

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY) 03/22/2000		2. REPORT TYPE FINAL		3. DATES COVERED (From - To) 3/15/95 to 12/31/97	
4. TITLE AND SUBTITLE SOUND PROPAGATION FROM THE CONTINENTAL SLOPE TO THE CONTINENTAL SHELF: REMOTE SENSING COMPONENT				5a. CONTRACT NUMBER N00014-95-1-0575	
				5b. GRANT NUMBER N00014-95-1-0575	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Kathryn A. Kelly and Michael J. Caruso				5d. PROJECT NUMBER 1300575.00 (WHOI #)	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research Attn: Dr. Lou Goodman 800 North Quincy Street ONR Code 322PO Arlington, VA 22217-5660				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for Public Release, Distribution is Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Satellite altimetry and AVHRR images were used in conjunction with in-situ measurements to understand the geometry and seasonality of the shelf/slope front and the fluctuations of the slope water along the East Coast of North America. The AVHRR images were used to show the location and orientation of the shelf/slope front and the altimeter was used to study the fluctuations of the geostrophic currents. The imagery was used in near real time during at-sea intensive observation periods to provide a context for the surveys and acoustic work. The altimeter data was also used to study the larger-scale and longer time period variations in sea surface height (SSH) and geostrophic currents.					
15. SUBJECT TERMS Satellite Altimetry, AVHRR Images Shelf/Slope Front, Geostrophic Currents					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	UU	5	19b. TELEPHONE NUMBER (Include area code)

Final Report ONR 322PO
Sound Propagation from the Continental Slope to the Continental Shelf:
Remote Sensing Component

Award #: N00014-95-1-0575

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LONG TERM GOALS

To use satellite altimetry and AVHRR images in conjunction with *in situ* measurements to understand the geometry and seasonality of the shelf/slope front and the fluctuations of the slope water along the east coast of North America.

OBJECTIVES

We used the AVHRR images to show the location and orientation of the shelf/slope front and used the altimeter to study the fluctuations of the geostrophic currents. The imagery was used in near real time during at-sea intensive observation periods to provide a context for the surveys and acoustic work. The altimeter data was used to study the larger-scale and longer time period variations in sea surface height (SSH) and geostrophic currents.

APPROACH

To use the altimeter data for sub-tidal geostrophic current estimates, it is first necessary to remove an estimate of the tidal component of SSH along each satellite subtrack at each time. Though tidal models have been greatly improved using satellite altimetry, they are not as accurate in shallow water (less than 1000 m) than they are in deep water. This is particularly problematic because the SSH gradients associated with shallow water currents are not large. Therefore we examined and compared several tidal models, including one from a hydrodynamic tidal model designed for accuracy in coastal applications and one derived from *in situ* current observations. Professor Christian LeProvost's group in Grenoble, France, ran the hydrodynamic model on a high resolution grid in the western North Atlantic coastal region specifically for our study. Dr. Alberto Scotti, working with Dr. Robert Beardsley at WHOI, computed a tidal correction from historical and Primer current meter velocities.

WORK COMPLETED

We completed an extensive comparison of the skill of five tidal models in removing tidal fluctuations from the altimeter data, by examining both SSH and geostrophic currents. Two tests of the tidal model's effectiveness were devised for this study, based on the expected contribution of the tides to SSH and velocity fluctuations. A good tidal correction should reduce the variance of both SSH and velocity because a portion of the signal is being removed. In addition, because the 10-day repeat cycle of the TOPEX/Poseidon satellite aliases the dominant semi-diurnal tides to periods near 60 days, the tidal correction should reduce the spectral energy near this period. Finally, the tidally corrected SSH should give a better agreement between geostrophic and *in situ* current estimates.

After the application of the tidal correction, the SSH anomalies were used to compute geostrophic currents. These currents were compared with current meter measurements provided by Dr. Robert Pickart at WHOI. The large-scale coherent variations in slope currents were examined for more than four years and some theories about the causes of interannual variations were examined.

RESULTS

The examination of tidal corrections showed that all of the tidal corrections reduced SSH variance and the 60-day period alias for SSH with relatively high skill. However, although the altimetric tidal corrections worked relatively well for velocity on the mid-shelf and in deep water, the correction increased the velocity variance over the outer shelf and slope on some subtracks (Figure 1). None of the corrections gave an overall reduction in velocity variance or in the 60-day alias for all of the subtracks. The worst results for velocity were obtained on the subtrack nearest to that on which the *in situ* observations were made. The *in-situ*-based correction had negligible skill in reducing velocity variance. Because of the inadequacy of the tidal corrections, it was not possible to examine the shelf/slope front, which would have required corrected SSH for shallow water. However, the slope currents are an indication of the overall strength of the shelf/slope front and an extensive analysis of the low-frequency slope currents was conducted, after removing all SSH variations at 60-day periods, as a proxy for a tidal correction.

