INTERPRETATION OF CLOUD WINDS

Tetsuya Theodore Fujita

The University of Chicago
5734 Ellis Avenue
Chicago, Illinois 60637
U.S.A.

ABSTRACT

Since the mid 1960s, when geostationary satellite data became available, the author made numerous attempts to compute satellite-tracked, cloud-motion winds, reaching a conclusion that the tracking accuracy is 1 m/sec or better. Nonetheless, the height assignment and type of tracer clouds could reduce the accuracy of converting motion vectors into wind velocities at cloud heights. In order to improve the accuracy of wind estimates, cloud truth experiments were conducted under the acronym of CHAMEX (Cloud Height And Motion EXperiment). It has been concluded that the improved inter- pretation/verification method will permit us to achieve the 1 to 2 m/sec RMS accuracy in estimated wind speeds.

1. Introduction

The Satellite and Mesometeorology Re- search Project (SMRP) of the University of Chicago performed cloud-motion compu- tations based on Applications Technology Satellites (ATS), finding that geostationary satellites are useful in determining cloud-motion winds over oceans where no sounding data are available. Fujita (1969) and Izawa and Fujita (1969) reported their optimism at the COSPAR Tokyo meeting. Since then, high- and low-cloud motions, as well as the drift of the dust clouds from Sahara to the western Atlantic were computed by Fujita (1971) with high accuracy.

Cumulus clouds, overland in particular, became a serious problem as tracers. A Lear-Jet experiment over the City of Springfield, Missouri by Fujita, Pearl, and Shenk (1975) concluded that the trackable life is only 5 to 10 min, necessitating rapid- scan pictures at 5 to 10 min intervals in computing winds. It was also found that small cumuli move with the cloud-base winds.

During the 1980s, the author undertook stereoscopic height computations based on GOES East and West, as well as GOES West and GMS Himawari stereo pairs. Fujita

(1982) concluded that the stereoscopic method, when used properly, will result in very accurate cloud heights inside the dual coverage area.

A synoptic verification of winds over the north Pacific region was made by generating a 217 mb (11.3 km) chart which includes winds from various sources (Fig. 1). This example proves the excellent verification of the cloud winds in the jet-stream region, as well as weak-wind areas. Without these cloud winds, the analytical results could be significantly inferior.
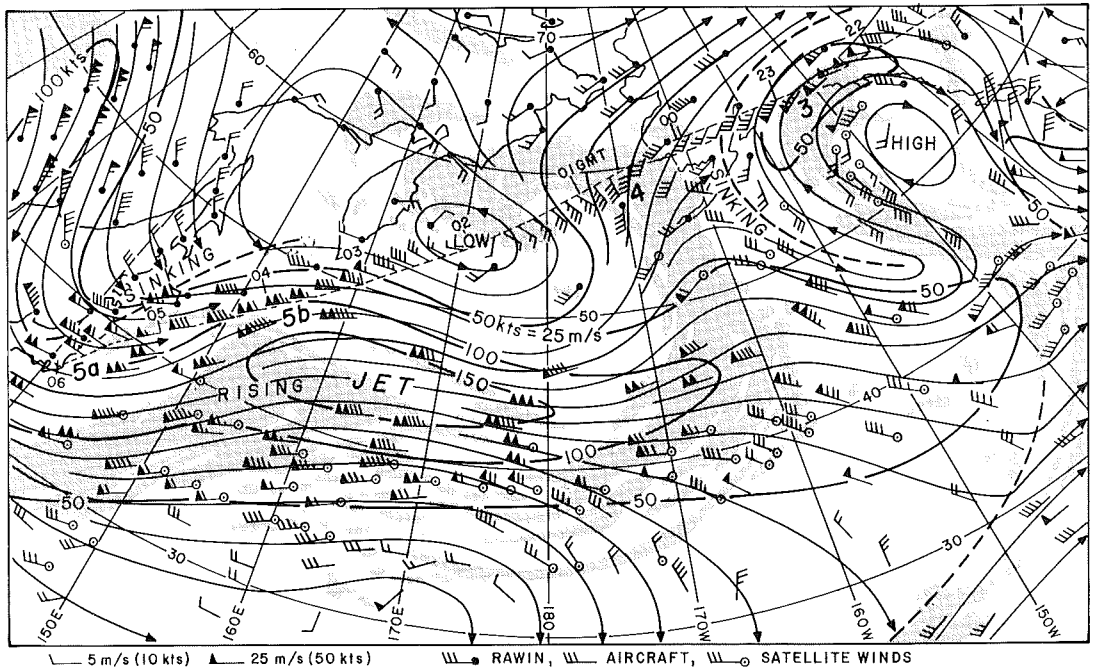

