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GEOSAT WIND AND WAVE MEASUREMENTS DURING LEWEX

During the Labrador Sea Extreme Waves Experiment (LEWEX), the Geosat altimeter provided measurements of wind speed and significant wave height over a broad region. Although the Geosat wind estimates are not significantly biased from the LEWEX common winds (±1 m/s, averaged over the entire experiment), Geosat often reveals a spatial structure in the wind field that is absent in the modeled winds.

INTRODUCTION

In the realms of remote sensing of the oceans and ocean modeling, we constantly search for absolute "ground truth" to measure the accuracy of a given instrument or model prediction. Unfortunately, no perfect yardstick exists by which any geophysical estimate can be assessed exactly. Efforts continue, however, because comparisons between various data sets can give insight into the inadequacies of each data set. Often, several different sources of data are needed to describe or predict adequately the edicts of nature.

In this context, the Labrador Sea Extreme Waves Experiment (LEWEX) was designed to include as many techniques as possible to measure both the directional and nondirectional properties of the wind and wave fields. The only spaceborne instrument yielding wind and wave estimates during LEWEX was the Geosat altimeter, built by The Johns Hopkins University Applied Physics Laboratory, which provided global estimates of wind speed and wave height from early 1985 to early 1990. This article discusses the Geosat wind speed and wave height measurements collected during LEWEX, and compares those wind speed measurements with the LEWEX common winds along the Geosat subtrack.[1]

THE GEOSAT ALTIMETER

The Geosat altimeter operated in an 800-km orbit from March 1985 to January 1990, measuring (among other things) significant wave height (SWH) and wind speed on the ocean surface. The altimeter laid down a ground track pattern that repeated every seventeen days, with about 145-km spacing between ascending crossings at the equator. Between one and three ascending or descending ground tracks were laid down in the LEWEX region each day.

Wind speed is derived from the altimeter measurements of backscattered radar cross section (RCS) by applying an empirically determined algorithm. The wind speed affects the sea surface roughness, which in turn modulates the RCS. In this work, a modified Brown algorithm[2] was derived by applying a cubic spline fit at 0.2-dB intervals.[3] Geosat wind speed measurements are estimated to have a 1-σ accuracy of 1.7 m/s for wind speeds up to 20 m/s (Ref. 4); above 20 m/s, the algorithm has not been adequately verified.

The SWH is determined from the slope of the altimeter-returned pulse. A smooth sea produces infinite slope; as the surface roughens, the slope decreases.[5] Geosat wave height measurements are estimated to have a 3-σ accuracy of 0.5 m. Both wind speed and wave height are measured every 0.1 s (0.67 km) along the ground track.

GEOSAT DATA DURING THE EXPERIMENT

Originally, the Geosat contributions to LEWEX had two important aspects: to provide "near-real-time" wind and wave estimates to serve as a planning guide for the experimenters aboard the CFAV *Quest* and HNLMS *Tydeman,* and to demonstrate how quickly Geosat data could be provided to scientists in the field. Before LEWEX, no attempt had been made to provide near-real-time data to an ongoing field experiment. In practice, Geosat data were provided to the LEWEX site between twelve and twenty-four hours after the measurement. Since Geosat data are received and digitized on sensor data records (SDR) at APL, the raw data could be obtained immediately after being released from the receiving station. After processing, the data were telefaxed to the experiment site. This near-real-time transmission of Geosat data took place for five days during LEWEX.

Processing of the SDR at APL included editing according to on-board "data-quality flags," computing 1-s averages of wind and waves, and computing latitude and longitude from Keplerian elements. The near-real-time ground tracks computed from SDR Keplerian elements are accurate to a few kilometers. The results presented here, however, use an improved Naval Aeronautics Group ephemeris to achieve an accuracy of a few meters. Typical examples of the data products transmitted in near-real-time during LEWEX are shown in Figure 1. Note the strong inverse correlation between radar cross section and wind speed, and the strong direct correlation between wind speed and SWH. These data were mea-

