Ground-Truth Experiment of Cloud-Drift Winds

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ABSTRACT

Basic research on the nature of the cloud-drift winds, being obtained by NESDIS at Madison, Wisconsin and at Ft. Collins, Colorado, has been conducted for better interpretation of the cloud-wind vectors and their heights. In conducting cloud-truth experiments, two whole-sky cameras have been operated at The University of Chicago and Downtown lakefront, while GOES-7 takes rapid-scan cloud pictures at 5-min intervals. The maximum range of stereo computations was increased significantly from 30 km to 70 km by developing and testing a new photogrammetric method.

1. Computations from ATS-III Color Pictures

ATS (Applications and Technology Satellite) III, launched on 5 November 1967, took a sequence of cloud pictures in color on November 18 and 19 before losing the color capability on the 20th. At that time, cloud trackings were done with 16-mm B & W movie projected on a digitizer board. The color image provided by ATS-III was excellent in tracking not only clouds but also dust storms over the Sahara Desert and the bands of wave-like clouds inside the gravity waves over the Atlantic. Also seen were formation and dissipation of tiny cumuli over the Gold Coast. Their motion could not be determined due to their extremely small size, far below the IFOV (Instantaneous field of view).

Figure 3 presents the cloud-drift winds tracked on the movie screen. Seen in the upper-left section are north-south bands of thin clouds modulated by the ridge and trough of the gravity waves. Although the wave clouds moved toward ENE at 50 to 70 kts, cumuliform clouds beneath the waves were drifting southward.

Numerous low clouds are visible in the southern sectors of the cut-off low with an eye-like clear area located around the circulation center. Cellular clouds were tracked in obtaining the 30 to 49 kts swirling speeds around the clear area. Over the vast areas of cloud cover, however, a number of holes in overcast were tracked in computing cloud-drift winds. Both cell and hole trackings resulted in similar winds, indicating that either cells or small holes can be tracked in estimating cloud winds. On ATS-III color pictures, we could identify middle and high clouds drifting above cellular low clouds. An attempt was made to determine higher-level winds around the cut-off low off the west coast of Spain.

The first and the last photos of the four color imagery at 1157, 1227, 1256, and 1333 UTC used in computing the cloud-winds show dust clouds over the Sahara Desert and gravity wave clouds over the Atlantic and the northern tip of South America. As expected, wave clouds did not move with wind.

