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Optimum Interpolation Analysis of Surface Pressure Using SEASAT-A Scatterometer Wind Data

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This is an unreviewed manuscript, primarily intended for informal exchange of information among NMC staff members.

1. Introduction

In June 1978, an experimental oceanographic satellite known as SEASAT-A was launched. The main objectives of this satellite program include ocean global measurements of the surface wind vectors, surface temperature, wave heights and marine geoid. The satellite carries, among five microwave sensors, a SEASAT-A Satellite Scatterometer (SASS), which can be used to infer surface wind vectors over the world's oceans. Algorithms for inferring surface wind stress and wind vectors have been under development (Jones et al. 1978).

Instrumentally, SASS measures normalized backscattering radiation with two radar beams on SEASAT-A such that the pointing directions of these two beams differ by 90°. The normalized backscattering radiation depends on wind speeds over the sea surface, incident angles that the radar beams make with the sea surface, and aspect angles (defined as the wind direction relative to the pointing direction of the radar beams). The two scanning modes of the SEASAT-A yield one true wind vector and up to three incorrect aliases. These incorrect aliases must be resolved before the data may be used.

Further, remotely-sensed data from a polar-orbiting spacecraft such as SEASAT-A are asynoptic, and their error structures are different from those of conventional data sources. Proper inclusion of SASS winds in meteorological analyses calls for a special analysis scheme. For this study, we shall use an operational optimum interpolation scheme of the National Meteorological Center (Bergman, 1979). This scheme, which possesses the flexibility required by different data bases with different error characteristics, is suitable for treating the SASS wind data.

The SASS wind data provide fine resolution wind vectors (about 100 km spatial resolution) over the world's oceans. These wind data may be used to improve surface pressure analyses that are currently generated by using sparsely available ship reports. The improved pressure analyses may in turn be used in the NMC's global data assimilation system (McPherson et al. 1979).

The main purpose of this paper is to present some results of surface pressure analysis experiments using the SASS wind data. Section 2 discusses the nature of the SASS wind data and Section 3, elements of the data processing procedure where an alias remover scheme will be presented for resolving the aliasing problems of the SASS wind data. Some examples of the surface pressure analyses are given in Section 4. A summary concludes the paper.

2. Nature of the SASS Wind Data

As pointed out earlier, the surface wind fields derived from SASS contain one true wind vector and up to three aliases. Fig. 1 shows the nature of the SASS wind data from two partial orbits, i.e., Revolutions 575 and 576. We see that the majority of the SASS winds are four-fold vectors at each observation point, only one of which is the true wind; the other are aliases. Moreover, wind directions at the nadir locations are indeterminate due to limitations in the sensor configurations. Consequently, these winds at nadir cannot be used.

The SASS data, provided to us by the Langley Research Center, including Rev. 575 and Rev. 576, were processed using Wentz's algorithm (Jones et. al. 1978). Although Jones et al. (1978) have tested the algorithm with a simulated SASS data set and concluded the algorithm's performance is good, the algorithm does not yet account for the atmospheric attenuation effects. As a consequence, wind speeds from the SASS data tend to be biased high near the center of a storm. Black (1979), comparing SASS wind speeds with surface wind speeds from ships, aircrafts, and cloud trajectories, concluded that the SASS winds were biased high by 4-8 m/s in Hurricane FICO. Jones and Pierson (1978), by comparing surface observed ship winds with SASS winds derived for Rev. 575 and Rev. 576, reached a similar conclusion. It should be pointed out that both orbits Rev. 575 and Rev. 576 were derived during fair weather conditions. Thus, it seems clear that lack of a correction factor for atmospheric attenuation effects causes a high bias to the SASS wind speeds under all weather conditions, On the other hand, Jones and Pierson (1978), by manually selecting the correct wind directions from both Rev. 575 and Rev. 576, found that the observed ship wind directions agreed quite well with the SASS wind directions.

