Proceedings of

International Workshop on Numerical Prediction of Oceanic Variations

Science and Technology Agency
Japan Meteorological Agency

Tokyo, Japan

7-11 March 1995

A Decadal Impact of the 1982-83 El Niño on the Northern Pacific Ocean

Harley E. Hurlburt, Gregg A. Jacobs and Jimmy L. Mitchell

Naval Research Laboratory
Stennis Space Center, MS 39529 USA

In a recent paper published in Nature we presented evidence which indicates that the effects of equatorial El Niño episodes are more far-reaching than previously believed [1]. In 1991 significant anomalies in both the ocean circulation and Sea Surface Temperature (SST) over the North Pacific Ocean were linked with this century's largest such episode, the 1982-1983 El Niño. This decadal link is provided by a Rossby wave which propagated across the entire Pacific Basin.

The effects of the 1982-83 El Nino at the Peru and Ecuador coasts were almost immediate: the Sea Surface Height (SSH) rose and SST increased [2]. The subsequent reduction in fish populations [3, 4] and the increased rainfall [5] severely impacted the regional economies [6]. These local effects, which last from 1 to 2 years, are normally associated with El Nino events.

Recently observed oceanic anomalies in SSH and SST indicate that during 1991 to 1993, a portion of the Kuroshio Extension transport was routed to a more northern latitude. In this paper we present evidence that the 1982-83 El Nino is responsible. The anomalous northward routing of a portion of the Kuroshio Extension advected warm waters further north than normal, resulting in extremely warm SST anomalies across the North Pacific during the early 1990's.

The observational evidence for this rerouting of a portion of the Kuroshio Extension comes from satellite altimeter and infrared data. Significant changes in SSH are seen in a combined analysis of altimeter data from the Geosat-Exact Repeat Mission satellite (Geosat-ERM) [7] and the European Remote Sensing satellite (ERS-1). The resulting change in SSH (Fig. 1a) represents a change in ocean circulation over the interval from 1988 to 1993. Similar results are obtained by a combination of TOPEX/POSEIDON and Geosat-ERM altimeter data.

In Figure 1a, a positive SSH anomaly centered just south of 40°N at 175°E lies north of the Kuroshio Extension. The anomaly indicates that a portion of the current is routed to a path that follows the northern slope of the anomaly. The circulation changes imply changes in SST as warm waters are advected further north. A consistent set of global SST has been compiled since 1985 by Reynolds [8]. A warm SST anomaly north of the Kuroshio Extension is clearly seen in Figure 1b extending from Japan to North America at 40°N. This SST anomaly is just north of the SSH anomaly as expected (Fig. 1). Thus, both satellite-sensed SSH and SST strongly suggest a northward shift of a portion of the Kuroshio Extension and a subsequent anomalous northward transport of warm waters.

Concurrent with the recent abundance of satellite data is a revolution in our ability to numerically resolve oceanic dynamical processes in models [9]. From a numerical model simulation, we use results which cover the decade from 1981 to 1993. The model simulation and observational data provide independent results. This synergy is very important as results from one source alone may be inconclusive due to errors or assumptions. SSH changes in the model simulation (Fig. 1c) indicate an anomaly from Japan to Alaska similar to that of the altimeter data. This suggests that the events which give rise to this ridge are realistically simulated in the model. The decadal simulation provides a unique, continuous, high-resolution data set which is used to identify the sequence of events which generate the observed trans-Pacific ridge. An animation of the model SSH variations from 1981 to 1993 clearly reveals that these events began in 1982 as a result of the El Nino.

The 1982-83 El Nino was initiated by the relaxation and subsequent reversal of easterly winds over the western and mid-Pacific [10] which generated an eastward propagating equatorial Kelvin wave. This Kelvin wave reflected from the American continents as a westward propagating Rossby wave. The subsequent propagation of the El Nino-generated Rossby wave across the entire North Pacific is shown in Figure 3.

