Improvements in Geostationary Satellite Wind Observations as a Result of the Global Weather Experiment and Applications of these in the Context of the WWW System**

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Abstract

The history and present status of satellite wind observing systems are reviewed and summarized. Through the GWE period (December 1, 1978 – November 30, 1979), cloud motion winds had been routinely derived from 5 geostationary meteorological satellites by 4 operating agencies; MSC/JMA, NESDIS/NOAA, ESOC/ESA and SSEC/UW. The former 3 agencies have kept deriving the satellite winds after the period.

The satellite winds agree well with conventional winds in most cases. The vector differences between satellite winds and radiosonde winds are 10m/s or less for high level winds and 5m/s or less for low-level winds. As a result of some improvements in operational wind derivation systems, the satellite wind observation has been stabilized in quality among the operating agencies.

The applicability of satellite wind derivation system is discussed. As the satellite winds have global coverage and as it is easy to handle them with computer, satellite winds are very useful for and essential to; (a) numerical weather prediction as initial data especially in tropical area and in southern hemisphere, and (b) the research of climate variation in relatively short period, the order of 2 to 3 years.

On the other hand, it has been noted that the cloud motion winds are derived in completely different way from the way of conventional observation. The problems caused from this are pointed out as that; (a) the satellite winds are mostly obtained only on two levels, and (b) the difficulty of height assignment sometimes causes conspicuous errors in the satellite winds, particularly at high-levels, e.g. over the area along jet-stream cirrus in mid-latitudes. In order to overcome these problems, it is considered that;

(a) The additional sensors such as water vapor (6.8 μm), split window (11.5 and 12.5 μm) and CO_2 (13.3, 14.0 and 14.2 μm) channels are helpful tools,

(b) Synthetic stereo produced from visible and infrared images are useful for middle-level wind derivation,

(c) The images with 15 minute intervals should be used for especially tracking cirrus moving quickly like that around sub-tropical jet-stream in winter, so that distinct improvements of the quality and quantity will be marked, and

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** This is a lecture note prepared for a Conference on the Results of the Global Weather Experiment (GWE***) and their Implications for the WWW held in Geneva on 27-31 May 1985. Concept of section 4 was given by Dr. T.Nitta, JMA, and sections 4.1 and 4.2 were originally written by Dr. A.Sumi, University of Tokyo, and Dr. T.Nitta respectively.

*** GWE; The GWE was previously called the FGGE (First GARP Global Experiment).

(d) Stereo height determination using images taken simultaneously over common field of view from two neighboring satellites is very helpful for verification of height assignment.

Finally, it should be emphasized that the satellite wind data are indispensable both operationally and in research work, and both in present and in future, though further improvements in current operational wind derivation system and further development of the application of satellite wind data are still required.

1. Introduction

In December 1966, the first Application Technology Satellite (ATS-1) was launched and put into geostationary orbit by the United States of America. The ATS-1 had had imaging function which gave us cloud distribution over approximately one-forth of earth surface with the same view at any time. It has been expected that the information on the cloud distribution, especially those over the data sparse areas like oceanic, mountainous and desert areas, would considerably contribute to both increasing knowledge on the behavior of the global atmosphere and the development of technique for analysing meteorological fields.

From two or more time-sequential pictures (images) taken by the ATS-1 the cloud motion vectors had been derived by tracking target clouds. The vectors were regarded as upper level winds over the data sparse area. At first, in 1967, Prof. T.Fujita and his collaborator at the University of Chicago, developed a cloud tracking system by the use of photo-processed animation film which is known as METRACOM system (Chang et al., 1973). Using the cloud motion data set, a number of researches were conducted at the University of Chicago and it was revealed that the data set was very useful for the flow pattern analysis over tropical area, hurricane vicinity, severe storm area, etc. First of all, it was shown that (a) the velocities of middle clouds computed from both ATS-1 and terrestrial photographs taken by stereo-camera network were very close to each other over a local area near Hawaii, and (b) cloud velocities are very useful in determining the mesoscale field of air motions which affect the cloud motions (Fujita et al., 1968). It was found that a large scale flow from the Southern Hemisphere recurved after crossing the equator and formed an anticyclone (Fujita et al., 1969b). Chang et al. (1974) showed that the tropical circulation could be described through the cloud motions much more accurately and realistically than before. Fujita et al. (1970) showed that cloud motion winds were useful for production of a complete and detailed analysis of the inflow and outflow fields in a hurricane vicinity, using together with airborne radar and satellite picture and aircraft and synoptic wind data. It was shown that detailed outflow pattern can be obtained in two excellent cases of tornado outbreaks (Fujita et al., 1969a). From these researches it was considered that the cloud motion winds would be very useful.

Furthermore, Leese et al. (1971) tried to track the target clouds automatically by a pattern recognition technique which was significantly in progress as the development of computer techniques and computer itself. The advent of the automatic cloud tracking technique implied its capability in the mass production of cloud motion vectors with the global coverage except for polar areas.

Since then, several wind derivation systems have been developed both on the research basis and the operational basis. For research purpose a cloud wind derivation system, which is called WINDCO, has been developed as a function of the McIDAS (Man-computer Interactive Data Access System) at the Space Science and Engineering Center (SSEC) of the University of Wisconsin (Suomi, 1975; Smith, 1975), and the AOIPS (Atmospheric and Oceanographic Information Processing System) at the Goddard Space Flight Center, NASA (Billingsley, 1976). They were man-machine interactive systems using a TV-screen on which animated movie is displayed. On the other hand, the NESS (National Environmental Satellite Service, now NESDIS: National Environmental Satellite Data and Information Service), NOAA, started the development of the manual and automatical wind derivation systems to be routinely processed in the late 1960s, and eventually they put them into overall daily routine operation in mid-1970s. The high-level target clouds, cirri, were manually tracked using a film-loop system, and the low-level target clouds, cumuli, were selected and tracked automatically.

Although the ATS-1 and the second ATS (ATS-3) had just visible (VIS) channels for imaging, the first Operational Synchronous Meteorological Satellite (SMS) launched in 1974 had been equipped with infrared window channel (11 μm) for imaging in addition to visible channel. From the infrared image, cloud top temperature could be estimated and converted into cloud top height (pressure and/or geopotential height) using vertical temperature profile. The height information has increased the usefulness of the cloud motion vectors as upper level winds.

To implement the FGGE program, Japan (MSC/JMA) launched GMS-1 at 140°E over the equator in 1977 and began their wind derivation in April 1978. The ESOC/ESA launched METEOSAT at 0° in longitude and began their wind derivation in July 1978. The U.S. satellites, SMS-2 and GOES-3, were stationed at 75°W and 135°W respectively. A U.S. satellite (i.e. GOES-1) was temporarily moved to 75°E

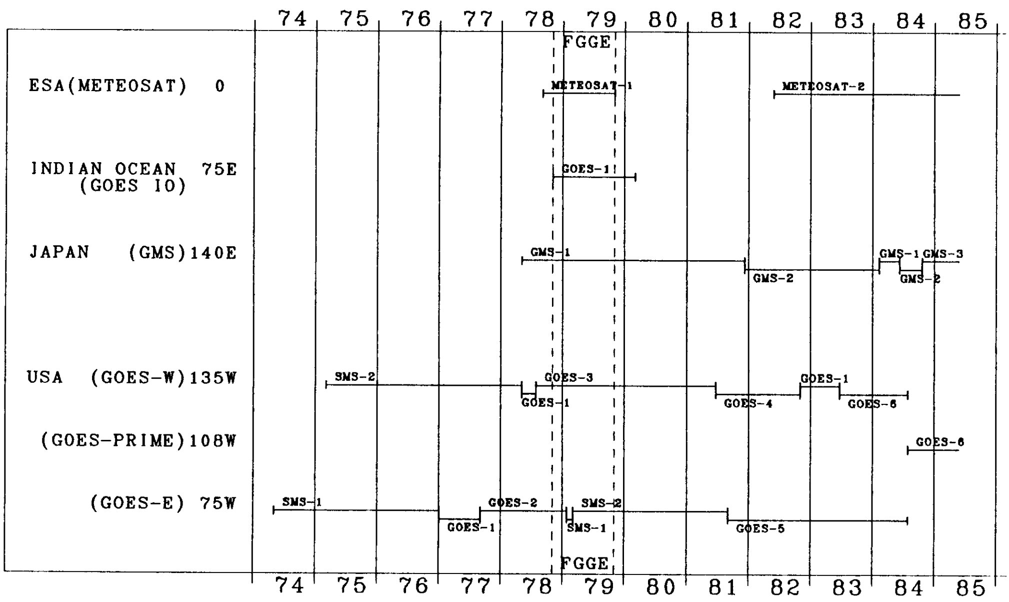


Fig. 1. The history of the geostationary satellites used for the wind derivation during and after the FGGE period.

over Indian Ocean and operated as GOES Indian Ocean (GOES IO) during the FGGE period (Mosher et al., 1980b). For the FGGE operation the cloud motion vectors had been derived from the images taken by those five geostationary satellites twice or three times a day. The history of the geostationary satellites used for the wind derivation during and after the FGGE period is shown in Fig. 1. The global data coverage is shown in Fig. 2.

2. Satellite Wind Derivation System

2.1. General

1) Images and their Registration

Either infrared (IR) or visible (VIS) images usually taken at 30-minute interval are used for target cloud selection and tracking, and IR, VIS and/or water vapour (WV) channel's images for the estimation of target cloud height and wind representative height. The nominal time of images used for tracking is shown in Table 1.

