Comparison of Satellite-Derived Wind Measurements with Other Wind Measurement Sensors

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Introduction

THE purpose of this paper is to compare the good data from the Jimsphere launches with the data from the satellite system. By comparing the wind speeds from the Fixed Pedestal System 16 (FPS-16) Radar/Jimsphere Wind System and NASA's 50-MHz Radar Wind Profiler, the validation of winds from Geostationary Operational Environmental Satellite 7 (GOES-7) is performed. This study provides an in situ data quality check for the GOES-7 satellite winds. Comparison was made of the flowfields in the troposphere and the lower stratosphere of case studies of pairs of Jimsphere balloon releases and Radar Wind Profiler winds during Space Shuttle launches. The mean and standard deviation of the zonal component statistics, the meridional component statistics, and the power spectral density curves show good agreement between the two wind sensors. The standard deviation of the u and v components for the STS-37 launch (consisting of five Jimsphere/Radar Wind Profiler data sets) was 1.92 and 1.67 m/s, respectively; for the STS-43 launch (there were six Jimsphere/Wind Profiler data sets) it was 1.39 and 1.44 m/s, respectively. The overall standard deviation was 1.66 m/s for the u component and 1.55 m/s for the v component, and a standard deviation of 2.27 m/s for the vector wind difference. The global comparison of satellite with Jimsphere balloon vector winds shows a standard deviation of 3.15 m/s for STS-43 and 4.37 m/s for STS-37. The overall standard deviation of the vector wind was 3.76 m/s, with a root-mean-square vector difference of 4.43 m/s. These data have demonstrated that this unique comparison of the Jimsphere and satellite winds provides excellent ground truth and a frame of reference during testing and validation of satellite data.

Balloon–Satellite Wind Comparison

The scientific value of any satellite-sensed physical parameter such as the wind must be validated through accurate in situ measurements. This is to ensure that the remotely sensed signal is truly a good measure of the parameter being assessed. The existing technology in measuring winds for the Space Shuttle launches has been obtained by the balloon-borne FPS-16 Radar/Jimsphere Wind System for the past three and one half decades. Now, NASA's 50-MHz Radar Wind Profiler also plays an important role in monitoring winds for substantial profile changes during the day of launch. These comparative balloon–satellite data sets have been evaluated and their spatial and temporal variability reported previously in Ref. 1.

Satellite winds obtained by the GOES were assessed from the National Oceanic and Atmospheric Administration/National Environmental Satellite, Data and Information Service (NOAA/NESDIS) and from the Systems Design and Application Branch at the University of Wisconsin. The GOES satellite wind measurements from the cloud motions during the space shuttle launches at launch complex 39A, KSC, Florida, STS-37 and STS-43, on April 5 and August 2, 1991, respectively, have been compared with the FPS-16 Radar/Jimsphere Wind System measurements. The results are presented in Table 1.

Scale-Length Determination

What scale length should be used as a standard in assessing the sensor performance in measuring winds is an important question. Thus, with the Jimsphere balloon, the signal-to-noise ratio was evaluated to obtain a reliable wavelength from the signal and the noise level. To obtain a valid wavelength to evaluate the troposphere and lower stratosphere wind field, 20 Jimspheres were simultaneously tracked by an FPS-16 radar and an FPQ-14 radar at Cape Canaveral Air Force Station, KSC, Florida, and from Patrick Air Force Base, Florida. The resulting data were used in validation of satellite-derived winds. Spectra and cross-spectra of the profiles for all 20 pairs were computed and averaged. If it is postulated that the measurements are composed of the wind plus independent radar noise, cross-sectioning is required to cause the autospectral estimates to converge to the spectra of the actual wind plus the spectra of white noise.[2]

