Prospects of Satellite Wind Sensing Systems in the Years 1995-2000*

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Abstract

A workshop on Space Systems Possibilities for Global Energy and Water Cycle Experiment (GEWEX) was held on 19–23 January 1987 in Columbia, Maryland, U.S.A. The GEWEX will concentrate on improving our knowledge of the transport of water and energy within the atmospheric system. It will be implemented during the period 1995–2000, because it is considered to be the timing that the Space Station Program will increase greatly the opportunities for new remote sensing instruments and earth observation according to future space plans.

For the construction of the observation systems and implementation of the GEWEX, following four major observation goals are introduced;

a. Tropical wind observation goal,
b. Earth radiation budget goal,
c. Global precipitation goal, and
d. Surface evaporation goal.

This article is the summary prepared for the author giving a presentation as a reviewer on prospects of wind sensing systems concerning tropical wind observation goal.

The satellite wind sensing system which is operated routinely is cloud motion wind (CMW) derivation system only. Global CMW derivation from 5 geostationary satellites were established just before FGGE period in 1978. CMW's have been very important input data to a numerical analysis especially over data sparse areas such as tropics, southern hemisphere, etc.

The microwave scatterometer wind data also have great impact to the numerical analysis over the data sparse areas. A few scatterometers are planned to be flown on board polar orbital satellites during the period of 1989–1991.

On board doppler lidar system is greatly expected as a future wind sensing system. Until the system reaches the stage of an operational use, there are still some problems to be solved; it needs much electric power supply and is too heavy in weight. Current highest possibility is 9.11 μm CO_2 pulsed laser on board advanced TIROS-N.

The prospects of satellite wind sensing systems in the years 1995–2000 are the followings;

a. Continuous operation of current cloud motion wind derivation from geostationary satellites,
b. Ocean surface wind derivation from microwave scatterometer on board polar orbital meteorological satellite, and
c. New instruments like doppler lidar system based on active sensor.

1. Introduction

The first basic requirement of GEWEX is a capability to accurately reconstruct the day-to-day evolution of the general atmospheric

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circulation especially in the tropics. It is necessary to obtain sufficient amount of wind data over tropics to meet those requirements, but there are few conventional upper air wind observations in the tropics. Currently, only cloud motion winds from geostationary meteorological satellites are routinely available as those from a satellite wind sensing system. Besides, the new instruments of satellite wind sensing system are greatly expected to be new data sources of winds.

At the NASA Workshop and Symposium on the Global Wind Measurements, the possibilities of satellite wind sensing systems have been intensively reviewed. The proceedings of the Symposium and Reports of the Workshop were referred to complete this report (NASA, 1985a and 1985b).

2. Wind Sensing Systems

2.1. Cloud Motion Winds (CMW's)

(1) General

The cloud motion wind derivation started just after launching First Application Technology Satellite (ATS-1) in December 1966. At first, Prof. T. Fujita and his collaborator as the University of Chicago, developed a cloud tracking system by the use of photo-processed animation film (Chang et. al., 1973). Using the CMW's it was revealed that the CMW data set was very useful for the flow pattern analysis over tropical area, hurricane vicinity, severe storm area and so on (Fujita et. al., 1968; Fujita et. al., 1969a; Fujita et. al., 1969b; Fujita et. al., 1970; Chang et. al., 1974).

Furthermore, Leese et. al. (1971) tried to track the target clouds automatically by a pattern recognition technique. The advent of the automatic cloud tracking technique implied its capability in the mass production of CMW's with the global coverage except for polar areas. Mid-1970's, NESC (now NESDIS/NOAA) began their operational wind derivation, and subsequently MSC/JMA and ESOC/ESA also started operational wind derivation in pre-FGGE year (1978) and at this time the global CMW derivation system was established.

As well known, five geostationary meteorological satellites have been nominally operated above the equator since FGGE period. But actually 4 to 3 satellites have been in operation after FGGE period. The CMW's are operationally derived from those satellite images by ESOC/ESA, NESDIS/NOAA and MSC/JMA.

The CMW's have some problems to be solved as described later, but they are currently unique data source with global uniform coverage except for polar area. Therefore, in this section, the capability of the CMW's in conventional wind data and potential capability in future among the other data sources to be available will be described. See Hamada (1985 and 1986) for the detailed description on CMW derivation systems, their histories and applications.

Each cloud motion wind vector is assigned to a suitable wind-representative level which is, (a) objectively estimated using the target cloud temperature calculated from IR, VIS and/or WV image data, (b) subjectively estimated by an analyst from cloud pattern analysis, or (c) estimated from statistical best-fit level. The height assignment procedure adopted by each operational center is shown in Table 1.

(2) Current problems with CMW's

a. Limitation of spatial coverage: No CMW is available over cloud-free area. In or around disturbance area, the CMW's cannot be derived or there are some difficulties to derive a number of CMW's.

b. Limitation of vertical resolution: The CMW's are generally obtained only at two levels in the vertical.

