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FINAL TECHNICAL REPORT
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by

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SUMMARY

Grant NAGW-266 began on October 1, 1981 and ended on December 31, 1984 for a total duration of 38 months. During that period papers were prepared for and appeared in SEASAT Special Issue 1 (1982) and SEASAT Special Issue 2 (1983), two papers were presented at the URSI Commission F Symposium and Workshop in Israel, three NASA Contractor Reports were prepared which were published by NASA, several brief summaries were given at Oceans '83 and Oceans '84, the principal investigator participated in the S Cube deliberations and report, and a draft paper with M. A. Donelan was prepared that may eventually provide an adequate theory for backscatter from the sea surface. References to these papers are given at the end of this final report.

A paper that summarized the three contractor reports prepared under the grant plus the contribution by Donelan and Pierson at the URSI meeting was submitted to JGR but reviewed unfavorably as simply a summary of four papers in the "gray" literature, which it was meant to be. Whether or not some possibly modified version of the attached paper will be accepted for the URSI special collection is presently to be determined. The paper by Donelan and Pierson (1984) is presently under revision.

STATUS QUO ANTE WOICESHYN, ET AL.

The research that was done can be divided into two parts. Although reservations were expressed concerning the SOS wind recovery algorithm and the power law model function, it appeared to pass the JASIN independent data base comparison test well enough to permit the claim that all was in good shape. Woiceshyn, et al. (1984) destroyed this pleasant state of affairs. The SASS winds were used by many to study wind fields over the ocean and to see if forecasts could be improved by their use. Two of the contractor reports were done to show how SASS winds could be used as summarized in the attached report. The one by Sylvester only depends on getting correct winds, but the one by Pierson, et al. would give different results had the wind recoveries been done in a way to eliminate the errors shown by Woiceshyn, et al. (1984). Many of the studies of the SASS winds are still valuable, especially in contrast to conventional transient ship data, but future scatterometer data need not contain the kinds of errors found in Woiceshyn, et al.

STATUS QUO POST WOICESHYN, ET AL.

The SASS/SOS method for recovering winds from backscatter data has been shown to lead to inconsistent results when V pol and H pol winds are compared. Efforts to recover from this condition are under way, although many other researchers are unaware of the present situation. There is no status quo post Woiceshyn, et al. because the scientific community is mostly unaware of these results due to the slowness by which scientific information is disseminated in the "white" publications.

If the power law were correct and there was actually backscatter from winds of 2, 1 and 0.01 m/s, Pierson (1984) showed that a maximum likelihood estimator (MLE) as opposed to the Sum of Squares (SOS) algorithm would recover light winds within the SASS specifications.

But Donelan and Pierson (1984) show that there is no Bragg backscatter for light winds and that the lowest speeds that can be recovered are incidence angle and water temperature dependent. A new model function that does not use a power law and that accounts for sea surface temperature is needed and is under study both theoretically and by means of the SASS Mode 4 data under NASA GRANT-690.

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ASPECTS OF THE DETERMINATION OF WINDS BY MEANS OF SCATTEROMETRY AND OF THE UTILIZATION OF VECTOR WIND DATA FOR METEOROLOGICAL FORECASTS

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Abstract

Research applicable to the URSI Commission F Symposium and Workshop of May 24 to May 23, 1984 is briefly summarized. The data that demonstrate that $(U(\lambda/2)/C(\lambda)) - 1$ is more closely correlated to the nondimensionalized wave spectrum at L-Band, $(\Phi(\omega)\omega^5/g^2)$, than either $\bar{U}_{19.5}$ or u_* are reproduced. The other results that are reviewed are available from the sources cited, three of them being detailed Contractor's Reports published by the National Aeronautics and Space Administration.

Introduction

In this review, we provide a summary of Donelan and Pierson (1984a) Pierson, et al. (1984a, 1984b) and Sylvester (1984). The first reference, has been used as the foundation for a new theory for backscatter from waves in Donelan and Pierson (1984b). Results from the first and second references were described at the URSI Commission F Symposium. The third reference is a complete version of the second. The last reference highlights some of the difficulties that result if the asynoptic data from a spacecraft are assimilated by means of a ± 3 hour data window.

