UDC 551.513.2:551.557.5:551.507.362.2:551.576.5(265)"1969.11"

THE USE OF SATELLITE CLOUD MOTIONS FOR ESTIMATING THE CIRCULATION OVER THE TROPICS

ARNOLD GRUBER, LEROY HERMAN, and ARTHUR F. KRUEGER
National Environmental Satellite Service, NOAA, Washington, D.C.

ABSTRACT

Resultant winds over the Pacific are derived from an Advanced Technology Satellite (ATS 1) for the month of November 1969. Since the method uses clouds as tracers, these resultant winds are biased toward cloud-producing circulation features. These biases appear to be smallest in the Tropics and, consequently, the winds here can be very useful for studies of the average circulation at low latitudes. Some of the important features of this circulation over the equatorial Pacific are clearly revealed.

1. INTRODUCTION

The purpose of this note is to present and evaluate some preliminary computations of resultant winds over the Pacific Ocean as deduced from ATS 1 cloud motions for November 1969. ATS 1 is a geostationary satellite with a subsatellite point located on the Equator at about 150°W. Figure 1 shows its field of view. The winds referred to were derived by tracking selected passive cloud features using a technique described by Hubert and Whitney (1971). It is apparent that this type of satellite can provide quantitative wind information in regions where little or no conventional meteorological data presently exist. It is hoped that this note will provide some measure of the potential of these satellite measurements for portraying the large-scale circulation, particularly in the Tropics. In addition, emphasis will be placed on the representativeness of these resultant winds and their applicability to future studies.

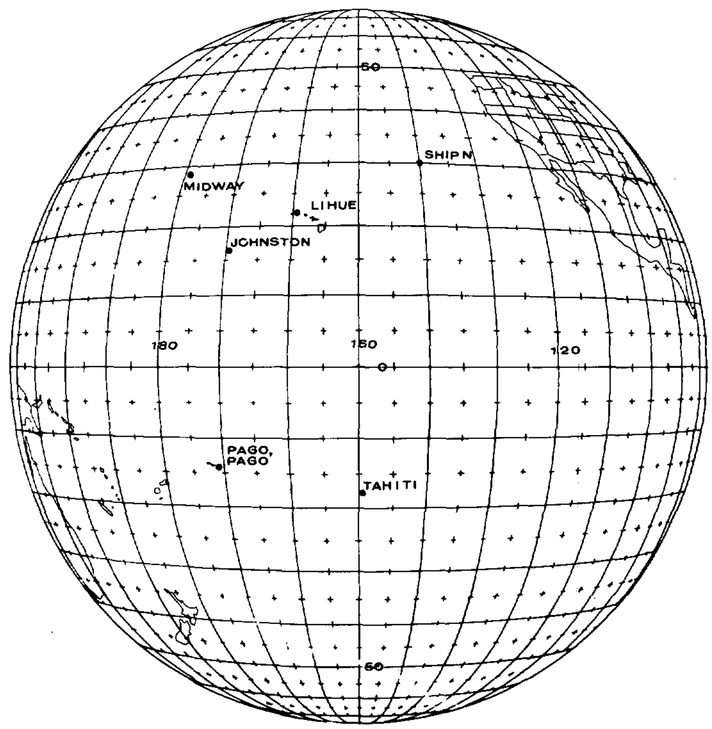

FIGURE 1.—Area viewed by ATS 1. Some of the rawinsonde stations used in this study are indicated.

2. PROCEDURE

Since November 1969 was designated as a pre-Global Atmospheric Research Program (GARP) month, considerable effort was expended in a careful reduction of the ATS cloud data to provide wind estimates. For this particular month, approximately 18,000 ATS wind vectors were computed and stored on magnetic tape. These measurements, which were made very close to 0000 GMT, were grouped into two categories of cloud motions—low and high level. From these, monthly resultant wind vectors were computed at both levels for 5° latitude-longitude squares. In carrying out the vector averaging, the procedure has been to average the observations in each 5° square each day. Usually, this represented about two or three wind observations per square. These daily mean values were then averaged for the month to obtain the resultant wind vectors.

