5.8 EVALUATION OF WINDSAT SURFACE WIND DATA AND ITS IMPACT ON OCEAN SURFACE WIND ANALYSES AND NUMERICAL WEATHER PREDICTION

Robert Atlas*
NOAA/Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

O. Reale
Goddard Earth Science and Technology Center, University of Maryland, Baltimore, Maryland

J. Ardizzone, J. Terry, J.-C. Jusem, E. Brin, D. Bungato
Science Applications International Corporation, NASA/GSFC, Greenbelt, Maryland

J.F. Le Marshall
Joint Center for Satellite Data Assimilation, Camp Springs, Maryland

ABSTRACT

A detailed evaluation of the latest version of WINDSAT surface wind data has recently been performed to determine the quality of these data and their usefulness for ocean surface wind analysis and numerical weather prediction. The first component of this evaluation consisted of both subjective and objective comparisons of WINDSAT wind vectors to other sources of ocean surface winds (e.g., ship and buoy observations, QuikSCAT satellite winds, or model derived wind analyses). This was followed by data impact experiments using a variational surface wind analysis, as well as an operational four-dimensional data assimilation system. The results of this evaluation demonstrate the usefulness of WINDSAT data, but also show deficiencies relative to current scatterometer measurements.

1. INTRODUCTION

Accurate observations of surface wind velocity over the oceans are required for a wide range of meteorological and oceanographic applications. Surface winds are needed to drive ocean models and surface wave models, to calculate surface fluxes of heat, moisture and momentum, and to construct surface climatologies. In addition, surface wind data are essential for nowcasting weather and wave conditions at sea, and to provide initial conditions and verification data for numerical weather prediction (NWP) models.

Prior to the launch of satellites capable of determining surface wind from space, observations of surface wind velocity were provided primarily by ships and buoys. Such conventional observations are important components of the global observing system, but are limited in coverage and accuracy. For example, reports of surface wind by ships cover only very limited regions of the world's oceans, occur at irregular intervals of time and space, and are at times of poor accuracy. Buoys, while of higher accuracy, have even sparser coverage. As a result, analyses based only on these in-situ observations can misrepresent surface wind over large regions and are generally not adequate for weather forecasting.

Since the 1970s, satellites have offered an effective way to fill data voids, as well as to provide higher resolution data than is available routinely. In response to the wind blowing across it, the ocean surface responds on many wavelengths. This response provides a mechanism for the microwave remote sensing of ocean surface wind from space. The active sensing of the radar backscatter of centimeter-scale capillary waves allows the retrieval of ocean surface wind vectors with some directional ambiguity. Passive microwave remote sensing of the ocean surface also has the capability of retrieving ocean surface winds through the response of the microwave emissivity to the surface roughness.

Over the ocean, scatterometer surface winds are deduced from multiple backscatter measurements made from several directions. At the moderate incidence angles which scatterometers operate, the major mechanism for this scattering is Bragg scattering from centimeter-scale waves, which are, in most conditions, in equilibrium with the local wind.

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* *Corresponding author address*: Dr. Robert Atlas, Director, NOAA/Atlantic Oceanographic and Meteorological Laboratory, 33149; e-mail: Robert.Atlas@noaa.gov.

Theoretical models have made much progress in recent years, but most scatterometer winds are derived with the aid of empirical relationships, called model functions, which relate the backscatter to the geophysical parameters, and which are derived from colocated observations. In current model functions, the backscatter depends very nonlinearly on wind speed and direction. Although the scatterometer winds are usually provided as neutral winds at some reference height, the measurement is physically most closely connected with surface stress. Several scatterometer measurements are made of the same earth location, and winds are obtained by optimally fitting these data.

Because of the nonlinearity of the model function, several wind vectors consistent with the backscatter observations are usually found. These multiple wind vectors are called aliases in the early literature and are now generally referred to as ambiguities. The ambiguities are the minima of a cost function, which is a function of wind speed and direction. The cost function measures the difference between the observed backscatter and those calculated for the given wind speed and direction. Each ambiguity is assigned a probability of being the closest (i.e., the closest ambiguity to the true wind vector). Ambiguities with small relative minima are more likely. The highest probability ambiguity is termed the rank 1 solution. For recent scatterometers, usually only the first two probabilities are large and the associated ambiguous wind vectors point in nearly opposite directions. Various filtering approaches (called dealiasing or ambiguity removal algorithms) may then be used to extract a horizontally consistent pattern. Once the ambiguity is removed, the wind vectors chosen are called the unique winds.