Additional material presented at the URSI Symposium by Woiceshyn and those working with him, plus even more recent results by all just named, such as Pierson (1984), cast doubt on the ultimate accuracy of the presently available SASS winds especially for speeds outside of the range covered by the JASIN data from about 5 m/s to 16 m/s. It should be noted that, because of the poor quality and sparce coverage of conventional meteorological data, it has taken until now to detect the inherent inconsistencies of the SEASAT SASS winds. Even if, in part, incorrect, SASS wind fields are nevertheless far superior to conventional wind fields.

Wind Speed Versus Friction Velocity

As summarized by Donelan and Pierson (1984a) in their abstract, "Studies of radar backscatter from the sea surface are referred either to the wind speed, $\bar{U}$, or friction velocity, u_*. Bragg scattering theory suggests that these variations in backscatter are directly related to the height of the capillary-gravity waves modulated by the larger waves in tilt and by straining of the short wave field. The question then arises as to what characteristic of the wind field is most probably correlated with the wave number spectrum of the capillary-gravity waves. This study reviews the justification for selecting $\bar{U}$ as the appropriate meteorological parameter to be associated with backscatter from L-band to K_u-band. Both theoretical reasons and experimental evidence are used to demonstrate that the dominant parameter is $\bar{U}/C(\lambda)$ where $\bar{U}$ is the wind speed at a height of about $\lambda/2$ for waves having a phase speed of $C(\lambda)$."

It is rather easy to show that if equation (1) is true, then if equation (2) is true at upwind, equation (3) is not and if equation (3) is true at upwind, equation (2) is not.
If $\bar{U}_{19.5}$ is used with a drag coefficient at $\bar{U}_{10}$ there is no power law at $\bar{U}_{10}$. Donelan and Pierson (1984b) show that the present power law formulation does not correctly describe radar backscatter.

$$u_* = (\alpha + \beta\bar{U}_{10})^{\frac{1}{2}} \bar{U}_{10} \tag{1}$$

$$\sigma^o = \gamma_1 \bar{U}_{10}^{\delta_1} \tag{2}$$

$$\sigma^o = \gamma_2 u_*^{\delta_2} \tag{3}$$

Moreover, ρu_*^2 represents the downward flux of momentum toward the sea surface and a shearing stress. The momentum (and energy) flux from the wind to the waves in brought about both by normal (pressure) and tangential (shear) stresses. Both calculations (Brooke Benjamin, 1959, Miles, 1962) and experiment (Kendall, 1970) demonstrate that normal stresses dominate the energy flux. Recent numerical (Al-Zanaidi and Hui, 1984) and experimental (Hsiao and Shemdin, 1983) studies have shown that the energy input from the wind through normal stresses is related to $((\bar{U}/C)-1)$.

Frequency spectra estimated from wave time histories recorded at the combined meteorological-limnological tower of the Canada Centre for Inland Waters were corrected for Doppler shift effects so as to obtain values of the spectrum at $\omega = 17.3$ corresponding to a wavelength, λ, of 20.7 cm. The wind instrumentation on the tower provided direct estimates of $\bar{U}_{11}$ and u_* from which $\bar{U}_{10}$ and $\bar{U}_{19.5}$ were obtained by means of Monin-Obukhov theory.

It was then possible as in Figs. 1, 2 and 3 to compare the normalized spectrum, $\Phi(\omega)\,\omega^5/g^2$, with the wind at 19.5 m, u_* and a new parameter $(\bar{U}(\lambda/2)/C(\lambda)) - 1)$ or, since $C(\lambda) = g/\omega$, $((\bar{U}(\lambda/2)\,\omega/g)-1)$. The data scatter far less in Fig. 3 than in either of the other two figures.