The number of days with observations of low-cloud motions is shown in figure 2A, while figure 2B shows the frequency of high-level observations. As is readily seen, the number of days of observations decreases markedly in the outer portions of the ATS viewing area. On the average, the number of low-level observations exceeded those for high levels. Over a large part of the area, measurements of low-level cloud motions were made on 25 or more days. Resultant high-level cloud vectors were most numerous from the Northern and Southern Hemisphere tropical convergence zones, which are rather conspicuous features of the Pacific (Taylor and Winston 1968). The smallest number of high-level vectors (10 or less) were calculated over the equatorial Pacific dry zone. On the average, there is some tendency for the number of resultant low-level winds to vary inversely with the number of

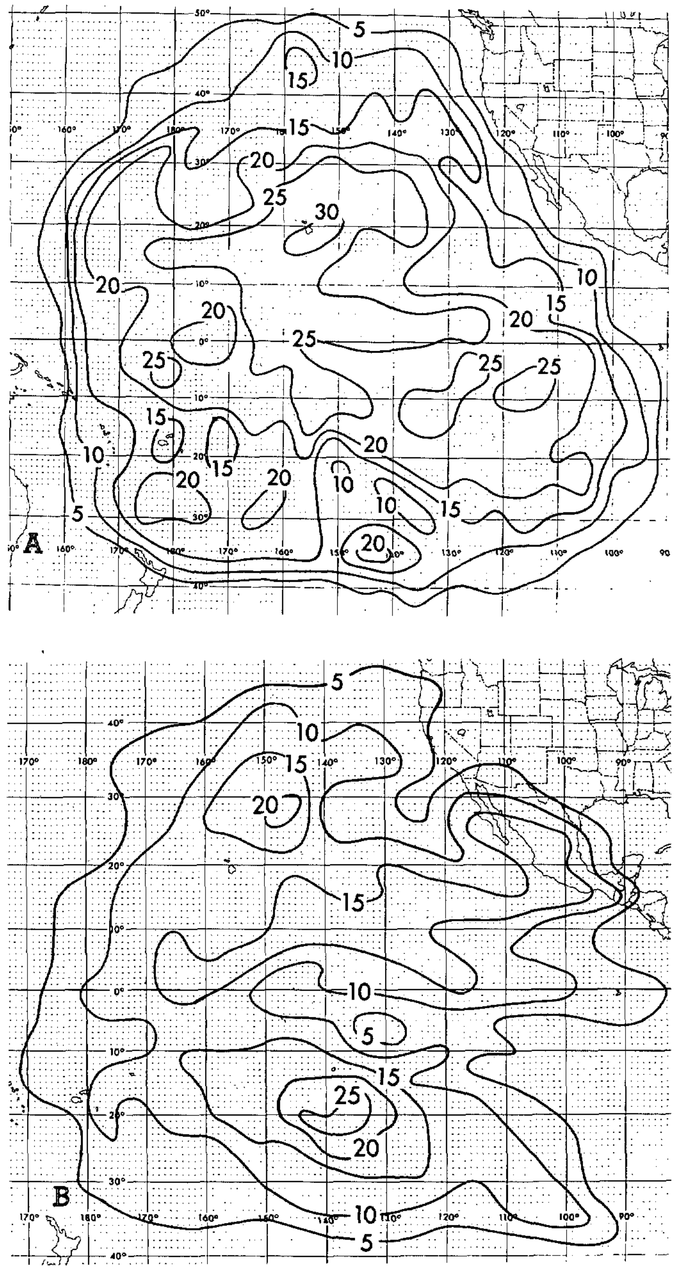

FIGURE 2.—(A) number of days with ATS observations of low-level cloud motions and (B) number of days with ATS observations of high-level cloud motions.