Each scatterometer design to date has different characteristics which are relevant to the use of the data. The scatterometers launched have all had similar orbit characteristics—sun synchonous, near polar orbits, at roughly 800 km altitude, with a period of approximately 100 minutes. The Seasat scatterometer (SASS) and the NASA scatterometer (NSCAT) had antennas on both sides of the spacecraft, affording two simultaneous swaths (each 500 km wide for SASS and 600 km wide for NSCAT) separated by a nadir gap (450 km wide for SASS and 350 km wide for NSCAT). SASS had two antennas on each side, while NSCAT had three antennas on each side. SASS operated in a variety of modes with different polarizations. The NSCAT antennas were V-pol for fore and aft and dual polarized for the mid antenna. The ERS scatterometer had three H-pol antennas only on the right side of the spacecraft. Due to the geometry of these fan beam observations, the backscatter values at a single location are observed within a time span of approximately 70 to 200 seconds, increasing with incidence angle. The SeaWinds scatterometer on QuikSCAT has a radically modified design, using a one meter rotating dish antenna to illuminate two spots on the ocean surface, which sweep out two circular patterns. With this design there is no nadir gap, and in the region of overlap away from nadir there are essentially four independent measurements. QuikSCAT has been providing high (25 km) resolution surface wind vectors over the oceans since 1999, and has proven to be extremely valuable for weather analysis and forecasting.

Several passive microwave instruments—SMMR, SSM/I, and Geosat—have provided us with large data sets of ocean surface wind speed. During the period 1978-1991, between Seasat and ERS 1, there were no scatterometer wind data, and the only space-based surface wind data are from these passive microwave instruments. Of these, the SSM/I that have flown aboard the Defense Meteorological Satellite Program (DMSP) satellites since 1987 have the best coverage and resolution, although the lack of wind direction in these data limited their initial utility in scientific studies. SMMR is similar in terms of coverage to SSM/I, but has lower resolution and accuracy. For SSM/I often two or three, and sometimes four instruments are operational, while for SMMR usually a single instrument was operational. Geosat and other altimeters are less useful for NWP, providing wind speed only, at high resolution along track at nadir. However, the altimeter height data have provided indirect validation of both scatterometer and SSM/I data.

WINDSAT is the most recent passive microwave satellite for measuring ocean surface winds, and the first passive system to determine direction as well as speed. It was launched on January 6, 2003 and produces fields of ocean surface wind vectors (with directional ambiguity that is removed objectively), sea surface temperature, total precipitable water, cloud liquid water, and ocean rain rate over a 1000 km swath width. In this paper, only the surface wind vectors are validated. The evaluation includes colocations against in-situ and remotely sensed observations and model analyses, as well as numerical forecast impact experiments with and without different WINDSAT data sets.