Because of the location of the tower in Lake Ontario, the fetch varies over a large range of values, depending on wind direction. The drag coefficient and hence, u_*, is not a unique function of $\bar{U}_{10}$, Donelan (1982). The coded points, are for various ranges of U/C_p, where C_p is the phase speed of the spectral peak. They show that a wide range of different spectral values were obtained along with a wide range of values of u_* even for the same wind at 19.5 meters. The third parameterization succeeds in reducing the scatter even under these conditions.

Four additional implications of this paper need to be noted. One is that the closure problem is not avoided. The wind profile must still be defined as a function of height above the surface, and consequently either CD_{10} or z_o must be defined. A second is that, in mid-ocean, the waves and winds will be more nearly in equilibrium so that an acceptable strictly wind dependent form for CD_{10} would be sufficient most of the time, except near fronts, for example. A third is that $(U(\lambda/2)/C(\lambda))-1$ can be less than zero for a light enough wind, in which case no waves with that wavelength will be generated directly by the wind. The consequences of this particular result, along with the added effects of viscosity and turbulent fluctuations, are explored more fully in Donelan and Pierson (1984b). There is no expected backscatter for winds below certain speeds for a given incidence angle and water temperature. Finally the wave spectrum no longer depends on the wind at some height but on the variation of wind with height, and, consequently, on whatever closure is used to define either CD_{10} or z_o. Wave forecasting models that involve nondimensionalized variables such as $gH/\bar{U}$, $C/\bar{U}$, $\omega\bar{U}/g$, and so forth, may be an oversimplification that can no longer be justified.

Synoptic Scale Fields From SEASAT Data

Present computer based numerical models for meteorological predictions and for the study of the ocean circulation have fairly coarse grids. Global one degree resolution for fifteen layers, or more, may be available in the not too distant future for the atmosphere. Even at this resolution far more data are available from SEASAT than can be used.

Pierson, et al. (1984a) contains only a portion of Pierson, et al. (1984b), and the reader is referred to the latter for a complete description of the results. The SEASAT-SASS winds were assumed to be correct for the analysis that was made. Even if correct, SEASAT winds contain two unremovable sources of error as shown by Pierson, (1983). These are (1) the combined effects of Rayleigh fading (or communication noise) and attitude errors and (2) the relatively small area of the sea surface sampled by a given SASS cell so that part of the mesoscale variability of the wind is added to the synoptic scale. The probability density function for the error structure of a SASS wind vector, given even a true synoptic scale wind vector as the expected value, is not easily determined.

However, the process of assimilating data for a synoptic scale initial value update for a numerical weather prediction often uses an error distribution for the measurements as in, for example, Bergman (1979). Assumed standard deviations for the error in the measurement by conventional means of the magnitude of wind at sea have been as high as 5 m/s.

Portions of four SEASAT revolutions over the North Pacific from the GOASEX program were processed in the form of superobservations by pooling dealiased vector winds from two degree latitude by two degree longitude overlapping "squares" so as to form a one degree vector wind field.

The SASS winds in the two degree square are composed of the synoptic scale wind at the center of the two degree square (an integer value of latitude and longitude) plus the synoptic scale horizontal wind gradient over the area plus the actual SASS "error" in measuring the synoptic scale wind at a point plus mesoscale variability. The synoptic scale gradients can be removed to first order, and the sampling variability is the result of the two effects described above. Rayleigh fading and, perhaps, attitude errors are uncorrelated and hence independent from one SASS wind to another. Only the longer wavelengths in the mesoscale can affect nearby measurements. Each SASS wind can thus be thought of as a measurement of the synoptic scale wind (with gradients removed) plus a random error in the synoptic scale wind direction plus a random error normal to the synoptic scale wind direction.