SSH, with the 60-day period variations removed, produced geostrophic current estimates which were highly correlated ($\rho > 0.7$) with near-surface subtidal currents in water deeper than about 1000 m. Currents were measured by current meters at a water depth of approximately 100 m for water depths of 2990 m, 2210 m, 1000 m. The highest correlations occurred in the deepest water, consistent with the assessment that tidal corrections are more accurate in deeper water.

Given the high correlations for the altimetric and *in situ* currents, the geostrophic currents along six subtracks along the Atlantic coast were examined. The seasonal current anomalies were relatively coherent over the region (approximately 1200 km along the coast, from Nova Scotia to New Jersey) and in agreement with previous observations. An EOF analysis of the currents

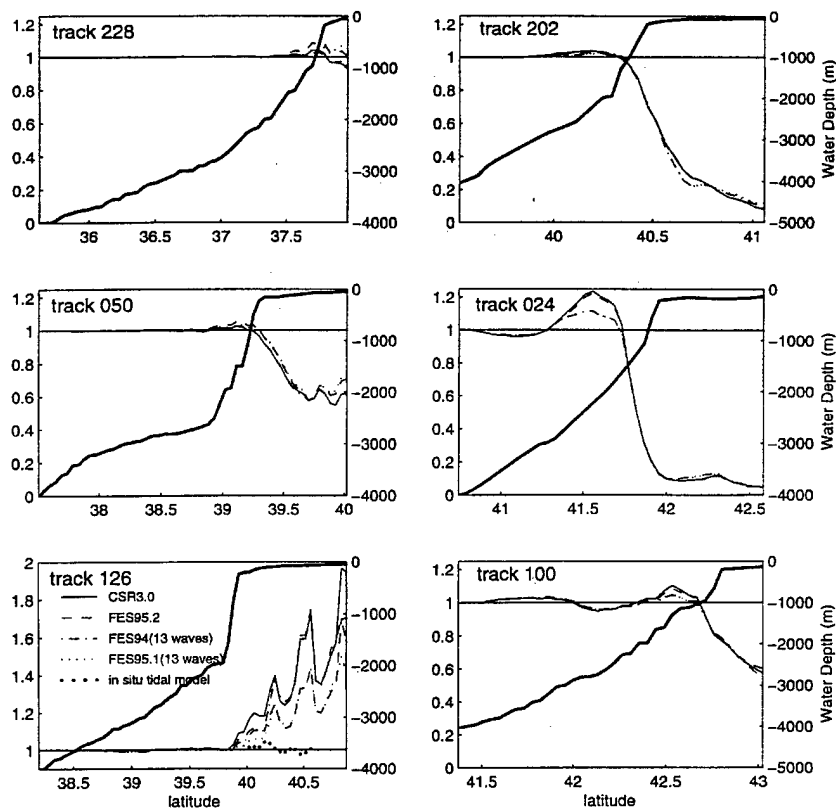


Figure 1. The ratio of the variance for the alongtrack SSH derivative with and without tidal corrections for six T/P tracks. Bottom depth is shown by the dark solid line.

(Figure 2) confirmed the dominance of the seasonal anomalies, but also revealed that the seasonal pattern was interrupted in 1996 and currents remained steadily toward the southwest through the winter. The second EOF of slope currents showed relatively large and localized fluctuations near the Gulf of Maine.

Some theories regarding the interannual variations in the currents were examined, including the possibility that changes in the Gulf Stream path or changes in the Labrador Sea caused the slope current anomalies. The Gulf Stream path for the region was computed using the method of Kelly and Gille (1995) and the Gulf Stream was found to have moved southward by nearly one degree of latitude during 1996. The Gulf Stream path variations were significantly correlated with the zonally averaged slope currents. Because the Labrador Sea is thought to be the source of the slope current water, changes in the SSH in the Labrador Sea, and specifically, the difference in

