Geof. Int. Vol. 22-4, 1983, pp. 311–327

ON THE ANALYSIS OF SEASAT WINDS

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(Received: February 10, 1983)
(Accepted: January 5, 1984)

ABSTRACT

A method for analyzing SEASAT-A-winds, which eliminates the ambiguity in SEASAT wind measurements, is formulated. The ambiguity is eliminated by using wind estimates from low-level cloud motions and synoptic cloud patterns (based on satellite pictures), surface wind climatology as well as space-time continuity. The method was applied to SEASAT data taken over the tropical Atlantic. The accuracy of the method has been evaluated by comparing the result of our analysis technique with independent observations from ships. The comparison shows that the analysis technique produced winds which are comparable in accuracy with ship winds.

RESUMEN

Se formuló un método para analizar los vientos de SEASAT-A el cual elimina la ambigüedad en la medición de los vientos de SEASAT. La ambigüedad se eliminó usando vientos estimados a partir del movimiento de nubes bajas y de patrones sinópticos de nubes (basados en fotos de satélite), de climatología de vientos de superficie así como de principios de continuidad en espacio y tiempo. El método se aplicó a datos de SEASAT tomados sobre el Atlántico Tropical. La exactitud del método ha sido evaluada comparando los resultados de nuestra técnica de análisis con observaciones independientes de barcos. La comparación muestra que la técnica de análisis produjo vientos que son comparables en exactitud a la de los vientos reportados por los barcos.

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INTRODUCTION

One of the important factors responsible for the slow advance of knowledge concerning the tropical atmosphere is the scarcity of observations over the vast ocean areas in the tropics. At the present time, the only available sources of the few observations are ships, buoys and island stations. A potential solution to the scarcity of observations, at least for surface winds, are wind measurements by meteorological satellites of the type exemplified by SEASAT-A. The SASS sensor aboard the SEASAT-A satellite is capable of providing surface winds (direction and speed) for areas within 200 and 700 km on either side of the satellite track. The surface winds are usually resolved to within 1° latitude x 1° longitude on the average; finer resolutions are possible. The accuracy of the SEASAT-derived winds is $\pm 2\ ms^{-1}$ or 10% (whichever is greater) for the wind speed and $\pm 20^{\circ}$ for the wind direction (Born *et al.*, 1979).

The surface wind direction and speed are deduced from scatterometer measurements (Grantham *et al.*, 1977) of radar signals which are backscatter from the sea surface. The strength of the radar backscatter is proportional to the sea surface roughness which, in turn, is a function of the surface wind. The surface wind is obtained from the radar backscatter through a technique utilizing a model function or geophysical algorithm (Jones *et al.*, 1978). Unfortunately, the technique provides more than one wind observation (generally four, sometimes three or two) at a single point – the so-called ambiguity or indeterminacy in the wind observation. Examples of this multiplicity in the wind observation can be seen in Fig. 1. Due to this multiplicity in the wind observation, one is faced with the difficult problem of selecting which of the multiple wind observations is the appropriate one. The customary solution to this problem is simply to select the one which is closest in direction to an independent observation of the surface wind from conventional platforms (ships, buoys, islands) in the vicinity of the SEASAT observation. Unfortunately, wind observations in the tropical oceans are extremely limited; there are no observations over large sections of the oceans. It is, therefore, necessary to devise a method for analyzing SEASAT wind observations which does not require independent surface wind observations from conventional platforms. In this article, we will describe an attempt to devise such a method. We will also present the results of an evaluation of the accuracy of the method.