Fig. 1 The first color photo (1157 UTC) of the four tracking pictures

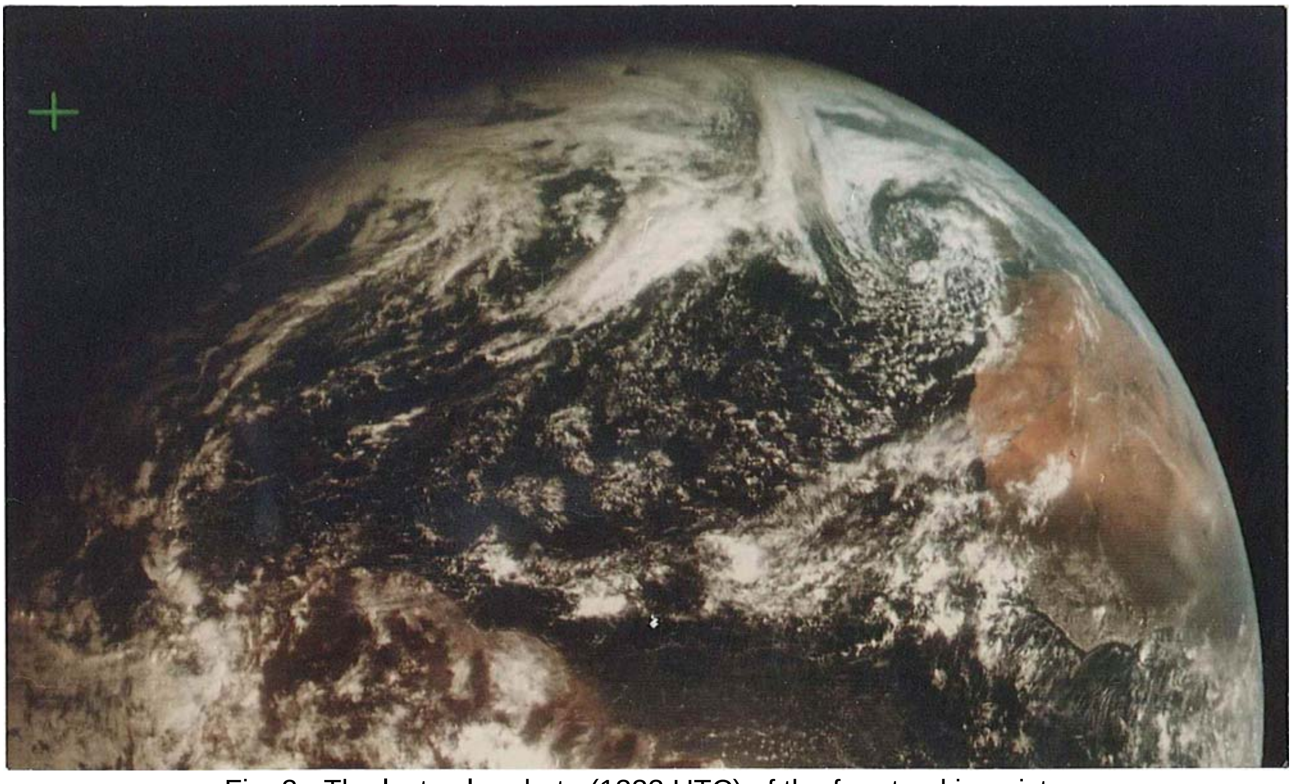

Fig. 2 The last color photo (1333 UTC) of the four tracking pictures

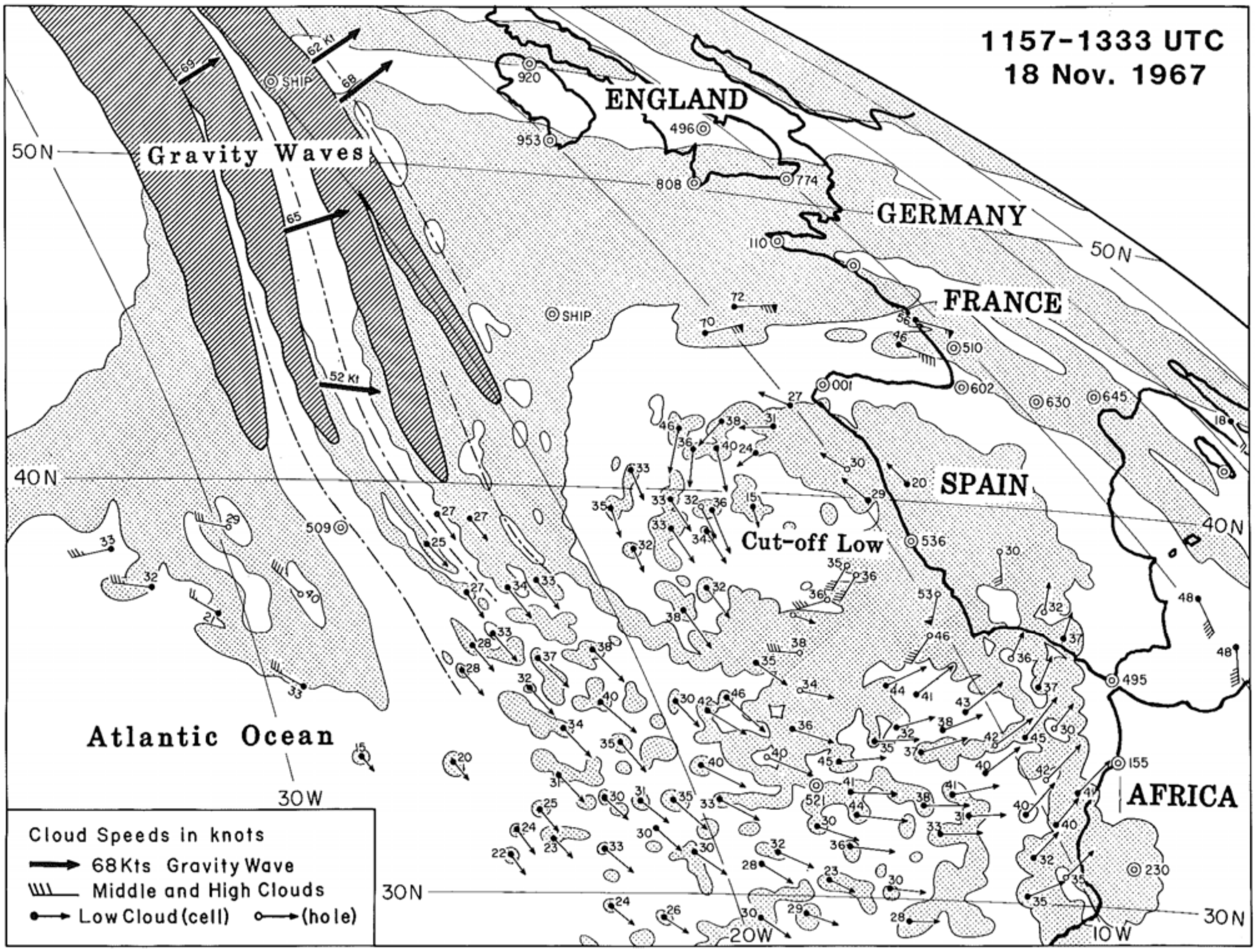

Fig. 3 Cloud-drift winds from four ATS-III pictures taken during a 96-min period on 18 November 1967. Four wave clouds, 19 high/middle clouds, 87 cellular low clouds, and 8 holes in overcast, were tracked to determine their cloud-drift winds.

2. Cloud-Drift Winds from GMS Pictures

In this experiment, four GMS pictures at 30-min intervals were tracked on both positive and negative pictures. It was found that low-reflectivity clouds can be tracked easily on positive pictures (Fig. 4 left) and high-reflectivity clouds, on enhanced negative pictures (Fig. 4 right). High-cloud winds computed by dual-image tracking are presented in Fig. 5.

In the 1970s, it was not feasible to assign a pressure altitude to each cloud wind. As a result, the pressure altitude at each upper-air station was determined