3. Preprocessing of the SASS Wind Data

In this section, we discuss an alias removal scheme making use of the NMC's analysis fields. The scheme is an iterative method consisting of five passes:

(a) First pass - This step resolves the SASS data in areas of uniform wind direction. Abundant examples of uniform wind fields are observed over the trade wind regimes in the tropics. Here we define uniform winds as winds with their directions coming from the same quadrant within a specified area. During the pass, the scheme locates the areas of uniform winds. Then, NMC's operational 1000 mb wind analysis is used to select correct wind directions over a 5° by 5° longitude-latitude grid box. Vectors thus resolved are then separated from ambiguous winds.

(b) Second pass - The SASS wind data are searched for non-ambiguous winds. If the non-ambigous wind distribution from the SASS data contains at least three vectors in the four quadrants of the 5° by 5° longitude-latitude box, these winds are used to resolve ambiguous vectors in the box. These resolved winds are then used for the next pass.

(c) Third pass - Optimum interpolation of the winds already resolved from the previous passes is used to select most probable wind directions from two-fold ambiguity winds.

(d) Fourth pass - Same as the third pass except that three-fold ambiguous winds are resolved.

(e) Fifth pass - Same as the fourth pass except that four-fold ambiguous winds are resolved.

Before it was used to process the real SASS data, the alias remover scheme was tested on a set of simulated satellite data generated for us by Langley Research Center. The test wind field selected was for an extratropical cyclone over the North Atlantic for 00Z, Feb. 5, 1978. The reader is referred to Jones et al. (1978) for details of the simulation studies. The advantage of using the simulated case is that we can compare the final dealiased wind field with the starting wind field; thereby we may evaluate the performance of the alias removal scheme. Our alias removal scheme was applied to the simulated satellite data using, as an aid, the following four cases selected from NMC archives:

Case 1: 1000 mb wind analysis valid at 00Z Feb. 5, 1976.

Case 2: 1000 mb wind analysis valid at 18Z Feb. 4, 1976.

Case 3: 1000 mb wind analysis valid at 12Z Feb. 4, 1976.

Case 4: 6-hour forecast field of 1000 mb winds valid at 00Z Feb. 5, 1976.

For each case, the recovered wind field (after alias winds were removed) was compared with the starting wind field and errors were calculated. Here, error is defined as percentage of resolved wind directions which do not agree with those of tthe starting wind field. The errors for the four cases are, respectively 3%, 7%, 29% and 3%. Thus, use of a timely NMC analysis to resolve aliasing problems appears satisfactory; however, use of 12-hr persistence (Case 3) could cause as much as 29% error.

The valid times for the two orbits, i.e., Revolutions 575 and 576 are respectively 0600 GMT and 0730 GMT, Aug. 6, 1978. Thus, based on the above results, it was deemed desirable to use the NMC 1000 mb wind analysis valid at 0600 GMT Aug. 6, 1978 for resolving the aliasing problem in the two orbits of the SASS wind data. It should be mentioned that among 338 winds in Rev. 575, there were 72 winds at the nadir locations. Similarly, among 185 winds in Rev. 576, there were 32 winds at the nadir locations. These winds at nadir locations were discarded in our alias removal effort and not used in the surface pressure analysis.

Fig. 2 shows the dealiased SASS wind field for both orbits 575 and 576. Superimposed on Fig. 2 is the NMC subjective surface pressure analysis. We see that orbit 575 passed through the right side of the surface high centered at 40°N latitude and 142°W longitude; and orbit 576 passed through the surface low centered at 49°N latitude and 160°W longitude. In general, the dealiased wind field agrees well with the surface pressure pattern except in the two shaded areas: one over the north-eastern part of the surface high; the other over the western part of the surface low. Within these areas, the resolved wind directions using the removal scheme did not agree well with the pressure pattern. The dealiased winds in these two areas constitute about 15% and 10% of the total SASS winds for orbits 575 and 576 respectively-these are the errors incurred by the alias removal scheme. These erroneous winds were further corrected by manually selecting the wind directions which were most consistent with the surface pressure pattern. These manually selected winds are shown in the shaded areas in Fig. 2. It should be noted that some of the manually selected winds were still not quite fitting the pressure pattern.