Fig. 1 Verification of satellite winds in comparison with rawin and aircraft winds over the Pacific. Winds on a dashed line extending from Alaska to Tokyo are INS winds from JAL 009 at 37,000' (11.3 km) altitude.

2. Cloud Height And Motion Experiment

The CHAMEX experiment was conducted at Cape Hatteras, North Carolina (35°N 76°W) in 1988 and at Key West, Florida (25°N 82°W) in 1989. In both experiments, special rawins were released for increasing both temporal and humidity resolutions. The main verification equipment was whole-sky cameras capable of recording time to the nearest second, and taking red-filtered image of clouds above 4° elevation angles (Fig. 2).

Stereoscopic computations of cloud heights and motions from Fig. 3 revealed that the east-side anvil (No. 1) was 1 km higher than the west-side anvil (No. 2). Anvil No. 1 was older and larger than No. 2. A GOES imagery at the whole-sky picture time shows a faster expansion rate of Anvil No. 1 (Fig. 4). As shown in this example, cloud motion vectors of growing anvils are characterized by mesoscale variations.

A drifting anvil off the coast of Miami, Florida (26°N · 80°W) shows interesting motion vectors (Fig. 5). The highest velocity of 14 m/sec was located around the anvil edge. Whereas, the central region was moving at 8 m/sec, only 60% of the anvil edge motion. The reason for the slow movement is the vertical motion deep inside the anvil cloud. In other words, the best tracer is the downwind edge of a drifting anvil cloud.
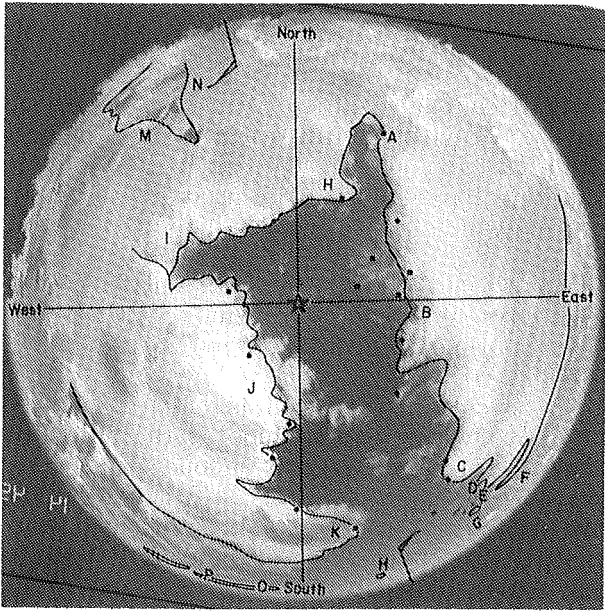
Fig. 2 A whole-sky photo by Camera A at 1848 GMT 16 SEP 89. From Fujita (1991) CHAMEX Report.
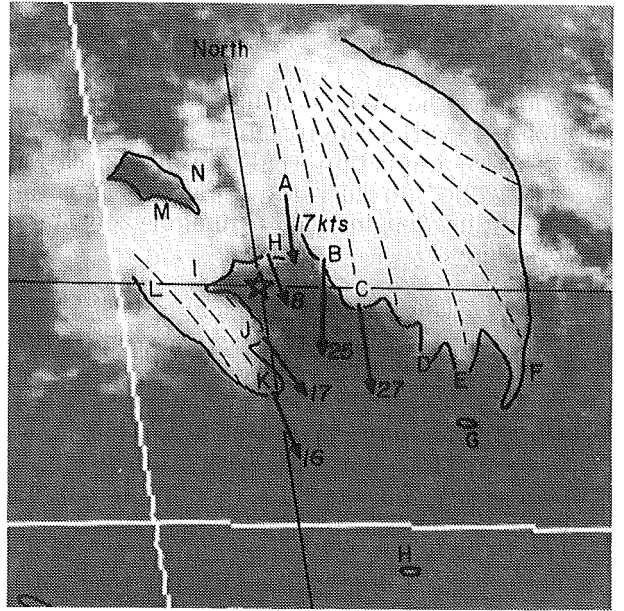