by selecting the best-fit pressure altitude between winds aloft and environmental cloud winds. The best-fit pressure altitudes shown by slant numbers, varied between 200mb and 500mb with average altitude of 250mb. Shown at each upper-air station are 250mb wind and height in 10-m unit.

High-cloud winds revealed a significant modification of high-level atmosphere due to the release of latent heat by numerous rainstorms embedded inside a relatively weak cyclonic circulation centered between Naze (Station 909) and Kagoshima (Station 827). Although the central pressure at 00 UTC 16 May was 1006mb at sea level, Naze received 127 mm rainfall and two small islands south of Kyushu received 163 mm and 203 mm, respectively. The difluence pattern of high clouds was considerable.

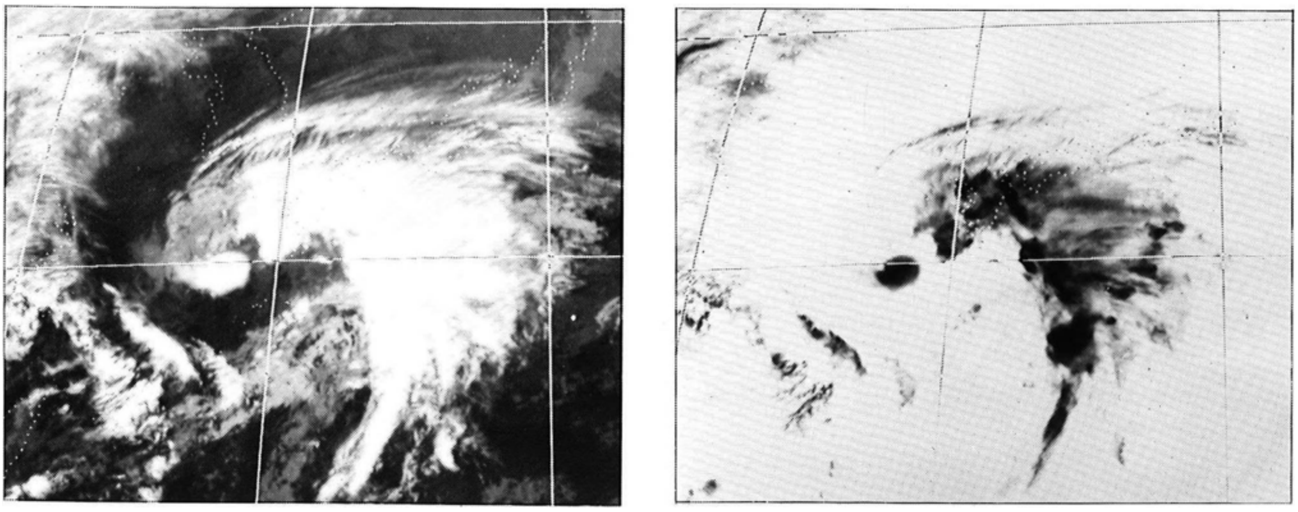

Fig. 4 GMS pictures at 2200 UTC 15 May 1978. Standard picture (left) was used in tracking high clouds in the outflow region and enhanced-negative picture (right), inside the region of thick high clouds.