Data Analysis

The following data analysis of the comparison of the wind components measured by the FPS-16 Radar/Jimsphere Wind System and the NASA 50-MHz Radar Wind Profiler provides an excellent quality check of the cloud motion vector (CMV) from GOES-7. Comparisons of the u and v wind components from the Jimsphere balloon and the Radar Wind Profiler are presented in Figs. 1 and 2 for STS-37 (Atlantis). Five Jimsphere/Radar Wind Profiler data sets from KSC on the STS-37's day of launch were compared at 0803Z, 1033Z, 1218Z, 1308Z, and 1438Z. The standard deviation of the differences for the u wind component was 1.92 m/s, and for the v wind component 1.67 m/s as illustrated in Figs. 1 and 2. The Radar Wind Profiler data are computed for a scale length every 150 m, cross-sectioned and plotted as dots over a scale length of 30 m. The Jimsphere data are computed for a scale length of 30 m and plotted as a line. Thus, the Jimsphere/Radar Wind Profiler data sets are plotted and compared every 30 m in Figs. 1 and 2. During the STS-43 launch, six Jimsphere/Radar Wind Profiler data sets were compared at 0902Z, 1047Z, 1202Z, 1302Z, 1352Z, and 1517Z. The standard deviation for u wind component differences was 1.39 m/s, and for v component differences was 1.46 m/s.

WINDCO System

Several different methodologies have been created for measuring cloud motion from geosynchronous satellite data. One methodology used an interactive computer for the computations.[3] This system known as WINDCO has been revised and adapted to different types of satellite data.[4] The most accurate method uses multichannel radiative data measured by the satellite instruments.[5] This procedure, used in analyzing wind data, is an improvement in the crucial step of determining the altitude of clouds, especially the high clouds in the troposphere.

The WINDCO system uses consecutive satellite images to obtain cloud vectors. It operates in three parts to measure the cloud motions from satellites:

1) The first part consists in the selection of cloud targets likely to be representative of winds. These are generally found in the brightest area at the lowest temperature within the cloud, but are sometimes found near the largest gradient of temperature.

Table 1 Statistical results on vector differences between balloon and satellite wind measurements

Launch	Mean, m/s	Standard deviation, m/s	Root mean square, m/s
STS-37	5.69	4.37	4.45
STS-43	5.91	3.15	4.41
Average	5.80	3.76	4.43

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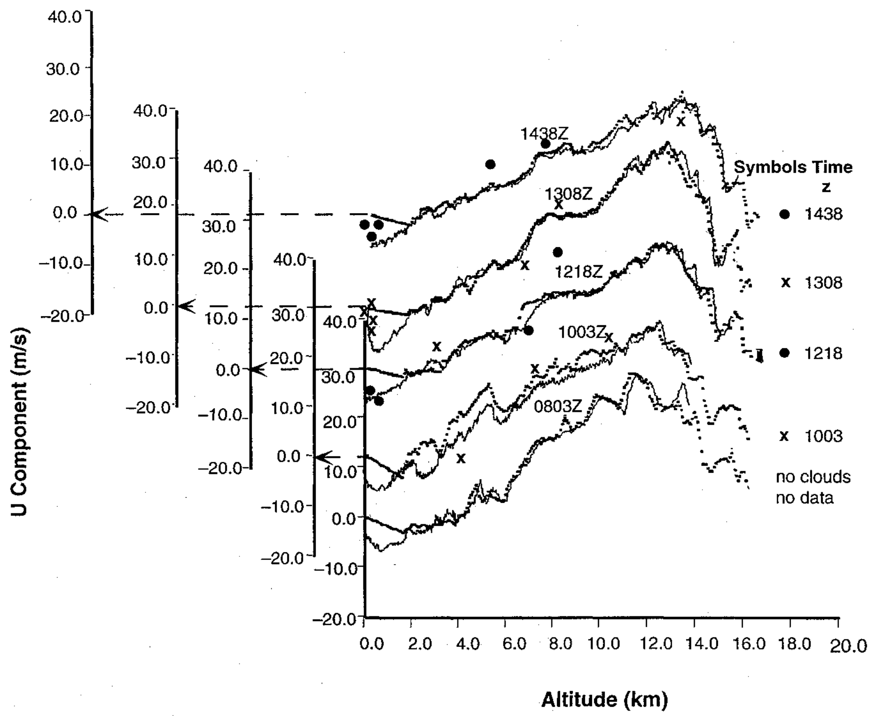

Fig. 1 Five *u* wind components of the NASA 50-MHz Radar Wind Profiler (data) overlaid on the wind profile of FPS-16 Radar/Jimsphere (solid lines) measured during the STS-37 launch, April 5, 1991, at KSC, Florida. Symbols x and o indicate GOES-7 Satellite wind data.

