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Analysis of SEASAT wind observations over the Indian Ocean

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ABSTRACT

Surface winds as observed by the SEASAT-A satellite over the Indian Ocean for the period July 15–17, 1978 are analyzed. The purposes of the analysis are: (1) to evaluate the accuracy of the SEASAT wind measurements by comparing these measurements with ship observations and (2) to determine the improvement introduced to the description of the synoptic-scale wind field at the surface by adding SEASAT data to ship and island wind observations. The results of our study indicate that: (1) on the synoptic scale, the accuracy of SEASAT-derived winds is comparable to that of conventional surface observations and (2) a significant improvement in the surface wind analysis is achieved by incorporating SEASAT wind information, especially in data sparse areas.

1. Introduction

A major portion, approximately 75%, of the tropics is covered by oceans. Over these oceanic regions, the primary sources of surface meteorological observations are occasional ships and a few isolated island stations. Thus, the tropics are regions with extremely insufficient number of observations. This insufficiency of observations has been the major obstacle to the understanding and the forecasting of the behavior of the tropical atmosphere. Since the gathering by ships of observations with spacing necessary to resolve even just the synoptic scale disturbances is impractical, one must look for an alternative solution to this observational problem. A possible alternative is remote sensing by meteorological satellites.

The first satellite which was designed to make surface wind measurements is SEASAT-A. It was launched on June 27, 1978 and was able to make observations until it malfunctioned on October 10, 1978. The satellite carried several microwave sensors which obtained information not only on surface winds but also on other variables such as ocean waves, clouds, water vapor, sea surface temperatures and others (Born et al., 1979). The surface wind direction and speed were deduced from scatterometer measurements (Grantham et al., 1977) of radar signals backscattered by 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 solved directly from the radar backscatter with the aid of a model function or geophysical algorithm. Unfortunately, due to the harmonic nature of the function, there is more than one solution for the wind vector (a maximum number of four) corresponding to one backscatter measurement. These solutions are approximately equal in speed but vary widely in wind direction. Only one of these represents the correct wind observation. In practice, the correct solution is selected by comparing the wind directions with a surface wind direction which is inferred from other sources of information, such as ship wind observations, the surface pressure field and others.

In this paper, we will describe the results of a study of SEASAT-derived winds over the Indian Ocean. The study has the following two objectives:

1. To evaluate the accuracy of the wind observations obtained by SEASAT.
2. To assess the improvement of the description of the surface wind field by the addition of SEASAT observations to conventional data.

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The SEASAT data which have been available for our study are rather few, being limited only to data from seven orbits made during the three-day period, July 15 to 17, 1978. The orbits are shown in Fig. 1.

In brief, the results of our study indicate that: (1) on the synoptic scale, the accuracy of SEASAT-derived winds is comparable to that of conventional surface observations and (2) a significant improvement in the surface wind analysis is achieved by incorporating SEASAT wind information, especially in data sparse areas.

2. Research procedure

The approach used to conduct the research consists of the following steps:

1. Analysis of wind observations from ships only, in order to produce conventional maps of the surface wind fields.
2. Analysis of corresponding SEASAT wind observations only, in order to produce SEASAT wind maps.
3. Comparison between conventional and SEASAT wind fields using Items 1 and 2.
4. Analysis of observations from all sources (ship, island and SEASAT) in order to produce final wind analyses.

In order to accomplish item 1, we plotted ship wind information along strips corresponding to areas covered by SEASAT observational data. In lieu of operationally-received ship reports, we used ship reports which are archived at the National Climatic Center, Asheville, North Carolina. By using the archived data, we are able to obtain the largest possible number of ship observations for analysis. The resulting number of observations is still relatively small. Therefore, in order to increase the number, we composited ship observations over a 36-hour period centered approximately at the SEASAT observational time. The ship observations are then analyzed by following the well-known streamline-isotach analysis technique. An example of the streamline-isotach analysis based on ship observations is shown in Fig. 2.

For the SEASAT wind analysis (Item 2) the first step to be done is to eliminate the ambiguity in the SEASAT observed wind direction. This is done by comparing each one of the SEASAT wind directions with the surface wind direction given by the ship analysis (Item 1) at the same location. The SEASAT wind observation whose direction is closest to the wind indicated by the ship analysis is selected as the appropriate SEASAT wind observation for both direction and speed. The selection is found to be difficult when two SEASAT wind directions are about equally close to the wind direction indicated by the ship analysis. The selected SEASAT observations are then analyzed using the same streamline-isotach technique employed in the analysis of the ship observations. An example of the SEASAT wind analysis is shown in Fig. 3. For each SEASAT reporting location, all possible solutions for the wind vector (a maximum number of four) are plotted. The chosen solutions are the ones whose wind directions match the direction denoted by the streamlines in the figure. Note that the streamlines patterns in the figure do not differ greatly from the streamline patterns of the ship wind field (Fig. 2). The similarity in the wind direction patterns is due to the wind direction selection process just mentioned. On the other hand, the corresponding wind speed patterns in Figs. 2 and 3 show some significant differences. This is due to the fact that SEASAT and ship wind speed observations are completely independent from each other.