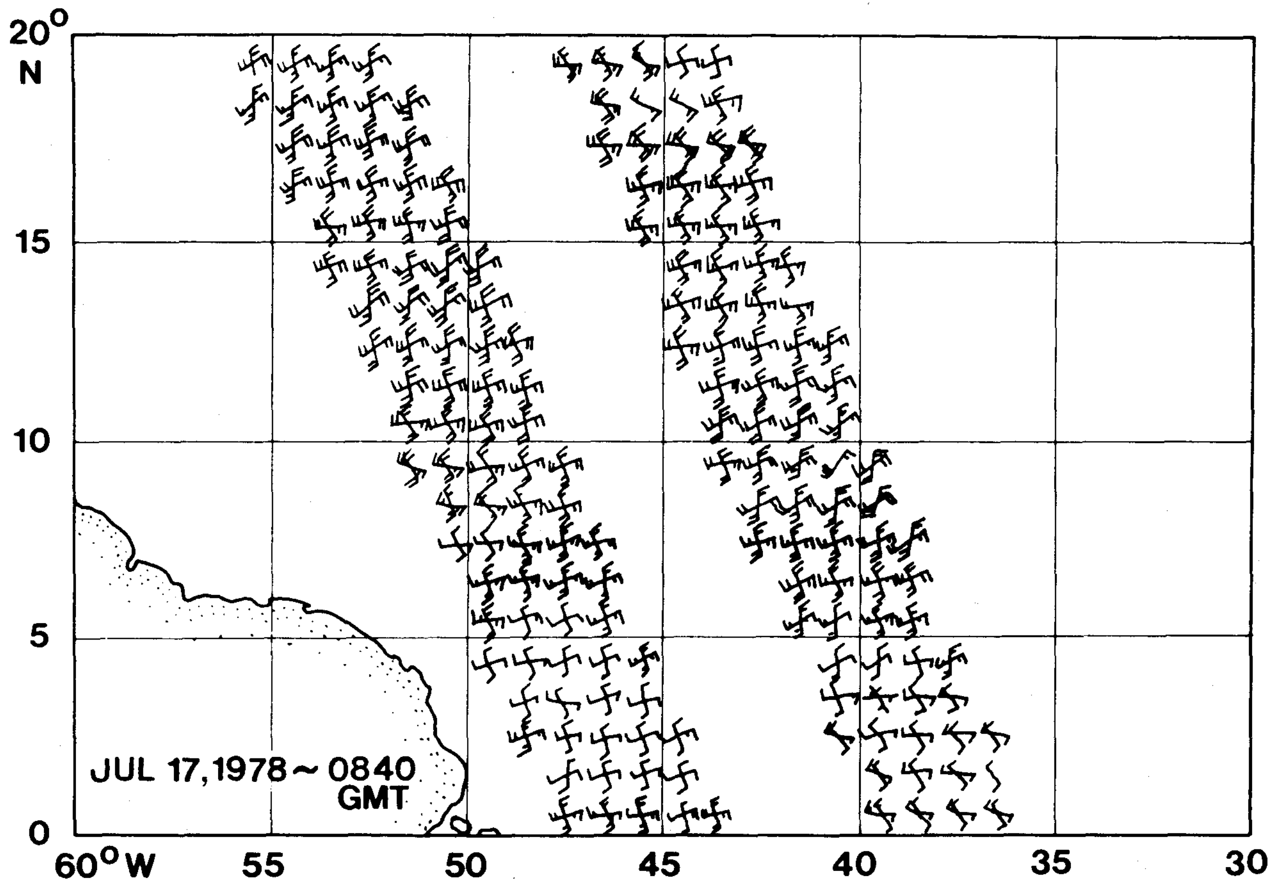

Fig.1. Examples of wind observations taken by SEASAT over the Atlantic near South America and the Lesser Antilles at about 0840 GMT July 17, 1978. Up to four observations are shown for each location; the observations are plotted according to usual meteorological convention (a barb represents 5 ms^{-1}).

METHOD OF ANALYSIS

In principle, our method is similar to the one mentioned above which uses surface wind observations as an aid for SEASAT wind analysis. The main difference is that, instead of using conventional surface wind observations for selecting the proper SEASAT-A wind observations, we use wind which is estimated from other sources. These sources are as follows:

(1) GOES satellite-derived winds at low levels

(2) Winds inferred from cloud patterns based on satellite still pictures

(3) Climatological surface wind distributions

(4) Wind maps from a previous synoptic time

The satellite-derived winds, Item (1), are based on the motions of cloud elements as indicated on successive cloud pictures; winds may be derived at the base of low level clouds which is normally about 600 m. The direction of these low level winds is, in most cases, a reasonable approximation of the direction of the surface flow; this is generally true over most regions in tropical oceans (Roll, 1965) with the exception of some limited areas in monsoon regions (e.g. eastern Atlantic off west Africa). On the average, changes could be either a veering or a backing of the wind with height by less than 15-20^{o}; these values are within the accuracy designed for SEASAT measurements. An example of low level winds derived from cloud motions is in Fig. 2, which is taken from Crozet *et al.*, 1979.

The surface wind estimates in Item (2) are based on the association between certain cloud patterns (characteristic size and shape) and specific types of synoptic-scale disturbances. Each type of disturbance, in turn, is characterized by typical surface wind patterns which may be regarded as idealized wind models. Since satellite cloud pictures are readily available from GOES observations, one can easily use them to determine the different types of synoptic disturbances which occur at a given synoptic time. Consequently, one can infer the winds at the locations of these disturbances with the aid of empirical wind models. Specific wind models are known for such disturbances as tropical cyclones, Intertropical Convergence Zone (Anderson *et al.,* 1974) and easterly waves (Frank, 1968). In addition to the size and shape of the cloud patterns, the orientation of cloud elements of the pattern gives important information concerning the wind (Gaby, 1967; Rogers, 1965). An example of typical flow patterns inferred from satellite cloud pictures on the basis of the orientation of cloud element is shown in Fig. 3 taken from Brandli, 1976.