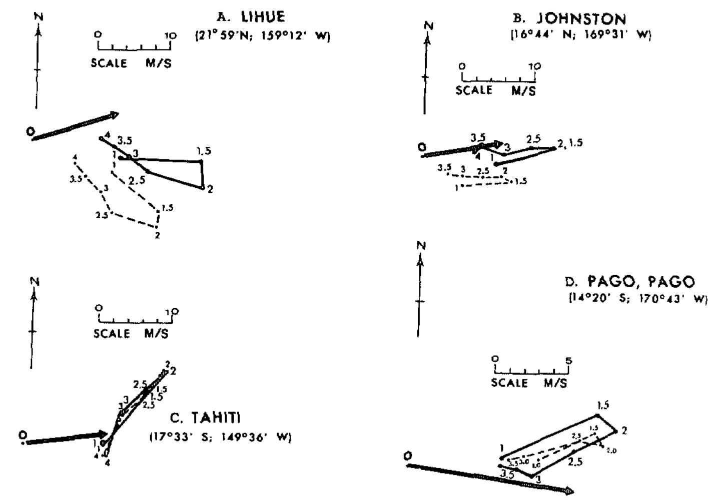

FIGURE 3.—Rawinsonde hodographs for resultant winds above 400 mb for (A) Lihue, Hawaii; (B) Johnston Island; (C) Papeete, Tahiti; and (D) Pago Pago, Samoa. Dashed lines indicate the monthly resultant wind at the levels specified in decibars. Solid lines indicate the resultant hodograph for the ATS period only. Resultant ATS high-level motion is indicated by the heavy vector. The number of days in the ATS mean is: Johnston Island, 13 days; Papeete, 22 days; Pago Pago, 15 days; and Lihue, 17 days.

high-level vectors. This, of course, indicates that the presence of higher clouds frequently obscures the satellite's view of any lower clouds that may be present.

The altitude for the low- and high-level wind fields is by no means clearly established. A statistical study carried out by Hubert and Whitney (1971) indicates that appropriate altitudes are 850 and 300 mb, respectively. It should be noted, however, that their study indicates considerable variability in these altitudes. Thus, resultant winds computed from these cloud motions may involve an averaging over different elevations.

3. REPRESENTATIVENESS OF RESULTANT ATS WINDS

The question of the representativeness of these resultant ATS vectors, especially when used as monthly mean winds, naturally arises. It should be remembered that clouds are not randomly distributed, but depend upon atmospheric circulation systems. Thus, it is obvious that, by using clouds as tracers, only the cloudy parts of a circulation are defined.[1] The flow under clear skies may be quite different. This is particularly the case in the westerlies, for here most of the middle and high clouds usually occur ahead of troughs. Consequently, one would expect high-level resultant ATS winds in the westerlies to show a bias toward poleward flow. An example of this is shown in figure 3A where the resultant high-level ATS wind (heavy arrow) in the vicinity of Lihue, Hawaii, may be compared with the monthly upper level resultant winds from the station's rawinsonde observations (dashed lines). Notice that the mean rawinsonde winds are northwesterly at all levels while the resultant ATS wind is from the west-southwest. Johnston Island (fig. 3B) shows the same bias although not as extreme. On the other hand, at Tahiti (fig. 3C) the agreement is good if the clouds are assumed to be at 350 mb. Similarly at Pago Pago, Samoa (fig. 3D), the agreement is fairly good since the ATS wind is within 20 deg. of the observed wind.

[1] The presence of clouds is a necessary but not sufficient condition for obtaining ATS winds, since it is possible to have an area of cloudiness which does not have any trackable elements.

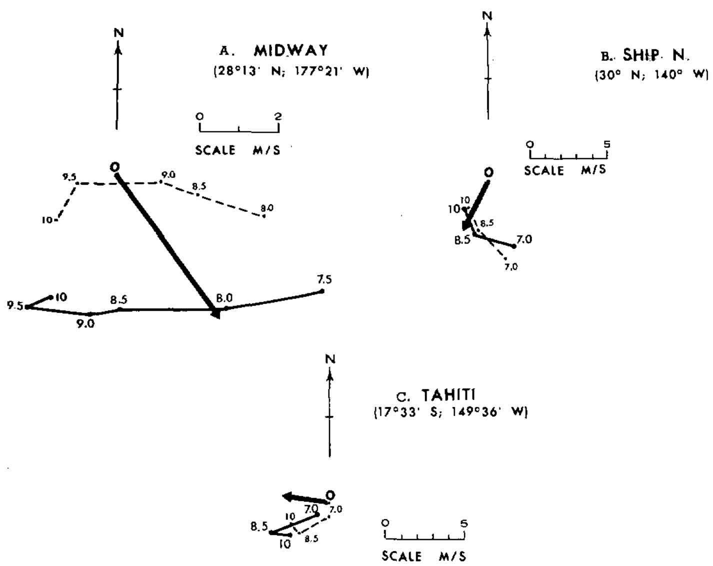

FIGURE 4.—Rawinsonde hodographs for resultant low-level winds for (A) Midway Island, (B) ship *N* (30°N, 140°W), and (C) Papeete, Tahiti. Winds are indicated as in figure 3. The number of days in the ATS mean is: Tahiti, 13 days; Midway Island, 14 days; and ship *N*, 23 days.