In order to assess the accuracy of the SEASAT wind description, we compared the SEASAT winds with corresponding ship winds at selected geographical points on the analyzed maps. A total of 267 points is selected arbitrarily along the tracks of the seven SEASAT passes over the Indian Ocean. The average spacing between points is about 250 km. Fig. 2 shows an example of the distribution of the points (indicated by small dots in the figure). For each selected point, the wind direction and the speed are extracted from both the SEASAT and the ship wind fields. Corresponding wind direction and speed values are then compared. Results of the comparison are described in Section 3.

Finally, in order to evaluate the improvement in the description of the wind field by incorporating SEASAT data (Item 4), we produced final wind maps by analyzing all types of available wind data (ship, island, and SEASAT observations). These observations are not entirely synoptic, the SEASAT observation being off by up to a few hours. The addition of SEASAT wind information eliminates to a great extent the large data-void

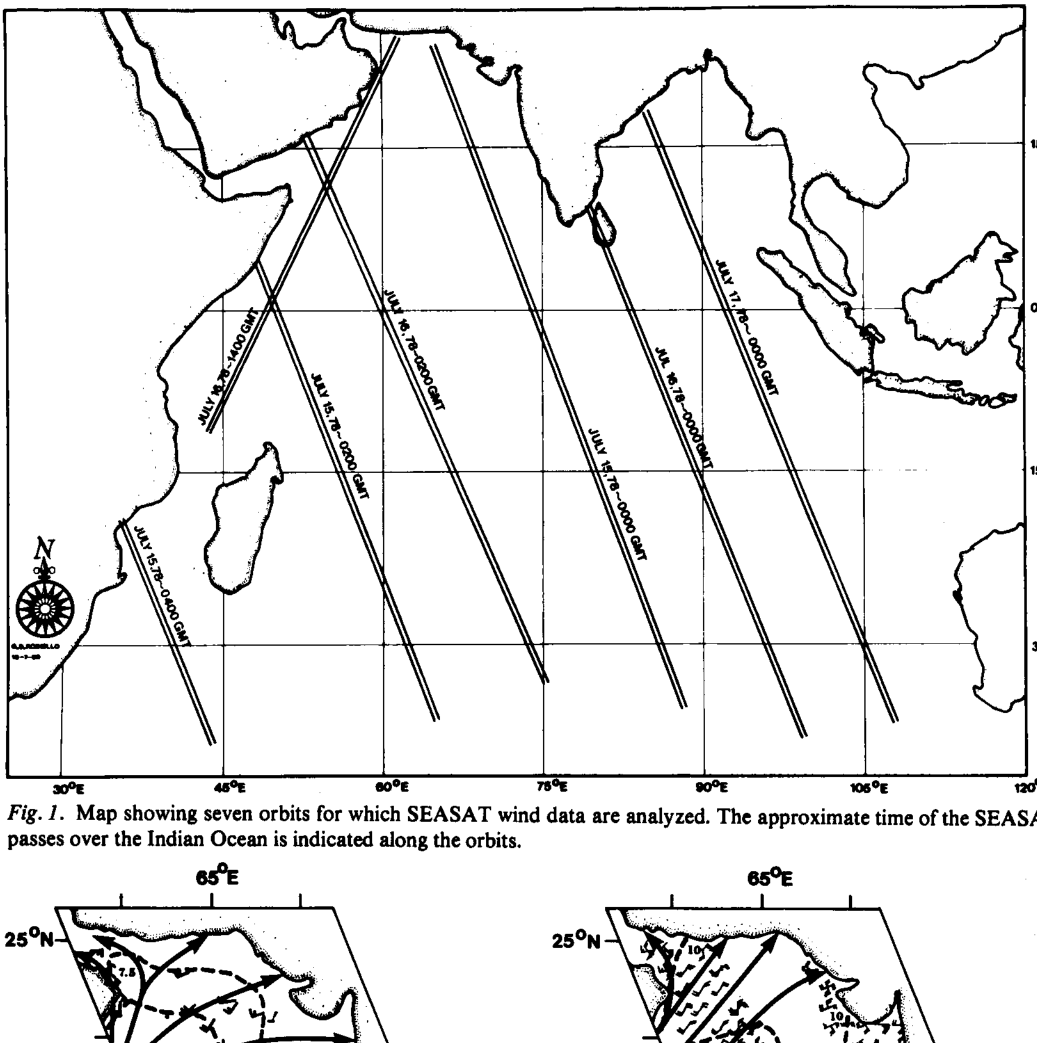

Fig. 1. Map showing seven orbits for which SEASAT wind data are analyzed. The approximate time of the SEASAT passes over the Indian Ocean is indicated along the orbits.

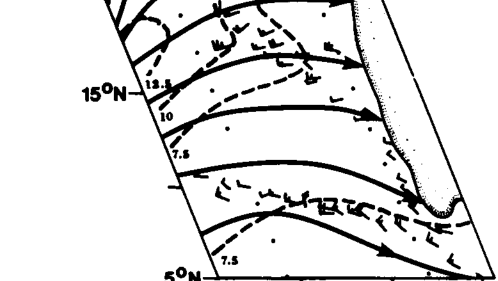

Fig. 2. Example of wind analysis based on ship observations. Ship data are plotted in the conventional meteorological form (full barb, 5 m s^{-1}). Solid lines are streamlines and dashed lines are isotachs at 2.5 m s^{-1} intervals. Small dots denote points at which SEASAT and ship winds are compared.