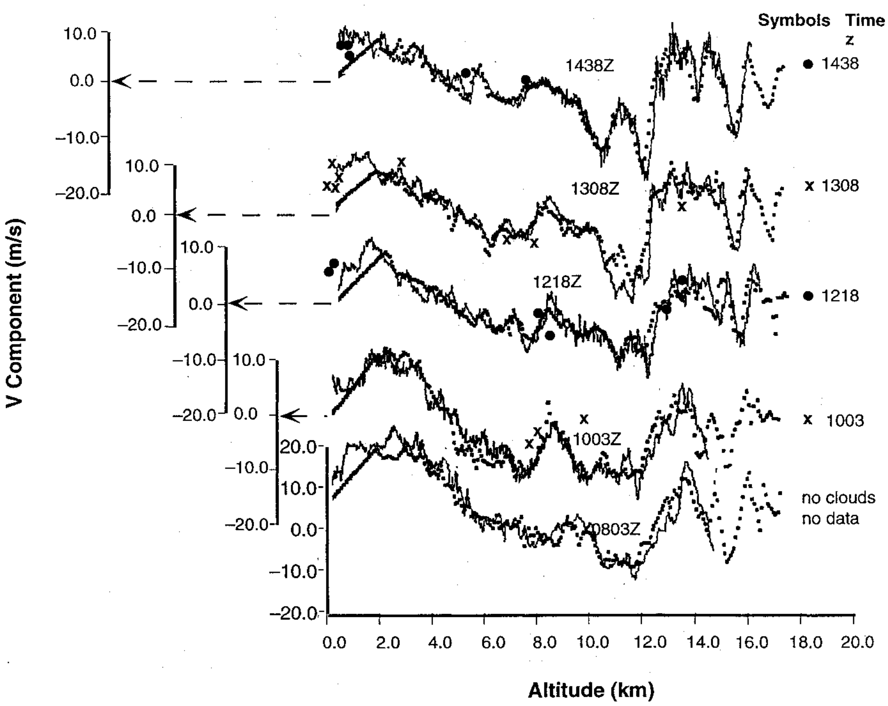

Fig. 2 Five *v* wind components of the NASA 50-MHz Radar Wind Profiler (data) overlaid on the wind profile of FPS-16 Radar/Jimsphere (solid line) measured during the STS-37 launch, April 5, 1991, at KSC, Florida. Symbols x and o indicate GOES-7 Satellite wind data.

2) The second part of the system determines the vector motion of the cloud. The pressure altitude of the cloud top is determined by one of several methods. An analysis of the wind produced by a numerical forecast is used as a first guess to establish the direction and speed most likely to be followed by the cloud in its movement from one picture time to the next. The cloud features are then matched from one picture time to another by shifting the positions, taking all possible combinations by correlation. Where the highest correlation coefficient is obtained, the cloud displacement over time is the measured vector.

3) The third part of the system is the validation of the cloud motions obtained. Because three pictures are used, two vectors can be obtained, and these are checked for uniformity. In addition, the operator generally checks for meaningful vectors that are reasonable and representative.

Validation of cloud motion vectors with vectors from other sources is routinely performed at National Meteorological Centers worldwide. However, these results are neither regularly published nor readily available. One exception, which was published by Whitney,[6] reported results of comparisons both with other geostationary satellites and with rawinsondes. In that study, data were collected in January and July for 1979–1982.

Whitney showed that rms vector differences for collocated satellite winds were mostly around 10 m/s for high clouds and 6 m/s for low clouds. In contrast, the differences between satellite winds and balloon vectors were larger. At high levels, differences ranged from 12 to 40 m/s for the Japanese Geostationary Meteorological Satellite, but only 10 to 18 m/s for GOES winds. The greater disagreement between satellite and rawinsonde winds was largely due to height assignment error where there were strong vertical shears or differences in the times of observations. Low-level satellite winds differed by about 6 to 9 m/s from rawinsonde measurements.