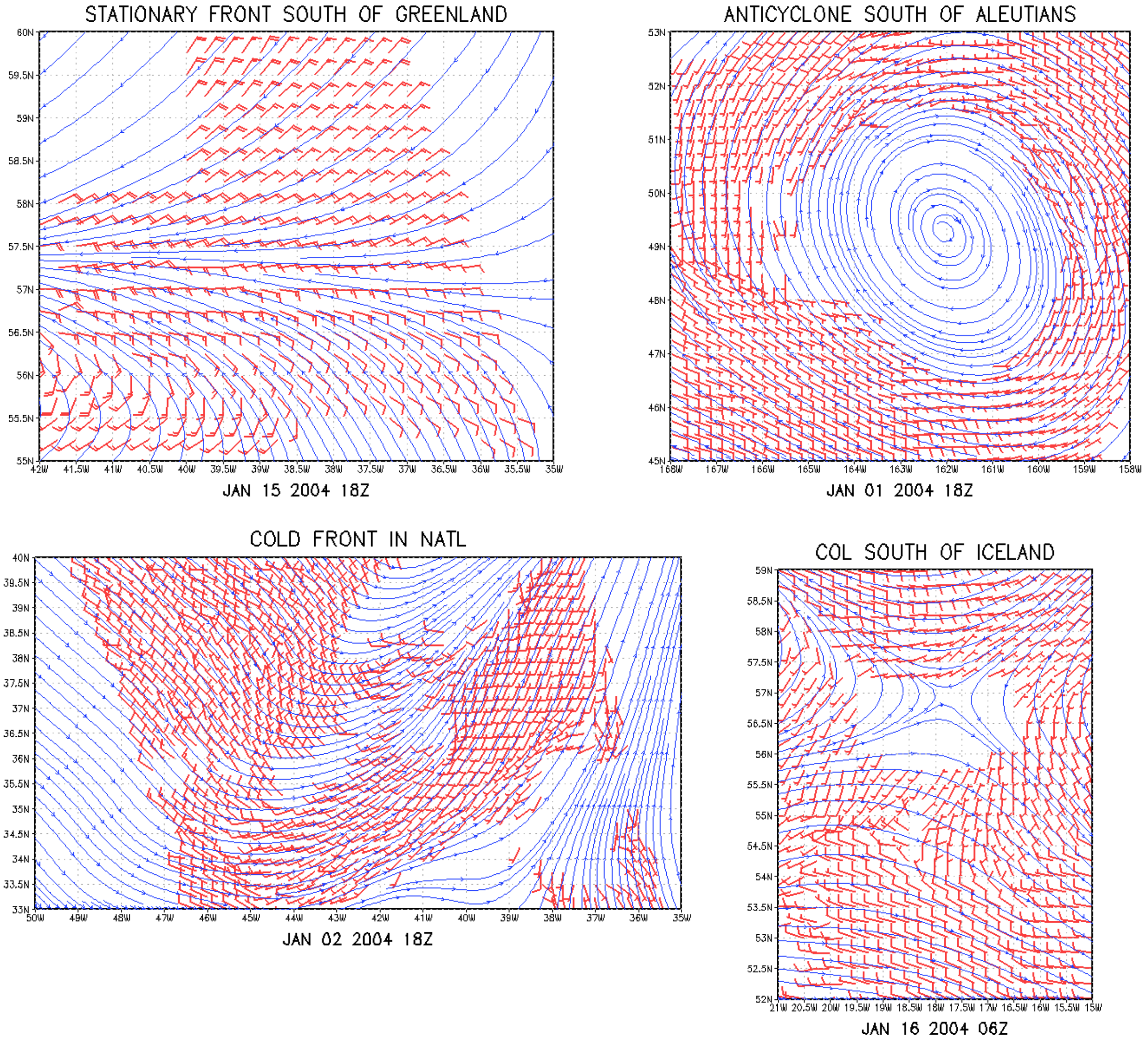

Fig. 1. Examples of WINDSAT surface wind vectors for a variety of synoptic weather patterns.

2. EXAMPLES OF WINDSAT SURFACE WINDS

Figure 1 illustrates WINDSAT surface wind vectors and streamlines for a stationary front, anticyclone, cold front, and pressure col over the oceans. These examples show that WINDSAT is capable of representing synoptic meteorological features in a realistic manner, but also illustrate some errors in wind direction. For example, the anticylonic wind shear in the southern portion of the col south of Iceland (lower right) is unrealistically sharp.

3. COLOCATIONS OF WINDSAT SURFACE WINDS WITH SHIP AND BUOY DATA

Colocation statistics were computed in order to define the differences between WINDSAT and other sources of surface wind information, as well as to evaluate the effectiveness of the directional ambiguity removal, and to determine the accuracy WINDSAT relative to QuikSCAT. Tables 1-6 present a summary of the collocations that were performed against ships and buoys (labeled All Conv). All ship and buoy observations within 50 km and 90 minutes of WINDSAT or QuikSCAT data were adjusted to an instrument height of 10 meters assuming neutral stability. Two versions of WINDSAT (the previous version V181 and the current version V190) are compared with QuikSCAT. Colocation results are presented for wind speed bins of 5-10, 10-15, and 15-20 m/s, as well as the summary over all speed bins.