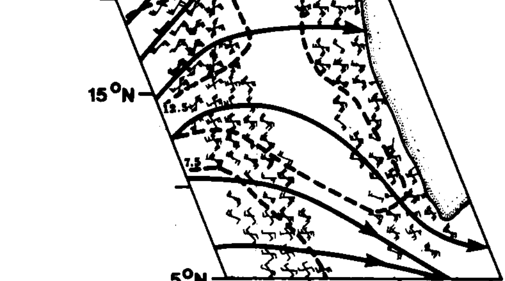

Fig. 3. Example of SEASAT wind analysis. All possible SEASAT wind solutions (up to four) are plotted for each SEASAT reporting location; solutions are plotted in the conventional meteorological form (a full barb, 5 m s^{-1}). Solid lines are streamlines and dashed lines are isotachs at 2.5 m s^{-1} intervals.

areas over the open ocean and, therefore, should lead to a more realistic surface wind analysis. Surface wind information is plotted on the maps as follows:

a. Wind observations from ships and islands are plotted as reported.
b. SEASAT-derived wind speeds are corrected before they are plotted. A simple correction of 2 m s^{-1} is subtracted although a more complicated way of correcting is indicated by the statistical results to be presented in Section 3.

These maps are then analyzed (streamline-isotach analysis technique) and compared with corresponding maps based only on ship and island observations. The comparison is done primarily in the wind speed; wind directions are not compared due to the selection process involving the wind direction. Results of the comparison are shown in Section 3.

3. Results

A considerable number of maps of streamline-isotach analysis were prepared based on ship observations (Item 1 of Section 2) as well as based on SEASAT observations (Item 3). For the sake of brevity, we show only two examples of such maps. The examples (Figs. 2 and 3) correspond to a portion of a SEASAT pass about 0000 GMT July 15, 1978. The comparisons between the ship and SEASAT wind field for all the seven orbits in Fig. 1 are described in terms of averages, standard deviations, histograms and scatter diagrams in this section (Item 3).

Differences between ship and SEASAT winds, both in speed and direction, are analyzed statistically. The results show that, in the mean, the wind direction difference (SEASAT minus ship) is 0.6 degrees; however, the standard deviation is about 20 degrees. This value of the standard deviation is within the accuracy which the SEASAT measurements was originally designed for; it is also comparable to the error of an individual ship observation. The average windspeed difference (SEASAT minus ship) is +2.2 m s^{-1} and the corresponding standard deviation is about 2 m s^{-1}. This standard deviation is also within the accuracy which SEASAT was designed for. To what extent do these values agree with previous studies of SEASAT data? Based on a comparison of 279 cases for the Gulf of Alaska (National Aeronautics and Space Administration and Jet Propulsion Laboratory, 1980), the average wind direction difference is +0.6 degrees and the standard deviation is about 16 degrees. For the same Gulf of Alaska data (183 cases), the mean speed difference is +2.0 m s^{-1} and the standard deviation is about 2.5 m s^{-1}. These values indicate that there are no significant differences between our results and those of the Gulf of Alaska studies. In interpreting the results of these two studies, one should mention that there is a difference in the way the comparison is made. In our study, the value of the wind speed and direction are read off from synoptic scale maps. In producing such maps, a certain degree of smoothing is done in the analysis of streamlines and isotachs. Thus the values which are compared are representative of synoptic scale motions. On the other hand, the comparison in the Gulf of Alaska cited here is based on SEASAT point measurements against interpolated values based on synoptic analysis of ship observations. The SEASAT point measurements in the Gulf of Alaska study, may represent subsynoptic rather than synoptic scale conditions.

The frequency distribution of the wind speed differences (SEASAT minus ship) for our study shows a skew-type distribution (Fig. 4). Note in the figure that the difference value of 3.5 m s^{-1} has the maximum number of cases (30); this maximum is followed by the difference values of 2.5 and 3.0 m s^{-1} with 27 cases each.

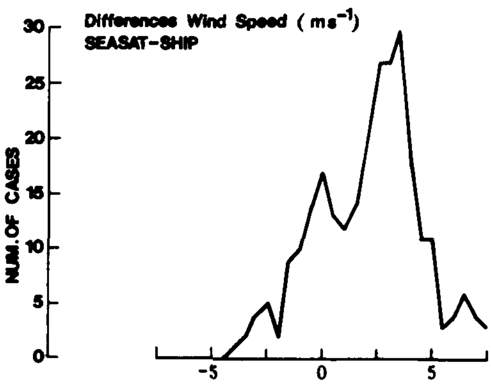

Fig. 4. Graph showing the frequency distribution of the wind speed differences (SEASAT minus ship) at selected points along the SEASAT passes.

In order to detect any systematic relationship between the above differences and other parameters such as wind direction and speed, we have constructed scatter diagrams. Fig. 5 shows the scatter diagram between the wind direction difference and the SEASAT wind direction. It is seen that, as expected, the wind direction difference is essentially independent of wind direction. Fig. 6 is the corresponding scatter diagram for the wind speed difference (SEASAT minus ship winds) as a function of the SEASAT wind speed. Note the large scatter shown by the data. In spite of the large scatter, however, we can see a tendency for the speed difference to increase with increasing SEASAT wind speed. It is important to mention that, if this speed difference is plotted against ship wind speed instead of SEASAT wind speed (diagram not shown), the tendency is just opposite, i.e. the difference tends to decrease with increasing wind speed. This tendency to decrease appears to be in agreement with the results of a study described in National Aeronautics and Space Administration and Jet Propulsion Laboratory (1980). However, the agreement is valid only if, in both studies, the difference is plotted against ship wind speed. In that study, it was not specified whether the plot is against wind speed based on surface observations or SEASAT wind speed. We assume that the plot is between speed difference and wind speed based on surface observations.