Up to now, propagation of a Rossby wave across the Pacific Ocean at these high latitudes has never been demonstrated. Comparisons of the Geosat altimeter data at 30°N with model results verifies the wave's trans-basin journey (Fig. 4). Rossby waves, observed at the coast of the American continents [11,12], were not anticipated to propagate an appreciable distance into the basin as coherent structures. The energy of the wave was expected to cascade to smaller scales (i.e., the wave could dissipate into eddies) and not to propagate as far as Hawaii at this latitude. However, our observations and simulations indicate that the Rossby wave not only remained intact as far as Hawaii, but continued across the basin and is coherent well over a decade later. The Rossby wave generated by the 1982-83 El Nino exists today in the northwest corner of the Pacific Ocean.

Two additional ocean model simulations were performed to help isolate the decadal effects of the 1982-83 El Nino. One simulation was initialized in 1984 after the El Nino and shows the absence of the El Nino-generated Rossby wave at 30°N (Fig. 4c). The other experiment starts in 1981, includes the 1982-83 El Nino, but wind forcing reverts to climatology in 1984 to exclude subsequent wind forced anomalies. It shows the Rossby wave (Fig. 4d), and because no knowledge of the ocean or atmosphere after 1983 was used, it demonstrates the potential for decadal predications of El Nino-generated Rossby waves and their effects. The ocean model has helped link observations that were widely separated in space and time. To do this it was essential that the ocean model (a) maintain the Rossby wave for over a decade and (b) propagate it with high accuracy.

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This work was sponsored by the Office of Naval Research (ONR) and by the Advanced Research Projects Agency (ARPA) under the Strategic Environmental Research and Development Program (SERDP).