It is also instructive to consider how well these ATS winds compare with the rawinsonde observations for exactly the same period, in other words, the average of the rawinsondes for only those days having ATS winds. This is also shown in the various hodographs of figure 3 (solid lines). It would be expected that this type of comparison should show a better agreement between the ATS wind and the rawinsonde observations. Generally, this is the case. An example of this is the hodograph for Johnston Island (fig. 3B) where the ATS wind agrees very well with the rawinsonde at 300 mb. While there is also better agreement at Lihue (fig. 3A), a residual direction difference of 20 deg. still exists at 350 mb. The reason for this is not readily apparent.

A comparison for some low-level ATS winds is shown in figure 4. Again, it appears that agreement is poorest in the westerlies where the variability is greatest. Quite often the low-level clouds that are tracked by ATS are convective elements occurring in cold air outbreaks over the oceans. In contrast, when the winds are southerly (northerly in the Southern Hemisphere) few low clouds are tracked because they are often obscured by higher clouds. Thus, the resultant low-level ATS winds can also be biased. The bias in this case would be toward too much northwesterly wind in contrast to the bias toward too much southwesterly flow at high levels. An example of this is Midway Island (fig. 4A) where the northwesterly ATS wind differs by about 40 deg. from the monthly mean rawinsonde (dashed line). The mean rawinsonde for the 14-day period of ATS observation suggests that the clouds were at 800 mb. Notice that the hodograph shows the wind to be backing with height, indicating low-level cold advection. Also, the hodographs indicate that the days *without* low-level ATS winds experienced more southerly flow.

Agreement in the undisturbed trades is much better. The resultant ATS wind near ship *N* (30°N, 140°W) agrees very well with the 850-mb wind obtained from the rawinsonde (fig. 4B). Quite possibly the resultant ATS winds for the trades are more representative than wind observations from islands. The disturbing influence of islands upon the flow is well known and probably accounts for the vector difference between the ATS wind and the resultant rawinsonde at Papeete, Tahiti, shown in figure 4C. Here, the mean ATS flow is from the east-southeast while the resultant low-level flow, measured by Papeete's rawinsonde, is northeast. Interestingly, this difference between the wind at Papeete and the undisturbed trade-wind flow has been described by Palmer et al. (1955).

This comparison between the ATS resultant winds and the corresponding rawinsonde observations has been necessarily very limited. Nevertheless, it should help in evaluating the mean ATS winds presented in the next section.

4. RESULTANT WIND FIELDS

A streamline-isotach analysis of resultant low-level ATS cloud motions for the Central Pacific during November 1969 is displayed in figure 5. In addition, the distribution of monthly mean cloud brightness using the method of Taylor and Winston (1968) is superimposed. The trade-wind flow appears to be very well depicted here; wind speeds in the northern trades averaged as high as 15 kt south of Hawaii, while the southern trades were as strong as 16–17 kt. The axis of the zonally oriented clear area south of the Equator (i.e., the Pacific equatorial dry zone) approximately coincides with the axis of the strongest Southern Hemisphere trades between 125° and 155°W. A slight confluence just north of the Equator, with lower wind speeds, indicates the northern tropical convergence zone. The semipermanent Southern Hemisphere convergence extending southeastward from New Guinea is also another prominent feature in figure 5. This represents a convergence between the southern trades and cooler air from higher latitudes of the Southern Hemisphere. The ATS equatorward flow northeast of New Zealand is probably not completely representative. The problem is similar to that described previously for Midway. Here, the ATS-tracked clouds probably represent cellular convection occurring in cold air flow toward lower latitudes. This convection appears to have been sufficiently deep so as to penetrate into the westerly flow in the midtroposphere. Isobaric analysis in this area (not shown) suggests that the low-level flow should be more southeasterly than these streamlines indicate.