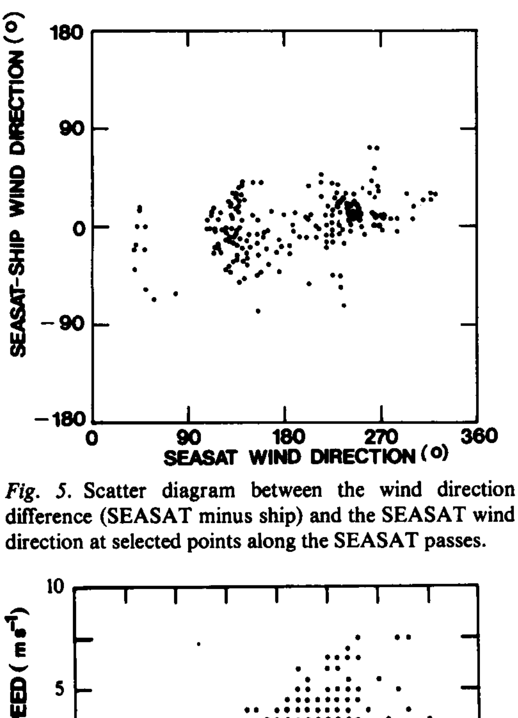

Fig. 5. Scatter diagram between the wind direction difference (SEASAT minus ship) and the SEASAT wind direction at selected points along the SEASAT passes.

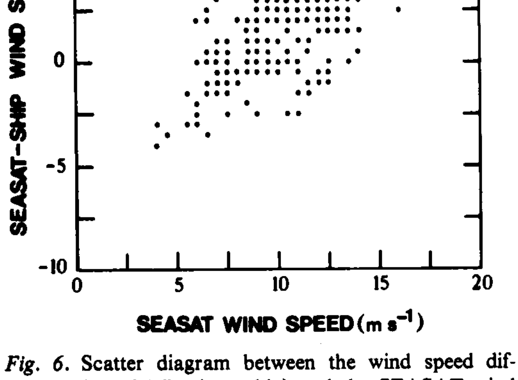

Fig. 6. Scatter diagram between the wind speed difference (SEASAT minus ship) and the SEASAT wind speed at selected points along the SEASAT passes.

The statistical results above indicate that there is no bias in the wind direction differences (SEASAT minus ship observations). However, in the case of the wind speed differences there is some bias, the SEASAT wind speed being larger than the ship wind speed. This bias is presumably due to the use of an incorrect geophysical algorithm for computing the SEASAT wind from the radar backscatter.

Finally, we will discuss the results of the study to assess the degree of improvement in the wind analysis if the SEASAT data are added to conventional data. In order to make the assessment, two maps are analyzed separately for each time period. The first map contains only conventional data while the second map contains both conventional (ship and island) and SEASAT data. Two separate analysts were employed to do each of the two maps in order to obtain two independent analyses. The analyses use data for the entire Indian Ocean and for two time periods, centered at 0000 GMT July 15, 1978 and 0600 July 16, 1978. The resulting maps show details in the streamline-isotach patterns which appear to be unjustified in terms of the density of the available data. The greater detail in the patterns is due to the experience of the analysts in drawing maps with limited data.

Fig. 7 shows the wind analysis for 0000 GMT July 15, 1978 based on conventional data only while Fig. 8 shows the corresponding analysis based on both conventional as well as SEASAT