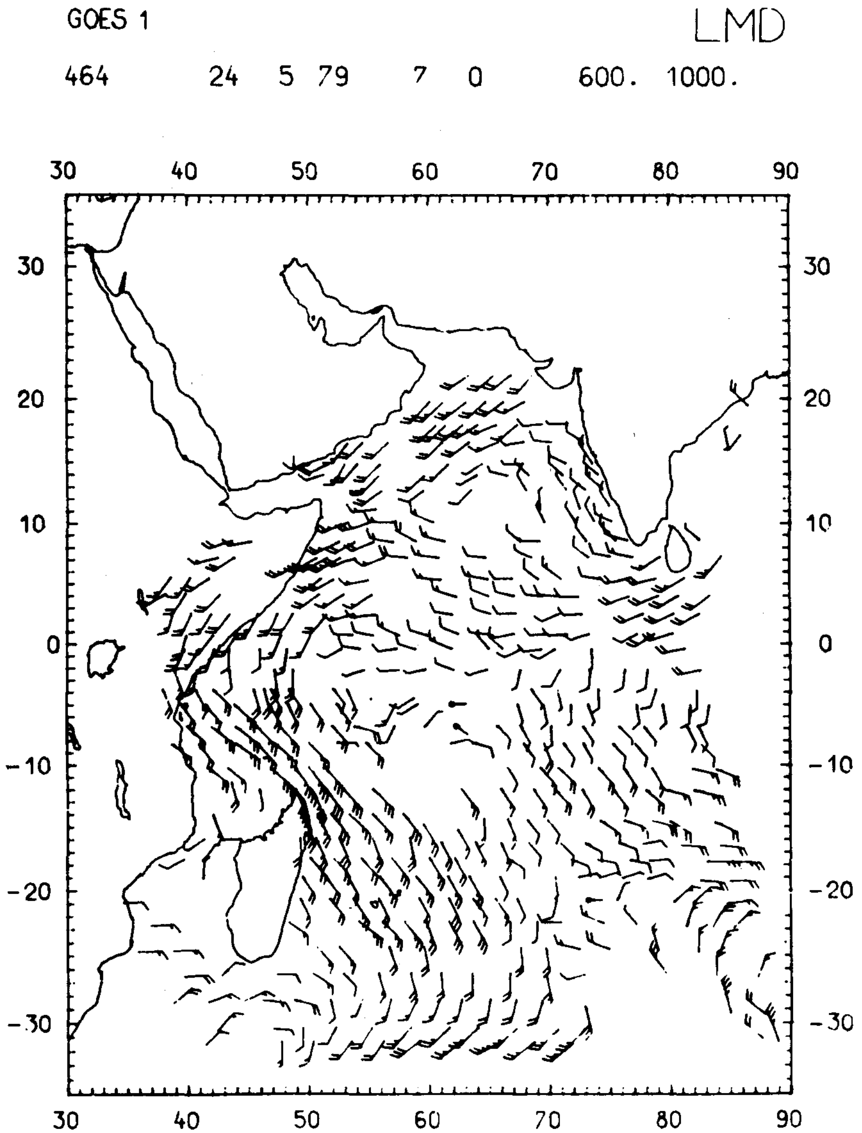

Fig. 2. Example of low-level winds derived from cloud motions. The example shown is for the Indian Ocean on May 24, 1979 (after Crozet *et al.*, 1979).

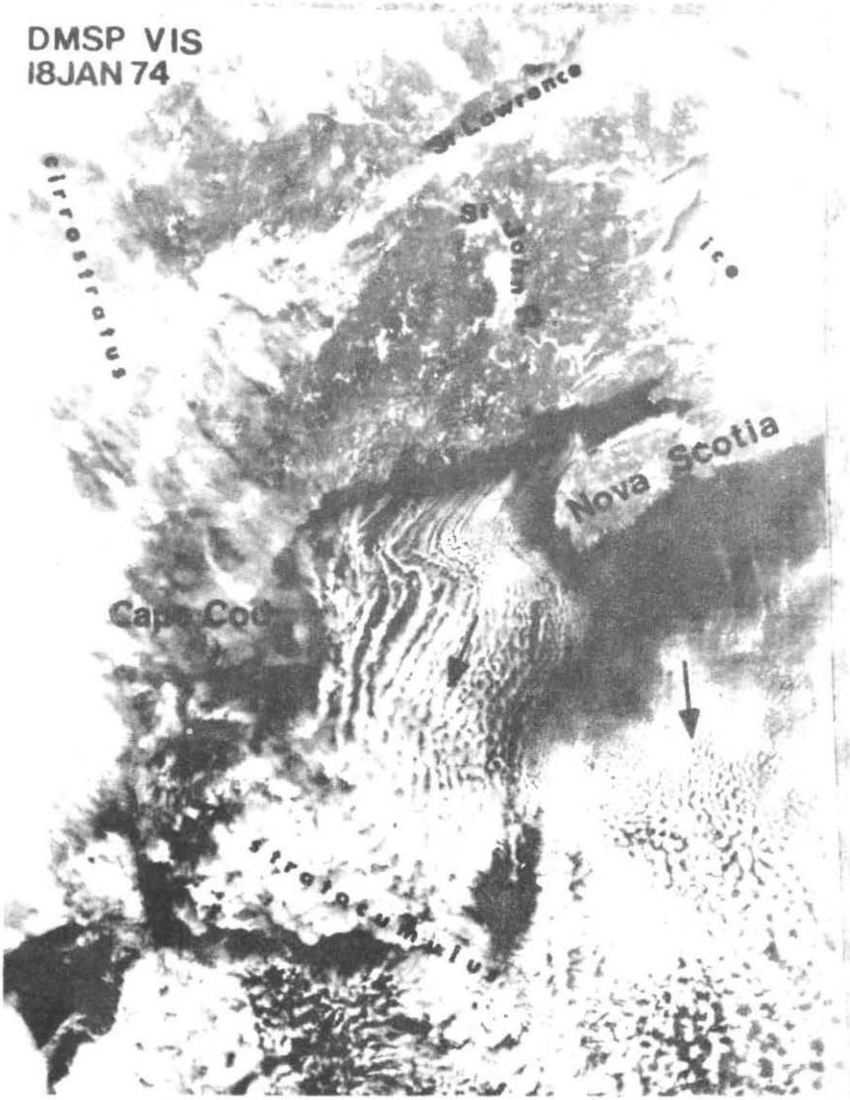

Fig. 3. Example of typical cloud patterns inferred from satellite cloud pictures. The example is for the Atlantic Ocean off U. S. and Canada on January 18, 1974 (after Brandli, 1976).

Climatological surface wind distributions, Item (3), are available from various climatological sources (e.g. Hastenrath and Lamb, 1977). An example of climatological winds from this source is shown in Fig. 4.

Lastly, an analyzed wind map for a previous synoptic time, Item (4), can be used for making wind estimates (on the basis of space and time continuity of meteorological patterns) at the current analysis time.