Only a minimum number of assumptions need to be made about the probability density function for the sampling variability of the winds obtained by SASS for a small area of the sea surface. These can be shown to be equivalent to describing the wind measured by the SASS parallel to the synoptic scale wind (V_{ps}) by equation (4) and the wind normal to the synoptic scale wind (V_{ns}) by equation (5) with the requirement that (6) through

(11) apply.

$$V_{ps} = \bar{V}_p - t_1 \Delta u \tag{4}$$

$$V_{ns} = -t_2 \, \Delta v \tag{5}$$

$$\int_{-\infty}^{\infty} f_1(t_1) dt_1 = 1 \tag{6}$$

$$\xi \, (t_1) = 0 \tag{7}$$

$$\xi(t_1^2) = 1 \tag{8}$$

$$\int_{-\infty}^{\infty} f(t_2) dt_2 = 1 \tag{9}$$

$$\xi \, (t_2) = 0 \tag{10}$$

$$\xi \, (t_2^2) = 1 \tag{11}$$

The SASS winds around a given point can then be pooled by averaging them to form a superobservation. Moreover, Δu and Δv can also be estimated from the data. It can then be shown that pooling M SASS observations to form a superobservation yields an estimate of the synoptic scale wind such that (12) and (13) hold.

$$V_{ps} = \bar{V}_p - t_3 \, (\Delta u)/M^{\frac{1}{2}} \tag{12}$$

$$V_{ns} = - \, t_4 \, (\Delta v)/M^{\frac{1}{2}} \tag{13}$$

As an example, a superobservation composed of 25 SASS winds has a standard deviation of one fifth of the standard deviation of the sample along with the same expected value. When resolved into east-west and north-south components these standard deviations for the superobservations were nearly always under 1 m/s and frequently about 0.2 to 0.3 m/s in the four passes that were studied.

Not only would the superobservations be very accurate compared to conventional data (given a correct relationship between wind speed and backscatter, which was assumed), but also they allow the estimation of their own error structure as this varies throughout the swath.

Although numerous authors such as, for example, Guymer (1983), have produced superobservation vector wind fields and various derived fields therefrom, no one to our knowledge has carried the analysis one step farther so as to determine estimates of the sampling variability of the vector winds and of quatities such as the horizontal field of divergence, vertical velocities, the wind stress and the curl of the wind stress. Pierson, et al. (1984b) show that all of these quantities computed for a 1° grid can be estimated by finite difference methods in spherical coordinates and that the sampling variability of the estimates is much smaller than the estimates themselves. The estimates also produce realistic fields that correlate well with geostationary cloud imagry and independent analyses of integrated water vapor, integrated liquid water and rainfall rates from the SMMR (Katsaros and McMurdie, this issue).

Since the preparation of Pierson, et al. (1984b), numerous deficiencies in the processing of the SASS backscatter data into winds have been revealed. The Sum of Squares (SOS) algorithm (Jones, et al. (1982)) resulted in discarding a large number of backscatter values that could have been used to derive a better model function and to detect areas of calm, or light, winds in the subtropical highs. The power law assumption similar to equation (2) but for 19.5 meter and generalized to be a function of aspect angle and incidence angle is now questionable, and if the results of Donelan and Pierson (1984b) are applied, the presumed advantages of the SOS algorithm vanish. Nevertheless, the methodology that was used by Pierson, et al. (1984b) can be applied to more nearly correct data from future systems.

Scatterometry wind data in the form of superobservations need to be assimilated in a way that will correct both the field of mass and the field of motion for the initial value synoptic scale specification for a numerical weather prediction. The methods developed by Bergman (1979), with an improved boundary layer model, would correct the analysis both on the sphere and as a function of height, A great advantage of the above data assimilation scheme is that it will correct an initial guess field for distances as much as 600 km away from a new data point. A scatterometer swath will consequently be able to influence an area about twice as wide as the actual swath itself for a given orbit segment.

Asynoptic Data Assimilation.

Efforts to demonstrate that actual scatterometry data on winds could be used to improve numerical weather predictions did not, at first, meet with any dramatic demonstrations of the value of the data. The dramatic effect that was hoped for was demonstrated only after Duffy and Atlas, (this issue) allowed the SASS winds, which are now believed to have errors, to influence the higher elevations in the model, produce a corrected wind field and a corrected field of mass and to account for the release of latent heat. The result was a substantial improvement in predicting the deepening and the high winds of the so-called QE-II storm. Many of the difficulties in the assimilation of scatterometer winds were avoided in this particular analysis because data for only a few minutes for two successive passes over the area involved were used.