For correct tracking of the target cloud, the relationship between target cloud location on the image and the location on the earth must be accurately determined. For this purpose, the orbital and attitude data of the satellite and some other imaging information like scan geometry are used to calculate the relationship between them. The error (absolute error) is generally 10 km or more on the earth surface. But the absolute error of image registration is not so serious because it vanishes in the calculation of vector from two time-sequential images if the images are relatively well registered. In order to increase the accuracy, the SSEC developed a new method in which a set of landmarks was used to adjust the image to earth location. Both of the NESDIS/NOAA and the MSC/JMA adopted similar method. In addition to this method, the MSC/JMA redetermine the attitude of the satellite using the landmark locations determined on five VIS images a day, and then predict the attitude for 4 days on. Furthermore, when each image is ingested the earthedge is extracted from the IR full disc image and then earth location in the image is finely tuned. The predicted attitude and orbital data, scan geometry of the satellite and fine-

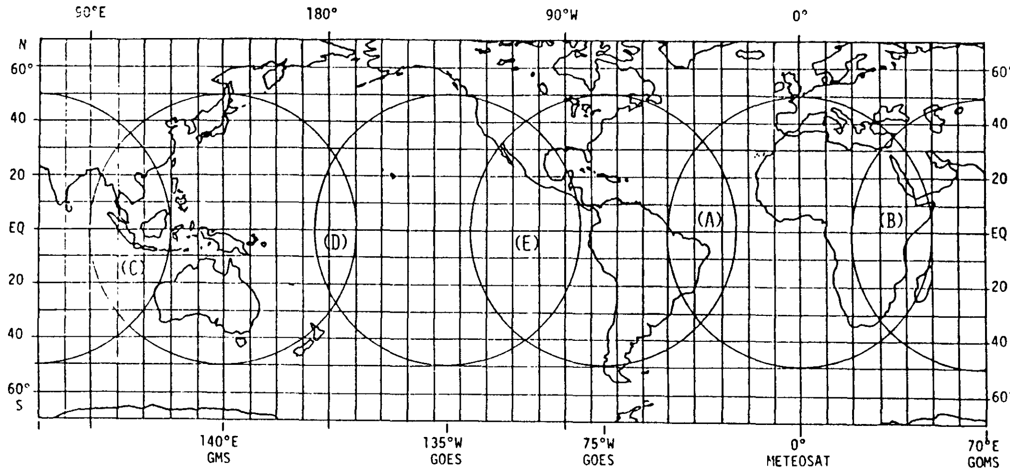


Fig. 2. The global data coverage of satellite winds. Each circle shows a 50° great circle arc (gca) from a spacecraft sub-satellite point (ssp), and each center's coverage of satellite wind derivation is approximately the region within the circle. The areas shown by (A) . . . (E) are the common fields of view of neighboring satellites.

Table 1　Nominal times of images used by operating agencies for wind derivation.

	MSC/JMA			NESDIS/NOAA						ESA	
Satellite	GMS			GOES-E			GOES-W			METEOSAT	
Synoptic time(GMT)	0000Z		1200Z	1200Z	1800Z	0000Z	1200Z	1800Z	0000Z	0000Z	1200Z
Tracking	VIS	(*)	IR	IR	IR	IR	IR	IR	IR	IR(*)	IR(*)
Low-level	2300 2330 0000	(A) (B) (C)	1100 1130 1200	1000(0900) 1030(0930) 1100	1500(1500) 1530(1530) 1600	2200(2100) 2230(2130) 2300	1015(1015) 1045(1045) 1115	1545(1545) 1615(1615) 1645	2215(2145) 2245(2215) 2315	1000(21) 1030(22) 1100(23)	2200(45) 2230(46) 2300(47)
High-level	2230 2300 2330 0000	(Z) (A) (B) (C)	1030 1100 1130 1200	0900(0900) 0930(0930) 1000(1000) (1030) (1100)	1530(1500) 1600(1530) 1630(1600) (1630) (1700)	2100(2100) 2130(2130) 2200(2200) (2230) (2300)	0915(0845) 0945(0915) 1015(0945) (1015) (1045)	1615(1445) 1645(1515) 1715(1545) (1615) (1645)	2045(2045) 2115(2115) 2145(2145) (2215) (2245)	(same as low-level)	
	* Image names for wind derivation. 1. Actual imaging time is approximately from T-29 min. to T-4 min., where T is nominal time.			1. Times between parentheses were effective until 1982. 2. Nominal times shown above are approximately actual start times. 3. For low-level wind derivation, two of those three images are used for tracking.						* slot number	

tuned earth location are used for wind vector calculation.

2) Target Cloud Selection and Tracking

There are generally two types of target cloud selection and tracking procedures; namely, manual and automatic procedures. In the automatic procedure, the cloud height information is used for selection of suitable target to be tracked. The tracking is performed by the pattern matching technique. In the manual procedure, on the other hand, an operator selects and tracks suitable targets either on a digitizer board on which photo-processed film-loop is projected or on a TV-screen on which animated movie-loop is electronically displayed. At the several Centers, combined procedures are used to various extents. The selecting and tracking procedures are summarized in Table 2.

3) Height assignment

The satellite wind is assigned to the most probable altitude which is estimated from (a) IR brightness temperature (TBB), (b) TBB and WV channel (6 μm) observation, (c) TBB and VIS brightness, (d) statistical wind representative height based on a previous investigation, or (e) subjective wind representative height. The height assignment procedures are shown in Table 3.

4) Quality control

It is necessary to remove unrepresentative winds among the resultant vectors. Some vectors are removed or flagged in the automatical procedure, and some in the manual procedure by a skillful analyst.

5) Delivery and archiving

Final vectors are coded into WMO formats

Table 2 Target selection and tracking procedures for satellite wind derivation

<table>
<tr><td></td><td colspan="2">Manual</td><td colspan="2">Combined</td><td>Automatic</td></tr>
<tr><td></td><td>Film-loop procedure</td><td colspan="3">Man-machine interactive procedure</td><td>Automatic procedure</td></tr>
<tr><td>Target cloud selection</td><td>Manual (off-line)</td><td colspan="3">Manual</td><td>Automatic</td></tr>
<tr><td>Tracking</td><td>Manual (off-line)</td><td>Manual</td><td>Semi-manual</td><td colspan="2">Automatic</td></tr>
<tr><td>Image display</td><td>Film-loop</td><td colspan="3">TV-display</td><td></td></tr>
<tr><td colspan="6">(Operating agencies)</td></tr>
<tr><td>NESDIS/NOAA</td><td>High-level (-July '82)</td><td colspan="2">High-level (July '82-)</td><td></td><td>Low-level</td></tr>
<tr><td>ESOC/ESA</td><td colspan="4"></td><td>High/low</td></tr>
<tr><td>MSC/JMA
*procedure</td><td>High-level
*FL</td><td>Low-level
*MM-2</td><td></td><td>Low-level (-Mar.82)
*MM-1</td><td>Low-level (April 82-)
*AS</td></tr>
<tr><td>SSEC/UW</td><td></td><td colspan="2">High/low-level</td><td colspan="2"></td></tr>
</table>

Table 3 Height assignment procedure at each center for satellite wind derivation

	(extracted information)
MSC/JMA low-level TBB → Tc → Pc (Tc → Pc with VTP) 650/600 < Pc < 950mb ⟹ Pw=850mb	→ Target cloud top height No wind representative height (- Dec. 21, 1981) → Wind representative height (Dec. 21, 1981 -)
MSC/JMA high-level Fixed height. Pw=300mb Climatological tropopause Statistical best-fit level	→ Indication of cirrus tracked wind (- Dec. 21, 1981) → Wind representative height (Dec. 21, 1981 -)
ESOC/ESA TBB, WV radiance, VIS radiance → ε → Tc → Pc=Pw	→ Wind representative height
NESDIS high-level (-July 1982) TBB → Tc → Pc=Pw or Subjective wind height	→ Wind representative height
NESDIS high-level (July 1982-) and SSEC TBB, VIS → Tc → Pc, Tb → Pb ⟹ Pw	→ Wind representative height
NESDIS low-level TBB → Tc → Pc (Tc → Pc with VTP) Pw=900mb	→ Target cloud top height → Wind representative height

TBB : Equivalence Black Body Temperature
Tc(Pc) : Cloud-top temperature (pressure height)
Tb(Pb) : Cloud-base temperature (pressure height)
ε : Emissivity
Pw : Wind representative height
VTP : Vertical temperature profile

(SATOB) for the teletype transmission to worldwide users through the GTS (Global Telecommunication System). During the FGGE period, the wind data were stored in tape in Level II-b Data formats to be sent to the FGGE Level II-b Space-based and Special Observing Systems Data Centre in Sweden.

2.2. Operational System

In this section the history of wind derivation procedures and some special matters at four following operational centers are briefly described, and further detailed summary of each center's operational wind derivation system is described by Hamada (1985). Three out of those centers conducted producing satellite winds globally between 50°N and 50°S. The SSEC contributed to produce not only the global winds, but also special dense ones over tropical areas in Pacific Ocean. During the FGGE period the data sets produced by the SSEC are shown in Table 4. After the FGGE period, the SSEC has not derived the cloud motion winds routinely.

2.2.1. Meteorological Satellite Center (MSC/JMA)

Japan has been deriving cloud motion winds by the Cloud Wind Estimation System (CWES) at the MSC since April 6, 1978. Cumulus tracked winds (low-level) and cirrus tracked winds (high-level) have been produced continuously except for short interruption due to satellite anomaly from the end of 1983 to mid-1984. The procedure for high-level wind derivation has been retained virtually unchanged since 1978, but that for low-level was changed on April 1, 1982 from the man-machine interactive operation to the full automatic one. The height assignment procedure was changed on December 21, 1981, and since then statistical best-fit levels have been assigned to the satellite winds. Until then climatological tropopause level had been assigned to the high-level winds and only cloud-top heights had been assigned to the low-level winds. On October 4, 1983, new quality control procedure, i.e., objective quality control (OQ) procedure was added to the existing ones; automatic assessment and manual quality control. The detailed procedures of the CWES operated during the FGGE period are described in Kodaira et al. (1981) and those of current CWES in Meteorological Satellite Center (1984).