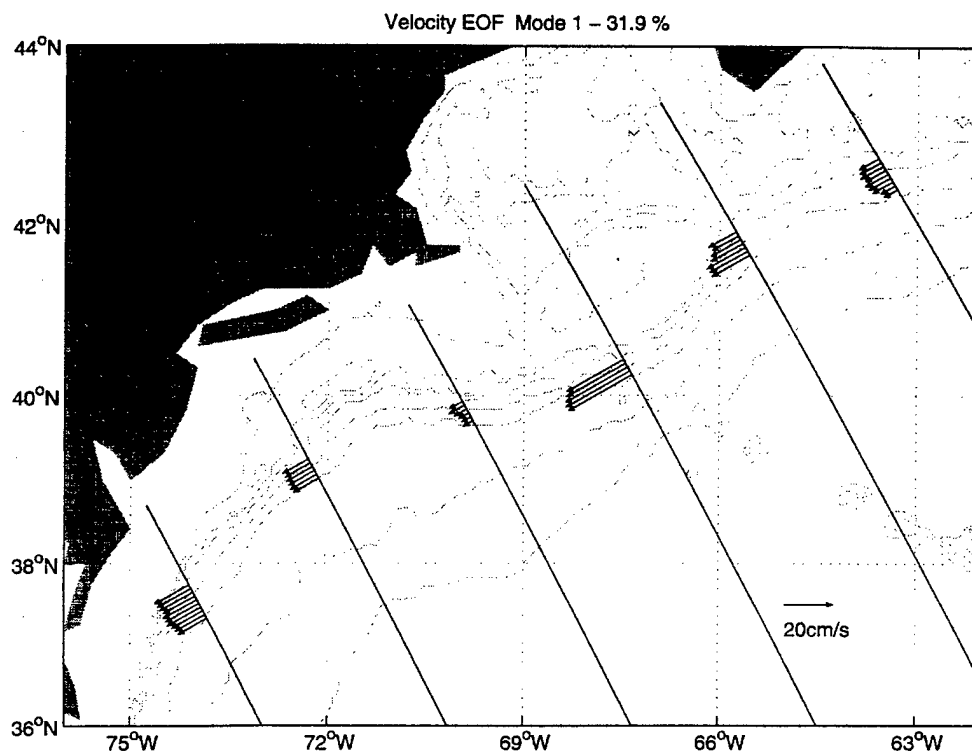


Figure 2a. Spatial function of the first EOF of the geostrophic velocity.

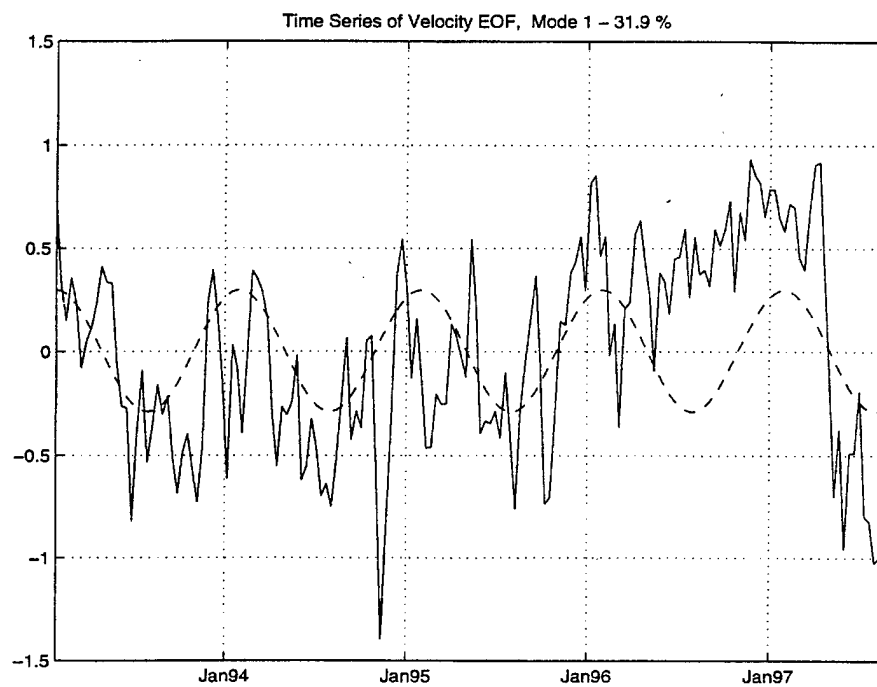


Figure 2b. Time series of the first EOF of the geostrophic velocity (solid) and the corresponding annual harmonics (dashed).

sea level between the Labrador Current along the Canadian coast (52°N) and SSH in the mid-Atlantic Bight region (37°N) were computed. This time series of alongshore pressure gradient was also found to be significantly correlated with the zonally averaged slope currents. Not surprisingly, the sea level difference and the Gulf Stream path were also correlated. Thus, neither theory can be eliminated as the cause for the slope current changes. However, it is suggestive that the slope current changes were part of the large-scale adjustment of the North Atlantic to abrupt change in the North Atlantic Oscillation in 1996.

IMPACT/APPLICATIONS

The analysis of tidal corrections for the altimeter demonstrates that, although the tidal corrections are useful for reducing aliasing in SSH, this SSH improvement does not translate into an improved velocity estimate, presumably because the large-scale SSH tidal variations over the shelf and slope are coherent, whereas the smaller scales in the tidal corrections are not sufficiently accurate to produce good gradients of SSH.

The analysis of slope currents showed that the current fluctuations are coherent over a region of more than 1200 km on the Atlantic coast and that the dominant fluctuation is seasonally reversing currents. However, there are interannual variations in the slope currents, which can overwhelm the seasonal cycle. These interannual current variations are related to large-scale changes in the western North Atlantic Ocean, probably owing to changes in the North Atlantic Oscillation. Thus the slope currents have a strong climate signal which probably has implications for slope water circulation, slope water characteristics, and fisheries.

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