OPTIMAL DESIGN FOR LONG-TERM ENVIRONMENTAL MONITORING

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1. Introduction

Coastal region is a rich resource area with complex physical processes. The impacts of anthropological activities on the oceans increase rapidly over this past century, which has caused drastic deterioration of coastal environment. In order to protect the coastal and ocean environment, the development of long-term environmental monitoring has become a critical issue. The objectives of designing long-term monitoring are as follows: 1) determining long-term variability of physical processes; 2) providing *in situ* information for contingency plan for mitigating coastal disasters; and 3) establishing correlation between biological and physical processes to protect living resources.

An important element in designing the monitoring program is the understanding of the physical processes at the site. Yet, the data from the monitoring program are indispensable inputs for our understanding of the physical processes. The optimal design of the monitoring program has to be an iterative process: monitoring leads to increasing understanding, and increased understanding leads to better monitoring. Recent field data collected at the Northeast Gulf of Mexico are adopted here for optimizing the design of further long-term monitoring.

The Gulf of Mexico (GOM) is one of the rich natural resource region. Other than oil and gas, the fishery industry and sandy beach for tourism provide a primary income for local economics. However, the GOM is also indices of global ocean that consists of many ocean physical processes such as Loop currents, eddies, fronts coastal jets, river plumes and wind induced flows (Lai, 1992). The Offshore Minerals Management program of the Mineral Management Service (MMS) has conduct series of studies to assure orderly access to resources on the Outer Continental Shelf to protect the environment.

2. Field Program

One of the studies is the DeSoto Canyon Intrusion Study. Canyon is an important ocean geological feature that controls the exchange of nearshore and offshore flows. Fourteen moorings along three isobaths were deployed at the Northeast GOM during 1996-1999 (Figure 1) to investigate local circulation and the physical processes that control the flow patterns and exchange mechanisms. Total of three years data were collected with water depth ranged from 100 m to 1300 m (MMS, 1999). Other than mooring, hydrographic data, meteorological data, and satellite images were also collected (see also Figure 1). The analysis of collected data is in the process and the results from the analysis will come out soon. Some of the preliminary results will be present here.

During summer and fall of 1998, two hurricanes (Earl and Georges) pass through the region. Most of the moorings function properly. Earl is a short and fast moving hurricane and Georges is strong and slow moving one. Hurricane Georges is a category II storm with estimated maximum winds of 105 mph (47 m/s) on September 27-28, 1998. The center of Georges went through Mooring line A as shown in Figure 1. We are focusing on the ocean response to the Georges. Preliminary results of storm-induced vertical transport have been analyzed.

3. Analysis of Data and Discussion of Results

To investigate the ocean response of passing hurricane, an Empirical Mode Decomposition (EMD) method developed by Huang et. al (1998) has been applied for data analysis. The EMD method offers a direct way to extract ocean response signal without loosing their physical characteristics. Wind data from two buoys during Hurricane Earl (9/2-9/3, '98) and Georges (9/27-9/28, '98) are shown in Figure 2. The spikes in the wind data clear identify the passage of hurricanes.

Kinetic Energy: A series of current data at station B3 is shown in Figure 3. All the current data are analyzed with EMD method. A typical example for the data at the water depth of 20 m is discussed in more details here. After decomposed with the EMD method, the data yield 10 components and shown in Figure 4.

Most of the high frequency (period shorter than the inertia oscillation) energy is contained in C1 to C4 components. Superimposed of these four components at all level should be able to estimate the vertical transport of energy. The total energy of these four components, U^2 and V^2, are shown in Figure 5. (The U is the current in East-West direction and V in the current in the North-South direction.) Energy level decades quickly after the depth reach 40 meters. From other analysis of thermal structure of the data, we found that 40 m is the depth of the main summer thermocline. In the upper layer (<40 m), the response from wind forcing is almost simultaneously. But the wind caused mixing is arrested by the thermocline, which plays an important role in vertical energy transport.