2.2.2. National Environmental Satellite, Data and Information Service (NESDIS/NOAA)

The NESDIS has routinely derived cloud motion winds from two geostationary satellites three times a day since mid 1970s including the FGGE period. Cumulus tracked winds (low-level) and cirrus tracked winds (high-level) have been produced. The procedure for low-level wind derivation has remained virtually unchanged since then, but that for high-level was changed in July 1982 from film-loop procedure

Table 4 Wind data sets produced by the SSEC during the FGGE period

	GOES IO		GOES E & W	GMS
Data set	Indian Ocean	MONEX	Tropical Wind	GMS
Period	entire FGGE	100-days	entire FGGE	entire FGGE
Synoptic Time	0000Z 1200Z	0600Z 1800Z	1800Z	0000Z 1200Z
Tracking	IR VIS/IR	VIS/IR IR	VIS/IR	VIS/IR
Resolution (mile)	3	2 (1)	2	–
Time int. (min.)	30	15 (7)	15/210	30

to man-machine interactive procedure. The man-machine interactive system is similar one to the McIDAS (Suomi, 1985) to be described in Section 2.2.4. For detailed explanation on the procedure, see Hubert (1979), Whitney (1984) and Bristor (1975).

2.2.3. European Space Operations Centre (ESOC/ESA)

European Space Agency (ESA) had derived cloud motion winds from METEOSAT-1 imagery at the Meteorological Information Extraction Centre (MIEC, ESOC) in Darmstadt, F.R.G. But the operation terminated on November 25, 1979 by satellite failure. In May 1982, they resumed their wind derivation from METEOSAT-2 imagery once a day (00Z) and in September 1982, twice a day.

At the MIEC, the satellite winds are derived automatically using three consecutive images at all levels. The wind derivation scheme has remained virtually unchanged since 1978. Detailed description of their wind derivation system is available in Bowen et al. (1979).

2.2.4. Space Science and Engineering Center (SSEC/UW)

The Space Science and Engineering Center of the University of Wisconsin (SSEC/UW) participated in the FGGE by supporting the collection of meteorological geostationary satellite data, and processing of cloud drift winds from these data (Chatters et al., 1975; Suomi, 1975; Smith, 1975). Following cloud drift winds were derived and sent to the FGGE Level II-b Space-based and Special Observing Systems Data Center in Sweden during the FGGE period (Mosher et al., 1980a and 1980b). The produced wind data sets are:

(a) Indian Ocean Wind Set: a cloud wind data set for the Indian Ocean region approximately 50°N to 50°S, 10°E to 110°E, from GOES Indian Ocean twice a day for the entire FGGE year,

(b) Tropical Wind Set: a high-density cloud wind data set for the tropical region approximately 15°N to 15°S, 20°W to 170°E from GOES-E and GOES-W once a day for the entire FGGE year,

(c) MONEX Wind Set: a high density cloud wind data set from GOES IO for the summer MONEX region from approximately 30°N to 20°S, 30°E to 100°E twice a day for a 100 day period starting on 1 May 1979, and

(d) GMS Wind Set: additional cloud wind data set from the GMS imagery for the region approximately 50°N to 50°S, 90°E to 170°W for the entire FGGE year.

The used images, observation times, etc. for the production of those wind data sets are shown in Table 4. After the end of FGGE period, no operational satellite winds have been derived at the SSEC.

The SSEC have developed the Man-computer Interactive Data Access System (McIDAS) since its foundation in 1969 (Suomi, 1975; Smith, 1975). The McIDAS has great capability to handle the large amount of satellite image data, weather report etc. and to process the data to extract various kinds of meteorological parameters (Chatters et al., 1975). As one of processings of the McIDAS, the WINDCO was developed to derive cloud motion winds. The WINDCO is basically man-machine interactive wind derivation system by the use of TV-display on which animated time sequential images can be displayed.

3. Characteristics of Satellite Winds and Problems

3.1. Representative Height of Satellite Winds

The satellite wind is derived in completely different way from the way of conventional observations like radiosonde observation. The satellite wind observation system is not the system to measure air motion directly but to measure cloud motion. The target cloud to be tracked has some dimensions, a few deca-kilometers in horizontal direction and a few kilometers in vertical direction. This causes a question: "Does the cloud seen from geostationary satellite move with wind?" It is essential to answer this question because improper altitude assignment causes cloud motion error as much as vertical wind shear between representative level and the assigned height, that is, the assigned altitude of the cloud motion is very sensitive to its accuracy.

1) Low-level winds

Cumulus clouds are very good targets to derive the cloud motion winds. Hasler et al. (1976, 1977 and 1979) investigated the relationship between cloud motion and environmental air motion in different altitudes of a cloud by the use of an aircraft equipped with inertial navigation system (INS). Both the cloud motion and air motion are simultaneously measured by the aircraft INS. During the later stage of their investigation satellite cloud motion was also derived from the GOES images. It was shown that the tropical cloud motion had excellent agreement with the wind (air motion) at cloud base (150m). Satellite measured cumulus cloud motions were very good estimators of the cloud-base wind (900-950mb) for trade wind and subtropical high regions. For cumulus clouds near frontal regions, the cloud motion agreed best with the mean cloud layer wind.

Although the tracks of smaller size cumuli than these of Hasler's case are taken up, there are very interesting tracking results performed by Fujita et al. (1975). The cumuli spatial size is about 1 to 2 km. The geometric centers of the cumuli are tracked at 1 min. interval over the City of Springfield, Mo. (Fig. 3). The shadow tracks in the figure appear somewhat like a stretched S shape, revealing that cloud obtained their north-westerly motion as they grew larger. The S shape trajectory is explained by the vertical wind profile at Springfield (Fig. 4), i.e. the height of environmental wind which contributes to drive the cumulus becomes higher as the cloud develops vertically.

As described previously, cumulus cloud moves with environmental air motion at the level of cloud-base. This fact has been confirmed statistically by several researches. One

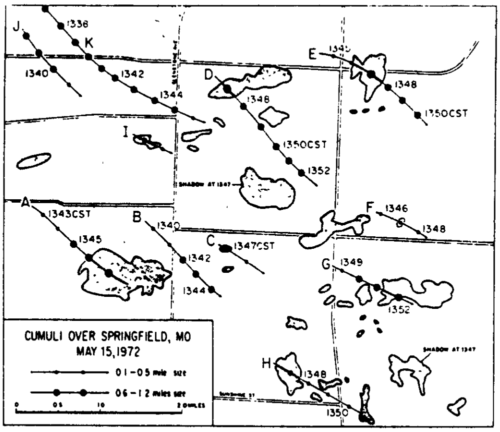


Fig. 3. Tracks of cloud shadows over Springfield. Note that some tracks curve like a stretched letter S. (After Fujita et al., 1975)

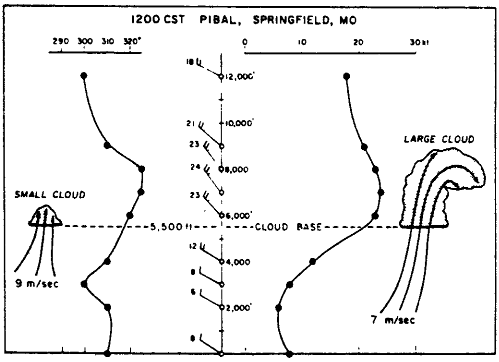


Fig. 4. A model of cumulus clouds used for tracking their shadows over Springfield on 15 May 1972. (After Fujita et al., 1975)

of the results is shown in Figs. 5 and 6 (Hamada, 1982b). Each satellite wind is compared with the radiosonde winds at 7/9 pressure levels between 700/600 and 1000mb observed by a radiosonde station. The statistics of the difference between them are produced separately in three cloud top height ranges, i.e., SFC- 800mb, 800-700mb and 700-600mb, and a whole range, SFC-600mb; but the range, SFC-800mb, in winter is omitted because of too small samples. In the study it is concluded that: (a) Throughout the year, low-level satellite wind agrees with nearby radiosonde wind at 850mb, and as the target cloud height becomes lower, the agreement between both types of winds gets better, (b) In winter, the satellite wind with the tracked cloud-top height lower than 800mb agrees with the radiosonde wind at 1000mb as well as at 850mb, (c) In summer, the satellite wind agrees with the radiosonde wind at any level lower than 700mb, and (d) In winter/summer, when the tracked cloud height is lower than 600/700mb, the satellite wind agrees with the radiosonde wind very well.

It can be concluded that *low-level cloud motion winds represent those at 850mb or lower and smaller cumulus tracked winds represent those at lower level.*

2) High-level winds

It is very difficult to determine correct temperature of cirrus cloud due to ambiguity of the emissivity of the cloud. Usually the emissivity is assumed to be unity. But thin cirrus, which is often good target to be tracked, has the emissivity less than 1.0. Towards the future improvement of the cirrus height estimation, various investigations have been conducted to be described briefly in section 3.3. But from

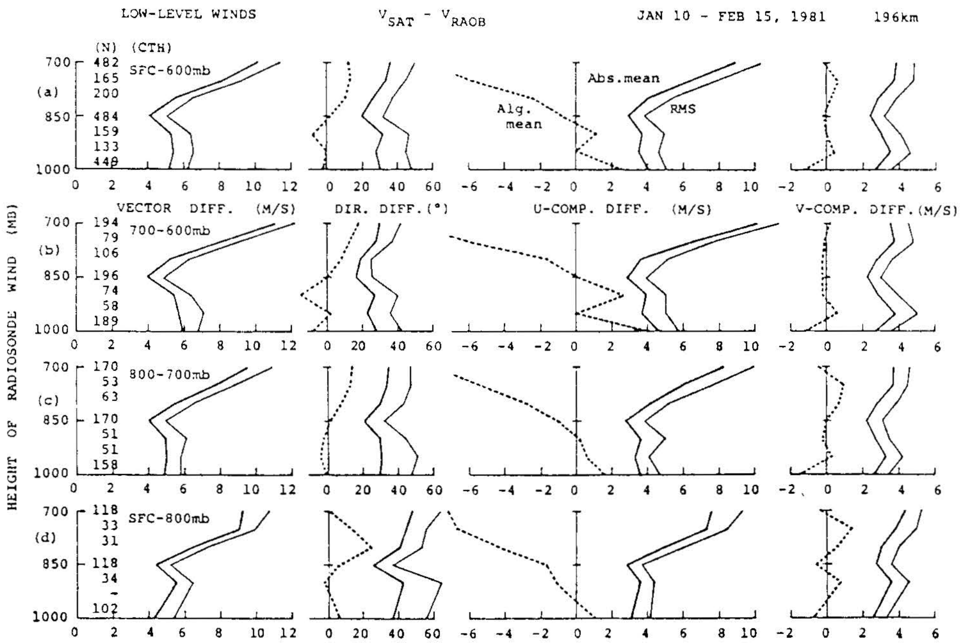


Fig. 5. The mean magnitude of vector difference between GMS low-level satellite wind and radiosonde wind in winter. The ranges of the target cloud top height (CTH) are: (a) from surface to 600mb, (b) from 700 to 600mb, (c) 800 to 700mb, and (d) lower than 800mb. (After Hamada, 1982b)