The combination of Items (1) to (4) provides a guide for the selection of the SEASAT wind. In using this guide, Items (1) and (2) which pertain to satellite-derived wind information have priority over Item (3) which pertains to surface wind

climatology. Climatology alone is used if satellite information is not available. In this connection, we recognize that the climatological wind may differ significantly from the actual synoptic-scale wind, even in the tropics where the wind directions are relatively steady. Item (4) is based on the continuity of wind patterns with time. If items (1) and (2) are not available, Item (4) may be used to estimate the wind direction by extrapolation in time. In terms of priority, we generally assign a higher priority to Item (4) over Item (3).

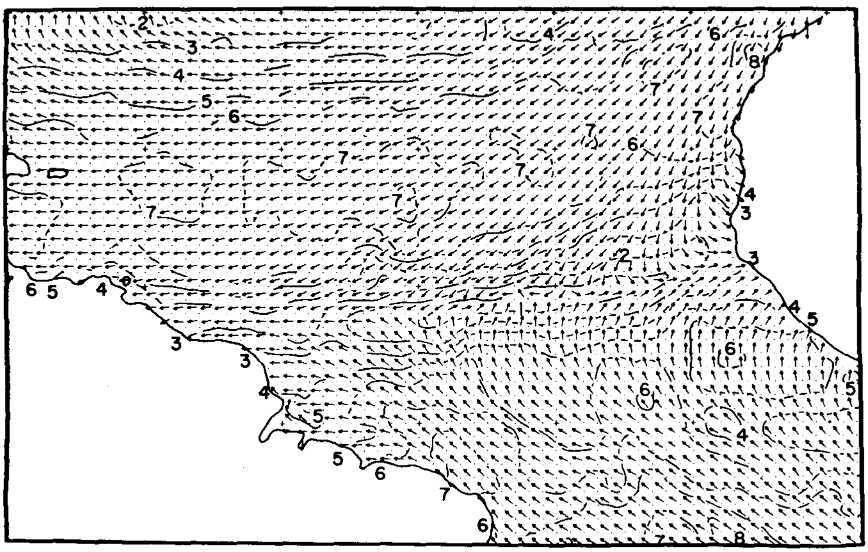

Fig. 4. Example of climatological winds at the surface for the Atlantic Ocean in the month of July (after Hastenrath and Lamb, 1977). Arrows show the direction of the resultant winds; isotachs show the resultant wind speed (ms^{-1}).

Our method of analysis is designed to exploit certain characteristics of the SEASAT-A wind observations which tend to make the selection process easier. The exploitable characteristics exist when SEASAT gives: *a)* only two solutions for the wind direction and *b)* greater than two solutions for the wind direction for which two of these solutions differ by a relatively small angular differences (no more than 40^o). In Item *a)* the SEASAT wind direction chosen as the correct solution is the one which is closest to the guidance. In Item *b)*, the averages of the wind directions which differ by less than 40^o are taken as potential solutions; the validity of the averaging procedure is supported by the fact that the error of the SEASAT wind direction is utmost 20^o. By the averaging, the selection is reduced to a case of two solutions as in Item *a)* and the appropriate solution is found using the guidance. When the SEASAT wind solutions do not meet the conditions in Item *a)* or *b)*, the solution chosen is generally the one whose wind direction is closest to the wind direction indicated by the guidance.

Finally, our method of analysis incorporates the principle of space continuity in order to extrapolate and interpolate wind distributions where there are no SEASAT wind observations (e.g. along a 400 km-wide area directly under the satellite track). Space continuity is also used as verification of the expected gradual transition in the wind field from areas showing two wind solutions to areas with four solutions and small angular differences in wind direction, and to areas showing four solutions with larger angular differences in wind direction. Space continuity is applied subjectively in the present study. However, it can be applied objectively in connection with objective analysis techniques.

The method of analysis can be understood more clearly by the following step-by-step procedure:

(i) Obtain estimates of the wind from the four sources, Items (1) to (4), described at the beginning of this section. These estimates are the guidance for the SEASAT wind analysis.

(ii) Make a screening of SEASAT-A wind observations. Separate the areas into three categories: a) areas with two SEASAT wind solutions, b) areas with four wind solutions but pairs of them showing small angular differences in wind direction and c) areas not included in a) or b).

(iii) Make the selection of the proper SEASAT-A wind observation on the basis of the above two Items (i) and (ii). Basically, the selection is made by comparing wind directions given by SEASAT (areas a and c) or the averaged wind directions (areas b) with the wind direction given by the guidance. The SEASAT wind direction or averaged wind direction in closest agreement with the direction of the guidance is the one selected.

An example of the wind analysis following the above steps is shown in Figs. 5 and 6. Fig. 5 shows the guidance used for the SEASAT wind direction analysis; Fig. 6 shows the SEASAT wind direction analysis (streamlines). Fig. 7 shows the SEASAT wind speed analysis (isotachs) which corresponds to the wind analysis in Fig. 6; the SEASAT wind speed is simply analyzed as a scalar field. The wind direction and speed analyses are manually produced; however, they can also be done with the aid of objective analysis techniques.