Table 1. Height assignment procedure at each operational center for cloud motion wind derivation.

	(extracted information)
MSC/JMA low-level TBB → Tc → Pc (Tc → Pc using 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 → ε → Tc → Pc=Pw VIS radiance	→ 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 using 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

c. Ambiguity of the representative height of CMW's: It is difficult to estimate the target cloud height when the cloud is thin (usually thin cirrus cloud) with an emissivity less than unity. This leads to the CMW height assignment error, which causes large CMW vector error when vertical wind shear is large.

d. Tracking problem on high-speed cirrus: When the cirrus around jet stream moves faster than 150 knots, the current cloud tracking system may not have its capability in tracking well the target. This situation is often seen in winter along the northern edge of subtropical high pressure over the northern Pacific where the Japanese GMS covers.

(3) To overcome those problems

a. Spatial coverage; Over cloud-free area, CMW's can be derived using water vapor (WV) channel's images (6.8 μm) or other channel's infrared data (i.e. CO_2 absorption channels). In or around disturbance area, low-level clouds might be tracked manually. It needs specific computer algorithm to track low-level clouds around disturbance because the cloud distribution is very complicated and cumulus clouds may be covered by thin cirrus clouds.

b. Vertical resolution; Mid-level winds (around 500 mb) can be derived using WV channel (6.8 μm) images (Eigenwillig et. al., 1982; Bowen et. al., 1979). CO_2 channel's images (14.2, 14.0 and 13.3 μm) may be also useful ones to derive three levels' CMW's (Menzel et. al., 1983).

c. Ambiguity of the representative height; The height estimation from window channel IR image can be corrected by the water vapor (6.8 μm) data (ESA's operational method, see CGMS XV ESA WP-17).

CO_2 channels' images (14.2, 14.0 and 13.3 μm) give accurate cloud height (±50 mb) in three levels (Menzel et. al., 1983)

Split window IR images (11 and 12 μm) give thin cirrus accurate height (Inoue, 1985).

Stereo observation from two neighboring satellites is powerful tool to evaluate the accuracy of height assignment being performed in routine operation. Accuracy of stereo cloud height determination is 500 m or less (Hasler, 1981; Mosher, 1980).

d. High speed jet cirrus; Currently 30 minute interval images are generally used for cloud tracking at each operational center. But this interval is not adequate to tracking high speed cirrus clouds. Some researches (Hamada et. al., 1985; Johnson et. al., 1980) indicate that it is better to use shorter interval images (15 minutes or less) for high-speed cirrus tracking. This problem will be solved by adopting 15 minute interval image for wind derivation.

2.2. Surface Winds from Microwave Scatterometer

In June 1978, the National Aeronautics and Space Administration (NASA) launched Seasat, which was the first satellite equipped with microwave scatterometer, SASS (Seasat A Satellite Scatterometer). The SASS data were collected for about 96 days during summer 1978, and provided a new data source of ocean surface winds. This active microwave sensor makes measurement of backscatter from wind-produced surface capillary-gravity waves (wave length, 1–3 cm), which can infer ocean surface wind stress and wind vectors (Jones et. al., 1982; Shroeder et. al., 1982). There is a directional ambiguity problem; that is, 4 directions are estimated principally and some other information on wind field has to be referred in order to focus to a right direction. The impact of SASS wind data on global data assimilation cycle and forecasts have been assessed (Baker et. al., 1984; Duffy et. al., 1984; Yu, T.-W. et. al., 1984). They showed that; (a) the impact of

SASS wind data on data assimilation cycle was large in the Southern Hemisphere, especially in large data gaps, but very small in the Northern Hemisphere; and (b) it was not possible to assess with confidence whether the forecasts made from analysis with SASS data was improved.

The new scatterometer is planned to be flown on board the satellites, NROSS (U.S.A.), ERS-1 (Europe) and RADARSAT (Canada) in between 1989 and 1991. The antenna number will be changed from 2 to 3, in order to alleviate the directional ambiguity problem.

2.3. Lidar Wind Sensing Systems

Doppler lidar is the direct tropospheric wind sensing system; that is, Doppler shift in the return signal from a laser pulse transmitted into atmosphere is measured to estimate lower atmosphere winds. The laser pulse must be transmitted at least from two directions because the lidar system measures the radial wind component along the line of sight of the transmitted pulse. Huffaker (1985) showed the geometry of the space-borne lidar wind measurement to determine two components of the horizontal wind velocity (Fig. 1). In principle, over a several kilometers swath along the satellite track two components of wind data can be collected. Further study will be required in order to get actual wind data from the space-borne lidar system.

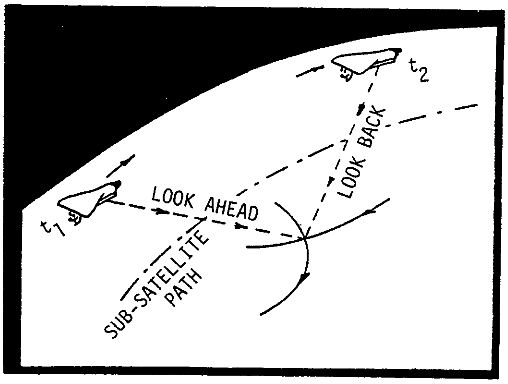

Fig. 1. Geometry of the satellite-borne lidar wind measurement (Huffaker, 1985).