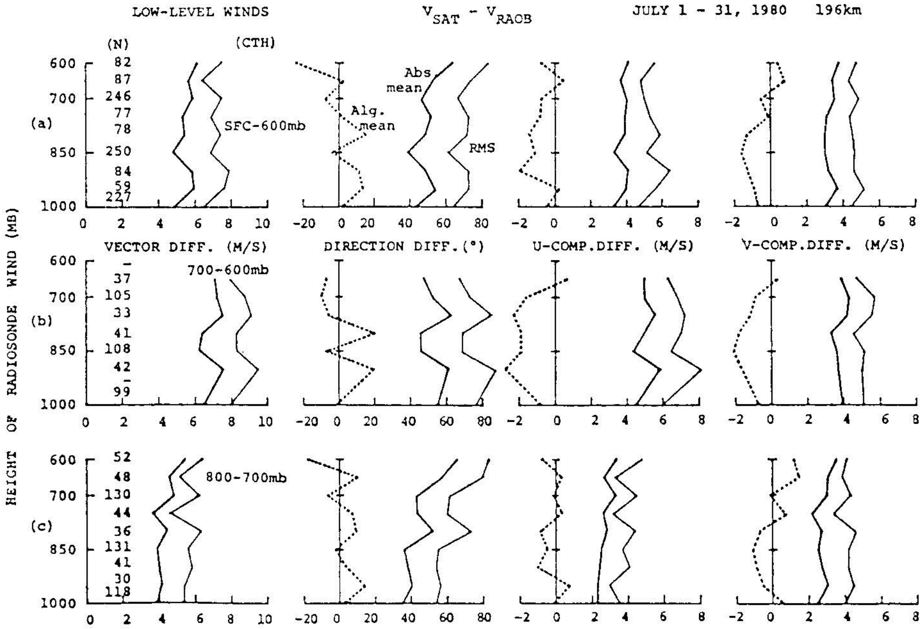


Fig. 6. Same as Fig. 5, but for in summer. The results on the comparison for the satellite winds with cloud top heights lower than 800mb are omitted, because of too small number of samples. (After Hamada, 1982b).

the operational point of view, each center adopts somewhat different height assignment procedure as already shown in Table 3.

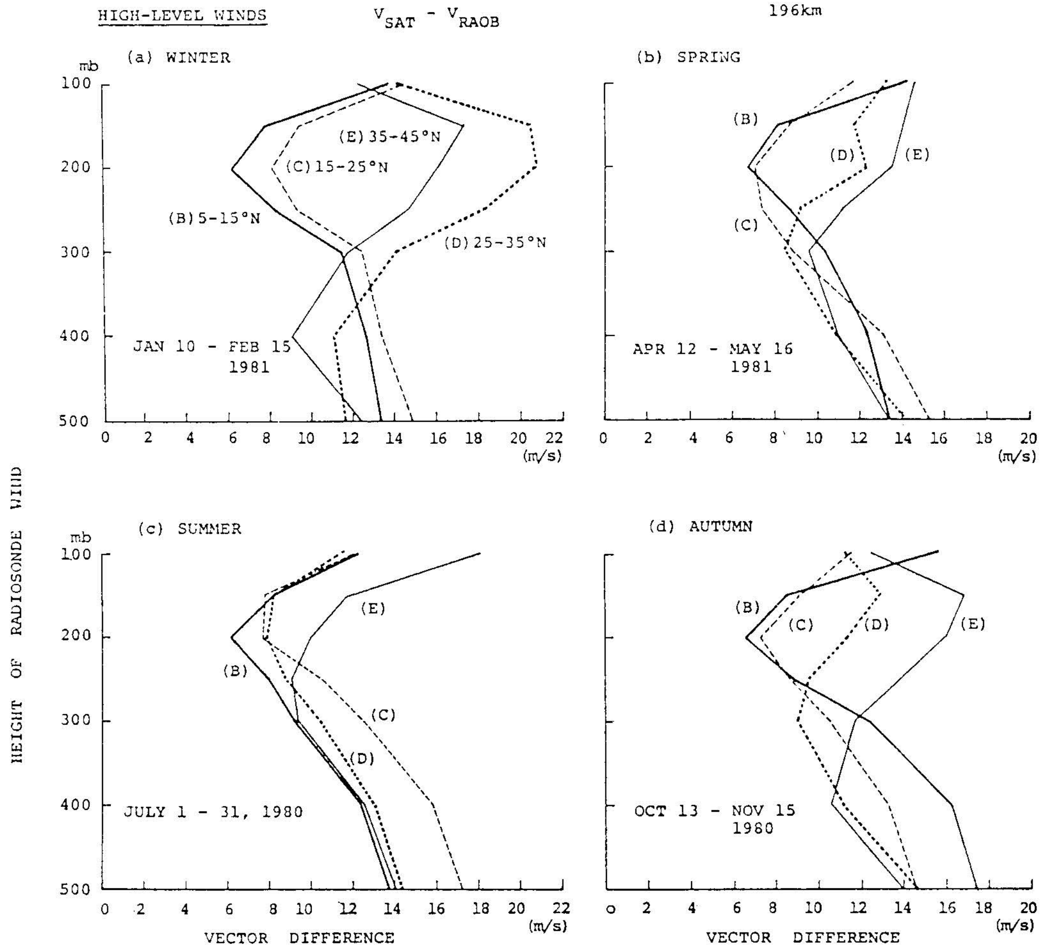
Hamada (1982b) investigated the relationship between a cloud motion wind and radiosonde winds at several vertical levels. A high-level satellite wind was compared with 7 different levels' winds observed by a radiosonde station in the Northern Hemisphere. The statistics are calculated over six different latitudes (subareas); 0-5°N, 5-15°N, 15-25°N, 25-35°N, 35-45°N and 45-50°N. Two of them, northernmost and southernmost areas, were eliminated from the comparison, because of too small samples. The results are shown in Fig. 7. The best-fit level varies seasonally and regionally. In winter in tropical region, 5-25°N, the minimum vector difference is found at the level of 200mb; in mid-latitudes, 25-45°N, at the level of 400mb. From these comparisons, representative wind heights of high-level satellite winds derived routinely by CWES were determined as shown in Table 5. The heights in the Southern Hemisphere was estimated from the results in the Northern Hemisphere, but no verification has been still carried out. On December 21, 1981 the MSC/JMA started assigning the high-level cloud motion winds to the statistical best fit level based on the results (Hamada, 1982b).

It can be concluded that *over the tropical area, the statistical best-fit level between high-level cloud motion and environmental wind is about 200mb and in mid-latitudes lower than that.*

3.2. Difference of Satellite Winds from Conventional Winds

In order to assess the homogeny and accuracy of the satellite winds which are derived routinely, the International Comparison of

Satellite Winds has been carried out twice a year since July 1978 under an agreement at the Coordination meetings of Geostationary Meteorological Satellites (CGMS). There are two types of comparisons, i.e., satellite-to-satellite comparison and satellite-to-rawin comparison. Satellite-to-satellite comparison means that two winds from different satellites over common field of view (as shown by A, B, ..., E in Fig. 2) are compared with each other, and



SEASON / SUB-AREAS / ITEM	(a) WINTER		(b) SPRING		(c) SUMMER		(d) AUTUMN	
	N	MEAN WIND	N	MEAN WIND	N	MEAN WIND	N	MEAN WIND
(B) 5 - 15°N	111	15.3	52	13.4	68	14.3	53	14.3
(C) 15 - 25°N	35	25.2	122	24.6	126	17.4	115	17.3
(D) 25 - 35°N	42	40.6	214	32.5	227	17.1	145	33.3
(E) 35 - 45°N	72	40.5	161	32.7	238	28.8	94	39.5

Fig. 7. The mean magnitude of vector difference between GMS high-level satellite wind and radiosonde wind in 4 latitude band areas. (After Hamada 1982b).

Table 5 Wind representative height to be assigned to high-level cloud motion wind derived from CWES* system. (After Meteorological Satellite Center, 1984)

Latitude	SEASON (Northern Hemisphere)	WINTER	SPRING	SUMMER	AUTUMN
Northern Hemisphere	North of 35°N	400 mb	300	250	300
Northern Hemisphere	25°N – 35°N	400 mb	300	200	300
Northern Hemisphere	EQ – 25°N	200	200	200	200
Southern Hemisphere	EQ – 25°S	200	200	200	200
Southern Hemisphere	25°S – 35°S	200	300	400	300
Southern Hemisphere	South of 35°S	250	300	400	300
	SEASON (Southern Hemisphere)	SUMMER	AUTUMN	WINTER	SPRING
		DEC 14/15 – MAR 14/15	MAR 14/15 – JUNE 14/15	JUNE 14/15 – SEP 14/15	SEP 14/15 – DEC 14

the statistics of the differences are tabulated as Type 1 Reports. Satellite-to-rawin comparison means that a satellite wind is compared with nearby radiosonde winds, and the statistics of the differences are tabulated as Type 2 Reports. The results are shown in Figs. 8 and 9, but the results on METEOSAT winds in Table 6. Those tables and figures are after Whitney (1983), but Japanese results (Fig. 9, a and b) are replaced by updated ones. The MSC revised Type 2 Reports from winter 1981 to 1983 and reported them as a working paper at the CGMS-XIII, because some errorneous radiosonde reports were used for the Type 2 comparison originally reported.