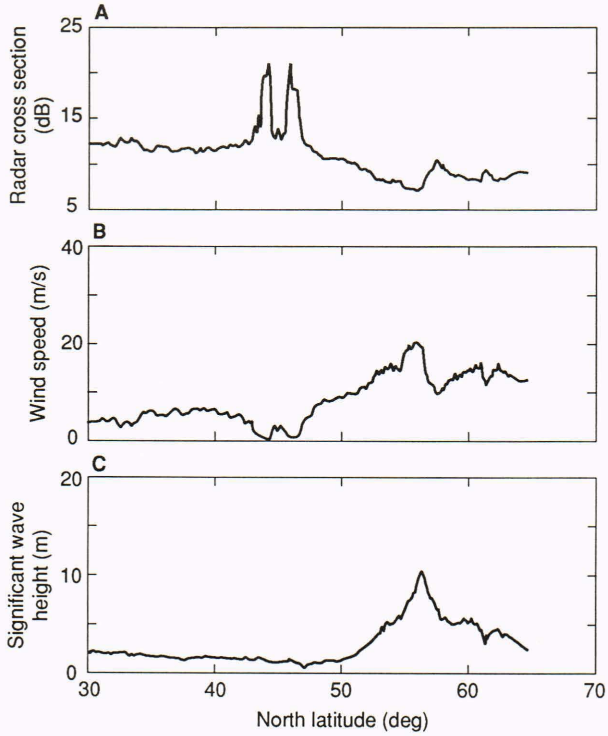

Figure 1. Example of Geosat measurements along a particular track on 18 March 1987. **A.** Radar cross section (dB). **B.** Wind speed (m/s). **C.** Significant wave height (m).

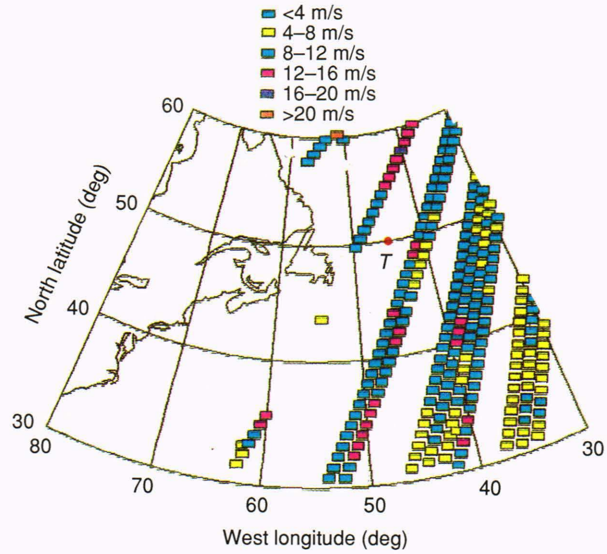

Figure 2. Composite map of descending ground tracks showing wind speed (m/s) for 11–20 March 1987. (*Tydeman* position is shown by *T* on this and following figures.)

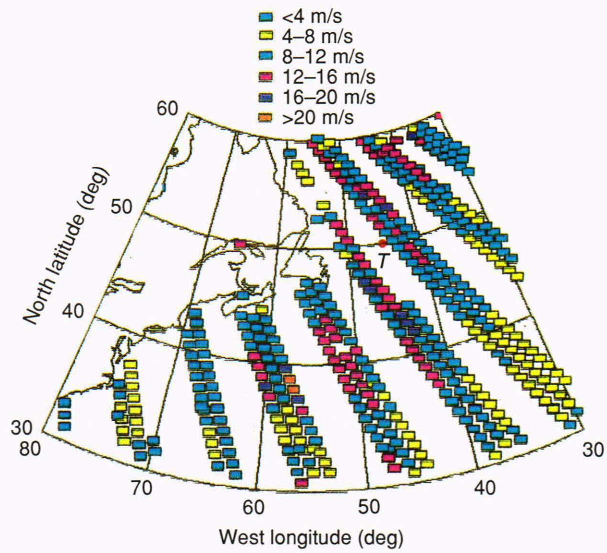

Figure 3. Composite map of ascending ground tracks showing wind speed (m/s) for 11–20 March 1987.

sured on 18 March 1987 along a track that passed to the east of both the *Quest* and the *Tydeman*.