The Doppler Lidar sensors have been intensively reviewed at NASA Workshop and Symposium on Global Wind Measurements. According to Menzies (1985), at present time, there are four major Doppler Lidar sensors which are being promoted for the measurements of tropospheric winds; (a) Incoherent Excimer Doppler Lidar, (b) Incoherent 0.5 μm Nd: YAG Doppler Lidar, (c) Coherent 1.06 μm Nd:YAG Doppler lidar and (d) Coherent CO_2 Doppler lidar. Among them, 9.11 μm CO_2 pulsed laser will be accommodated by space-shuttle (Osmundson et. al., 1985) or advanced TIROS-N polar-orbiter (Gurk et. al., 1985).

3. Prospects of Satellite Wind Sensing System

(1) Continuous operation of current system

Cloud motion winds (CMW's) will be continuously derived from 5 or more geostationary meteorological satellites. If those satellites will be in full operation, the CMW's will be still indispensable as global wind data during the Years 1995–2000.

(2) Microwave scatterometer for ocean surface wind

It is planned that several satellites will be launched equipped with microwave scatterometer to measure ocean surface winds.

(3) New instruments

Doppler Lidar system will not be dream during the Years 1995–2000. Doppler Lidar winds will be complement of other source's winds covering global area including polar area.

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ACRONYMS

ATS	Applications Technology Satellite
CGMS	Coordination of Geostationary Meteorological Satellites
CMW	Cloud Motion Wind
ERS-1	First European Remote Sensing Satellite
ESA	European Space Agency
ESOC	European Space Operations Centre, ESA
FGGE	First GARP Global Experiment (WMO/ICSU)
GEWEX	Global Energy and Water Cycle Experiment
GMS	Geostationary Meteorological Satellite
IR	Infrared
JMA	Japan Meteorological Agency
MSC	Meteorological Satellite Center, JMA
NASA	National Aeronautics and Space Administration, U.S.A.
NESC	National Enrivonmental Satellite Center (now NESDIS)
NESDIS	National Environmental Satellite Data and Information Service, NOAA
NOAA	National Oceanic and Atmospheric Administration, U.S.A.
NROSS	Navy's Remote Ocean Sensing System (U.S.A.)
RADARSAT	(Canadian satellite)
SASS	Seasat A Satellite Scatterometer
VIS	Visible
VTP	Vertical Temperature Profile
WV	Water Vapor

1995－2000年における衛星による風観測システム

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全球エネルギーと水循環実験（GEWEX）における衛星システムの可能性に関するワークショップが，1987年1月19日より23日までアメリカ合衆国の首都ワシントン郊外のコロンビアで開催された。GEWEXは，日々の天気や気候などに大きな影響を与えるエネルギーの輸送，水の循環の構造を解明する事を目的に，1995年～2000年の時期に達成されているであろう衛星からの種々の観測システムを最大限に利用して強力な観測体系を組織しようというものである。今回のワークショップでは，この観測システム組立てのための4つの目標：

①熱帯の風の観測

②地球の放射収支の観測

③熱帯の降水の観測，および

④地表面の蒸発量の観測

を決め，それぞれグループ討論が行なわれた。

本稿は、筆者が①の風の観測システムについての reviewer として準備した報告書である。

現在，現業的に運用されている衛星の風の観測システムは雲移動ベクトル（CMW）のみである。CMW は1978年12月から１年間にわたって実施されたFGGE を契機に，赤道上空に配置された５個の静止気象衛星画像から定常的に観測されるようになった。CMW のデータは，数値予報の全球解析の初期データとして，特に熱帯や南半球の，既存のデータの少ない地域で重要な役割を演じてきている。

現業的な運用はなされていないが，マイクロ波散乱計による海上表面の風データもまた南半球などのデータの少ない領域において数値予報のための解析に大きな影響を持っている。1989年から1991年にかけてマイクロ波散乱計搭載の衛星がいくつか打上げられることになっている。

将来のシステムとしては，衛星に搭載されるドップラーライダーへの期待が大きい。ドップラーライダーは電力の消費量が多いこと，重量が大きいことなど衛星搭載までには解決するべきことも多いが現在9.11μm のCO_2パルスレーザーによるものがスペースシャトルあるいは改良型TIROS-N に搭載が可能であると考えられている。

結論として，1995年～2000年にかけての衛星からの風観測システムとしては，

①現行の静止気象衛星による風観測の維持

②マイクロ波散乱計等による海上表面の風観測

③ドップラーライダーなどのアクティブセンサによる全球の風の観測

が主な手段である。もちろん今後の開発に待つ部分も多々あると言うことができる。