According to the Type 1 Reports (Fig. 8; satellite-to-satellite), the differences between winds from two neighboring satellites have been gradually decreasing for high-level and have had no great variation for low-level. According to the Type 2 Reports (Fig. 9; satellite-to-rawin), GMS-rawin comparison has had great seasonal variation especially for high-level. The differences became smaller in winter 1982 and after then, because the height assignment procedure was improved at the MSC (Hamada, 1982a).

Other than the International Comparison there have been a number of comparisons of satellite winds with conventional winds (Hubert et al, 1971 and 1972; Salomonson, 1975; Suchman et al, 1976; Bauer, 1976; Hamada, 1982b). Those results are summarized that the magnitude of mean vector difference between satellite wind and radiosonde wind is 5 m/s or less for low-level wind and 10 m/s or less for high-level wind, and those differences are smaller in tropical area than in mid-latitudes.

3.3. Vertical Resolution of Satellite Winds

As described above satellite winds are derived mostly in two vertical layers, i.e., high-level and low-level. Those winds correspond to cirrus tracked winds and cumulus tracked winds respectively. In current operational system it is not easy to derive mid-level winds because of the difficulty of both mid-level cloud identification and target height estimation. In order to increase vertical resolution of satellite winds, the way to obtain the height information has to be improved. For the purpose several methods will be briefly reviewed in this section. Some of them need additional channels' data besides both 11 μm IR and VIS channels. METEOSAT has had 6.8 μm WV channel since beginning of the operation in 1978. The first VAS (VISSR Atmospheric Sounder), which was launched into geostationary orbit aboard the GOES satellite on September 9, 1980, had 12 infrared channels and a VIS channel for imaging. The VAS is installed in current GOES spacecrafts, both eastern and western satellites.

(1) Use of WV radiance

The WV (6.8 μm) channel data have been already used at the ESOC/ESA as described in Bowen et al (1979), which is briefly summarized by Hamada (1985). The emissivity of a cloud can be estimated from a simultaneous measurements of the cloud by both 6 μm WV

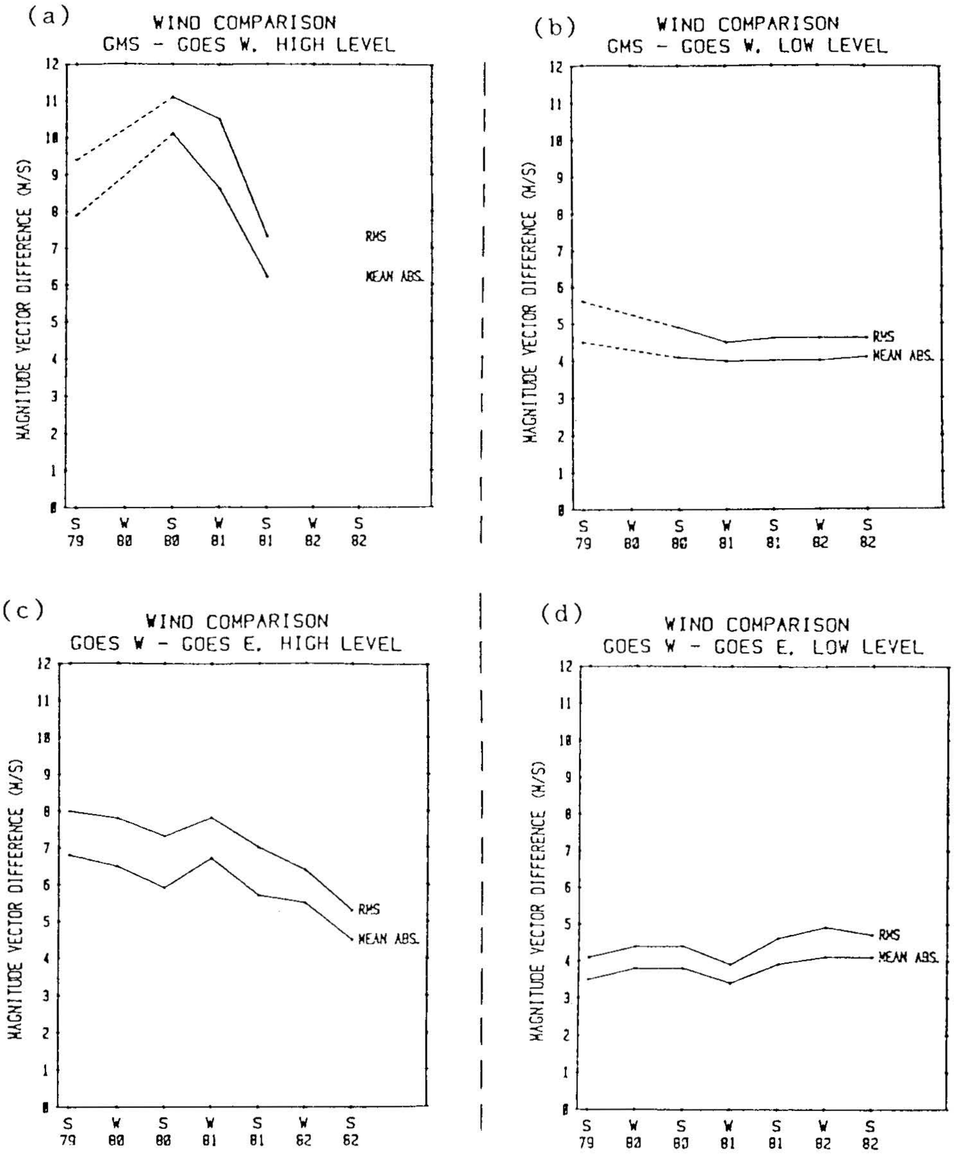


Fig. 8. Satellite-to-satellite wind comparison (Type 1 Report of International Comparison of Satellite Winds). (After Whitney, 1983)
(a) GMS – GOES W. High-level. (b) GMS – GOES W. Low-level.
(c) GOES W – E. High-level. (d) GOES W – E. Low-level

and 11 μm IR channels. This makes the height assignment of cloud motion more accurate.

According to Eigenwillig et al. (1982), using enhanced mid-tropospheric cloud imagery observed by METEOSAT WV channel, WV structures were tracked on an interactive image processing system. The WV wind vectors can be assigned to levels between 400 mb and 500 mb. This may increase the number of mid-level winds.

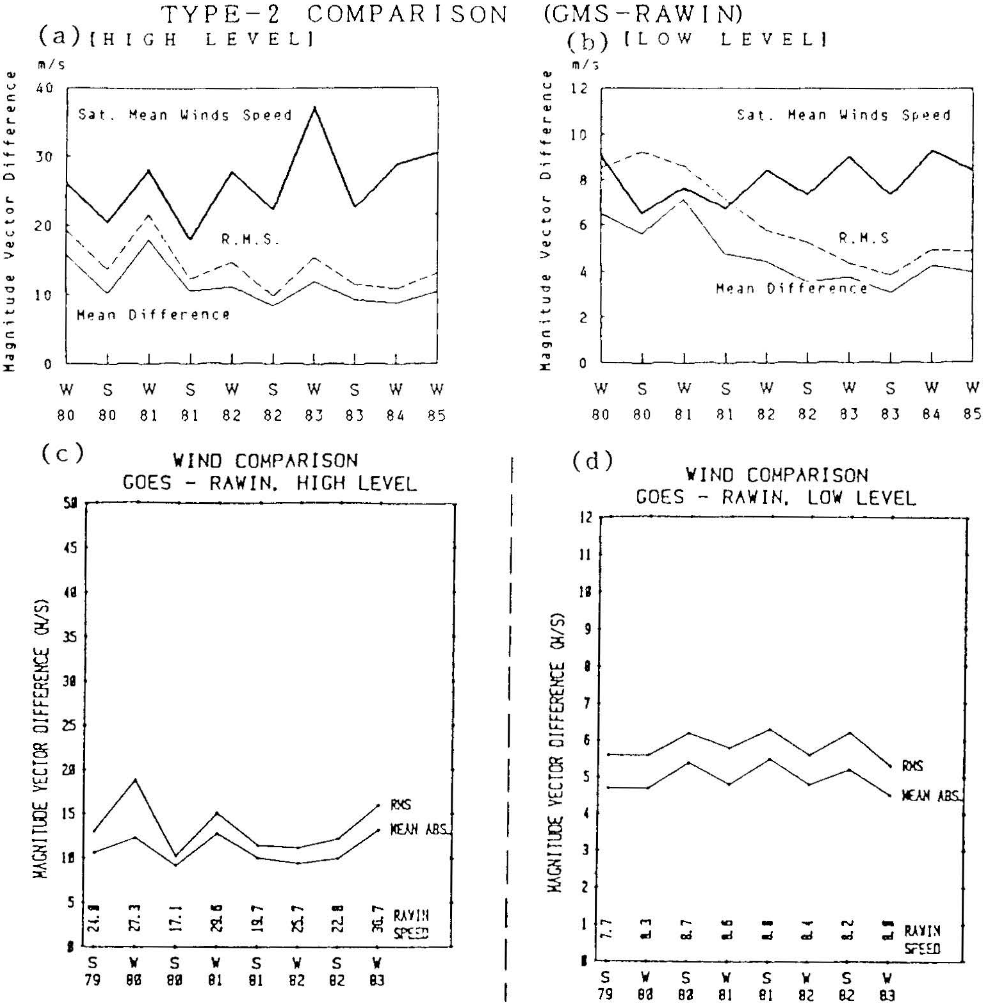


Fig. 9. Satellite-to-rawin comparison (Type 2 Reports of International Comparison of Satellite Winds).
(a) GMS – Rawin. High-level. (b) GMS – Rawin. Low-level.
(After Met. Sat. Ctr., 1985)
(c) GOES – Rawin. High-level. (d) GOES – Rawin. Low-level.
(After Whitney, 1983).
* Japanese results (a and b) were replaced by updated ones; The MSC revised Type 2 Reports during winter 1981 to 1983, and reported them as a working paper at the CGMS–XIII, because some erroneous radiosonde reports were used for the original Type 2 Reports.