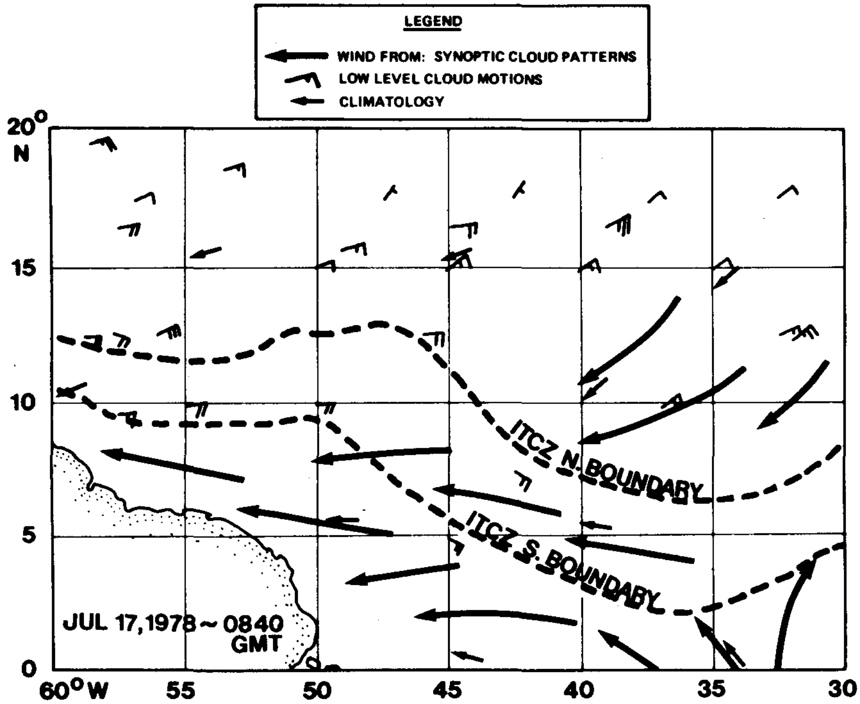

Fig. 5. Guidance for the SEASAT wind direction analysis in Fig. 6. The guidance shows a) the location of the ITCZ boundaries at 1630 GMT July 17, 1978 based on a GOES satellite picture and the typical direction of the surface flow inferred from cloud patterns, b) low-level winds inferred from cloud motions for 0000 and 1200 GMT, July 17, 1978, and c) climatological surface wind directions (taken from Hastenrath and Lamb, 1977).

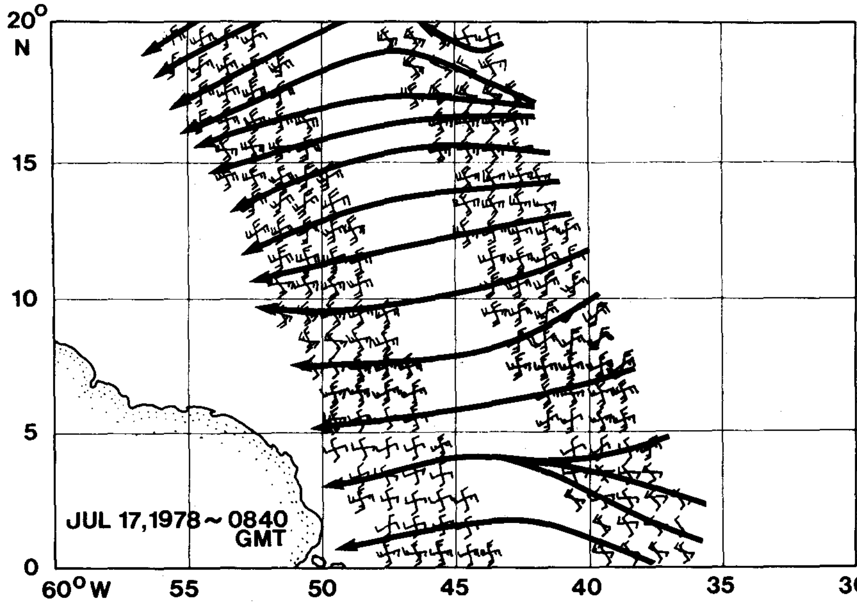

Fig. 6. Wind direction analysis (streamlines) of SEASAT observations taken over the Atlantic Ocean near South America and the Lesser Antilles at about 0840 GMT, July 17, 1978.

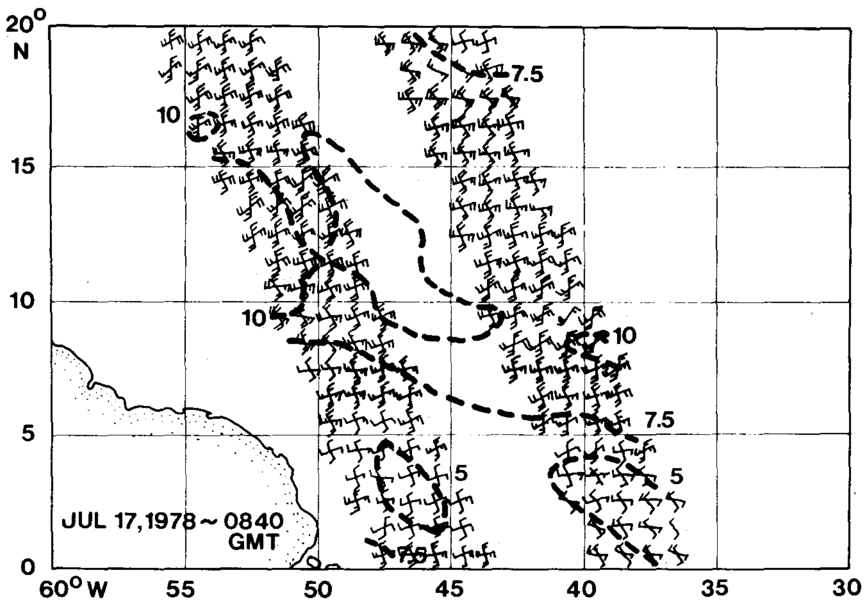

Fig. 7, Wind speed analysis (isotachs in ms^{-1}) of SEASAT observations taken over the Atlantic Ocean near South America and the Lesser Antilles at about 0840 GMT, July 17, 1978.