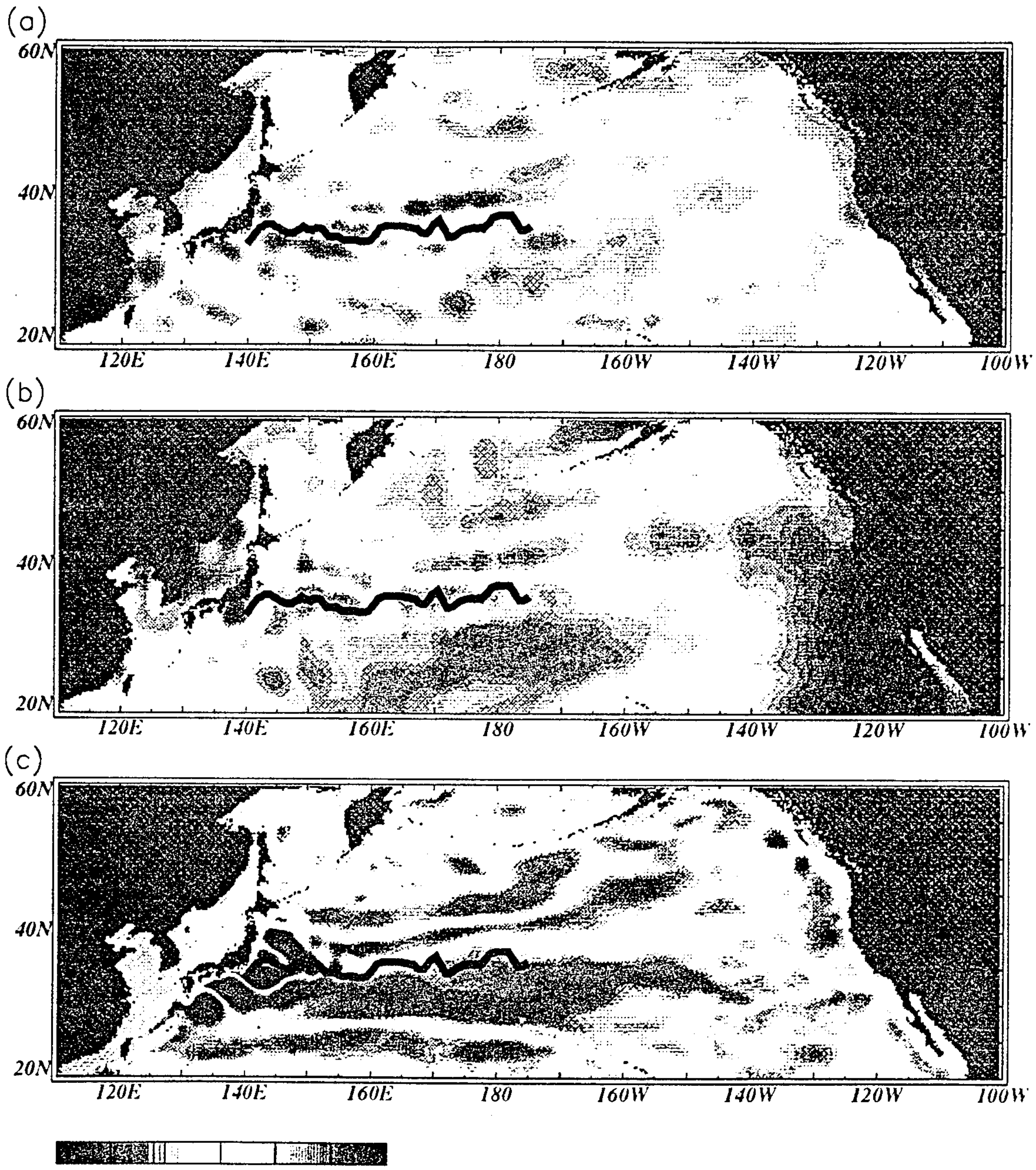

Fig. 1: (a) Change in SSH from the Geosat-ERM (Nov 86 - Oct 89) to ERS-1 (Apr 92 - Mar 93). The color bar indicates changes from -15 to 15 cm. The climatological position of the Kuroshio Extension [13] is plotted so that the positions of the features may be compared. (b) Deviation of SST from satellite IR averaged over Apr 92 - Mar 93 from a mean over 1985-92. Data are supplied by infrared radiometer satellites [8]. The color bar indicates anomalies from -1 to 1°C. (c) Change in model SSH from the time of the Geosat-ERM (Nov 86 - Oct 89) to the ERS-1 time frame (Apr 92 - Mar 93). These are the same time periods as covered by the altimeter satellites in (a). Figure 1c is from a 1/4° 6-layer global ocean model [14,15,16]. This simulation is forced only by winds and is spun up to statistical equilibrium by forcing with the Hellerman and Rosenstein wind stress climatology [17]. Subsequently, the model is forced from 1981 to 1993 with daily 1000 mb winds derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) with the annual mean replaced by that of Hellerman and Rosenstein [16]. The model reproduces all of the major current systems of the North Pacific including the equatorial currents and the Kuroshio Extension [16].