(2) Use of CO_2 channels data of VAS

Menzel et al. (1983) developed improved cloud motion vector derivation system with altitude assignment using three CO_2 channels of VAS.

The VAS channel 3 (14.2 μm band) senses contribution from high-level cloud above 350 mb and channels 4 (14.0 μm) and 5 (13.3 μm) from mid-level centered at 500 mb and low-level cloud at almost surface respec-

Table 6 International comparison of Satellite Winds (METEOSAT). (After Whitney, 1983)

	METEOSAT－GOES E(Type 1)				METEOSAT－RAWIN(Type 2)			
	LOW		HIGH		LOW		HIGH	
	S79	W83	S79	W83	S79	W83	S79	W83
RMS Vector Dif.	4.5	–	12.0	–	6.0	9.6	12.9	12.4
Mean Vector Dif.	3.8	–	10.0	–	5.1	7.4	9.1	10.4
RMS Dir. Dif.	29.3	–	14.2	–	41.9	65.0	37.4	38.6
Abs. Mean Dif.	20.5	–	10.2	–	28.8	38.9	23.9	23.2
Alg. Mean Dif.	–4.5	–	–1.2	–	–4.7	3.5	2.2	1.5
RMS Speed Dif.	3.2	–	10.7	–	4.5	4.9	11.0	8.8
Abs. Mean Dif.	2.5	–	8.3	–	3.5	3.4	6.6	6.4
Alg. Mean Dif.	0.9	–	–7.4	–	2.0	–1.9	–3.8	–3.4
Mean Rawin Speed	N/A	N/A	N/A	N/A	8.5	–	14.7	–

tively. At first upper level cloud motions can be differentiated from middle and low-level ones using animation of 14.2 μm imagery. Subsequently mid-level motions can be observed using the simultaneous animation of the 14.2 and 14.0 μm band imagery. Similarly, low-cloud motion can be observed by the animation of 14.2, 14.0 and 13.3 μm band imagery.

To estimate a cloud top temperature, the CO_2 absorption method is used, i.e., cloud top pressures are determined from the ratio of the deviations in cloud produced radiances and corresponding clear air values for three CO_2 channels in a radiative transfer equation formulation. In the article it was shown that; (a) CO_2 cloud motion wind vectors were in good agreement with radiosonde wind and (b) CO_2 cloud heights were within a 50 mb rms deviation from radiosonde, bispectral and stereo height determinations each.

(3) Use of 12 μm split window channels data

Inoue (1985) showed that from the 12 μm split window channels data of NOAA-7 polar orbiting meteorological satellite, it was easy to identify semi-transparent cirrus clouds from cumulonimbus area or cloud-free area. Currently, the automatic cloud tracking system sometimes fails to identify a semitransparent cirrus cloud because the retrieved temperature range shifts to lower temperature which was caused by the upwelling radiance beneath the cloud. The split window channels data will give us useful information to identify transparent cirrus.

(4) Stereo height determination from simultaneous observations by two satellites

From simultaneous observations from two neighboring satellites it is possible to produce stereo view of the cloud distribution on TV-screen, where two pictures from the simultaneous observations are superimposed in red and green respectively. The cloud can be easily seen in stereo view using red and green glasses. The height of a cloud is calculated from the geometry among the satellites and the cloud. The accuracy of the cloud height determination is about 500 m or less (Hasler, 1981, and Mosher, 1980), but it depends on accuracy of navigation, difference of observation time, the separation of two satellites and so on. This is very important tool to evaluate the accuracy of the height assignment being performed in routine operation excluding emissivity problem.

(5) Use of artificial stereo view of satellite picture

VIS and IR pictures observed by a satellite are used for the artificial stereo view method.

Basic concept of this method is that each VIS pixels are shifted eastward in amount proportional to the IR brightness to produce artificial image. Both the artificial VIS image and the original VIS image are simultaneously displayed in the same way as that for real-stereo view described above. The artificial stereo movie made it easy that an operator identified mid-level clouds at SSEC (Mosher, 1982). In this method, the thin cirrus is seen lower than actual height, but this is very effective tool to identify and derive mid-level winds because any special image observation is not required to perform this method.

Those methods for increasing height resolution of satellite winds will provide fundamental basis for future improvement.

3.4. Data Coverage and Number

Satellite wind data are available in the area between approximately 50°N and 50°S. Usually they are derived in the region within 50°gca (great circle arc) from the sub-satellite point as already shown in Fig. 2. Average number of satellite winds operationally derived both in FGGE period and in the latest period are shown in Table 7. According to the latest results each center has derived about 30,000 wind vectors a month, i.e., 500 vectors an observation. The number of winds is sufficient as an average number.

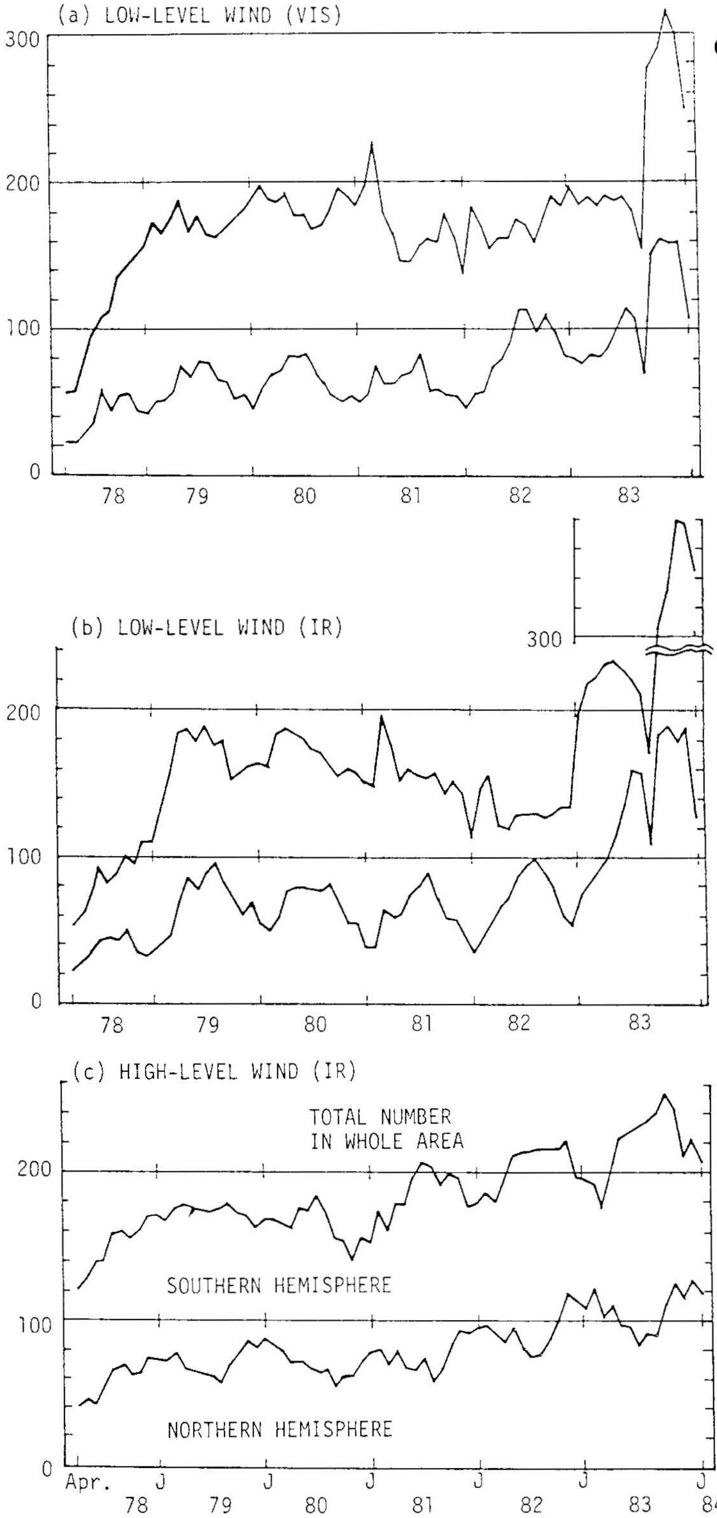
The history of the number of satellite winds derived at the MSC is shown in Fig. 10. They are monthly mean from the beginning of their operation in April 1978. The seasonal variation is clearly observed and its phase of Northern Hemisphere and Southern Hemisphere is opposite. This may be caused by the difference of meteorological situation of the observation field.

It is very important that the data coverage is even over the observation area. Fig. 11 shows global distribution of satellite winds at 12z, January 1, 1986. Bold wind arrows are high-

Table 7 Average number of satellite winds routinely derived at each center

Agency	Satellite	FGGE	Latest	
ESOC	METEOSAT	T* 24968/month	27650/month 29251	(Jyly–Dec. '83) (Jan.–June '84)
NESDIS	GOES E GOES W	T* 46000**	H* 6000** L* 24000**	(two satellites) (do.)
MSC	GMS	H* 10445 L* 9866	H* 13254 L* 18630	(Sep.–Nov. '84) (do.)
SSEC	GOES IO	T* 42500**		
SSEC	GOES E GOES W	T* 44600**		
TOTAL		T* 178000**	90000**	

* T; Total number, H; High-level winds, L; Low-level winds.
** Approximate numbers.



(a) Low-level at 00Z. Visible images are used for tracking.

(b) Low-level at 12Z. Infrared images are used for tracking.

(c) High-level at both 00Z and 12Z, but numbers are per an observation. Infrared images are used for tracking.

Fig. 10. The history of monthly mean number of satellite winds routinely derived at the MSC. (After Ichizawa, 1984).