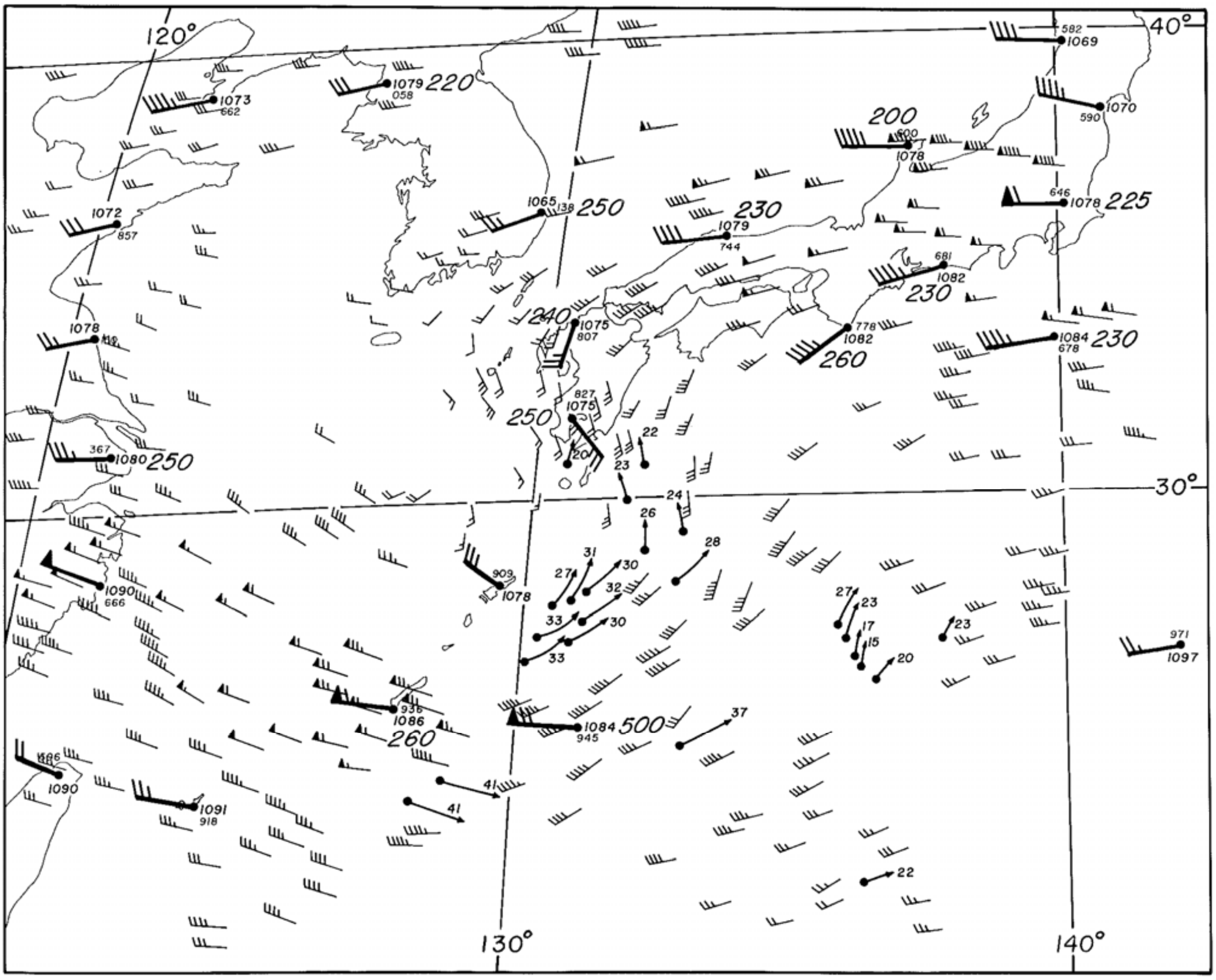

Fig. 5 Cloud-drift winds of high clouds (standard wind symbols) and convective towers (arrows) computed from GMS pictures at 2200, 2230, 2300, and 2330 UTC on 15 May 1978. Photos courtesy of Meteorological Satellite Center at Kiyose, Japan.

3. Verification with Stereoscopic Whole-Sky Cameras

In summer 1993, a cooperative research on the verification of cloud-drift winds was initiated by NESDIS at the University of Wisconsin (Paul Menzel), NESDIS at Colorado State University (Jim Purdom) and The University of Chicago (Ted Fujita). GOES-7 is operated in the rapid-scan research mode, taking infrared and visible pictures at 5-min intervals, while two whole-sky cameras take stereoscopic pictures at the lakefront of Downtown Chicago and at The University of Chicago (8230 m baseline distance).