The high-level ATS motions are striking. These are shown in figure 6 with the mean monthly brightness

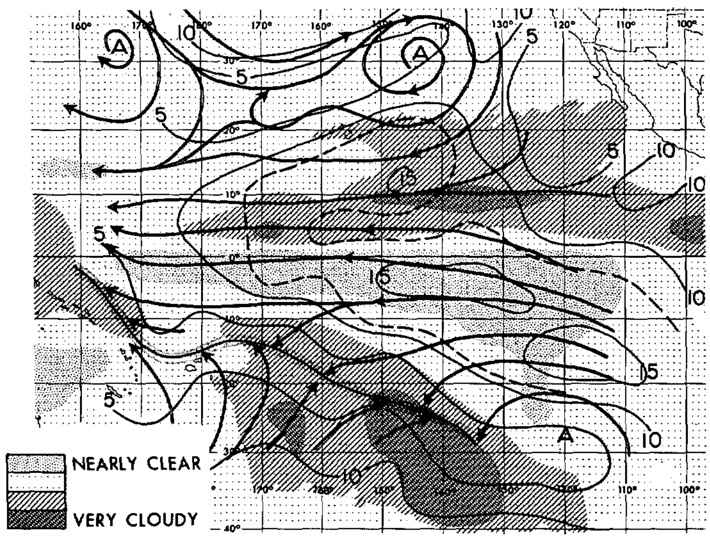

FIGURE 5.—Resultant low-level ATS wind field for November 1969. Streamlines (heavy solid) and isotachs (light solid) for every 5 kt are indicated. The monthly average cloud brightness is superimposed.

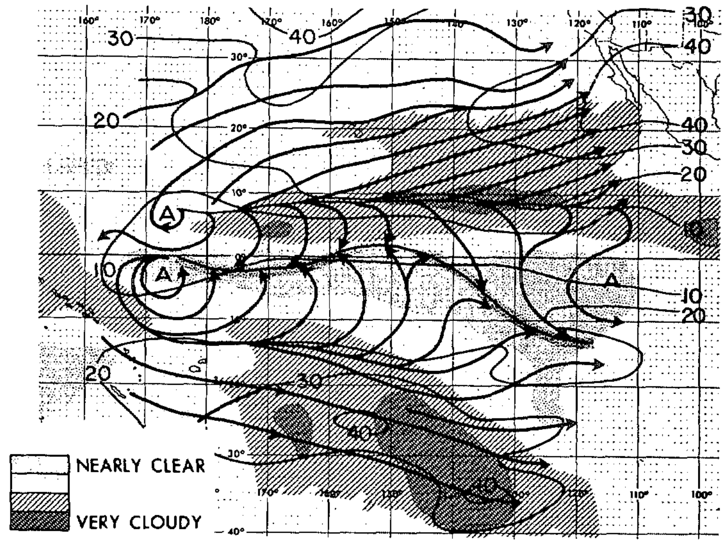

FIGURE 6.—Resultant high-level ATS wind field for November 1969. Streamlines (heavy solid) and isotachs (light solid) for every 10 kt are indicated. The monthly average cloud brightness is superimposed as in figure 5.

pattern again superimposed. Over the southern low-level convergence zone, high-level difluence is indicated with one branch flowing northward toward the Equator and converging with the outflow from the Northern Hemisphere tropical convergence. Notice the correspondence of this high-level confluence with the equatorial Pacific dry zone. Figure 5 indicates that the maximum southern trades roughly parallels this high-level confluence. This is reminiscent of Riehl's (1963) conclusion that the trades should be accompanied by a high-level convergence or shear line which acts as a channel for a series of high-level transient eddies.[2] It should be noted that the actual number of ATS high-level cloud vectors over the equatorial dry zone was small (fig. 2B). Undoubtedly, the cirriform clouds produced in the convective regions north and south gradually fade away here as the air subsides. Thus, the dry zone appears as a mass sink for these semipermanent convective systems. Southeastward from the Equator and 150°W this upper confluence line shows cyclonically curved flow. This high-level trough is a typical feature and also shows up, for example, in Sadler's (1970) analysis of aircraft reports. The amplitude of this mean trough and upstream ridge system shows a maximum at about 10°S and decreases rapidly southward.

The preceding discussion reveals a fairly good agreement between the distribution of cloudiness and the major features of the tropical circulation. Admittedly, the outflow indicated over the tropical convergence lines north and south of the Equator in figure 6 is probably excessive for the month as a whole. Similarly, the high-level confluence over the equatorial dry zone is also excessive. Were wind observations available for the cloud-free days, these features would probably be smoothed out. Despite this, some of the essential features of the equatorial circulation over the Pacific are revealed. The picture that emerges is an exaggerated but useful one.