EVALUATION OF THE WIND ANALYSIS

Our method is capable of producing a SEASAT wind field which is completely independent from surface wind information given by ships or any other conventional surface platform. Therefore, a comparison of our analyzed SEASAT winds with ship winds provides a test of the winds from our analysis. This test is rigorous due to the complete independence of the SEASAT winds from ship observations. For comparison purposes, wind directions and speeds at the locations of ship observations are read off the SEASAT wind maps. These directions and speeds are then compared with the corresponding directions and speeds reported by the ships. The SEASAT wind analyses which are used in our comparison are the analyses for the seven SEASAT passes over the Atlantic-Caribbean shown in Fig. 8; the analyses cor-

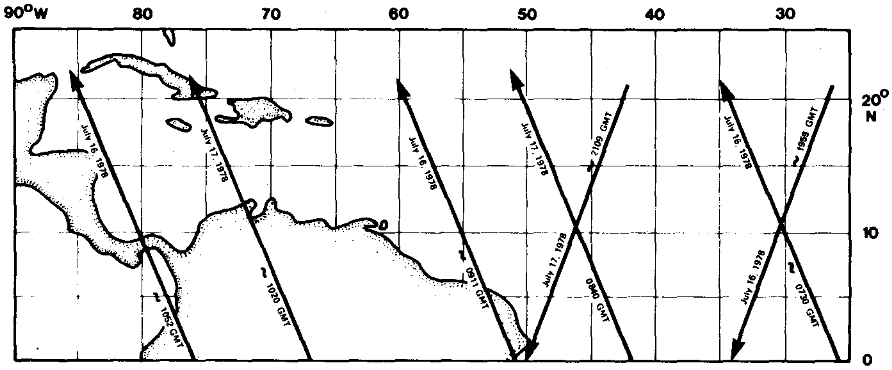

Fig. 8. Map showing seven SEASAT passes over the Atlantic Ocean area between 0 and 20°N on July 16 and 17, 1978.

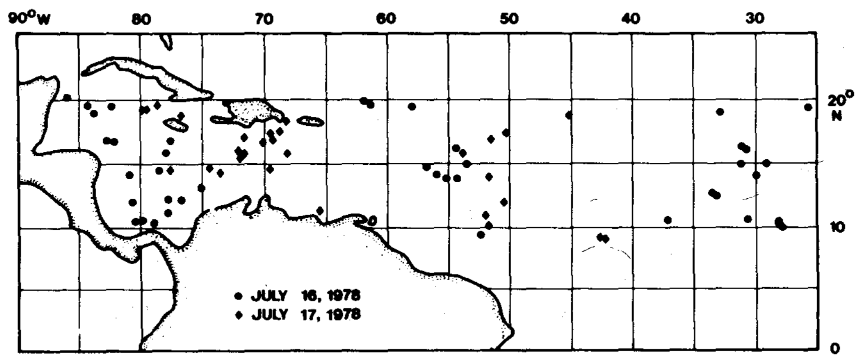

Fig. 9. Map showing the geographical location of the comparison cases of SEASAT vs ship winds on July 16 and 17, 1978.

respond to the period of July 16 and 17, 1978 and for tropical areas between 0 and 20°N. The ship reports which are compared with the analyzed SEASAT winds are those which are taken within 12 hours of the SEASAT passes; these ship reports are extracted from maps prepared by the National Hurricane Center, Coral Gables, Florida. Seventy cases were available for the comparison. The geographical locations of these cases on July 16, 1978 (41 cases) and on July 17, 1978 (29 cases) are shown on the map in Fig. 9.

Fig. 10 is a plot of the wind direction differences (SEASAT minus ship) in the ordinate and the SEASAT wind directions in the abscissa. Note the larger scatter shown by the plot; also note that, as expected, the differences are essentially independent of the SEASAT wind direction. The mean value for the difference in the figure is 7.1 degrees and the corresponding standard deviation is about 25 degrees. Both the mean and the standard deviation are larger than the respective values in previous SEASAT wind evaluations (National Aeronautics and Space Administration and Jet Propulsion Laboratory, 1980; Fernández-Partagas and Estoque, 1981).

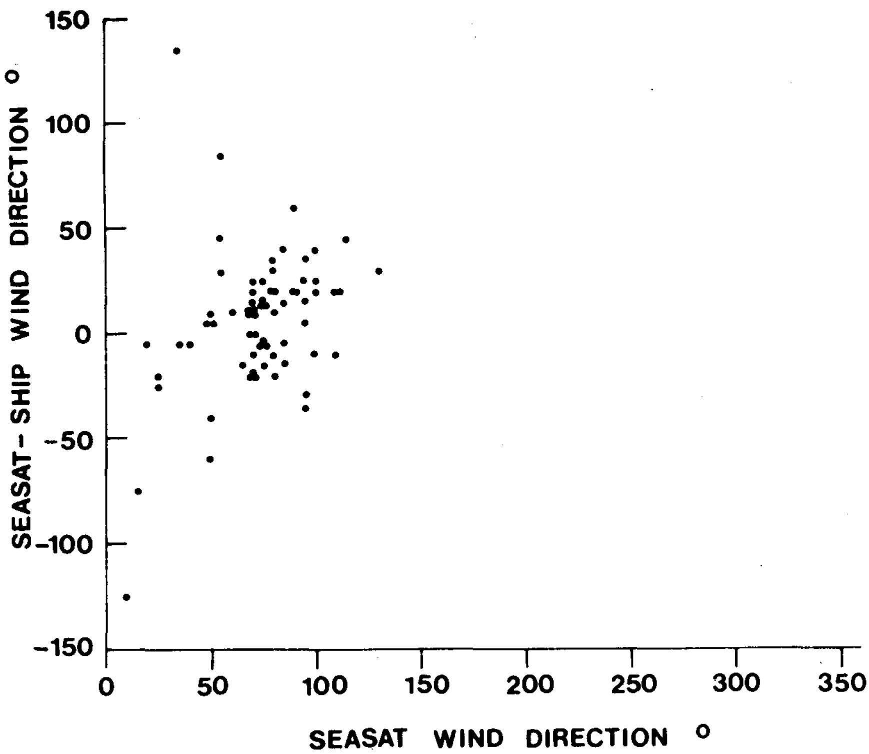

Fig. 10. Graph showing wind direction differences (SEASAT minus ship) vs. SEASAT wind direction (°) for the seventy comparison cases on July 16 and 17, 1978.