After each experiment, Menzel and Purdom compute operational cloud-drift winds, obtaining accurate winds within 70 km range of Chicago downtown. Menzel emphasizes his cloud-height assignment by CO_2 and water vapor channels while Purdom improves cloud heights based on cloud shadows on the ground. Fujita uses improved whole-sky stereo photogrammetry to determine cloud winds and heights within the 70-km range of Chicago. The three groups determine their best winds and heights independently in an attempt to improve the ultimate, operational wind products.

Presented in this paper is the 27 August 1993 case when three distinct high clouds identified as **Pelican cloud**, **Fish cloud**, and **Bait cloud**, crossed the Lake Michigan Shoreline north of Downtown Chicago. The overall cloud pattern in Fig. 6 was provided by Purdom. It should be noted that the geographic features in this GOES-7 picture were determined by elevating grid lines and shoreline to **9.24 km ACL** (Above Camera Level), the mean stereoscopic height of the tracked clouds. Although the position of high clouds relative to the elevated grid lines is correct, elevated grid lines viewed from GOES-7, as perspective center, shift away from the subsatellite point on the equator. As seen in the picture, the Lake Michigan shoreline is shifted toward the northeast by 10 km from the true shoreline on the earth.

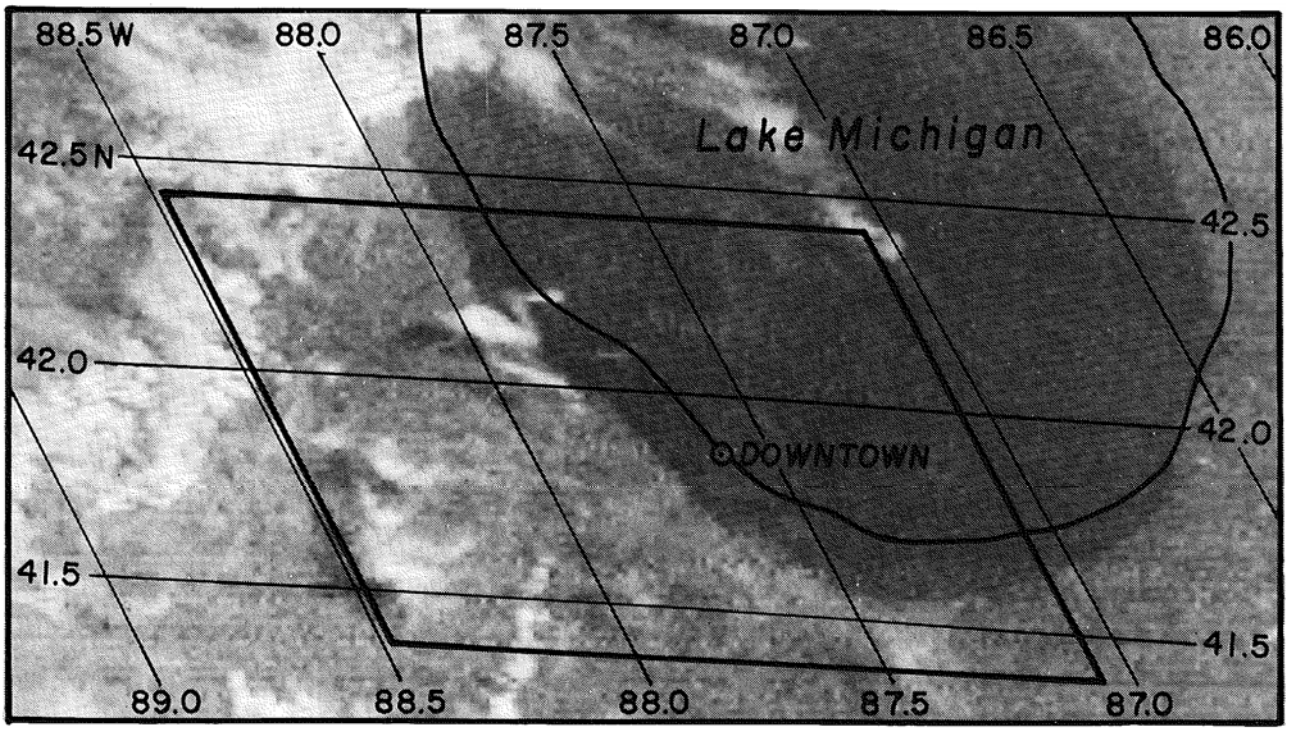

Fig. 6 GOES-7 visible picture at 1201 UTC (picture start time) superimposed upon the geodetic latitudes and longitudes elevated at 9.24 km ACL. The area of the cooperative analysis is bounded by heavy N-S and E-W lines. Basic data - Subsatellite point: 0.63° N, 112.62° W; Solar zenith angle 33.6°, Satellite zenith angle 47.9°.