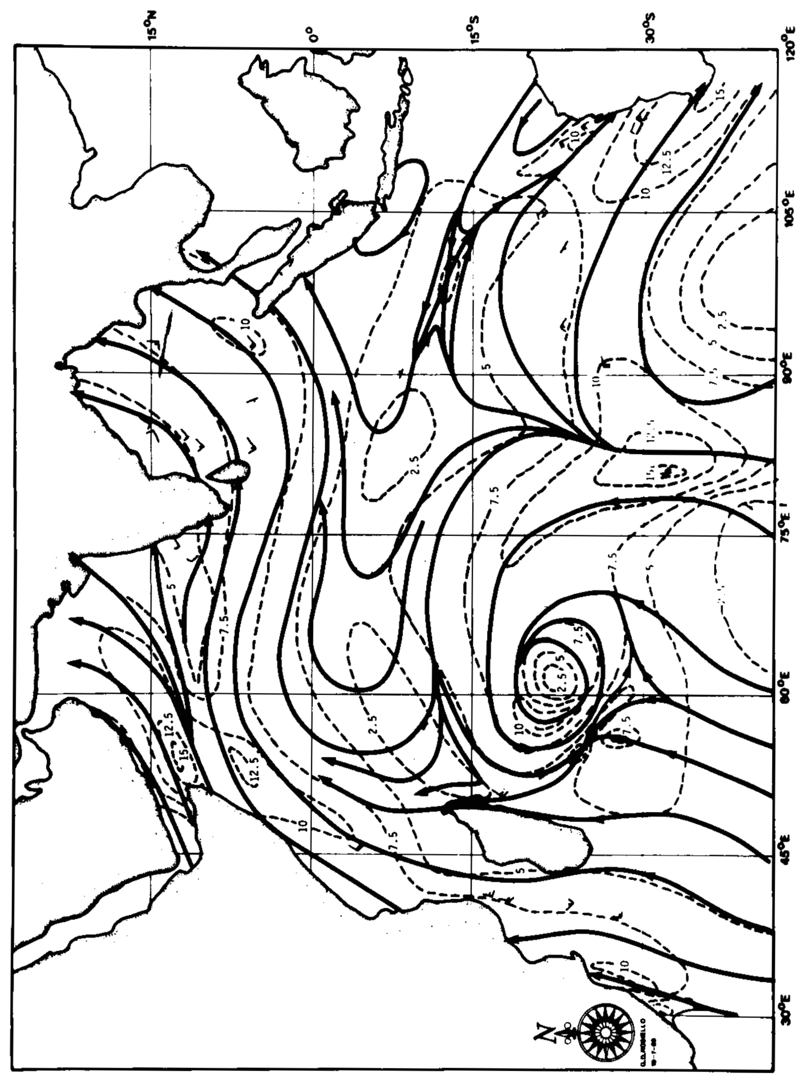

Fig. 7. Surface wind analysis for 0000 GMT July 15, 1978 based on conventional data only. Data are plotted in the usual meteorological form. Solid lines are streamlines; dashed lines are isotachs at 2.5 m s^{-1} intervals.

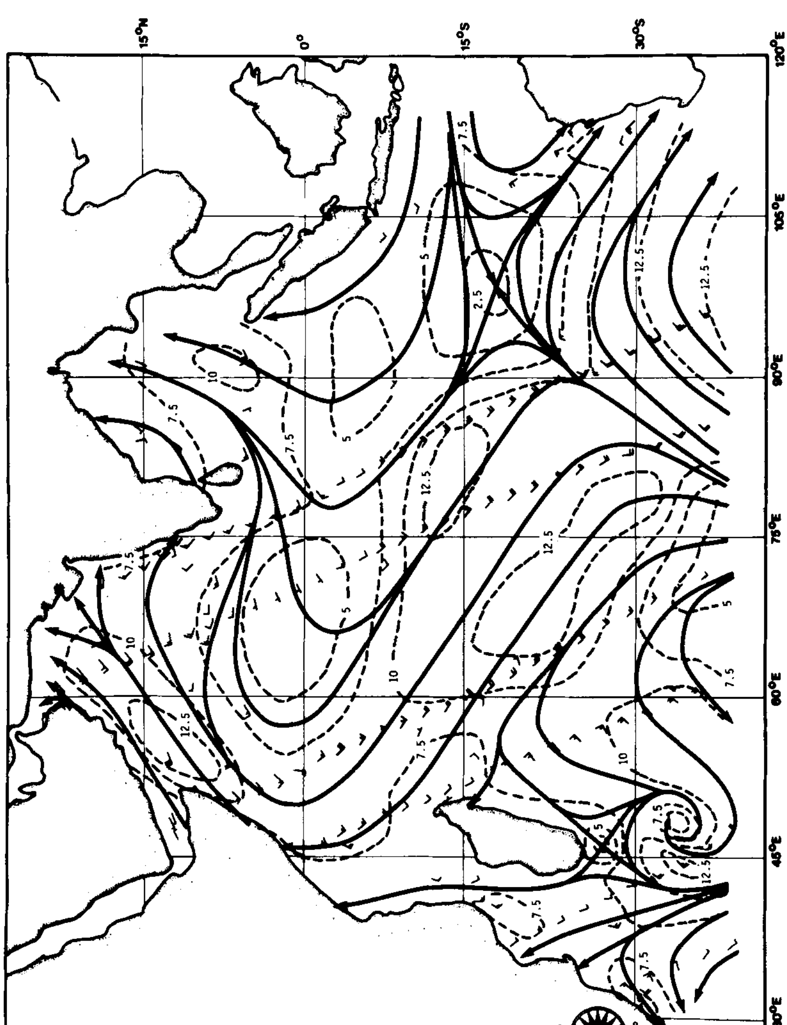

Fig. 8. Surface wind analysis for 0000 GMT July 15, 1978 based on both conventional and a selection of SEASAT data. Data are plotted in the usual meteorological form. Solid lines are streamlines; dashed lines are isotachs at 2.5 m s^{-1} intervals.