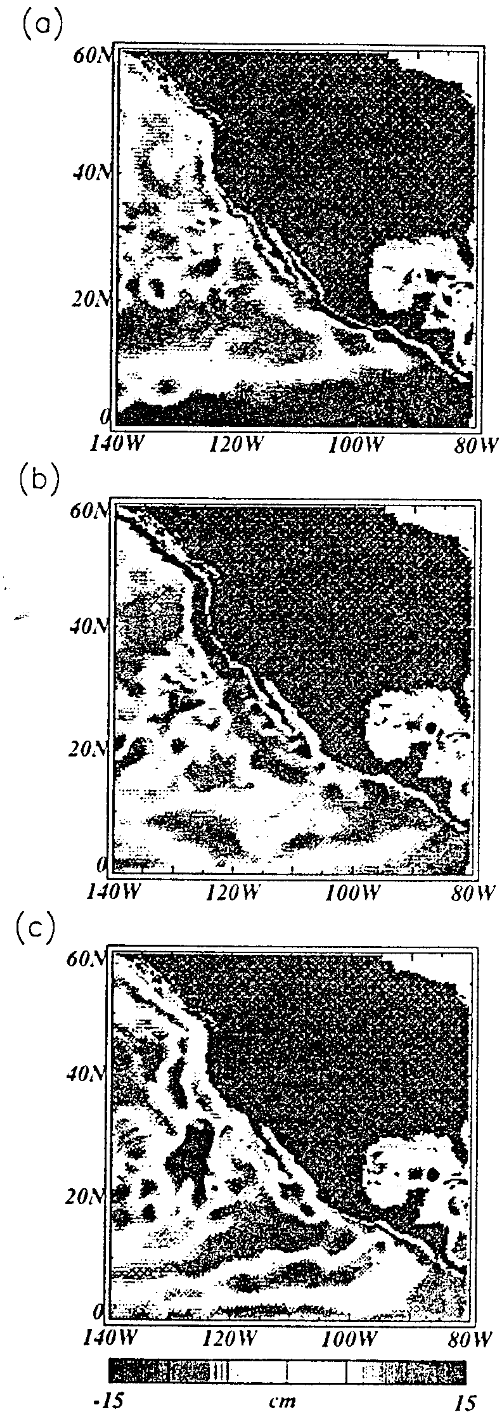

Fig. 2: (a) Model SSH deviation in Aug 1982 from a mean over Jan 81 - Dec 92. The SSH high along the equator and along the coast of the American continents is a signature of the 1982-83 El Nino event caused by an eastward propagating equatorial Kelvin wave [18,19]. (b) Model SSH deviation 5 months after the time of Figure 2a. Upon reaching South America, the equatorial Kelvin wave generates poleward propagating coastal Kelvin waves along the western coasts of the Americas. The SSH high along the equator diminishes significantly, but coastal Kelvin waves, which propagated up the North American coast, leave a high in SSH along the entire coast. Historically, in response to other El Nino events, coastal Kelvin waves have been observed to propagate along the coast of North America as far as the Aleutian Islands [20]. (c) Model SSH deviation 9 months after the time of Figure 2a. The high SSH along the North American continent begins to peel away from the coast as a westward propagating Rossby wave.