The tables show that overall the latest version of WINDSAT is improved over the preceding one, but in general is less accurate than QuikSCAT. One

Table 1. RMS Speed Differences versus All Conv

Colocation Data	All Bins	5-10	10-15	15-20	Time Period
V181	2.596	2.439	2.564	3.119	12/01/03-02/29/04
V190	2.430	2.188	2.455	3.160	12/01/03-02/29/04
QuikSCAT	2.343	2.010	2.393	3.308	12/01/03-02/29/04

Table 2. Speed Bias versus All Conv

Colocation Data	All Bins	5-10	10-15	15-20	Time Period
V181	0.569	1.150	0.100	-1.407	12/01/03-02/29/04
V190	0.454	1.042	-0.044	-1.485	12/01/03-02/29/04
QuikSCAT	0.095	0.734	-0.472	-1.939	12/01/03-02/29/04

Table 3. RMS Direction Differences for Selected Alias versus All Conv

Colocation Data	All Bins	5-10	10-15	15-20	Time Period
V181	29.112	33.676	20.634	16.793	12/01/03-02/29/04
V190	27.274	31.332	19.800	18.524	12/01/03-02/29/04
QuikSCAT	23.916	27.195	17.323	19.682	12/01/03-02/29/04

Table 4. Percent Correct versus All Conv

Colocation Data	All Bins	5-10	10-15	15-20	Time Period
V181	75.662	75.500	78.482	67.327	12/01/03-02/29/04
V190	74.196	75.670	73.394	66.007	12/01/03-02/29/04
QuikSCAT	93.340	90.812	97.083	97.697	12/01/03-02/29/04

Table 5. Directional Bias for Best Alias versus All Conv

Colocation Data	All Bins	5-10	10-15	15-20	Time Period
V181	-0.534	-0.381	-0.577	-1.535	12/01/03-02/29/04
V190	-0.426	-0.228	-0.448	-1.421	12/01/03-02/29/04
QuikSCAT	0.398	0.767	-0.007	-1.074	12/01/03-02/29/04

Table 6. Directional Bias for Selected Bias versus All Conv

Colocation Data	All Bins	5-10	10-15	15-20	Time Period
V181	-1.558	-1.665	-1.204	-2.713	12/01/03-02/29/04
V190	-1.946	-2.071	-1.344	-3.155	12/01/03-02/29/04
QuikSCAT	0.464	0.846	0.287	-1.878	12/01/03-02/29/04

of the most significant problems for WINDSAT is the ambiguity removal skill (see Table 4), where WINDSAT is substantially less accurate than QuikSCAT.

4. IMPACT OF WINDSAT DATA

The impact of WINDSAT data was assessed first on analyses using the Variational Analysis Method (VAM) that was previously developed for the assimilation of satellite surface wind data by AER and NASA-GSFC. In this application of the VAM, the NCEP operational analysis was used as the background field (first guess) for the global variational analysis, and only WINDSAT data in different forms (as wind speed only, as ambiguous wind vectors, or as unique wind vectors) were assimilated. Figure 2 presents the impact of assimilating either WINDSAT speeds, ambiguous winds, or unique winds on the analysis of cylones. From the figure, it can be seen that there is a significant impact relative to the operational NCEP analysis, and that the impact increases as more directional information from WINDSAT is assimilated. On average, when the unique WINDSAT vectors are assimilated two cyclones are added that the operational analysis did not contain. In nearly every analysis, one cyclone in the operational NCEP is deleted. A significant impact on the position and intensity of cyclones also occurs. Figure 3 shows an example of one such impact. The NCEP analysis shows a single cyclone. The VAM analysis with WINDSAT speeds or ambiguous winds modifies this cyclone somewhat. The VAM analysis with the unique WINDSAT wind vectors clearly shows a double cyclone structure. This impact was confirmed by comparison with independent data, geostationary imagery, and later analyses.