Problems arise in the global assimilation of the data. Scatterometer wind data can be imagined to fall on the upper (northern) and lower (southern) sides of a drill bit with the axis of the drill being time. Very little data are consequently available exactly at a synoptic time of 0000, 0600, 1200 and 1800 GMT. For an initial value update at 0000GMT or 1200GMT only the past 12 hours of wind data are available. Except for gaps between swaths, 12 hours of data do indeed cover the global ice free ocean since, as the earth turns beneath the plane of the orbit through 180°, northbound swaths cover half the earth and southbound swaths cover the other half.

As reviewed by Sylvester (1984), two methods have come to the fore for the assimilation of global scatterometer data. One uses ten minute blocks (at least in early simulations) centered on a time step of the model and the other assumes all data within ± 3 hours of the above synoptic times to have been observed simultaneously at that synoptic time.

The consequences of the latter assumption were investigated by Sylvester (1984) by assuming a frozen three day repeat orbit over the Nothern Hemisphere during December 1980 and January 1981 for which the tracks of the cyclone centers had been documented in the Mariners' Weather Log. Errors in locating the cyclonic centers, in calculating the velocity of a cyclonic center and in locating fronts are then found as a result of this assumption of a large data window.

The "Abstract" and "Summary and Conclusion" of Sylvester (1984) are given in full below.

Abstract of Sylvester (1984)

"The scientific community has been given great assurances of the usefulness and the validity of the SASS data. Notwithstanding, an area of uncertainty exists in the current techniques for the insertion of real-time information from spacecraft in computer based numerical predictions.

"This study examines the operational aspect of an intermittent assimilation scheme currently utilized for the specification of the initial value field. The main focus here is to quantify the absolute 12-hour linear displacement error of the movement of low centers. This error is attributable to the ± 3 hour window used in the assimilation cycle when asynoptic data are inserted in computer models. A series of SEASAT repeat orbits over a sequence of "best" low center positions are simulated by using the Seatrak satellite calcultor provided by the Jet Propulsion Laboratory. These low centers are, upon appropriate interpolation to hourly positions, located at various times during the ± 3 hour assimilation cycle.

"Error analysis for a sample of best cyclone center positions taken from the Atlantic and Pacific oceans reveals a minimum average error of 1.1° of longitude and standard deviation of 0.9° of longitude. The magnitude of the average error seems to suggest that by utilizing the ± 3 hour window in the assimilation cycle, the quality of the SASS data is degraded to the level of the background since the errors that result from the assimilation technique have comparable magnitudes to those realized in conventional data.

"A further consequence of this assimilation scheme is the effect which is manifested as a result of the blending of two or more juxtaposed vector winds, generally possessing different properties (vector quantity and time). The outcome of this is to reduce gradients in the wind field and to deform isobaric and frontal patterns of the initial field."

Summary and Conclusion of Sylvester (1984)

"Evidence exists as to the applicability and the potency of the SASS data. A recent paper by Pierson, et al. (1984b) demonstrates useful synoptic properties of the data. The addition of high-quality real-time global wind information to the existing background meteorological field should have positive effects on our computer based weather forecasts. If some notable improvement is not effected, it is because we fail to utilize the data efficiently.

"In the search for the best ways of incorporating the new data, scientists have embarked upon divergent paths and have arrived at different results. Phillips (1976), Tracton (1981), Ghil, et al. (1979) and Atlas, et al. (1982) have all, in part, agreed that the disparate results are an implication that satellite impact is highly dependent on the particular analyses and forecast system used to incorporate the data. Two dominant schools of thought have emerged in this competitive arena. One main difference in their methodology is grounded in the format for inserting asynoptic satellite data in their models. The two methods in competition are the intermittent and the time- continuous assimilation techniques.