Unfortunately, only two Geosat ground tracks were sufficiently close to the ships during LEWEX to be useful in the planning activities. Geosat proved most useful in accurately revealing the complex spatial structure of the wind and wave field. Figures 2 and 3 show composite mean wind speed estimates from 11 to 20 March, and Figures 4 and 5 present the corresponding composite SWH. Each value represents an average over 15 s along the track. Geosat passed over regions of high winds and waves around 40°N, 50°W and 53°N, 45°W. A smaller area of winds at 16 to 20 m/s also can be seen near 38°N, 38°W. The space–time sampling of Geosat was too coarse to track individual storms.

The highest wind measured by Geosat was 25 m/s, but most winds were below 16 m/s for all eleven days. The highest SWH measured was 10 m (see Fig. 1). No pass came close enough to the experiment site to allow extensive direct comparisons with the other instruments used during LEWEX.

COMPARISON: GEOSAT WIND SPEEDS AND LEWEX COMMON WIND FIELDS

The LEWEX common wind fields (referred to hereafter as the model winds) were produced by Cardone.[1] The wind field was provided at six-hour intervals over the region from 20°N to 67.5°N and 20°W to 80°W. For comparison, Geosat data were averaged over 15 s or 100 km along track, about the same scale as Cardone's coarse model grid.

Geosat winds at the center of the 15-s average were compared with the LEWEX winds at the nearest grid point, resulting in a maximum spatial separation of 140 km. All comparisons were simultaneous within three hours. Over the ten-day period from 10 to 20 March, twenty-six Geosat tracks permitted 702 comparisons of Geosat wind speed with model wind speed.

Comparisons from nine of the twenty-six tracks analyzed are shown in Figures 6 through 8. Geosat track positions for the midpoint of a fifteen-point average, along with the grid points chosen from the model, are shown in the upper half of each figure. The means of some Geosat and model winds differ substantially, but others are in good agreement. For example, in Figure 6C (bottom), both estimates agree within about ±1 m/s

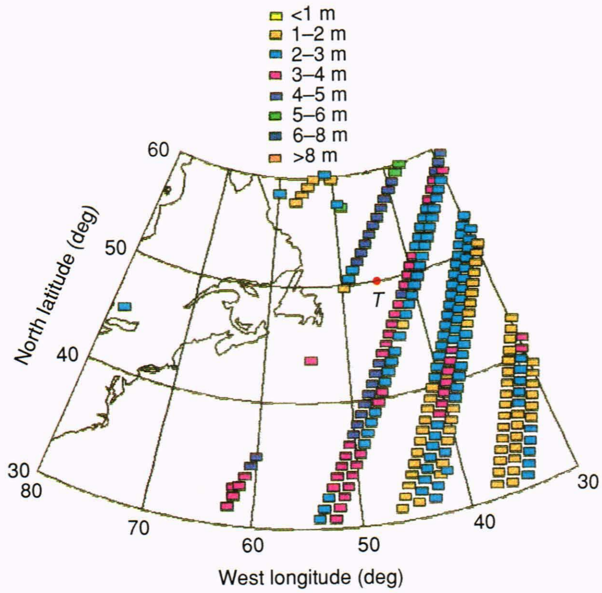

Figure 4. Composite map of descending ground tracks showing significant wave height (m) for 11–20 March 1987.

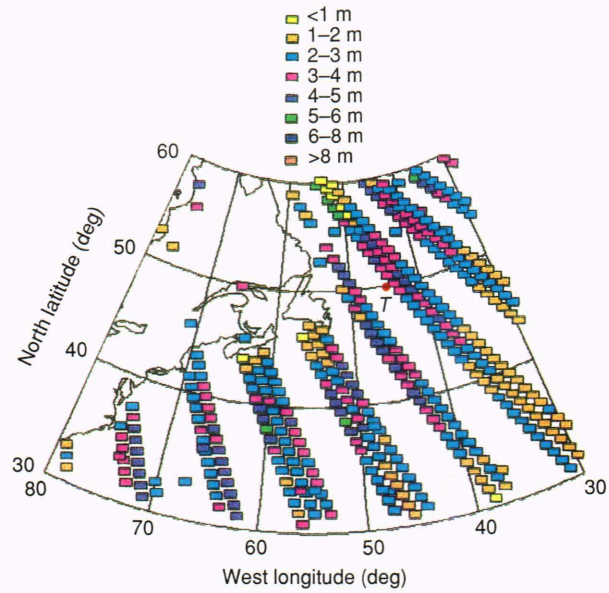

Figure 5. Composite map of ascending ground tracks showing significant wave height (m) for 11–20 March 1987.