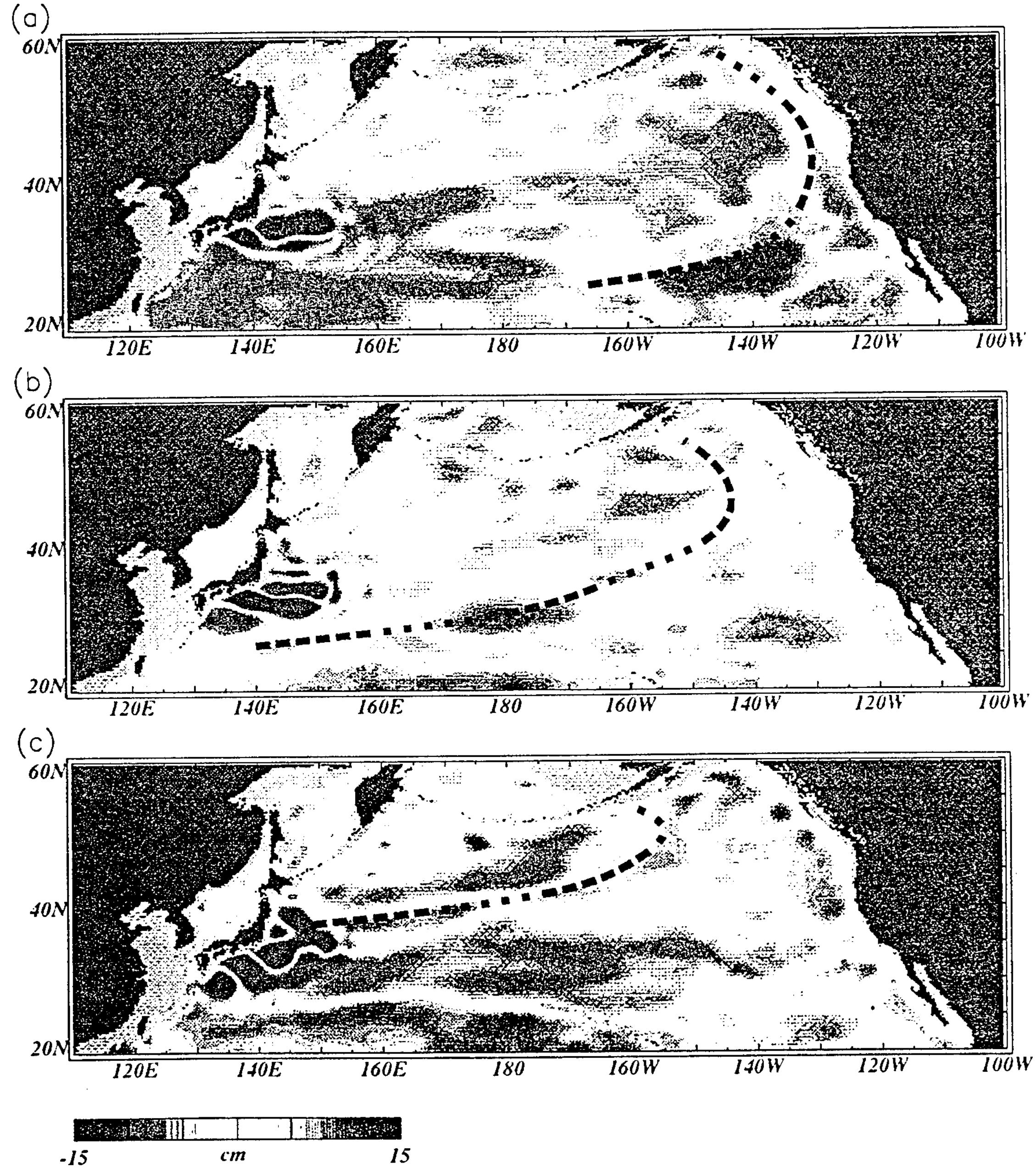

Fig. 3: Model SSH is averaged over one year to filter out short time-scale variability (a: over Mar 84 - Feb 85, b: over May 87 - Apr 88, c: over Apr 92 - Mar 93), and the 11 year model mean SSH is subtracted. The Rossby wave SSH ridge is indicated by the dashed line. Model SSH deviation (a) 2 (b) 5 and (c) 10 years after the 1982-83 El Nino. The decrease in Rossby wave phase speed with increasing latitude causes bending of the wave front [11]. After 10 years the Rossby wave has moved to a position extending from Japan to Alaska.

