was photographed by ATS III every 14 minutes. Fig. 11 shows every third picture taken between 1548 and 1805 CST (Central Standard Time) near Dallas, Texas. It is seen that the storm started in the form of several cells of overshooting tops surrounded by thick cirrus clouds. As the storm developed, however, the cirriform clouds in the immediate vicinity of the large storm dissipated, forming narrow, dark areas around the storm. The only reasonable explanation for this is the development of compensating downward currents around the storm. A similar phenomenon on a much larger scale has been known for hurricanes and typhoons. It would be very important to study the phenomena of cloud dissipation around a vigorous storm in an attempt to estimate the field of vertical motion from pictures taken by ATS satellites.

6. Conclusions

Although our history of using ATS pictures for wind speed determination has been very short, the author is convinced that detailed vector analysis of cloud velocities would be of extreme value in estimating wind velocities over regions with no upper-air data. If we study very carefully the mode of cloud formation and dissipation, it will become necessary to estimate the fields of mesoscale vertical motion as well as wave motions in the atmosphere.

Acknowledgements

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