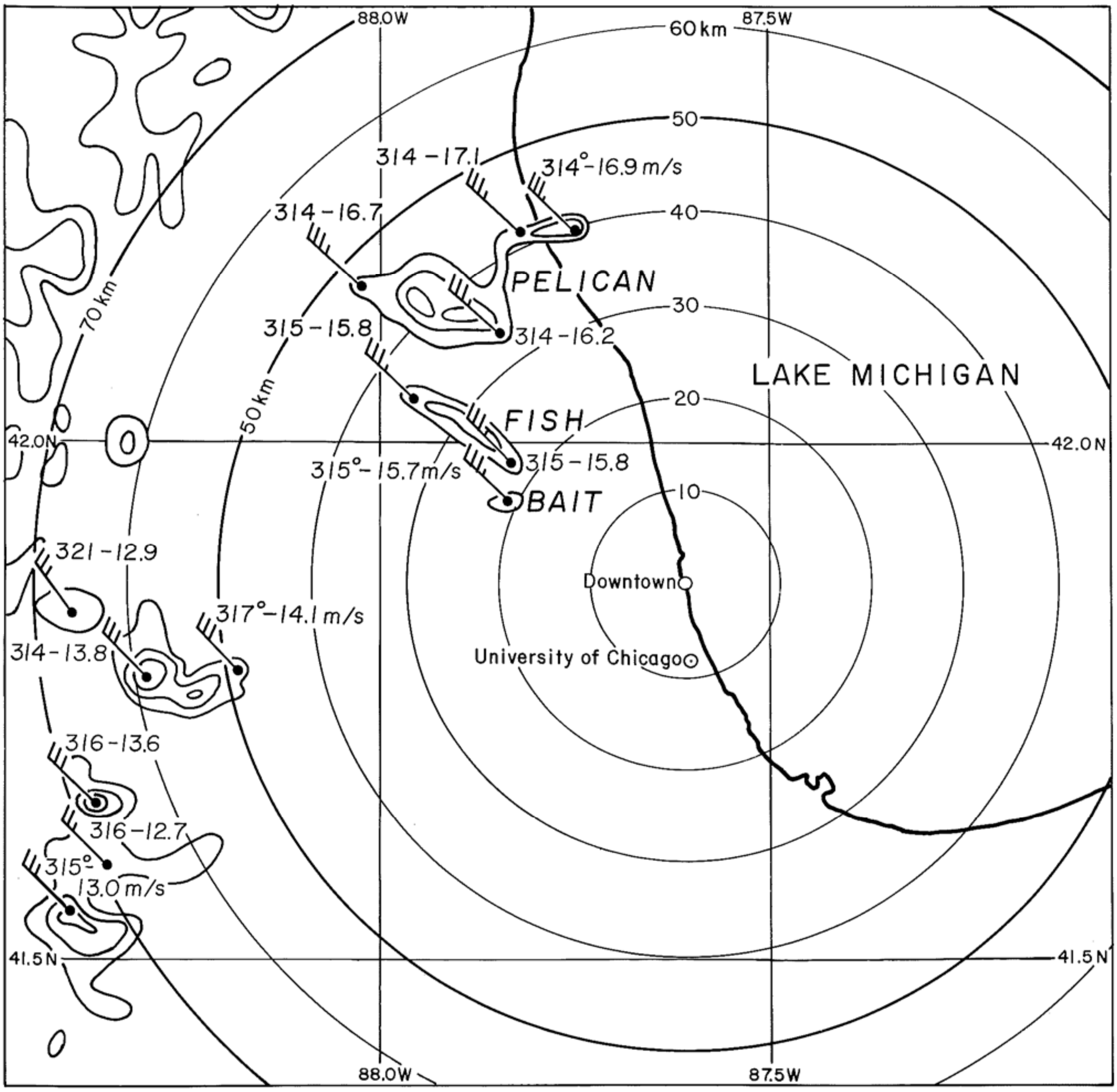

Fig. 7 High-cloud winds computed from GOES-7 pictures at 1631 and 1701 UTC on 27 AUG 93.