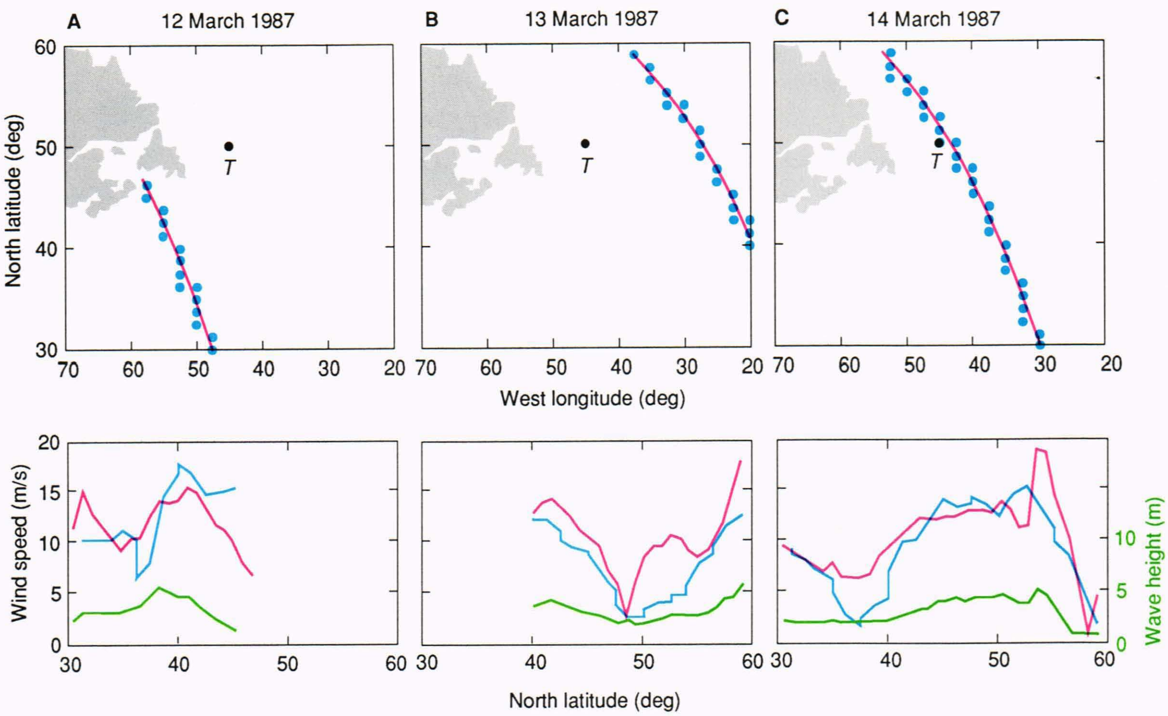

Figure 6. Plots of Geosat ascending tracks and model points closest to track points. **A.** 12 March at 1100 UT. **B.** 13 March at 0920 UT. **C.** 14 March at 1029 UT. Bottom: Corresponding plots of Geosat wind speed (blue), model wind speed (red), and significant wave height (green).

between 40°N and 50°N but differ by 3 to 5 m/s between 35°N and 40°N.

The time and spatial differences between compared estimates from Geosat and the model winds contribute to the differences between the two data sets. Thus, even if both data sets were identical, some differences would result simply from the lack of interpolation. Computations of the wind speed autocorrelation functions along the Geosat tracks indicate that a 50% decorrelation occurs anywhere between 150 and 700 km. Monaldo[6] found that hourly measurements of wind speed from two National Data Buoy Center buoys were essentially uncorrelated after six hours and that at least a 1.3-m/s change could be expected between wind speed measurements made two hours apart. Even so, the time and spatial differences between these LEWEX comparisons (three hours