The impact of WINDSAT on four-dimensional data assimilation and forecasting was assessed using the GEOS-4 data assimilation system (also known as FVDAS), that is run at the NASA Goddard Space Flight Center. The control for this experiment assimilated all conventional surface based and space-based data that is routinely assimilated at

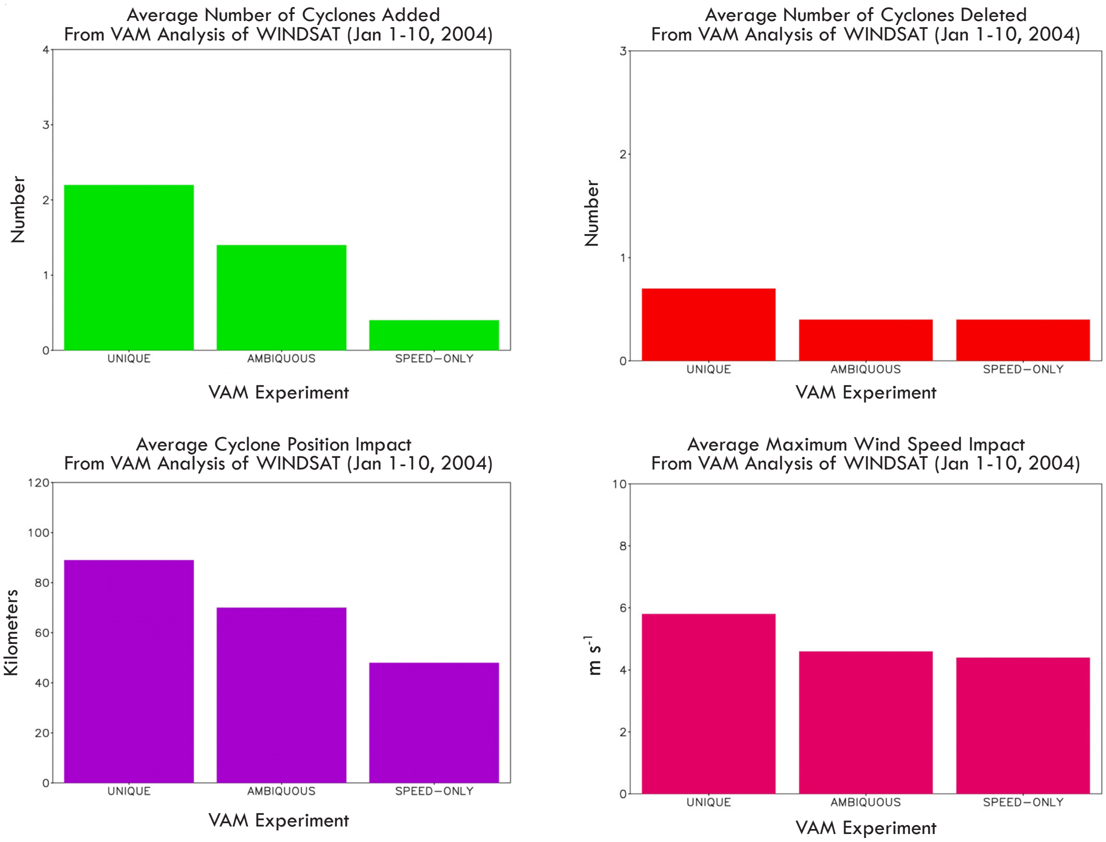

Fig. 2. Impact of WINDSAT data on VAM analyses of cyclones.