5. SUMMARY

Using clouds as passive tracers presents unique problems, many of which are discussed in the report of Hubert and Whitney (1971). When these ATS vectors are used to obtain resultant winds, additional problems appear. The most important is a bias in the observations because cloud occurrence depends upon the circulation itself. Resultant winds computed from ATS cloud motions indicate the average flow when there are traceable clouds. Upon close examination, it appears that the largest biases occur in the westerlies, particularly those of the winter hemisphere, while the smallest are at low latitudes. This suggests that these resultant ATS vectors can be quite useful in the Tropics. One possible use would be in monitoring the strength of the trades. Another possible use is in a study of certain semipermanent features of the Tropics such as the intertropical convergence zone or monsoon. Here, ATS resultant winds represent a time mean, averaged over the most active periods of these circulations. This can be of considerable interest, perhaps more so than a mean that includes periods of relative inactivity combined with the periods of major convection.

We are not suggesting, however, that ATS winds be used exclusively. The most satisfactory way of using

[2] An example of such a shear line for the North Atlantic summer trades appears in Stone (1942, cf. his fig. 5).

them is in daily wind analysis in conjunction with all the existing rawinsonde and aircraft reports. This is the procedure used by the National Meteorological Center which now produces a tropical analysis each day. The analysis scheme is described in Bedient, et al. (1967) and Bedient and Vederman (1964). These analyses, if they can provide reasonable interpolation over areas with no data, should form the basis for computation of resultant winds. While these tropical analyses were produced in November 1969, the large number of ATS winds used in this study were derived later and did not enter the operational analyses. Consequently, use of these analyses for resultant winds and evaluation of them relative to resultants from the ATS winds alone were not feasible.

ACKNOWLEDGMENTS

The authors acknowledge the encouragement from, and stimulating discussions with, Dr. Jay Winston, Mr. Lester Hubert, and Mr. Linwood Whitney.

REFERENCES

Bedient, Harold, and Vederman, Joseph, "Computer Analysis and Forecasting in the Tropics," *Monthly Weather Review*, Vol. 92, No. 12, Dec. **1964**, pp. 565–577.

Bedient, Harold A., Collins, William G., and Dent, Gloria, "An Operational Tropical Analysis System," *Monthly Weather Review*, Vol. 95, No. 12, Dec. **1967**, pp. 942–949.

Hubert, Lester F., and Whitney, Linwood F., "Wind Estimation From Geostationary Satellite Pictures," *Monthly Weather Review*, Vol. 99, No. 9, Sept. **1971**, pp. 665–672.

Palmer, Clarence Edgar, Wise, C. W., Stempson, L. J., and Duncan, G. H., "The Practical Aspect of Tropical Meteorology," *Air Force Surveys in Geophysics*, No. 76, U.S. Air Force Cambridge Research Center, Mass., Sept. **1955**, 195 pp.

Riehl, Herbert, "Stationary Aspects of the Tropical General Circulation," *Geofisica Internacional*, Vol. 3, No. 3/4, Mexico City, D. F., Mexico, July/Dec. **1963**, pp. 53–178.

Sadler, James C., "Mean Monthly Upper-Tropospheric Winds of the Central and Eastern Tropical Pacific From Aircraft Reports," *Proceedings of the Symposium on Tropical Meteorology, Honolulu, Hawaii, June 2–11, 1970*, American Meteorological Society and World Meteorological Organization, Honolulu, **1970**, pp. JI-1–JI-7.

Stone, Robert G., "On the Mean Circulation of the Atmosphere Over the Caribbean," *Bulletin of the American Meteorological Society*, Vol. 23, No. 1, Jan. **1942**, pp. 4–16.

Taylor, V. Ray, and Winston, Jay S., "Monthly and Seasonal Mean Global Charts of Brightness From ESSA 3 and ESSA 5 Digitized Pictures, February 1967–February 1968," *ESSA Technical Report* NESC 46, National Environmental Satellite Center, Suitland, Md., Nov. **1968**, 9 pp. and 17 charts.

[*Received December 7, 1970; revised March 22, 1971*]