4. Surface Pressure Analysis Experiments

We mentioned earlier that the model used for surface pressure analysis was based on an optimum interpolation scheme. A brief summary of the interpolation scheme follows. Let the observed surface pressure and wind components (P, U, V) be composed of a "guess" value ($\overline{p}$, $\overline{u}$, $\overline{v}$) plus a deviation (p, u, v). Then the analyzed surface pressure at a grid point p_g may be expressed as a linear combination of the deviation quantities,

$$P_g = \bar{P}_g + \sum_{i=1}^{\ell} a_i p_i + \sum_{j=1}^{m} b_j u_j + \sum_{k=1}^{n} c_k v_k$$

where there are ℓ pressure deviations, m west wind deviations, and n south wind deviations. The quantity $\bar{p}_g$ is the guess value of surface pressure at the grid point. The unknown coefficients a, b, c, etc., may be determined by minimizing the mean-square interpolation error,

$$E = \overline{\left(P_g - \bar{P}_g - \sum_{i=1}^{\ell} a_i p_i - \sum_{j=1}^{m} b_j u_j - \sum_{k=1}^{n} c_k v_k\right)^2}$$

where the overbar denotes an ensemble average. For details of the scheme, the reader is referred to Bergman (1979).

As pointed out earlier, the SASS wind data must be corrected for the surface frictional effect before they may be used in the optimum interpolation of surface pressure; for this study, we used a simple regression equation developed by Druyan (1972) to account for this effect. Because of these two simplifications, we realized that the error level for the SASS wind data might be larger than it was originally specified. In the following pressure analysis experiments, we thus decided to arbitrarily specify an error level for the SASS wind data to be the same as that for ship wind data. The area chosen for analyzing the surface pressure is between 120°W and 180°W in longitude and between 10°N and 70°N in latitude-covering the eastern part of Pacific Ocean (see Fig. 2). Within this limited area, there were about 85 ship reports of pressure and winds and 500 SASS winds at 0600 GMT 6 August 1978--the time of the surface pressure analysis. The majority of the ship reports lie between 55°N and 15°N--only 4 ship reports south of 15°N and 3 ship reports north of 55°N. The guess pressure field is a 6-hour forecast of sea level pressure by the NMC hemispheric primitive equation model.

Two basic pressure analyses were performed: (1) coarse-mesh analysis with a 2.5° longitude-latitude grid, and (2) fine-mesh analysis with a 1.25° longitude-latitude grid. The coarse-mesh analysis has a grid length of 390 km at 60°N, and consequently, only the synoptic scale pressure wave may be resolvable. On the fine-mesh analysis, meso-scale pressure waves may be resolvable. Fig. 3 shows the coarse-mesh surface pressure analysis without SASS wind data. The corresponding pressure analysis with SASS wind data is shown in Fig. 4. A comparison of the two figures shows little difference in surface pressure within the area of 15°N and 55°N. The positions and intensities of the surface low and high centers are unchanged by the addition of the SASS wind data, and the isobar pattern also remains unchanged.

However, south of 25°N and north of 55°N significant differences in surface pressure analyses exist between those made with SASS winds and those without SASS wind data; this might be due to the lack of ship reports (less than 4) in this area. As a consequence the optimum interpolation scheme places more weight on SASS wind data. On the other hand, due to the large number of ship reports within the area of 15°N and 55°N, the addition of SASS wind data causes no significant changes in surface pressure. Under this circumstance, the SASS winds may not improve the definition of the pressure field.

Finally, to determine the effect of grid size on the surface pressure analysis, we also performed a fine-mesh analysis. The changes between pressure analysis made with SASS wind data and that without are consistent with the results of the coarse-mesh analysis (not shown). This suggests that the grid size of the analysis system has little effect on the surface pressure.

5. Summary

In this paper we discussed the nature of the SEASAT-A satellite scatterometer (SASS) wind data, a procedure to process them and a way to use them. An alias removal scheme designed for resolving the directional ambiguity was presented, and the scheme was tested with two partial orbits of the SASS wind data. As the scheme must rely on a guess pressure field, we find that errors amounting from 10% to 15% in the resolved SASS wind field can occur because of use of the alias remover scheme.