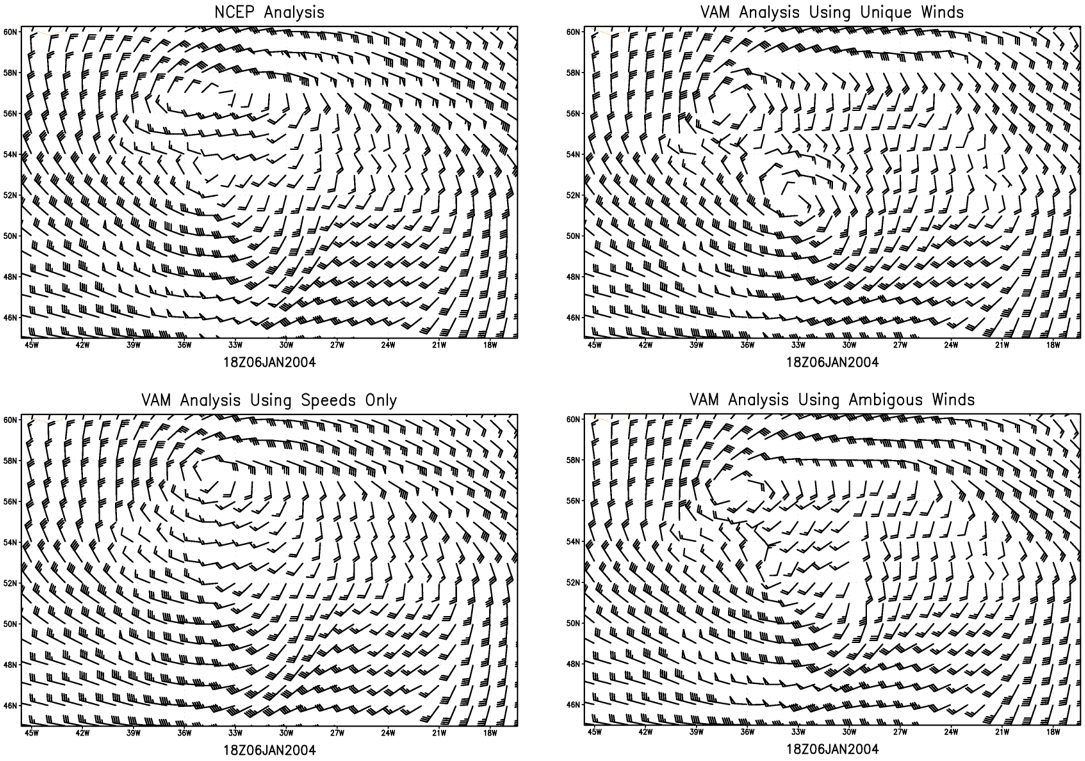

Fig. 3. Impact of WINDSAT data on the analysis of a cyclone in the North Atlantic.

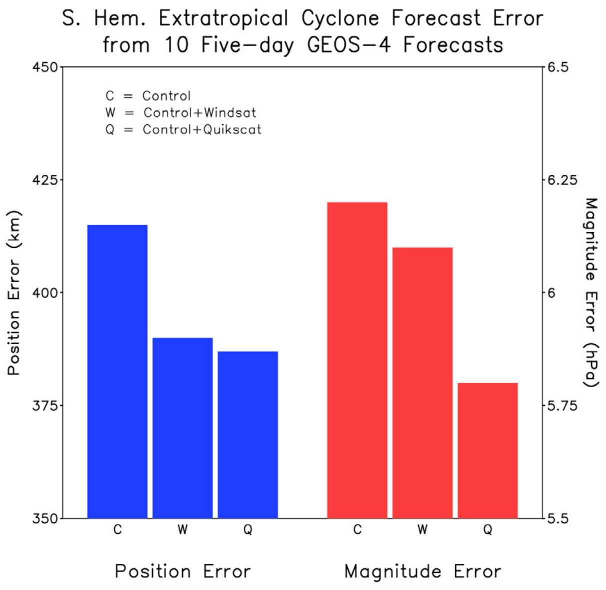

Fig. 4. Relative impact of WINDSAT and QuikSCAT data on five-day forecasts of cyclones.

GSFC, with the exception of any satellite surface wind data. In subsequent runs, either WINDSAT V190 unique wind vectors or QuikSCAT unique wind vectors were added to the Control, and the relative impact of each was then evaluated. Figure 4 shows the relative impact of WINDSAT and QuikSCAT data averaged over ten 5-day forecasts for the Southern Hemisphere with the GEOS-4 global model. This figure shows a positive impact of either WINDSAT or QuikSCAT on cyclones. The impact of QuikSCAT is slightly larger than WINDSAT for cyclone position, and significantly larger for cyclone magnitude. In the Northern Hemisphere (not shown), the impact is smaller and less consistent than for the Southern Hemisphere, and the impact of QuikSCAT is substantially better than for WINDSAT. In addition, experiments conducted at the Joint Center for Satellite Data Assimilation (JCSDA) have also shown a positive impact of WINDSAT data on numerical weather prediction.

5. SUMMARY

A detailed geophysical validation of WINDSAT data is being performed. This includes: colocations with in situ data, satellite observations, and model analyses; synoptic evaluations by highly skilled meteorological analysts; objective quality control; and impact experiments using multiple data assimilation systems. All of the measures thus far indicate potential for WINDSAT to improve ocean surface analyses and weather prediction, although there are significant limitations relative to scatterometry.

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