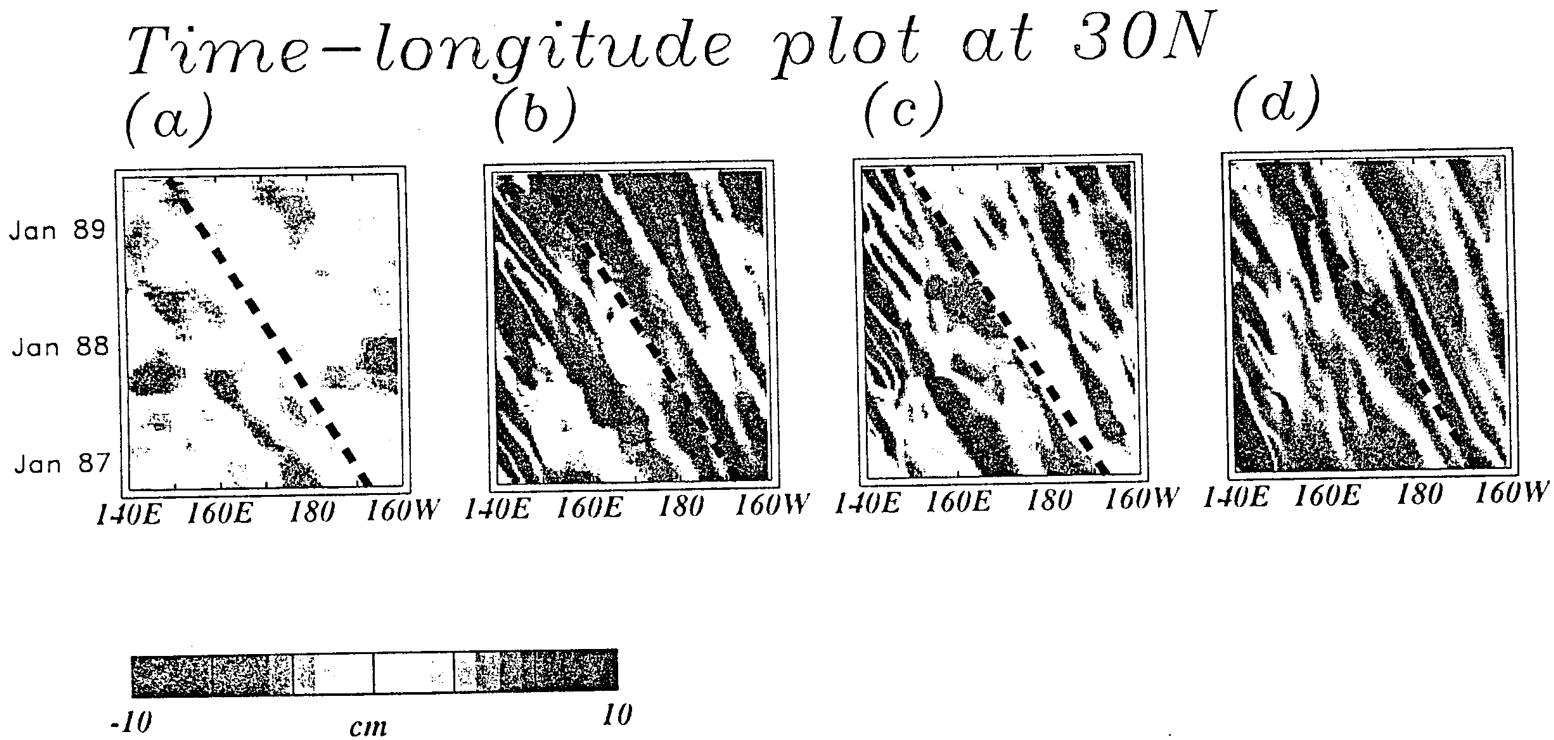

Fig. 4: SSH variation along 30°N from Japan to north of Hawaii (a) from the Geosat altimeter mission and (b) from the model over November 1986 to July 1989. The mean SSH from 140°E to 160°W at each point in time has been removed to reduce the effects of the annual steric anomaly due to seasonal heating and cooling of the ocean surface. The dashed line indicates the propagation of the Rossby wave generated by the 1982-83 El Nino across the Pacific Ocean. The propagation speed at 30°N for the wave is 4.9 cm/s which is very close to the theoretical value of approximately 5 cm/s for a non-dispersive, internal Rossby wave. (c) In another model experiment, the wind anomalies which cause the equatorial Kelvin wave associated with the 1982-83 El Nino are removed by starting it in 1984. The equatorial Kelvin wave and subsequent Rossby wave never occur in the model simulation. (d) In another model experiment, the predictive skill of the model is demonstrated by forcing with observed winds only over the period 1981-84 and climatological winds afterward. The equatorial Kelvin wave results and the Rossby wave chain of events occur. Thus, this phenomena is predictable on decadal scales.

REPORT DOCUMENTATION PAGE

Form Approved
OBM No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1995

3. REPORT TYPE AND DATES COVERED
Proceedings

4. TITLE AND SUBTITLE
A Decadal Impact of the 1982-83 El Niño on the Northern Pacific Ocean

5. FUNDING NUMBERS
Job Order No. 73508905
Program Element No. 0601153N
Project No.
Task No. LR0320444
Accession No. DN153067

6. AUTHOR(S)
Harley E. Hurlburt, Gregg A. Jacobs and Jimmy L. Mitchell

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Oceanography Division
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/PP/7323--95-0056

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Proceedings of International Workshop on Numerical Prediction of Oceanic Variations

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

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14. SUBJECT TERMS
Eddies, Ocean Modeling, Meteorology, Satellites

15. NUMBER OF PAGES
8

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102