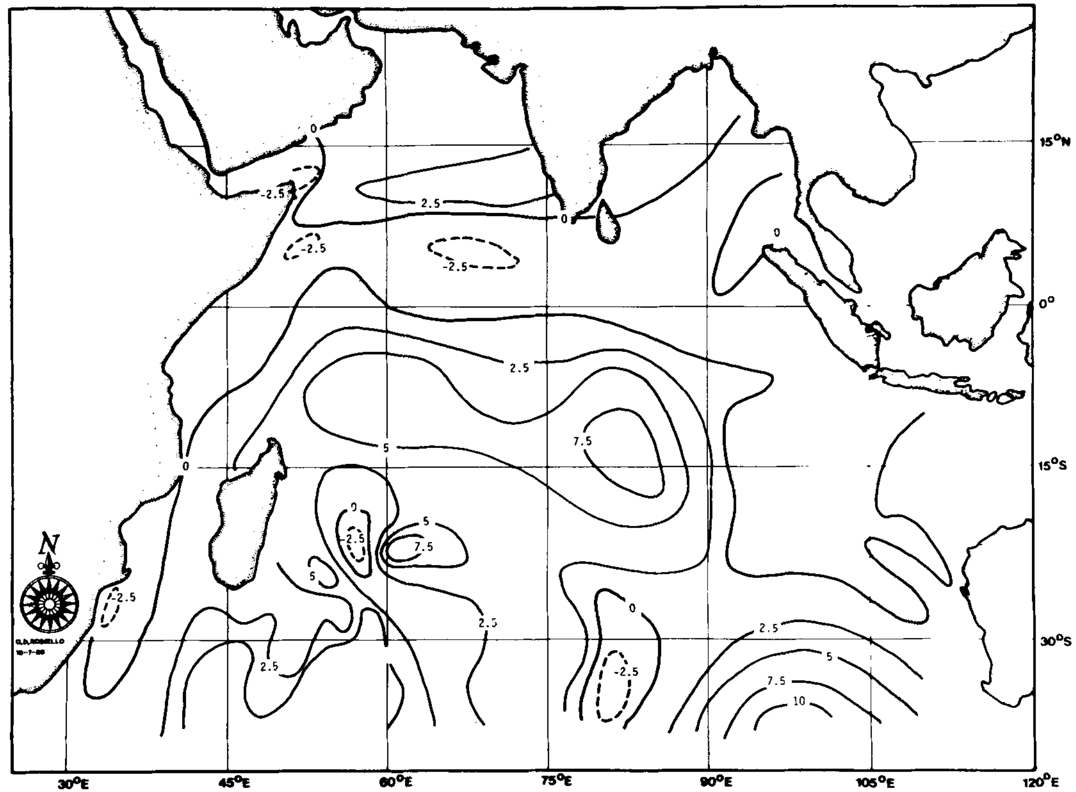

Fig. 9. Wind speed differences (speeds in Fig. 8 minus speeds in Fig. 7) at 2.5 m s^{-1} intervals. Zero and positive differences are denoted by solid lines; negative differences are denoted by dashed lines.

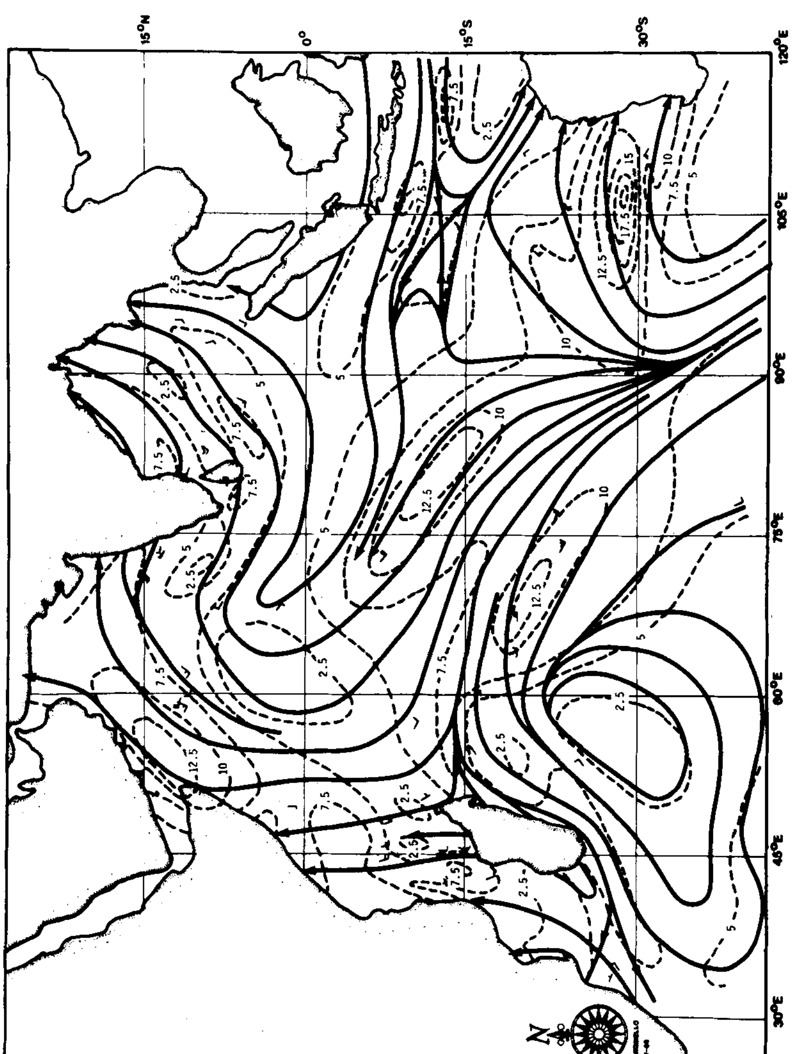

Fig. 10. Surface wind analysis for 0600 GMT July 16, 1978 based on conventional data only. Data are plotted in the usual meteorological form. Solid lines are streamlines; dashed lines are isotachs at 2.5 m s^{-1}.