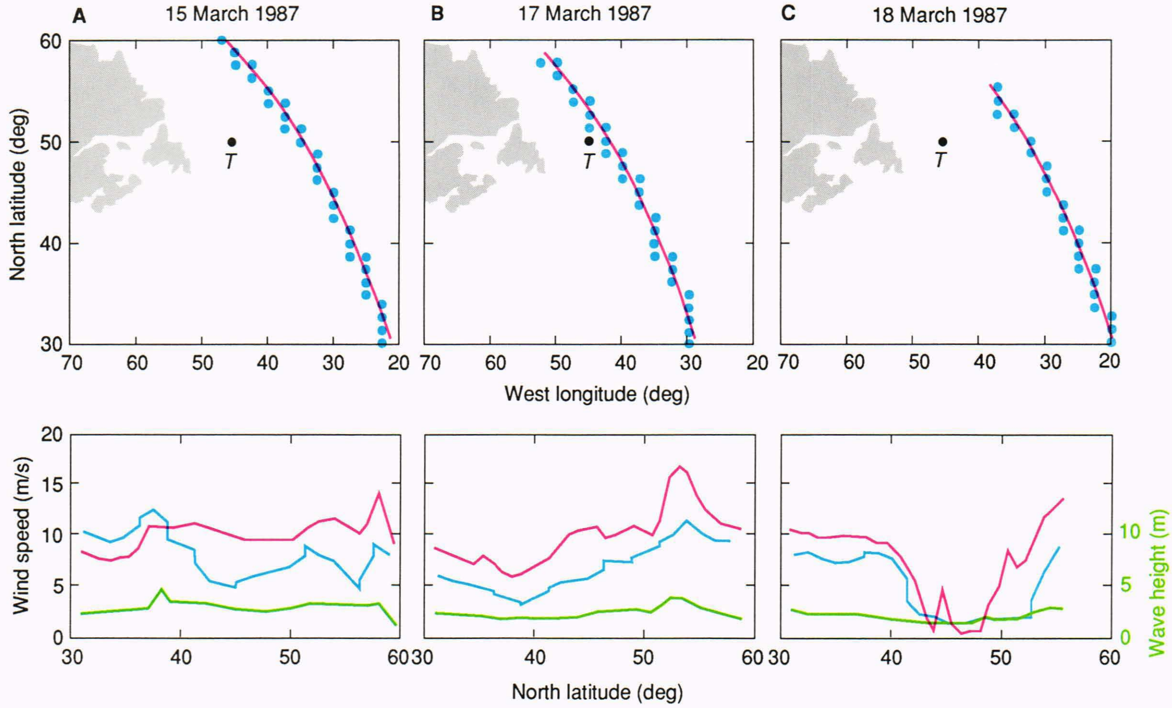

Figure 7. Same as Figure 6, except for: **A**. 15 March at 0958 UT. **B**. 17 March at 1106 UT. **C**. 18 March at 1036 UT.