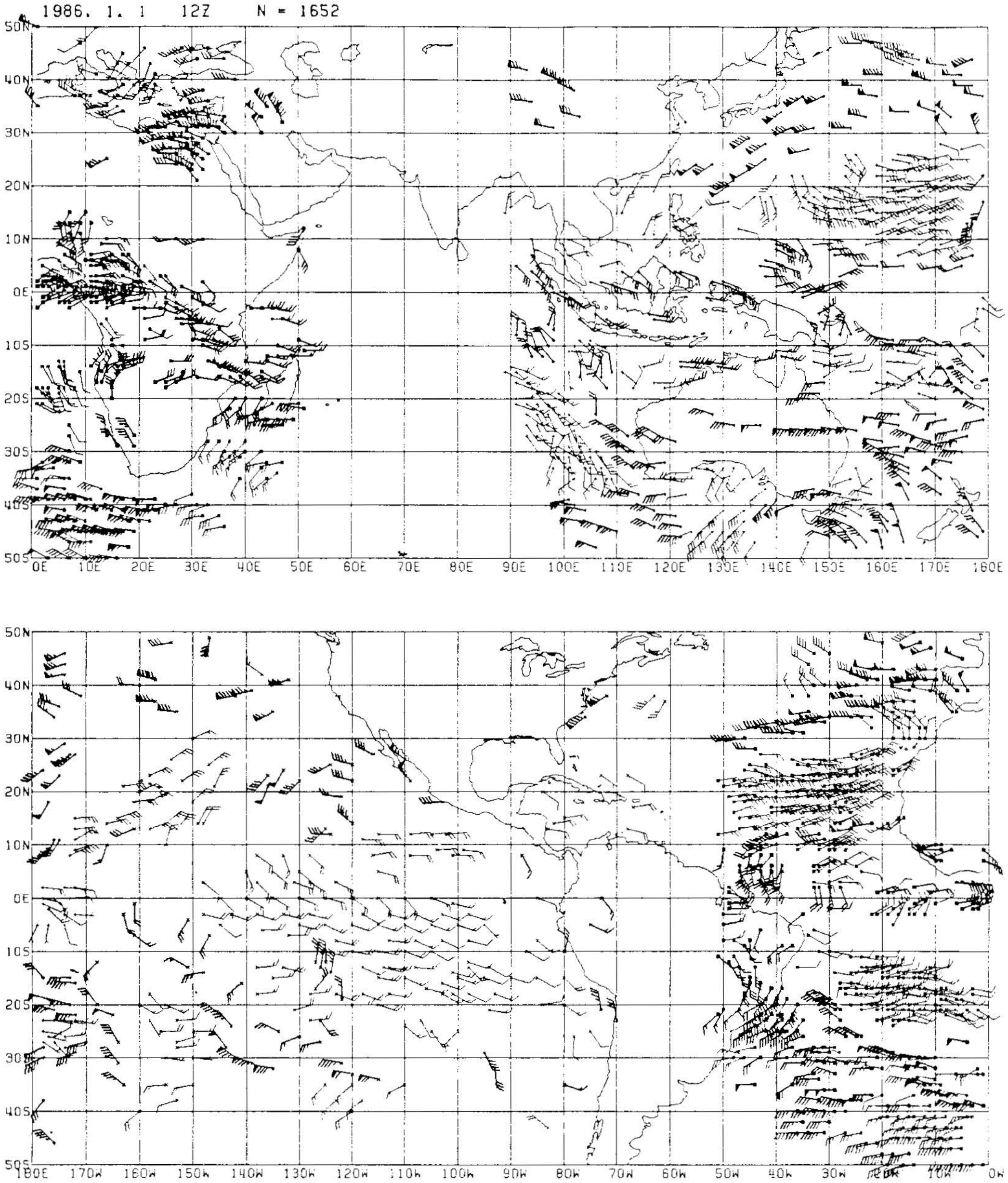


Fig. 11. Global cloud motion winds at 12Z January 1, 1986, which were available through the GTS. Bold wind arrows are high-level winds and others low-level ones, partially mid-level ones.

level winds and others low-level winds. The map shows that low-level winds cover the area where high-level winds do not cover and vice versa. This fact indicates that it is hard to track multi-layer targets simultaneously by the current automatic tracking system on the operational basis.

3.5. Life-time of Target Cloud and Time Interval of Images

The images taken at 30 minute interval have been used for operational low-level cloud tracking by all three operating agencies; NESDIS, ESOC and MSC, and during the FGGE period by the SSEC. For high-level wind derivation different time intervals, from 30 minutes to 2 hours, are used at those agencies. In this section the impact of the time-interval of the images on the resultant cloud motion will be discussed.

(1) Life-time of target cloud

It is clear that the time-interval of the images used for tracking target cloud has to be shorter than the life-time of the target, otherwise the cloud will dissipate by the time at which the successive image is taken.

Fujita (1970) showed half-life of jet-stream cirrus and of cumulus clouds in the southeast sector of a hurricane as classified by the cloud size (Tables 8 and 9). According to the results the jet-stream cirrus with the size of 10 km or more, which is suitable target to be tracked, has the half-life of two hours or more which is enough to be tracked. Half-life of cumulus clouds in the southeast sector of a hurricane is 36 minutes for the horizontal size of 10 km and 1 hour for the size of 20 km, which are shorter than that of jet-stream cirrus. Tecson et al. (1977) also showed that cirrus with the size of 6-9 km were estimated to have a life-time of up to 5 hours. From the view of life-time, shorter interval of the images is desirable

Table 8 Half-life of jet-stream cirrus. (After Fujita, 1970)

Size of jet-stream cirrus		Half-life
2 – 3 n.mi.	(4 – 6 km)	49 min.
4 – 6	(7 – 11)	130
10 – 13	(19 – 24)	40 hrs.

Table 9 Half-life of cumulus clouds in the southeast sector of a hurricane. (After Fujita, 1970)

Size of cumulus clouds		Half-life
2 – 3 n.mi.	(4 – 6 km)	23 min.
4 – 6	(7 – 11)	36
7 – 9	(13 – 17)	44
10 – 13	(19 – 24)	60

than longer one for low-level wind derivation, and it seems that there is no dependence upon time interval for high-level wind derivation if it is two hours or less.

(2) Image granularity

Image pixel is available at a grid point with a certain spacing, which is called image granularity. The amount of granularity is constant value for each kind of image. The granularity of GMS at sub-satellite point (ssp) is shown in Table 10. Fig. 12 shows half-pixel error of resultant wind due to the image granularity. From the figure if infrared (visible) images of GMS with 15 (3-6) minute interval are used for tracking, the error of wind is estimated as much as 3 m/s at ssp. However in order to reduce the error caused by the image granularity, the location with maximum correlation value on a matching surface is interpolated between the grid points by fitting bi-directional quadratic. This interpolation method was introduced to the McIDAS at the SSEC at first and currently to all three operating agencies' systems. By the way, cloud motion vector is calculated as a ratio of cloud displacement to the time interval. Therefore, in view of image granularity the longer time interval of images is desirable than shorter one.

Table 10 The granularity of GMS image

Image	Granularity at ssp (GMS)		
Visible	Pixel	0.86 km	
	Line	1.25	
Infrared	Pixel	1.8	(GMS-1)
		3.6	(GMS-2 & 3)
	Line	5.0	

*Pixel : East-west direction
Line : North-south direction

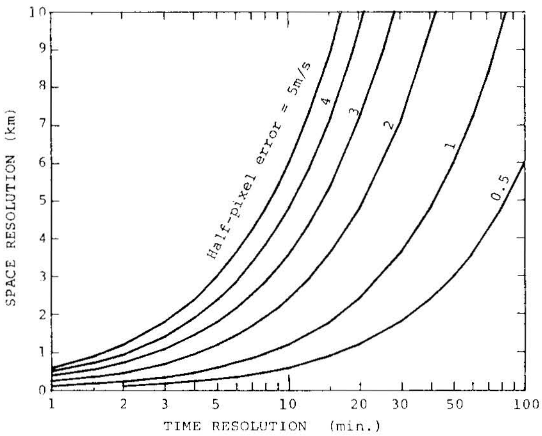


Fig. 12. Half-pixel error due to image granularity.

(3) What is the best time-interval of images for satellite wind derivation?

Low-level winds

Johnson et al. (1980) derived low-level cumulus tracked winds using rapid scan images over central United States of America. Winds from 30, 15, 6 and 3 minute intervals were derived. As the time-interval got shorter, the number of low-level cloud winds much increased, and spatial coverage of vectors also became greater. But much more operator time was needed for tracking on the rapid scan images. Rodgers et al. (1979) also derived low-level cumulus tracked winds using rapid scan images in the vicinity of tropical cyclone. The number of low-level cloud winds also much increased for shorter time-intervals. In both cases 10 to 5 times as many winds could be calculated using 3 or 7.5 minute rapid scan images as when using 30 or 15 minute interval images. In Johnson's case, only larger clouds with longer life-times and somewhat greater velocities were trackable over a 30 minute interval. These larger clouds seem to represent the wind at a somewhat higher and faster level than the smaller cumuli. This result is similar to the case of Fujita et al. (1975) which was introduced in Section 3.1.

From those results, shorter time interval images produce more number of winds and somewhat lower level's winds with larger spatial coverage than longer ones. Considering image granularity, life-time and operator time, *15 minute interval images are better than current 30 minute ones for operational low-level wind derivation.*

High-level winds

Final wind vectors are calculated operationally from the images with:

(a) 30 min. interval at the NESDIS (from July 1982 to present) and at the SSEC,

(b) 1 hour interval at the ESOC,

(c) 1.5 hour interval at the MSC, and

(d) 2 hour interval at the NESDIS (until July 1982).

The time intervals are very different from an operating agency to another. Although the life-time of cirrus is long enough to track the cloud at any operating agencies, the characteristics and the quality might be different from each other.