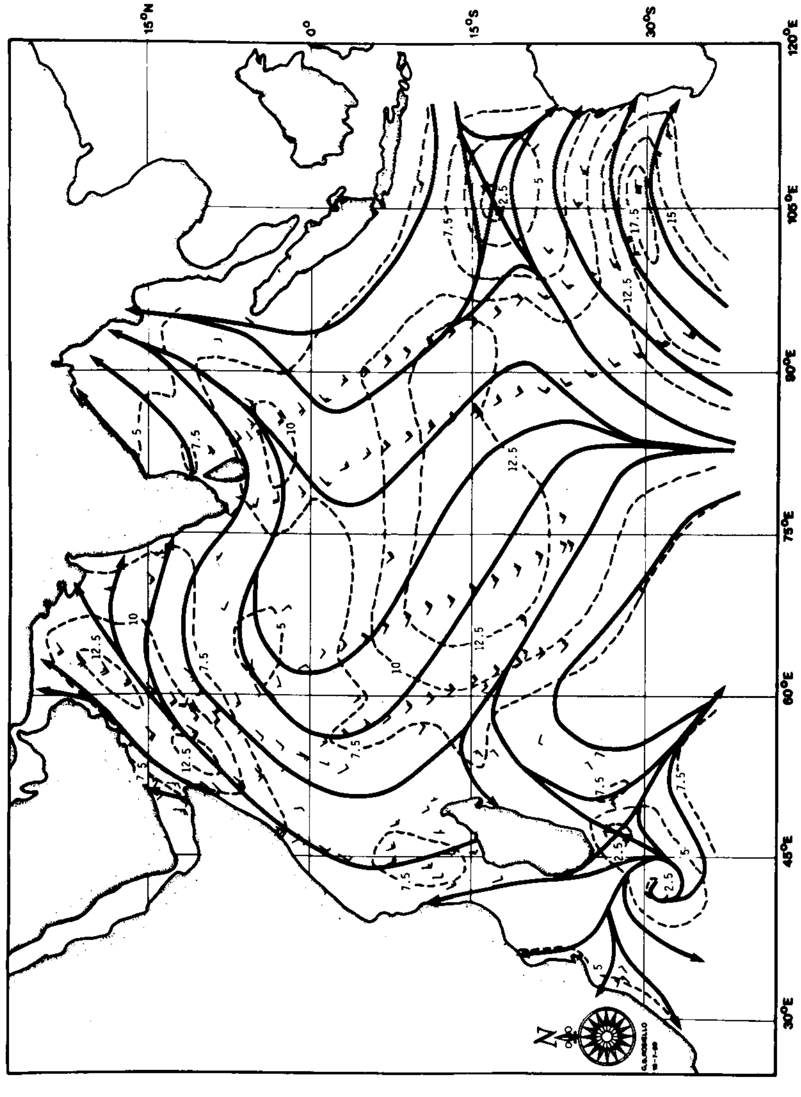

Figure 11. Surface wind analysis of 0600 GMT July 16, 1978 based on both conventional and a selection of SEASAT data. Data are plotted in the usual meteorological form. Solid lines are streamlines; dashed lines are isotachs at 2.5 m s^{-1} intervals.

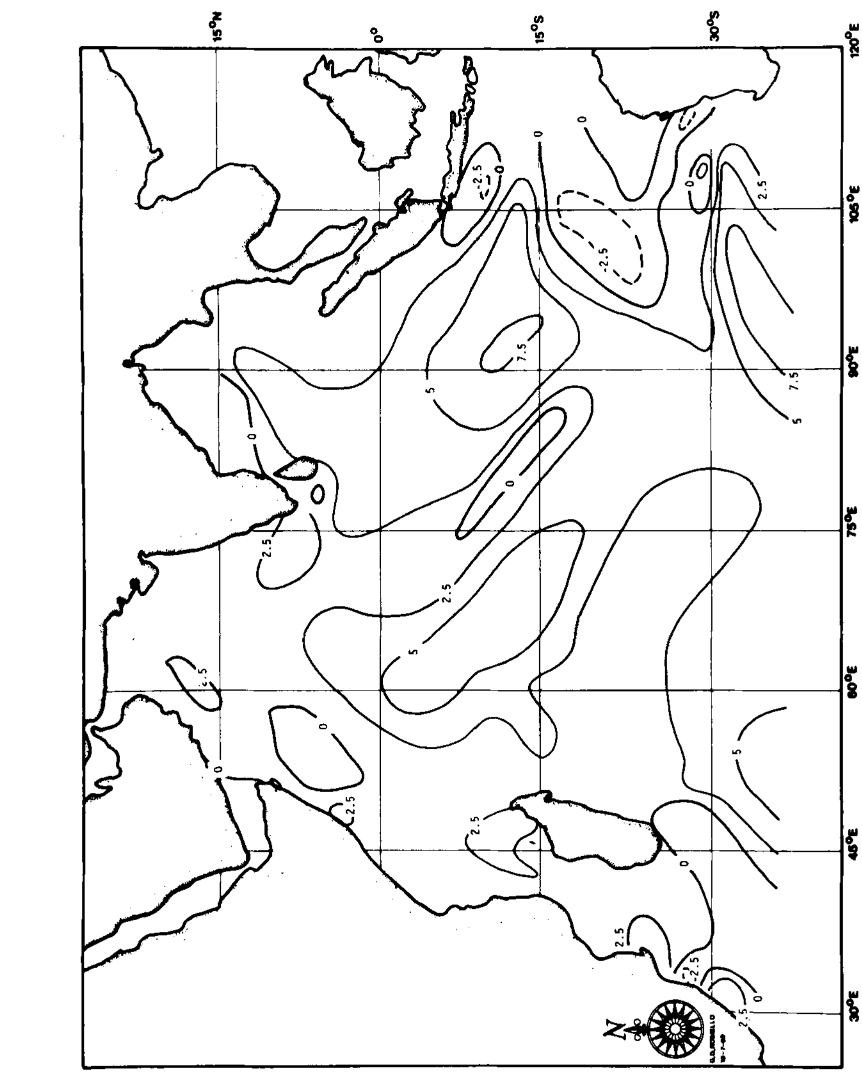

Fig. 12. Wind speed differences (speeds in Fig. 11 minus speeds in Fig. 10) at 2.5 m s^{-1} intervals. Zero and positive differences are denoted by solid lines; negative differences are denoted by dashed lines.