"The researchers who practise the time-continuous technique claim to have enjoyed a great measure of success. Those who use the intermittent method have reported relatively marginal success, or in a few cases, practically none at all (see Tracton (1981)). In actual fact, workers associated with the NMC have registered beneficial impacts mainly in areas where there is a paucity of background conventional data, as for example, in the Southern Hemisphere.

"The omission of any noticeable impact in the Northern Hemisphere experiment can be easily explained. These researchers collected data from that area during the summer. In this season the North Atlantic is relatively inactive with respect to meteorological events. There are scarcely any organized features that could produce well-defined gradients in the wind field. Weak or non-existing gradients would not therefore have any tangible effect on the existing conditions. Impact was registered when Southern Hemisphere data were assimilated because of the reverse situation — meteorological activity is heightened in the winter hemisphere.

"The main investigation has been centered around the ± 3 hour assimilation window that has been adhered to by certain groups of investigators. The scheme has been adjudged to be questionable on account of the unsound mapping procedure relating to the element of asynoptic observations. Asynoptic data are treated as if they belong to the nearest main synoptic hour, for example, information of 0910z and 0845z are treated at 1200z and 0600z respectively.

"A series of best low center positions from the Atlantic and Pacific oceans have been simulated incorporating a method of repeat or frozen orbit, aided by the Seatrak Satellite calculator. These low centers are located at various times during the passage of SEASAT. Given the asynoptic nature of satellite observation, the sighting of a low center by the SASS can occur at any time. These times are not necessarily at main synoptic hours. The result of this study shows that there is a low incidence of occurrence of the coincidence of SEASAT sightings times and synoptic hours. Within ± 30 minutes of main synoptic times, the data shows 12% of coincidence. When the time elements of asynoptic observations are mapped into these main synoptic times, errors are created in the inferred speeds of low centers from one map update time to another. These are the errors that multiply in the forecast cycle and contribute to the gross errors that are present in the output (forecast).

"Analysis of the a sample chosen from the Atlantic and Pacific oceans has revealed an average absolute 12 hour linear displacement error of 1.1° of longitude and a standard deviation of 0.9° of longitude. About 84% of the sample has errors in excess of 0.5° of longitude; sixteen percent has errors larger than 2°.

"If the results of the sample studied are considered indicative of the general wrong placements of low centers, then they are suggesting that these errors have levels comparable to those (about 2° of longitude) presently realized in the conventional data. The results may further help to provide a simple explanation for the low skill score that relates to forecasts that are products of the ± 3 hour intermittent assimilation when SASS data are included in a background with conventional data. In this context, inclusion of satellite winds could, at best, create no added positive impact on the forecast, but could on occasions, cause a degrading of the background field as the magnitude of the 12 hour displacement errors are sometimes twice as large as those found in the conventional field.

"Recalling that the input data are the best low center positions after careful reanalyses, the derived errors represent a lower bound condition. With the known inaccuracies and the paucity of conventional data relating to the placement of low center, a large average error is therefore descriptive of "operational" analyses performed, for example, at NMC. Thus a mean error in excess of 2^{o} of longitude can be expected when the intermittent assimilation technique is utilized.

"Not only is the wrong placement of lows problematic but also the many effects that are rather concommitant with it. For the one thing, the meteorologist will receive the wrong signals with reference to the life cycle of the cyclone. Whether or not the cyclone is filling or deepening cannot be known with any measure of certainty. Added to all this is the fact that the instantaneous discontinuity of time that results from the ± 3 hour mapping procedure creates blurred surface winds fields, deformed isobaric patterns and frontal systems. In general, poor analyses will result. Other problems must also be considered. The special cases of dwell and sampling at intermediate synoptic hours help to confound the situation even more. To use only data that are nearest a synoptic time would signify the loss of valid information.

"The errors that have been studied have come about on account of the intermittent assimilation method utilized. It thus seems logical that a hard look should be given to this method with the aim of revising it. Inserting real-time SASS data by the continuous scheme will certainly help to irradicate some, if not most, of the existing problems that have been discussed. At least the continous assimilation technique should be tested so that the maximum amount of good data can be used with the aim of making better weather forecasts."

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