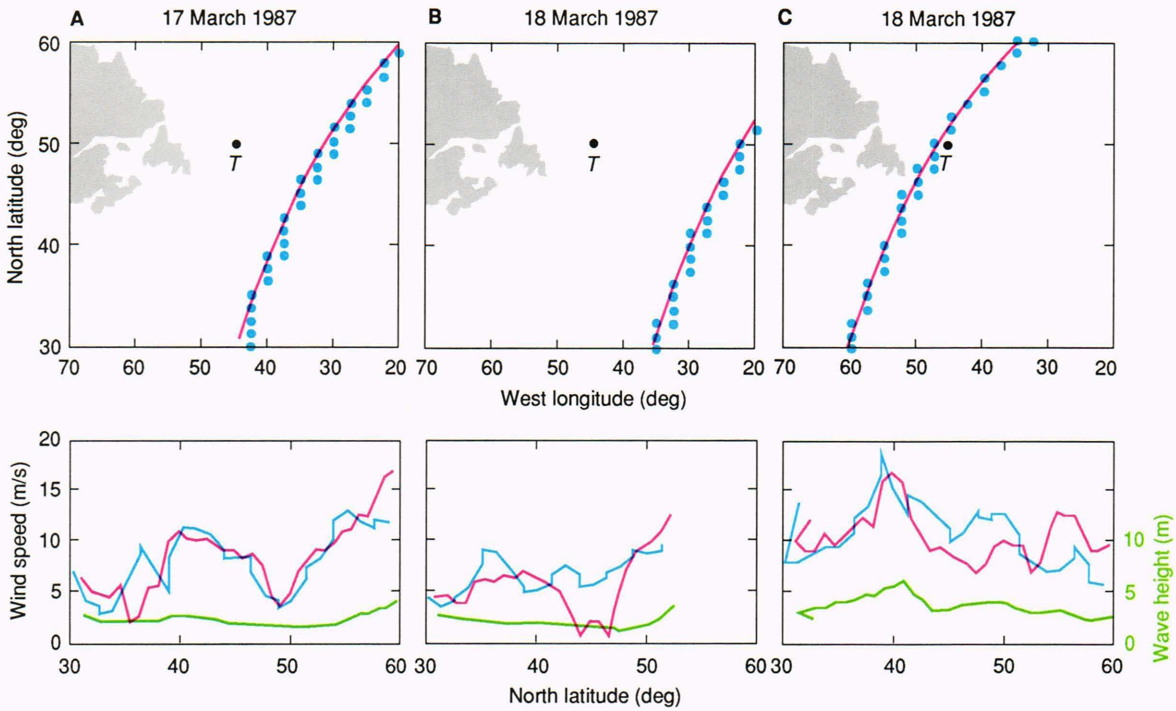

Figure 8. Same as Figure 6, except descending tracks for: **A**. 17 March at 0052 UT. **B**. 18 March at 0020 UT. **C**. 18 March at 0220 UT.

and 100 km) cannot account for all of the differences observed.

In Figure 6 (bottom graphs), the trends of the measurements are, in general, the same, but the differences in magnitude are quite large at certain locations. For example, in Figure 6B (bottom) between 50°N and 55°N, both estimates are increasing with latitude, but Geosat shows a much steeper gradient than the model. This example of higher-frequency spatial structure is typical of the Geosat wind estimates and may be an indication of small-scale features not captured in the model. The Geosat SWH estimates usually correlate well with the Geosat wind speed estimates. In Figure 7 (bottom), the Geosat winds are substantially higher (often greater than 2 or 3 m/s) than those of the model. No attempt was made to smooth the model or Geosat data along the track, thereby accounting for the jagged nature of the data. Figure 8 shows three more comparisons. In Figure 8A (bottom), both estimates track well (usually within 1 m/s), but in Figures 8B and 8C (bottom), the differences approach 5 m/s over substantial regions along the pass. Figure 8C (bottom) indicates that the model winds are biased high on this day in the northern portion of a storm to the southwest of LEWEX (45°N to 50°N).

For a statistical measure of the average disagreement between Geosat and the model wind speed estimates, Table 1 shows mean and rms differences for 692 comparisons along twenty-seven Geosat tracks. Mean differences along a single pass range from −5.1 to +3.2 m/s. The range for rms differences is from 1.0 to 6.6 m/s. The number of points in each computation is given in the last column. For all days, the mean difference was −0.6 m/s, and the rms difference was 3.4 m/s, using 692 data points. To determine whether greater bias at higher wind speed exists, we repeated the computations using only model wind speeds greater than 10 m/s. The results are shown in Table 2. Model winds greater than 10 m/s were biased high by 1.5 m/s, whereas the rms difference for all 215 points dropped to 2.5 m/s. Again, the rms error in Geosat wind estimates is 1.7 m/s, so rms differences of 3.4 and 2.5 m/s may not be significant.

The exact error structure in the LEWEX common winds cannot be determined with a single set of Geosat estimates. Comparisons with ship measurements[7] showed that on some days during LEWEX, the model/ship rms differences in specific regions ranged from 5 to 10 m/s, and the mean differences ranged from 0 to +2.7 m/s. We recognize, of course, that measurements obtained from ships of opportunity can have large errors (see the article by Pierson in this issue), but if even a portion of this error is due to the model winds, then the differences between Geosat and the model are probably not significant when averaged over the entire experiment. Nevertheless, a significant amount of spatial structure in the wind field clearly exists, although it is entirely missed in the model.