We showed that one way to use the SASS wind data was through an optimum interpolation of the surface pressure analysis. Comparison of a surface pressure analysis with SASS wind data against one without, showed a large pressure difference over the areas where ship reports are sparse. On the other hand, over the areas where ship reports are plentiful, the change in pressure analysis due to addition of the SASS wind data is negligible. This result suggests that, in operational use, it may be desirable to use SASS winds only in those areas where ship density falls below an assigned threshold value. This result further suggests that the most beneficial use of the scatterometer wind data may come not in the surface pressure analysis but in the lower tropospheric wind field. However, more orbits of the SASS wind data are required for demonstration of this potential.

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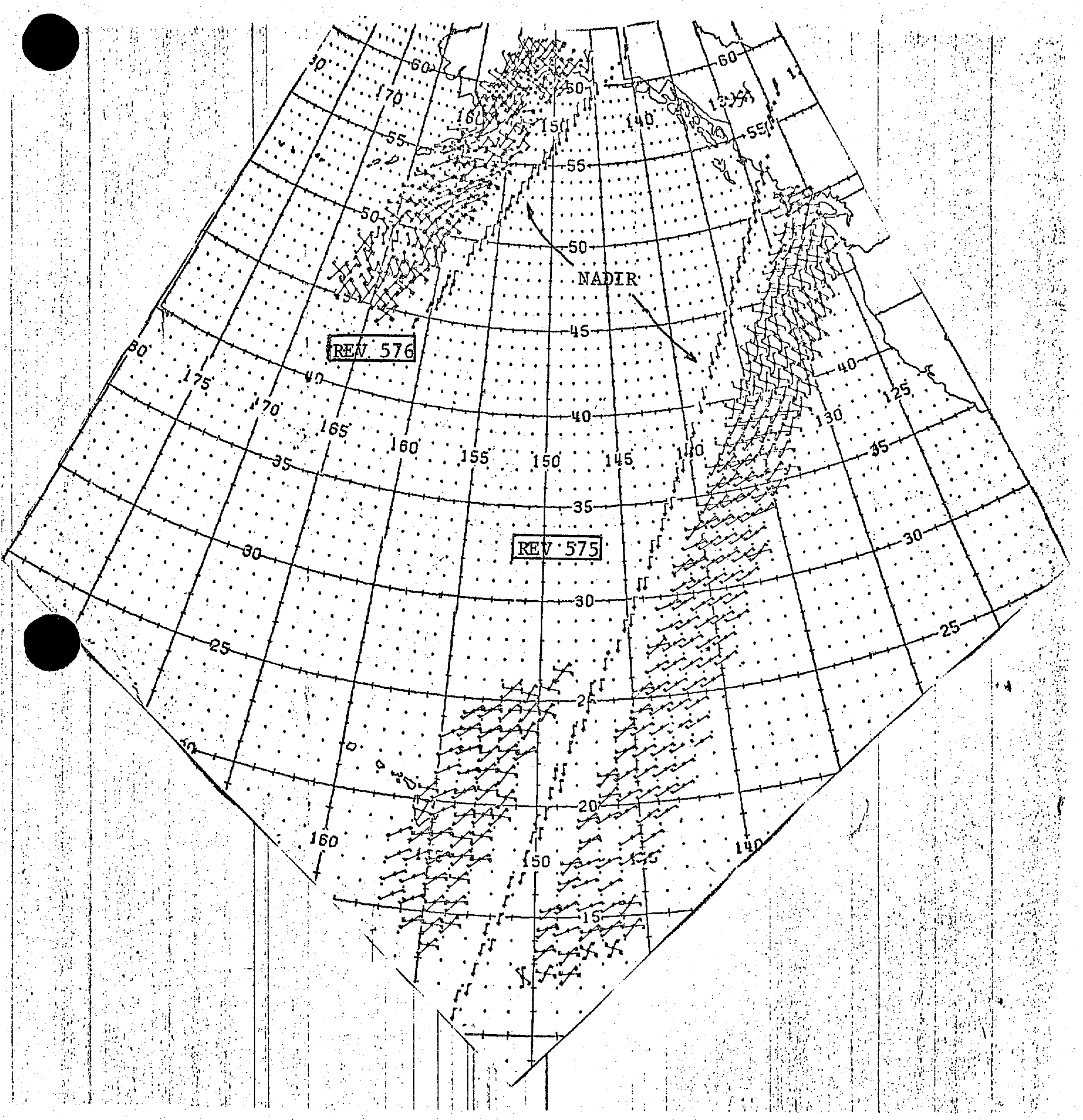

Fig. 1 Two partial orbits (Revolutions 575 and 576) of scatterometer-derived wind vectors from SEASAT-A satellite.