In order to assess the impact of the time interval of images used for cirrus tracking on the resultant winds, cirrus clouds around a sub-tropical jet-stream were tracked on the images with both 15 and 30 minute intervals on the same day over the United States of America by the McIDAS system at the SSEC (Hamada et al., 1985). In the article it is concluded that the 15 minute interval images are better for tracking cirrus clouds around the jet-stream core than the 30 minute interval images, because:

a. It is easier for an operator to identify and track target clouds on the 30 minute interval images than the 15 minute interval images,

b. The number of satellite winds from 15 minute interval images is much more than from 30 minute interval images, and

c. Satellite winds possibly fill up the vacancy of conventional radiosonde winds.

Johnson et al. (1980) showed that as the time-interval of images became shorter from 30 to 3 minutes, mean satellite wind increase from 20.1 to 25.5 m/s. In another Johnson's case the same results were shown. It was recommended that the 30 minute interval images be used on cirrus cloud tracking.

From those results, it can be suggested that *the images with a time-interval between 15 to 30 minutes be used for cloud tracking. The 15 minute interval images should be better for tracking cirrus moving faster like that around sub-tropical jet-stream, and 30 minute interval for tracking other cirrus.*

Time-interval of images. From the results mentioned above, the author would like to suggest that 15 minute interval images be best for both high- and low-level wind derivation.

4. Applicability of Satellite Wind Data

In this section some applicability of satellite cloud motion winds is briefly discussed in order to increase their value. Generally, as the cloud motion winds have global coverage, particularly over the data sparse area like ocean, and as it is easy to handle them with computer, they are usable for numerical weather prediction as initial data. Over the tropical region the cloud motion winds are sometimes essential, e.g., to study the ENSO (EL Nino-Southern Oscillation), because they are obtained continuously and globally. But their accuracy is somewhat less than that of conventional winds and they are generally obtained only at two levels in the vertical. Other than these, there are various aspects which must be taken into account for using the wind data. They are summarized in Table 11. Furthermore, the satellite wind data may have value as a component of combined (or composite) meteorological data set to clarify the nature of the global circulation of the atmosphere.

4.1. Impact on the Data Assimilation Cycle and Forecasts

During FGGE period, intensive satellite wind observations were conducted by using 5 geostationary satellites, which supplied a number of wind data (level II-a and II-b data) in the data-

Table 11. Positive and negative aspects of satellite wind data

Positive	Negative
1. Global coverage, particularly over the ocean (data sparse area.) 2. Horizontally dense. 3. Air motion field is directly observed. 4. Variation of motion field is readily available if so operated. 5. Easy to handle with computer.	1. Accuracy is less than that of conventional wind, mostly qualitative. Error due to representative height is large. 2. Obtained only at two levels in the vertical. 3. Accumulation of past data is still insufficient for climate research. 4. No observation is available over the cloud-free area such as desert.

sparse region, especially in the tropics.

Through the experience in research and operational works it has been widely acknowledged that satellite wind data played an important and essential role in the FGGE programme. This is clearly indicated in the research works. For example, it should be noted that the low-level wind circulations over the western Pacific in the tropics during the northern hemisphere winter are completely and reliably described for the first time by these wind data. In the observational studies which used these wind analyses (Sumi and Murakami, 1982; Lau et al., 1983), it was demonstrated that in the FGGE winter the divergence center shifted from the maritime continent to the region near the dateline. This fact suggests the possibility of the interannual variations of the tropical monsoon circulations.

For the summer monsoon, the impact of the satellite wind data was also remarkable, because these data are the unique observation over the Indian Ocean. Reliable analysis during unprecedently large amount of data (Krishnamurti et al., 1979, 1980a and 1980b) have made it possible to investigate the details in the summer monsoon circulations.

The same conclusions described above have been confirmed in the operational numerical weather prediction (NWP). The impacts due to the satellite wind data have been investigated in the Observing System Experiment (OSE). The conclusions obtained through the OSE will be briefly described in the following.

Positive impacts on the forecasts were noticed (Kallberg et al., 1981). They are summarized as follows;

(1) The satellite wind data have a large impact on the tropical forecast for 1 to 3 days, and on the numerical forecasts for the southern hemisphere. These were due to the fact that in many cases synoptic circulations are detected only by these cloud tracked winds in the tropics and southern hemisphere.

(2) In the northern hemisphere the impact is relatively smaller but still positive. As is well known, the data obtained by other observed system are often available there. However, such an important aspect of satellite wind data that impact of satellite wind data in the tropical analysis easily propagates into that in mid-latitudes was indicated by Sumi (1982).

Recently, El Nino/Southern Oscillation (ENSO) events collect much attention. For the ENSO the tropics, especially the western Pacific region, is a key area and the reliable analysis in the tropics has become more and more important and necessary. Especially, observations by Japanese GMS Satellite is essential for the study of ENSO. In this sense, the satellite wind observation will be indispensable in the context of WWW programme.

In conclusion, satellite wind data are effective and important for the analyses and forecasts. Therefore, they should be continued for the operational weather services in the context of WWW programme.

4.2. Climate Research

The satellite wind data are very useful for climate research because they have global and dense coverage and it is easy to handle with computer. However, as the accumulation of past data is still insufficient, they are usable at present only for the study of relatively short period climate variation shown in the following:

General

1. Convenient to perform observational studies of general circulation of the atmosphere, and

2. Usable to evaluate: stream line field, transport of physical quantities (qualitative ap-

proach) and eddy activities.

Specific

1. Essential to study the ENSO (EL Nino-Southern Oscillation), relation between air motion and sea surface state such as sea surface current, deep ocean current, etc.,

2. Evaluation of atmospheric jet-stream; middle-latitude westerlies in upper level, Somali jet in lower level, etc.,

3. Analysis of air motion field in lower latitudes/ITCZ region, and

4. Analysis of air current over and around mountain at least partially.

5. Summary

From the discussions described in previous sections, they will be summarized as that;

1. Satellite observation has been stabilized in quality among three operating agencies lately,

2. Cloud motion winds are very useful for numerical weather prediction as initial data especially in the tropics and in southern hemisphere, and

3. Cloud motion winds are very useful for the research of climate variation in relatively short period, the order of 2 to 3 years.

Finally, the author would like to emphasize that the satellite wind data are indispensable both operationally and in research work, and both at present and in future.

Acknowledgement

The author wishes to express his appreciation to Dr. T. Nitta, Chief of Planning Division and Dr. A. Sumi, University of Tokyo, for intensive review of the manuscript and giving useful comments and advice. The author thanks Messers I. Kubota, K. Kato, J. Ichizawa, T. Oshima and K. Kimura of the MSC for reviewing the manuscript and sharing their knowledge and some material, and Mr. T. Tada, Chief of Electronic Computation Center (ECC), as well as Mr. M. Kamita and Dr. Y. Yamagishi of ECC for reviewing the manuscript.

The author also thanks Mr. L.F.Whitney of NESDIS and Dr. B.D.Mason of ESOC for contribution of much material and information for the preparation of this paper.

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全球気象実験（GWE)* の結果として得られた静止気象衛星風観測の改善とそのWWWへの適用

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GWE (FGGE)* の期間（1978年12月1日～1979年11月30日）には，日本の気象衛星センター（MSC／JMA），米国の環境衛星局（NESS，現在の NESDIS／NOAA），欧州衛星運用センター（ESOC／ESA）および米国ウィスコンシン大学宇宙科学技術研究所（SSEC／UW）の4つの機関により，5個の静止気象衛星画像を使用して定常的な風観測が行なわれた。SSEC 以外の3機関ではその後も観測が続けられ現在に至っている。

GWE 期間中およびその後のいくつかの調査結果から見れば，衛星風データはラジオゾンデの観測風と良く一致している。両者のベクトル差の大きさは，上下層でそれぞれ10m／s，5m／s程度以下である。GWE後のシステムの改善により，算出機関間のデータの質の差も少なくなってきており，安定した観測体系を形成してきている。

これらの衛星風は，極地方を除く全球をカバーすること，計算機で容易に大量のこれらのデータを取扱うことができることから，特に次の様な利用が有用である。

(1)数値予報の解析場作成のための入力データとして重視されている。とりわけ熱帯地方と南半球では他の種類のデータが得られない，あるいは少ない事もあって衛星風データが不可決である。

(2)全球的に均質なデータが得られることから，気候変動の研究にも重要なデータである。観測開始後日が浅いため当面は比較的短い期間（2～3年程度）が対象になるが，将来もっと長期の気候変動の研究のためデータの蓄積を行なうことが重要である。

しかしながら，衛星の風観測システムが従来の風観測システムと測定の方法が根本的に異なることから，いくつかの注意すべき事柄が存在する。通常は上・下層の2層の風しか得られない事，時として得られた風の高度決定の困難さに起因するエラーが大きくなる事などである。これらの改善及び結

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* GWE：全球気象実験は，はじめは第1次地球大気開発計画（FGGE）と呼ばれていた。

果の評価のためには次の様な方法が考えられる。

(1)現行の可視と赤外窓領域（12μm）の観測の他に水蒸気チャンネル（6.8μm），赤外窓領域の分割（11.5と12.5μm）あるいはCO_2チャンネル（13.3，14.0および14.2μm）の観測が有力な手段として期待されている。

(2)中層の風を得るためには，赤外観測温度に基いた疑似ステレオ方式が有用である。

(3)高速の絹雲の追跡には，変形や移動距離の大きすぎることなど精度の劣化を少なくするため，現行の30分間隔の画像を使用するより15分間隔の方が良い。このことにより個数・精度とも大巾な改善が期待できる。

(4)算出高度の評価には，2衛星の共通観測領域の同時画像取得によるステレオ方式高度決定が有用である。

最後に，衛星風についてはシステムとして改善すべきことや，利用面について今後の調査・研究に待つべき所も少なくないが，現業的にも研究目的にも，また現在・将来とも欠くべからざるものであることには変わりないことを強調しておきたい。

本稿は，1985年5月27日から31日までスイスのジュネーブで開催されたWMO／ICSU主催の会議「全球気象実験の結果とWWWに関する会議」において筆者が標記の題で発表した時に準備した詳細な講義ノートをまとめたものである。このうち各国の風計算システムについては，既に本技術報告に掲載されている（Hamada,1985）。