data. The ship and island observations were made exactly at synoptic time (0000 GMT). However, the SEASAT observations were made during three passes, roughly at 0000, 0200 and 0400 GMT. SEASAT information is plotted only at 115 points along the swaths. It may be mentioned that the addition of SEASAT observational data increases the number of wind observations by about 200% with respect to the number of conventional observations. It may be seen that the flow patterns are generally similar for both maps. However, the actual differences in wind speeds between the two maps are relatively large as shown in Fig. 9. The figures show three extensive regions with differences greater than 5 $m\ s^{-1}$. These regions are located over the central, the southeast and the southwest sections of the Indian Ocean. These are, as expected, areas with practically no conventional wind data.

Figs. 10 and 11 show the wind maps for 0600 July 16, 1978. The SEASAT observations used in Fig. 11 are based on passes at approximately 0000, 0200, and 1400 GMT. The addition of 98 SEASAT observations increased the total number of observations (conventional plus SEASAT) by about 100%. A comparison of the wind fields for the two maps shows that the streamline patterns are similar to one another. The geographical distribution of the wind speed differences (Fig. 12) is similar to that one for 0000 GMT July 15, 1978 (Fig. 9). However, there is one noticeable exception in that the area of maximum difference over the central Indian Ocean is split into two parts.

For the purpose of estimating the improvement in the wind analysis associated with the introduction of SEASAT data, we could assume that the analysis based on the conventional plus the SEASAT wind data represents a good approximation of the true wind field. We will assume, in addition, that the analysis based only on conventional data is erroneous due primarily to the lack or sparsity of observations. The difference (Figs. 9 and 12) between the two analyses may, therefore, be regarded as errors in the analysis if SEASAT data are not available. The values of differences greater than 5 $m\ s^{-1}$ over extensive regions are certainly serious, especially in terms of their effects as initial conditions for numerical weather prediction. We may conclude, therefore, that the incorporation of SEASAT data in the description of the surface wind field would result in a significant improvement in the accuracy of the initialization of numerical prediction over the oceans.

4. Concluding remarks

In this study we have attempted (1) to assess the accuracy of SEASAT derived winds and (2) to estimate the improvement of surface wind analysis which is accomplished by adding SEASAT data to conventional data. The geographical area of investigation is the Indian Ocean, which is characterized by extensive regions with little observational data from ships or islands. The research is done with the aid of synoptic scale wind analyses of observations; raw observational data were not used directly in the assessment of the accuracy. Since a certain amount of smoothing is done in the synoptic scale analysis, the results of this study apply only to large-scale synoptic conditions.

Our study shows that the accuracy of SEASAT-derived winds is comparable to that of conventional ship observations. In the case of island observations, the precision of such observations is certainly greater than SEASAT observations. However, the representativeness of island observations may be seriously affected by local topographic effects. Thus island observations may not prove, in practice, to be better than SEASAT observations in representing synoptic scale features of atmospheric flow patterns.

In regard to the improvement of surface wind analysis by adding SEASAT to conventional data, our study shows that considerable improvement is achieved, primarily in the wind speed description. The improvement is particularly significant in areas with little conventional data. From an operational viewpoint, the degree of improvement found in our study would be an underestimate. This is due to the fact that we used archived observational data instead of operationally-transmitted data from ships; the former are much greater in amount than the latter. Since the open oceans are generally data-void areas, the impact of SEASAT observations in the quantitative description and the prediction of global weather is enormous. In this connection, it is pertinent to mention that wind observations at levels above the surface are now operationally available from geostationary satellites. It is clear, therefore, that future SEASAT-type observations, in combination with geostationary satellite observations, would enable us to produce three-dimensional descriptions of the wind field on a synoptic basis. The availability of such descriptions would, in turn, increase tremendously our quantitative understanding of the atmosphere over oceanic regions and lead ultimately to accurate numerical weather prediction, especially in the tropics.

5. Acknowledgements

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АНАЛИЗ НАБЛЮДЕНИЙ ВЕТРА НАД ИНДИЙСКИМ ОКЕАНОМ СПУТНИКОМ СИСАТ

Анализируются данные о наблюдениях спутником СИСАТ-А ветра у поверхности над Индийским океаном за период 15–17 июля 1978 г. Целью анализа было: 1) оценка точности измерений ветра этим спутником путем сравнения их с данными корабельных наблюдений и 2) определение улучшения, вводимого в описание поля ветра у поверхности синоптического масштаба добавлением данных спутника СИСАТ к наблюдениям ветра с кораблей и островов. Результаты нашего исследования показывают, что 1) в синоптическом масштабе точность данных этого спутника сравнима с таковой для обычных наблюдений ветра у поверхности и что 2) учет данных спутника СИСАТ дает значительное улучшение в анализе ветра у поверхности, особенно в областях с резкими данными.