Fig. 4 Stereoscopic winds superimposed upon the GOES East image at 1841 GMT. An asterisk denotes whole-sky Camera A.
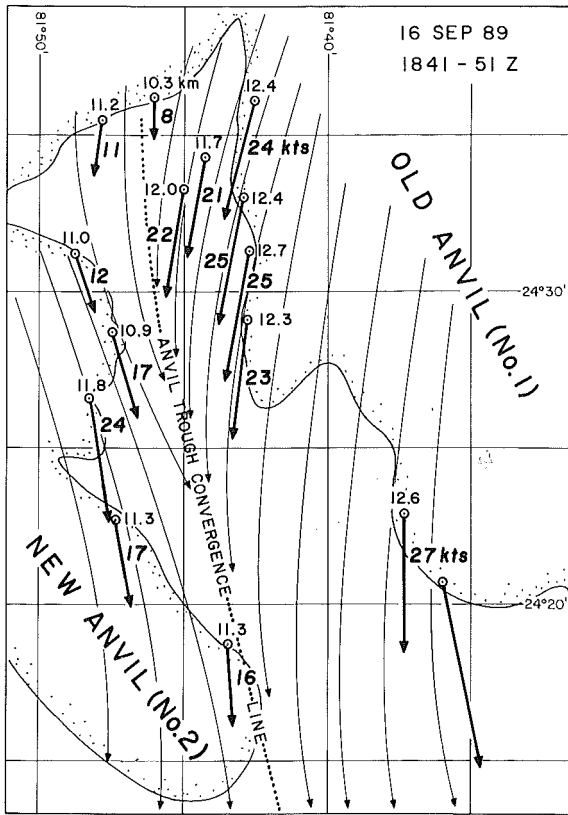

Fig. 3 A cloud-wind map at 1841 GMT 16 SEP 89 obtained by stereoscopic method. Wind speed in kts and cloud height in km.
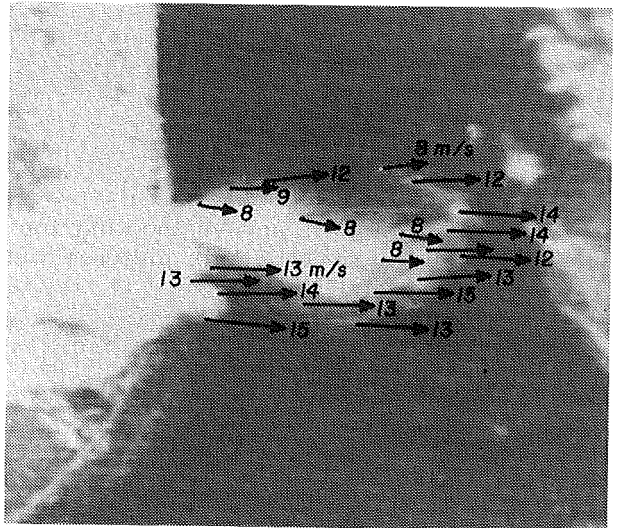

Fig. 5 Twenty cloud-motion winds obtained by tracking various parts of a thunderstorm anvil off the coast of Miami, Florida. In general, the leading edge of a drifting anvil cloud moves faster than the central region of the cloud.