The smaller values in previous studies are probably due to the fact that the SEASAT wind is selected to agree as closely as possible to ship wind observations. In this study the ship observation was not used as a guide in the SEASAT wind selection; therefore, the SEASAT vs ship wind comparison in this study is considered to be more meaningful than that in previous studies.

Fig. 11 is a plot analogous to the one in Fig. 10 but for the wind speed. The ten-

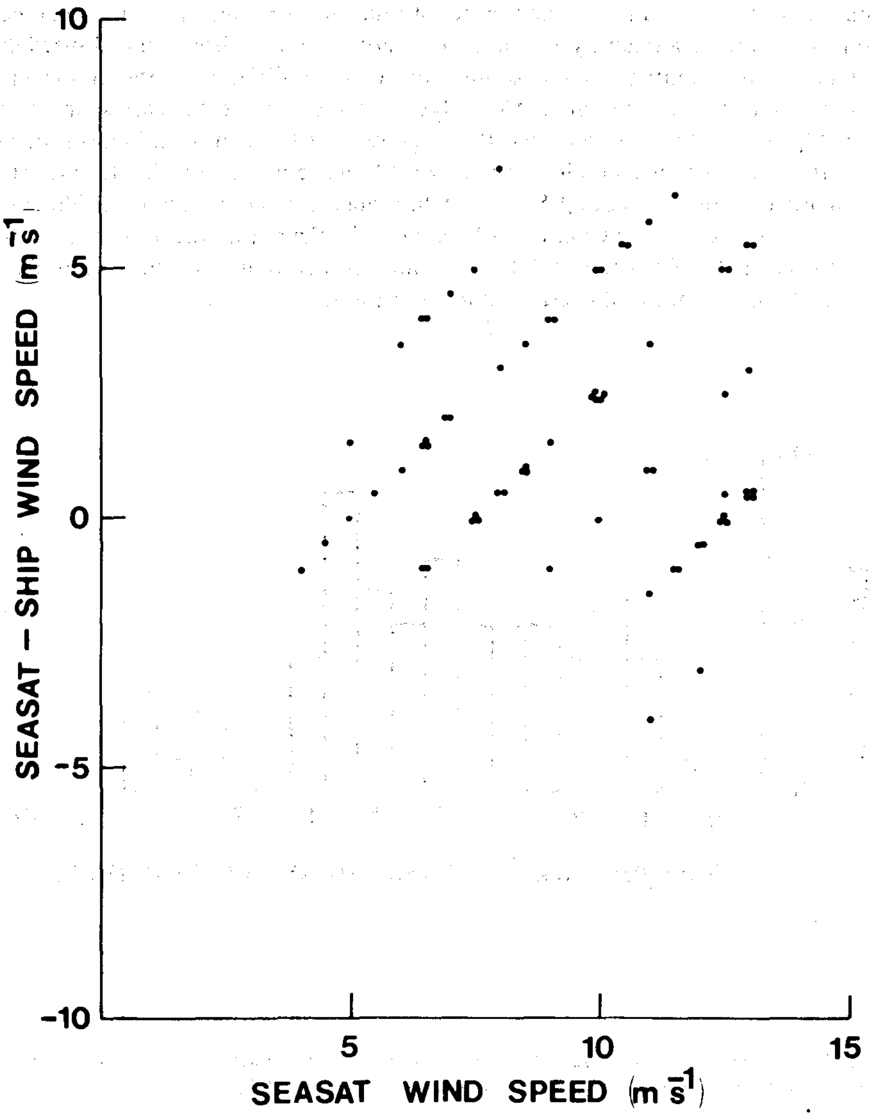

Fig. 11. Graph showing wind speed differences (SEASAT minus ship) vs. SEASAT wind speed (ms^{-1}) for the seventy comparison cases on July 16 and 17, 1978.

dency for the wind speed differences to increase with the SEASAT wind speed previously suggested by Fernández-Partagas and Estoque (1981) is not quite obvious in Fig. 11. The mean speed difference for all the cases in Fig. 11 is 1.7 ms^{-1}. These values are slightly smaller than those in previous studies and they continue to show a bias in the SEASAT wind speed (SEASAT overestimating the surface wind speed).

So far, the comparison between the SEASAT and ship winds has been done separately for the wind direction and speed. A much more meaningful way of comparison is the use of a quantity which involves both the wind direction and speed differences. This quantity is the magnitude of the vector difference between the wind vector obtained from the SEASAT analysis and the wind vector corresponding to the ship report. We have obtained the magnitude of the vector differences for the seventy cases. The magnitude of the mean difference is found to be 4.2 ms^{-1}; the standard deviation is about 1.8 ms^{-1}. A histogram for the magnitude of the wind vector differences is shown in Fig. 12. Note in the figure that the magnitude of the difference ranges from 0.5 to 9.0 ms^{-1}; note, in addition, that the magnitude of 5.5 ms^{-1} corresponds to the largest number of cases.