CO_2 Slicing Method

Data from 2 visible–infrared spin-scan radiometer atmospheric sounder (VAS) were utilized to determine simultaneous heights and velocities of cloud motion winds. A CO_2 cloud slicing technique was employed that combines the clear-air radiances with cloud radiances in the radiation transfer equation. The CO_2 slicing and absorption methods are presented here. Tracking of clouds can be accomplished by utilizing time sequences of CO_2 channel images as indicated by Menzel et al.[5] This CO_2 slicing method improves CMV determination. The cloud motions can be observed by the animation of channels 5, 8, and 10 in the infrared range of 6.7, 11.6, and 13.0 μm.

The high resolution of wind measurement from satellite imagery detects atmospheric motion through measurement of cloud displacement. In a sequence of images from a geostationary satellite (GOES-7), clouds move with the wind, and from these images it is possible to describe the motions of the atmosphere.[6] Methods used to derive the "cloud drift" require using good geostationary satellite images of geometric fidelity with time intervals of 30 min between images. In order to get a greater density of cloud motion vectors close to the KSC station, they were selected manually. This was done by choosing a target, following it by eye, and letting the computer do the vectoring and pressure. This is the procedure used in assessing the CMV.

These results show a considerable improvement in the verification of the satellite winds over those reported by Whitney. There are several possible reasons for this improvement. First, the cloud motions were measured in a research mode where the pressures and time constraints of operational work do not apply. Second, the CO_2 method of determining the very important variable of cloud height is thought to be considerably more accurate than the old method of using the infrared window for obtaining heights. Third, the Jimsphere wind measurements used to verify the cloud motions have been shown to be more accurate than radiosonde wind measurements.[7]

The cumulative effects of these refinements in the procedure should naturally produce smaller errors than those found in previous verifications. However, the fact remains that a cloud motion is measured through the depth of the atmosphere in which the cloud exists, and never can be precisely compared with a balloon measurement at a particular level. Without knowledge of the cloud depth this difficulty cannot be overcome and will remain a source of error.

Conclusion

This research has demonstrated the results of the comparison of measured winds between the FPS-16 Radar/Jimsphere Wind System and the GOES-7 Satellite. The scientific value of any satellite-sensed physical parameter such as wind must be validated by accurate in situ measurements. The in situ data were obtained by the Jimsphere balloon system, which has been used for the past three decades in measuring winds for the space shuttle launches. The Radar Wind Profiler plays an important role in monitoring winds for substantial profile changes during the day of launch. During the STS-37 and STS-43 Space Shuttle launches, the wind measurements were compared with NASA's 50-MHz Radar Wind Profiler. The results were a standard deviation of 1.66 m/s for the u component and 1.55 m/s for the v component, giving a standard deviation of 2.27 m/s for the vector wind. This role for the day of launch, when there are no clouds at all levels, is satisfied because the winds are light. These launch wind data of STS-37 and STS-43 at KSC, Florida, were compared with GOES-7 satellite wind data. The average distance of wind measurement between the GOES-7 satellite cloud winds and Jimsphere balloon winds was 65 km. The global comparison of satellite and Jimsphere vector winds shows a standard deviation of 3.15 m/s for STS-43 and 4.37 m/s for STS-37. The overall standard deviation of the vector wind was 3.76 m/s with a root-mean-square vector difference of 4.43 m/s. It was demonstrated that this unique comparison of winds obtained by the Jimsphere and the Radar Wind Profiler provides a frame of reference for comparison with satellite data.

These results show a considerable improvement in the verification of the satellite winds over those previously reported. There are several possible reasons for this improvement. First, the cloud motions were measured in a research mode, where the pressures and time constraints of operational work do not apply. Second, the CO_2 method of determining the very important variable of cloud height is thought to be considerably more accurate than the old method of using the infrared window. Third, the Jimsphere wind measurements used to verify the cloud motions have been shown to be more accurate than radiosonde wind measurements.

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Effect of Payload on Risk of Vehicle Loss Due to Engine Failure

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Introduction

THE future of humanity's presence in space is critically dependent on cheaper, more reliable access to Earth orbit. One method to reduce costs while increasing reliability is to automate processes that have previously been performed by hand. Another method to increase reliability is to increase safety margins. However, this will result in a reduction of the amount of payload per

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