3. Severe Thunderstorms

Although the true nature of the cloud motion atop the anvil cloud has not been known, two important features are so-called "warm wake" in infrared imagery and the overshooting top in visible imagery obtained at low angles.

Unlike tropospheric convective tops, overshooting tops extending several kilometers above anvil clouds are often 10 to 20°C colder than the environment. Upon reaching the maximum height, the cold and heavy top behaves like a large rock thrown into the pool of anvil particles, consisting mostly of ice crystals. The collapse of an overshooting top is a combination of sinking and spreading motions with insignificant horizontal motion in comparison with the environmental winds at anvil height. As a result, horizontal motion of an overshooting top should not be used as the cloud-motion wind at the anvil-top height.

The warm wake is a wake-shaped warm area extending downwind from an overshooting/collapsing region of an anvil cloud. Although a warm wake moves, either fast or slow, its motion is often unrelated to the environmental winds at the anvil-top level. Recently, we are encountering cases where a warm wake turns into a cold wake. We should not use the wake motion in estimating the environmental wind at the anvil-top height.
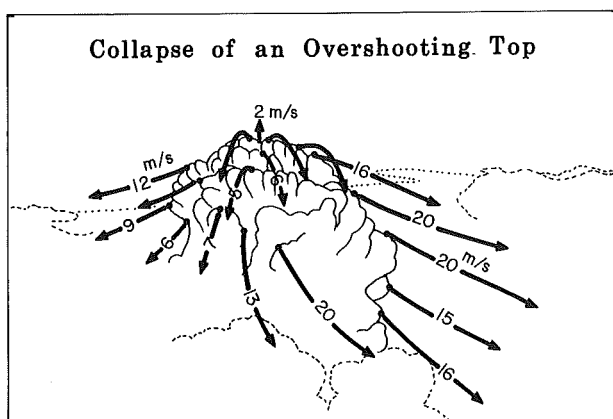

Fig. 6 A view of an overshooting top (left) over Cotulla, Texas at 1218 CST on 12 May 1972. A series of six pictures were used in determining the collapsing motion of the cloud top (right).

4. Tracking of Artificial Clouds

Artificial clouds, such as forest-fire smoke, condensation trail, rocket plume, etc., can be tracked by geostationary satellites for estimating the winds in which they are embedded. Discussed in this section are trackings of a condensation trail and a rocket plume photographed by both wide-angle and whole-sky cameras during the CHAMEX at Key West and the CAPE experiment at the Kennedy Space Center, both in Florida.

The contrail on 14 September 1989 to the south of Key West grew into a 5-km wide band. The cloud was tracked for a 10-min period, 1831 - 1841 GMT, obtaining the cloud height between 11.6 and 12.6 km MSL. Its motion was approximately 16 m/sec from between 253° and 264° (Fig. 7).

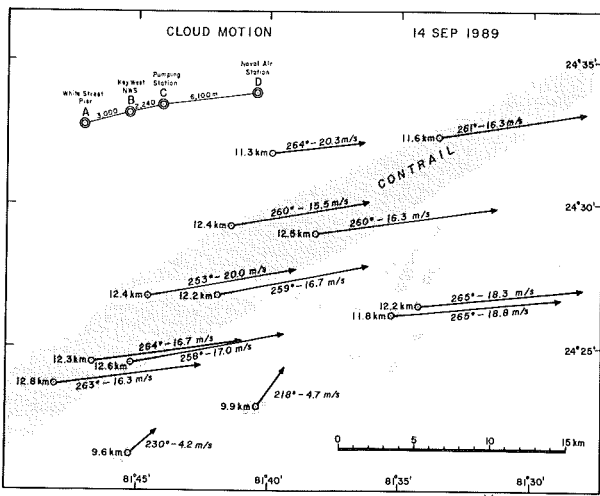The same contrail was clearly visible in the rapid-scan GOES photos taken at

Fig. 7 A condensation trail tracked by four whole-sky cameras, A through D, at Key West, Florida.