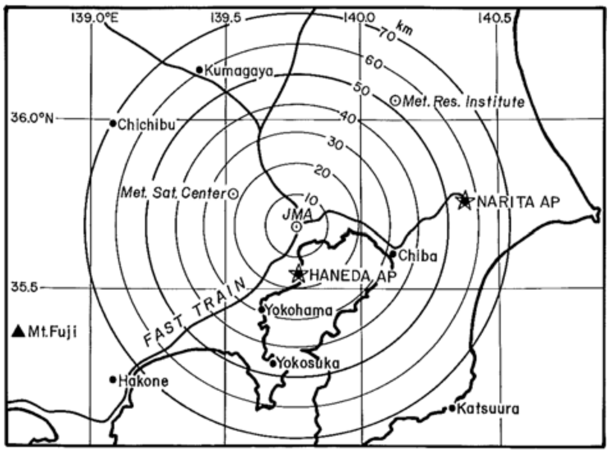

Fig. 8 70-km range markers centered at the Japan Meteorological Agency. The maximum range of stereoscopic computations reaches beyond Narita Airport and MRI at Tsukuba.

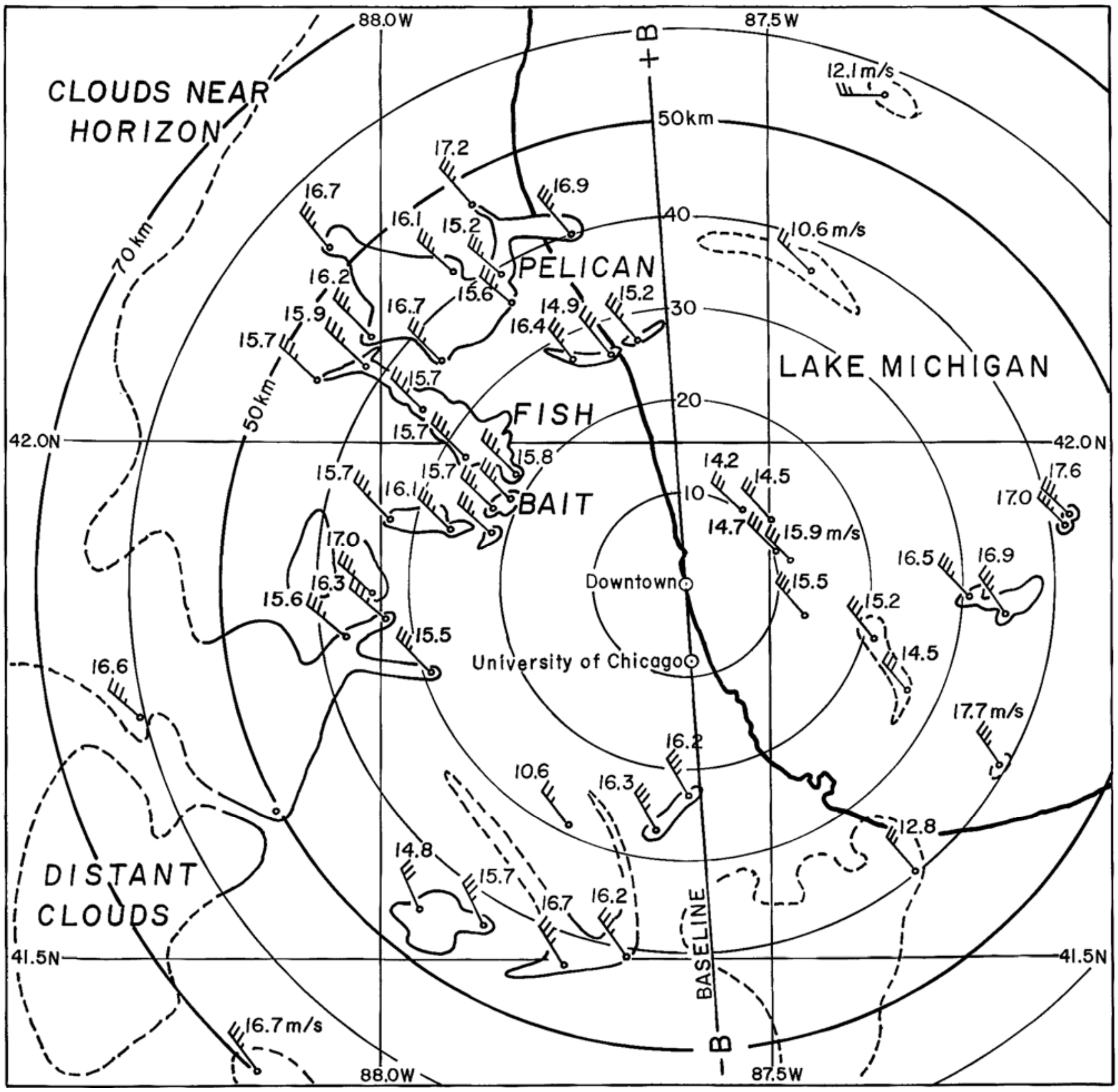

Fig. 9 Cloud-drift winds computed from whole-sky stereo pictures taken at one-minute intervals between 1648 and 1700 UTC on 27 AUG 1993. The downtown site is located inside a small lakefront park between Meigs Field (CGX) and Adler Planetarium. The University of Chicago site is located on the roof above the 5th floor of the Geophysical Sciences Building.

Fig. 10 Skyline of downtown Chicago seen from the Whole-Sky camera site on the lakefront. Sears Tower (azimuth 305.0°), the world's tallest building, the Amoco Building (335.0°), and the John Hancock Tower (342.7°) are significant skyscrapers.

The foregoing computations of cloud-drift winds and cloud heights, based on GOES-7 and whole-sky imagery, revealed that the winds determined independently are very close to each other. In particular, the scatter in windspeeds is no more than 1 m/s. On the other hand, RMS of winds directions is approximately 2°, due mainly to the types of cloud targets. Cloud elements identifiable on whole-sky imagery could be very small and faint. Whereas, the threshold of satellite-tracked clouds must be over 1 km size with distinct brightness.

The vertical extent of high clouds is much smaller than that of convective clouds. Some high clouds are characterized by over 1-km thickness and storm-top clouds are often very thick and extensive (see Fig. 4). Their heights, estimated from satellite, while looking downward, and those computed stereoscopically, while looking upward, should be different. We might have to select so-called **good targets**.

4. Whole-Sky Photogrammetry