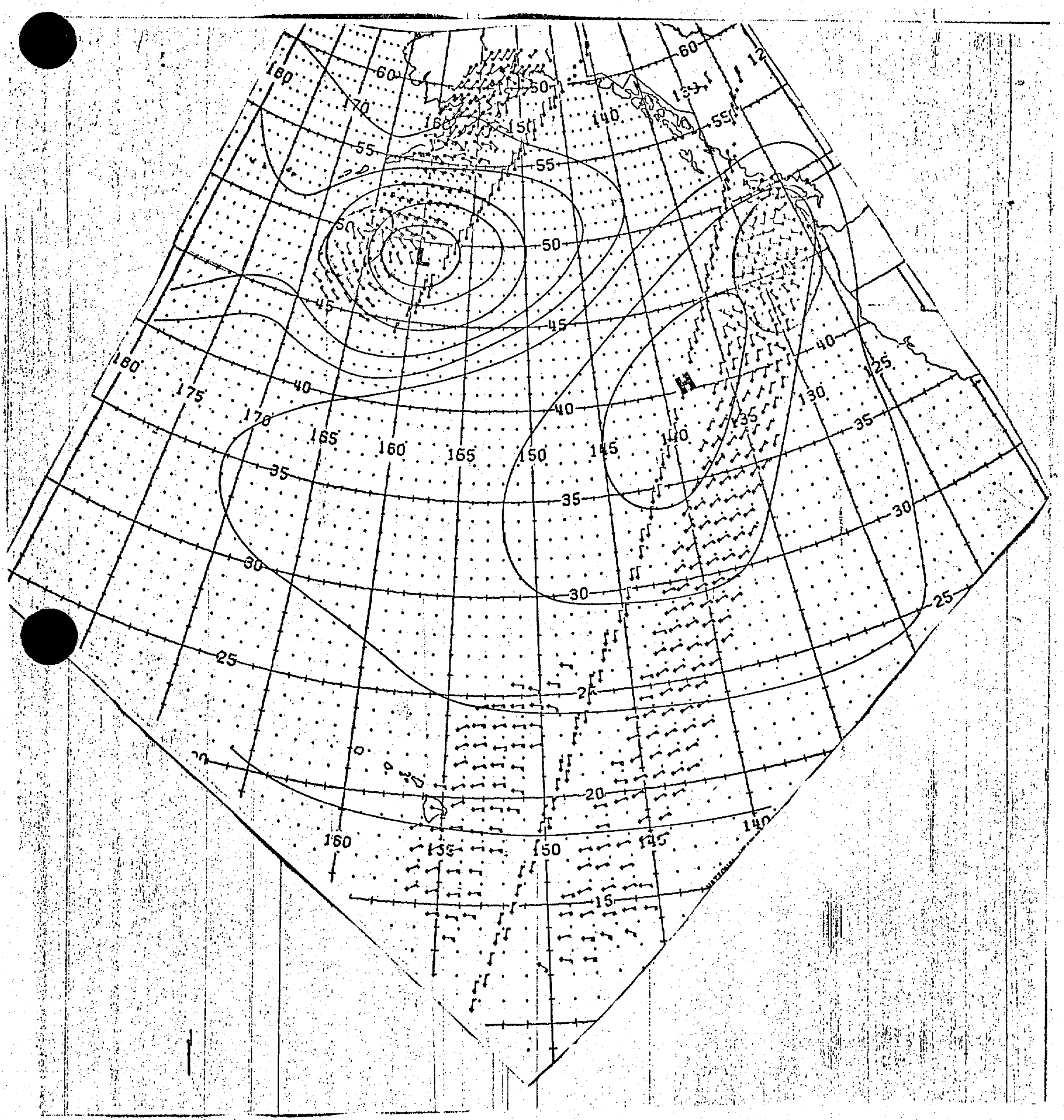

Fig. 2 Dealiased scatterometer wind vectors from SEASAT-A satellite. Superimposed is the NMC's subjective surface pressure analysis.