Fig. 8 The same contrail seen and tracked on GOES rapid-scan images at 5-minute intervals.

5-min intervals, giving us a golden opportunity in performing dual computations of the contrail by both satellite and ground-based cameras. GOES-tracked cloud velocities in Fig. 8 turned out to be very close to those measured stereoscopically. Because the contrail height was assigned by the stereo method, the RMS error in velocity computations was approximately 1 m/sec.
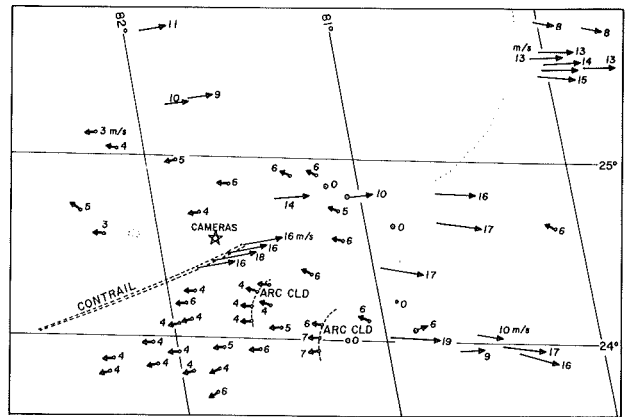
Space Shuttle Atlantis launched at 1102 EDT 2 August 1991 left behind a trail of plume extending to 45-km MSL (Fig. 9 left). A series of whole-sky photos taken at 2.5-min intervals showed the distorted plume within 10 minutes after the launch (Fig. 9 right).

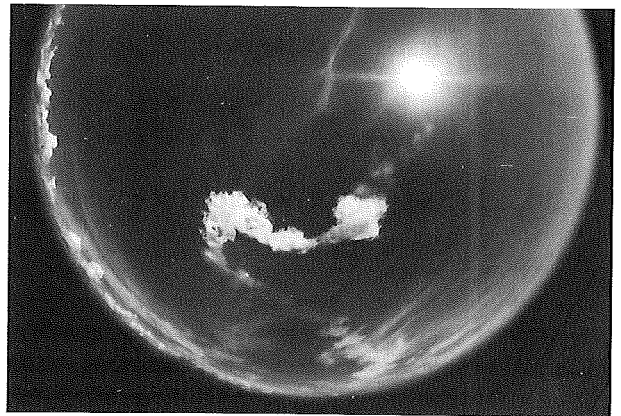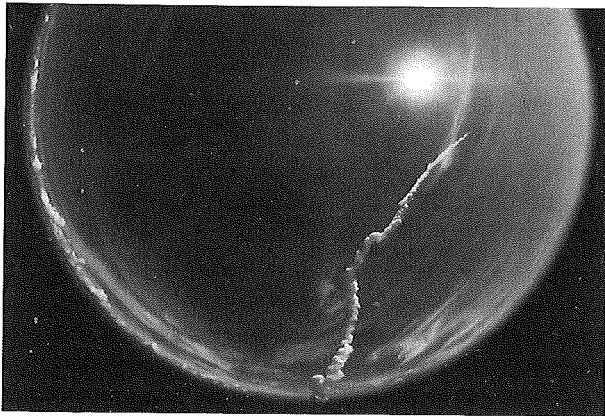For verifying the motion of high clouds, cirrus clouds in ground-based photographs