CONCLUSION

We have presented the wind and wave fields as estimated by Geosat during LEWEX. Geosat wind speeds were compared with slices through the LEWEX common wind fields. For the entire experiment, the rms differ-

Table 1. Statistical comparison of model wind speed estimates minus Geosat wind speed estimates.

Date (March 1987)	Mean difference (m/s)	Rms difference (m/s)	Number of points
12	−1.39	4.38	32
12	1.22	4.05	20
12	−2.11	1.73	30
12	−0.09	4.86	23
13	−2.45	3.09	27
13	3.06	6.58	23
13	−1.53	1.19	3
13	−1.55	2.80	37
13	2.06	0.99	4
14	−2.43	3.06	14
14	−0.67	2.88	39
14	−5.11	3.43	17
14	−3.75	2.64	37
15	−1.58	2.84	37
15	−4.31	5.60	29
15	−0.17	2.11	29
15	1.23	4.24	27
15	1.64	2.12	17
16	0.31	3.11	37
17	−3.21	4.92	12
17	−2.37	1.92	38
17	0.09	2.58	35
18	−2.46	2.78	35
18	−0.49	2.57	14
18	1.08	2.67	27
18	0.73	3.20	37
18	3.17	4.16	12
All days	−0.60	3.44	692

Table 2. Statistical comparison of model wind speed estimates minus Geosat wind speed estimates for model winds greater than 10 m/s.

Date (March 1987)	Mean difference (m/s)	Rms difference (m/s)	Number of points
12	3.2	3.53	12
12	2.1	3.11	18
12	3.1	4.2	13
13	−2.0	3.3	11
13	6.3	5.7	15
13	−0.7	0.03	2
13	0.8	2.3	14
13	2.1	1.0	4
14	2.1	1.92	3
14	0.3	2.2	18
14	−2.3	0.4	4
15	1.8	1.4	11
15	−0.1	0.6	6
15	4.3	3.0	15
16	3.5	2.1	13
17	1.7	3.8	5
17	4.2	0.7	2
17	1.1	2.9	15
18	−3.4	0.4	2
18	1.8	3.0	5
18	−1.1	0.7	2
18	2.8	2.5	5
18	4.1	0.8	5
All days	1.5	2.5	215

ence was 3.4 m/s, and the mean difference (model minus Geosat) was −0.6 m/s. Geosat tracked closest to the research vessels *Quest* and *Tydeman* on 16 March, passing just to the west of the *Quest*. At closest approach, the Geosat SWH was 4.7 m, compared with 4.6 m measured by the Endeco buoy at the *Quest* and 2.9 m measured by the Wavescan buoy at the *Tydeman*. The sparse sampling of Geosat ground tracks on any given day is inadequate to initialize wind models. The Geosat estimates, however, reveal a spatial wind structure that is not well modeled.

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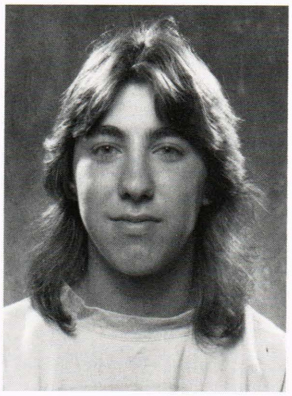
THE AUTHORS

ELLA B. DOBSON has been at APL since 1962 and is a member of the Principal Professional Staff. She received a B.S. degree in mathematics from Fisk University in Nashville in 1960 and a masters degree in numerical science from The Johns Hopkins University in 1970. She is a member of Phi Beta Kappa and Beta Kappa Chi. Ms. Dobson has conducted research on remote sensing of the atmosphere and oceans for most of her career. For the last six years, her research has focused on oceanographic circulation along with winds and waves.



STEPHEN P. CHAYKOVSKY was in his junior year at Hammond High School when he collaborated on this work. His interests include space and space vehicles, aerodynamics, flight dynamics, and propulsion, with a special interest in flight structures. In the spring of 1988, he participated in the Mentor Program sponsored by the Howard County Public School System, working on a one-to-one basis with Ms. Dobson. He is currently a freshman at The University of Maryland, College Park.