This technique of computing cloud-drift winds and cloud heights was improved during the past few months since the onset of the cooperative cloud-truth experiment by Mezel, Purdom, and Fujita. The new computation method now permits us to track clouds near the whole-sky horizon with 80° or even larger zenith angles. Use of fine-grain B & W film with dark-red filter also contributed to the tracking capability of distant clouds. Examples of computation output are presented.

CLOUD HEIGHT — 1700 UTC — 27 AUG 93

Cloud	Camera	a	b	Z.angle	Height (km.)	Lat. N	Lon. W
1	DT	15.0	60.4	76.7	9.04	42.201	87.754
1	UC	13.5	62.9	79.0			
2	DT	26.9	58.0	78.8	9.23	42.234	87.881
2	UC	23.7	61.0	80.4			
3	DT	27.7	55.5	76.5	9.18	42.163	87.844
3	UC	25.1	59.0	78.7			
4	DT	28.0	54.2	75.2	9.99	42.135	87.828
4	UC	25.0	58.1	77.6			
5	DT	46.3	43.1	78.0	9.15	42.112	88.016
5	UC	41.8	49.4	79.5			

HIGH-CLOUD WIND — 1648-1700 UTC — 27 AUG 93

Cloud	Camera	Time	a	b	Z.angle	Direction	Speed (m/s)	Lat. N	Lon. W
1	DT	1648	21.8	60.8	79.6				
1	DT	1700	15.0	60.4	76.7	318	16.9	42.201	87.754
2	DT	1648	30.8	58.1	81.1				
2	DT	1700	26.9	58.0	78.8	317	17.2	42.234	87.881
3	DT	1648	33.3	55.0	79.3				
3	DT	1700	27.7	55.5	76.5	308	15.2	42.163	87.844
4	DT	1648	34.0	53.9	78.6				
4	DT	1700	28.0	54.2	75.2	308	15.6	42.135	87.828
5	DT	1648	46.7	45.6	80.5				
5	DT	1700	46.3	43.1	78.0	316	16.2	42.112	88.016

Above: Example of cloud heights at 1700 UTC from stereo-pair pictures at DT and UC. Below: High-cloud winds computed by tracking on DT pictures for 12 minutes. The mean cloud height of 9.24 km was used. Input values, in 0.05" units, measured on circular image, zenith at the origin of rectangular coordinates, are: R radius of image, b ordinate, positive in the direction of the baseline, toward north, and a abscissa, positive toward west.