Fig. 9 Two whole-sky pictures of the Atlantis plume taken at 1105 EDT (left), 3 minutes after launch and at 1115 EDT (right). Within 10 minutes, the plume was distorted by the jet-stream winds between 9 and 14 km MSL.
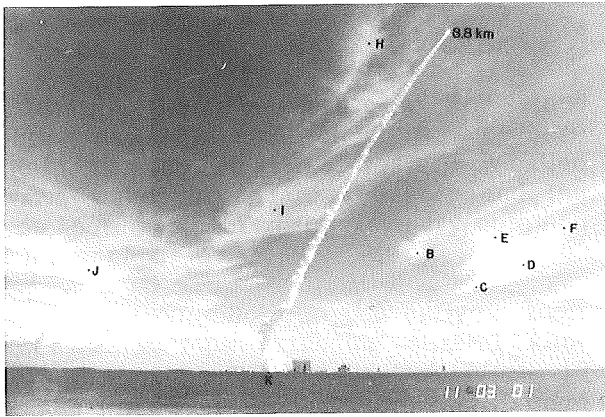
Fig. 10 Elements of the cirrus clouds photographed with the Atlantis plume. Cirrus motions were computed from both whole-sky and wide-angle imagery.
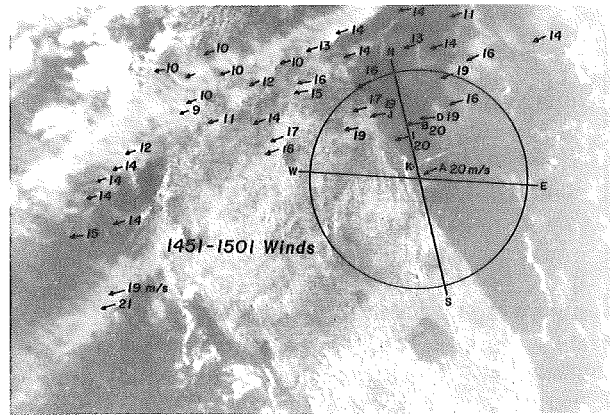

Fig. 11 Satellite cloud-winds computed from the 5-min imagery of GOES at 1046, 1051, and 1101 picture-start times. A 10-min tracking period was used in computing the cirrus winds.

were identified by letters (Fig. 10) and tracked. Meanwhile, identical cirrus clouds in GOES rapid-scan imagery were tracked in determining cirrus winds (Fig. 11). The result indicates that satellite-tracked cirrus winds are very accurate, say with 1 m/sec error, as long as the heights are assigned precisely.

Acknowledgements

References

Fujita, T.T., (1969) "Present status of cloud velocity computations from the ATS I and ATS III satellites." Proceedings, Open Meetings of Working Groups of the 11th Plenary Meeting of COSPAR, Tokyo, May 1968, pp 558-570.

Fujita, T.T., (1971) "Application of ATS III photographs for determination of dust and cloud velocities over the northern tropical Atlantic." J. Meteor. Soc. Japan, 49, Special issue, pp 813-821.

Fujita, T.T., E.W. Pearl, and W.E. Shenk, (1975), "Satellite-tracked cumulus velocities." J. Appl. Meteor., 14, 3, pp 407-413.

Fujita, T.T., (1982) "Principle of stereoscopic height computations and their applications to stratospheric cirrus over severe thunderstorms." J. Meteor. Soc. Japan, 60, 1, pp 355-368.

Fujita, T.T., (1991) "Cloud height and motion experiment CHAMEX." WRL Res. Paper 230, Univ. of Chicago, 39 pp.

Izawa, T., and T.T. Fujita, (1969) "Relationship between observed winds and cloud velocities determined from pictures obtained by the ESSA III, ESSA V, and ATS I satellites." Proceedings, Open Meetings of Working Group of the 11th Plenary Meeting of COSPAR, Tokyo, May 1968, pp 572-579.