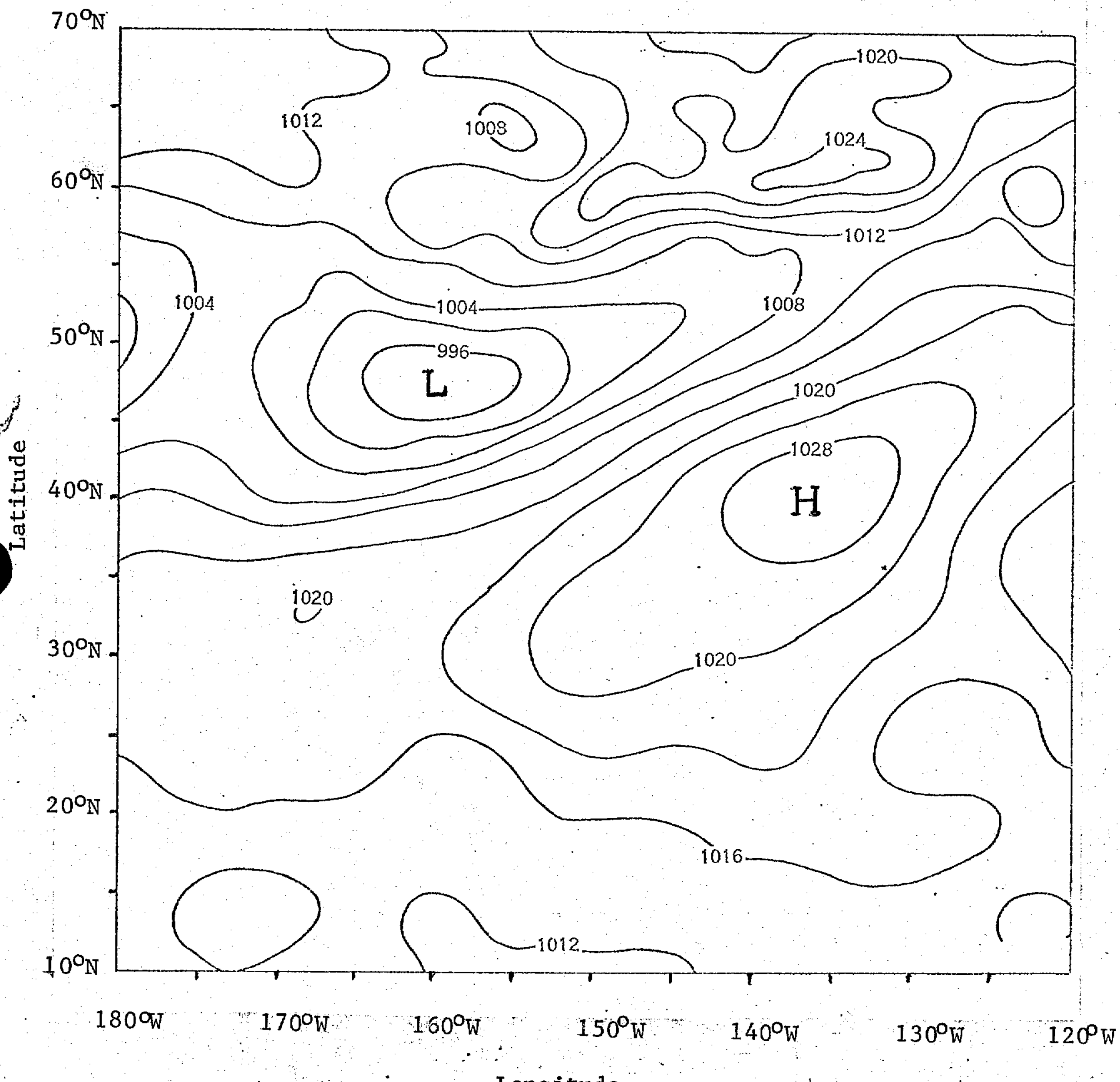

Fig. 3 Optimum interpolation analysis of surface pressure using ship winds and pressure data.