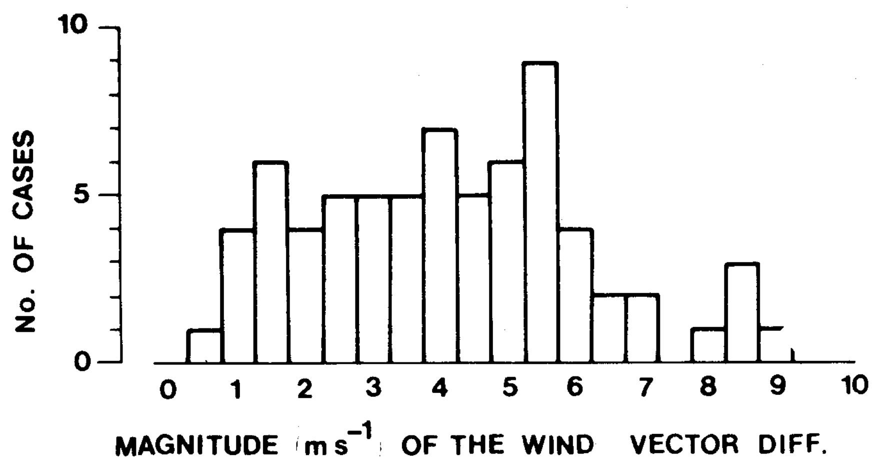

Fig. 12. Histogram for the magnitude (ms^{-1}) of the vector difference between SEASAT and ship winds for the seventy comparison cases on July 16 and 17, 1978.

The mean vector difference of 4.2 ms^{-1} is due in part to the error in the SEASAT wind speed. It has been noted in a previous paragraph that the SEASAT observation tends to overestimate the wind speed by about 1.7 ms^{-1} on the average. It is obvious, therefore, that it would be possible to decrease the mean vector difference by taking into account this tendency to overestimate. In order to confirm that this is indeed the case, we recomputed the SEASAT winds by applying a uniform correction of -1.7 ms^{-1}. Then we calculated a new set of vector differences between the recomputed SEASAT winds and the ship winds. We found that the corresponding average vector difference is about 3.5 ms^{-1} which is 0.7 ms^{-1} less than the original value of 4.2 ms^{-1}. This difference is a combined effect of errors in the ship observations and errors in our analysis technique. In order to estimate the error in our technique we will assume for simplicity that the ship observations have negligible errors (in making this assumption, we may be overestimating the error of our analysis technique). If these errors are negligible, the errors of the SEASAT analysis technique is equal to the mean vector difference of 3.5 ms^{-1}. It is interesting to compare this value to (1) the expected error on the basis of the design of the SEASAT scatterometer and (2) the typical error of a ship observation. The errors expected in a SEASAT observation are 20^{o} in wind direction and 2 ms^{-1} or 10% in wind speed (Born *et al.*, 1979). For a typical speed of 7.5 ms^{-1} and a direction error of 20^{o}, the magnitude of the vector difference due to the error in SEASAT measurements (both in speed and direction) is approximately 3.3 ms^{-1}. On the other hand, the typical error of a ship observation is estimated to be about 20^{o} and 2.5 ms^{-1}. This error is indicated by Cardone *et al.* (1980). The value is likely to be conservative because other authors (e.g. Brown *et al.*, 1982) mention $\pm 30^{o}$ errors in wind direction and ± 4.0 ms^{-1} in wind speed for ship reports. In addition, it may be mentioned that there is a $\pm 10^{o}$ uncertainty in the wind direction due to the use of meteorological codes for reporting. On top of this, there is also a bias in the reporting of wind direction in favor of the four cardinal and the four intercardinal points of the compass (see, e.g. Quayle, 1981). In estimating the wind speed from the sea state, one usually has an uncertainty of about ± 2.5 ms^{-1} for a typical wind speed of 7.5 ms^{-1}; this uncertainty is related to the way wind speeds are specified in the Beaufort scale. Winds obtained from ship anemometers are not significantly more accurate than winds estimated from sea state. This is due to the short period of sampling (2 minutes) in the wind speed and the frequently bad exposures of the anemometers. For errors of $\pm 20^{o}$ in wind direction and ± 2.5 ms^{-1} in wind speed, the corresponding magnitude in the vector error in the ship report is about 3.6 ms^{-1} for a typical wind speed of 7.5 ms^{-1}. It may be concluded, therefore, that the error in our analysis technique is approximately equal to the SEASAT instrumental design error and also the ship observational error.

CONCLUSION

We have described in this article a method for analyzing SEASAT-A winds in tropical regions which eliminates the ambiguity in the SEASAT wind measurement. The ambiguity is eliminated by using wind estimates from low-level cloud motions and synoptic cloud patterns based on satellite pictures, surface wind climatology as well as space-time continuity. In addition, the method takes advantage of certain characteristics of the SEASAT wind observations such as the existence of 1) only two solutions at a single point and 2) small angles between solutions. The accuracy of the method has been evaluated by comparing the results of the analysis technique with independent observations from ships. The comparison shows that our analysis technique produces winds which are comparable in accuracy with ship winds. The method is, therefore, operationally feasible for use in tropical regions, whether or not ship observations are available.

ACKNOWLEDGMENT

The authors are grateful to Donald C. Gaby, James B. Lushine and Stanley W. Wright of the National Environmental Satellite Service, Coral Gables, Florida for their help in interpreting wind patterns from satellite pictures. Thanks are due to Gary Rosiello for drafting the figures. The research was supported by NOAA under Contract No. NA-79-SAC-00737.

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