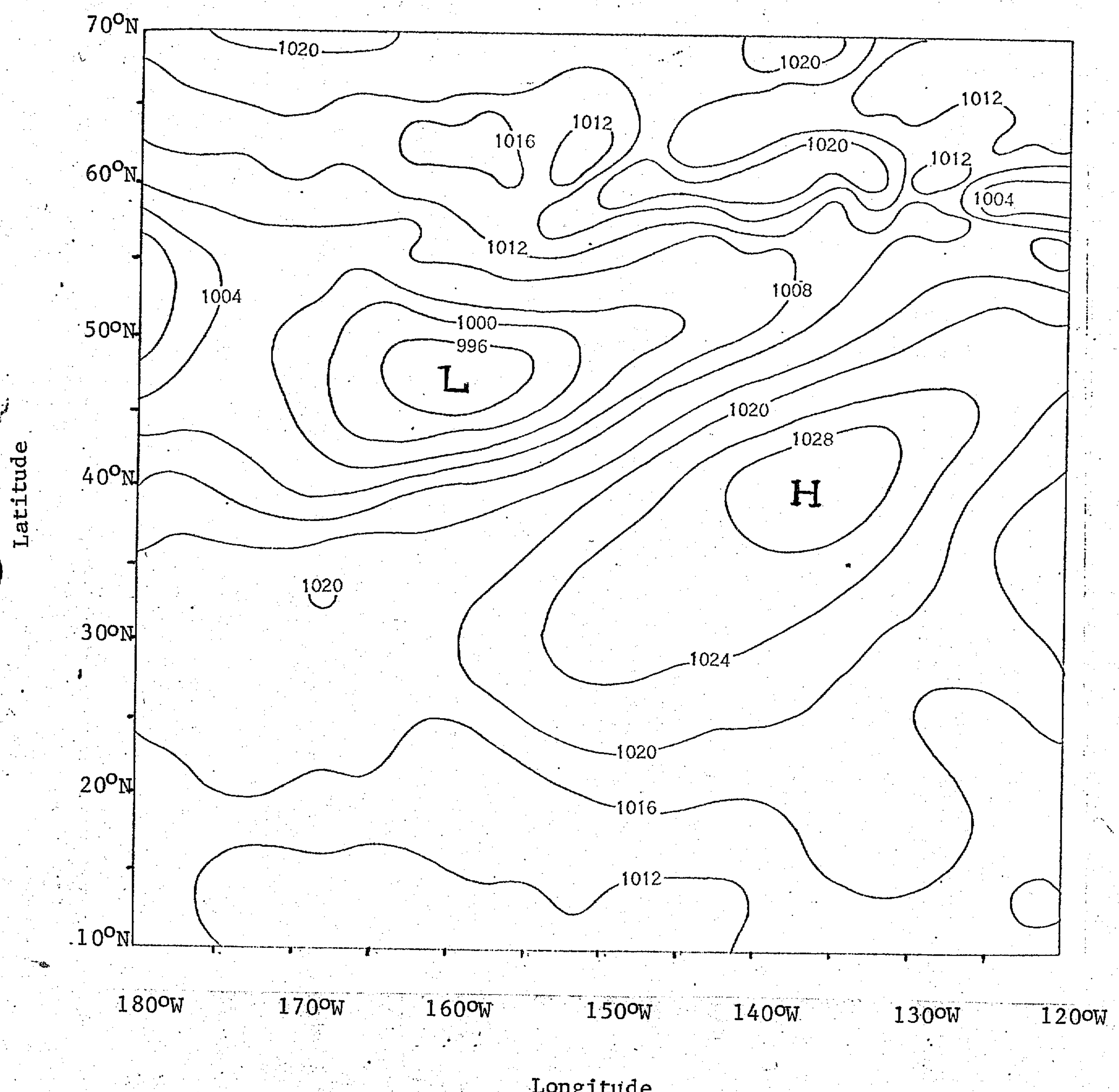

Fig. 4 Optimum interpolation analysis of surface pressure using scatterometer-derived wind data (Revolutions 575 and 576) in addition to ship wind and pressure data.