Inertial Oscillation: After deducting the high frequency components, the residual is the inertia current. The persistence of oscillation induced by the storm wind is clearly shown in Figure 3. This indicates that the inertial oscillation (IO) of NEGOM region is enhanced by resonance with that of diurnal forcing (Simpson, et. al, 2000). Measured data at station B3 are analyzed to investigate the characteristics of inertial oscillation. The same EMD method but with different iteration scheme is used here to capture the intermittent of the data. The decomposed data using above technique is similar to the one given in Figure 4. In this case, most of the energy in the inertia oscillation is represented by a single Intrinsic Mode Component, C5. The progressive vector diagram of U and V is plotted to identify the inertial oscillation and compares with local wind vector to show its independency of wind forcing. The results for three different depths are shown in Figure 6.

Four curves representing flow patterns are shown in this figure. Two outside curves are hurricane wind measured from Buoy 39 and 40 with different scales to be plotted in the same figure. The large circles of wind represent a large scale of wind passing through the region. Since these two buoys are located at the same quadrant of the storm radius, the flow patterns are similar. For the measured currents, we plot mean current and decomposed current (IMF) with superimposed of C5, C6, and C7 components. Although the hurricane wind is going around a big circle, the inertial oscillation are generated and rotated in different patterns. The starting points of the curves are marked with small circle. The rotations of IO are anticyclonic motions that are consistence with other field observation (Simpson, et. al, 2000). The inertial oscillation starts with a big shift by strong input from hurricane wind but settle down with uniform rotation with 5 to 6 cycles before they damped. This pattern persist through water depth of 72 m where measured by uplooking ADCP. At he water depth of 500 m, the similar pattern of IO exist but with irregular shape (Figure 6c). At the bottom of the mooring site with water depth of 1290m, some pattern of IO exist but the effect other physical parameters such as pressure gradient and/or damping may start to control the flows (Apel, 1987). The IO at the bottom of the deep water becomes harder to identify.

Inertial oscillation is a near rotary motion as shown in Figure 6. The frequency of oscillation, T_i, can be estimated as:

$$T_i = 2\pi/2\Omega\cos\theta ,$$

where Ω is the earth's angular velocity and θ is the polar angle that is equivalent to latitude of the earth. The latitude of the DeSoto Canyon is 29 degree; therefore, the estimate inertial frequency is 0.972 cpd (cycle/day). Using the standard Fourier analysis, one can easily show that the spectral peak is very close to this value, but this value represents only the mean. Influenced by the ambient background motions, the true frequency of the oscillation is ever changing. To show this nonstationary nature of the true oscillation, we decide to use the Hilbert Spectral representation, which is shown in Figure 7. Here the frequency of the main inertia component is shown to be variable, but it is centered around the mean value.

4. Conclusion

A large field program that consists of three arrays of mooring and hydrographic survey has been conducted over the NEGOM region. During the course of study, several storms and hurricane pass though the region. Hurricane Georges of 1998 was chosen to investigate the response of ocean by strong wind. The recent developed EMD method has been applied to extract vertical energy transport. Preliminary results indicate that the main thermocline at 40 meters acts as a strong barrier to the storm induced mixing in the upper ocean layer. The strong wind also initiates the inertial oscillation. The resonance of inertial oscillation has been observed at the deep-water site. Although the numbers of oscillation reduce as they enter deeper water, the penetration of IO has been measured to bottom of 1000 m depth. The inertial oscillation generates a large scale of anticyconic motion that may be considered as a major contributor of the vertical transport of kinetic energy. Based on the study of this study, the long-term monitoring station should set up along the steep slope of the shelf region to capture exchange of cross-shelf flow. However, further analytical analysis and numerical model should be used to validate the recommendation.

References

Apel, J.R., 1987: Principles of Ocean Physics, Academic Press.

Huang, E.H., Z. Shen, S.R. Long, M.C. Wu, H.H. Shih, Q. Zheng, N.C. Yen, C.C. Tang and H.H. Liu, 1998: The Empirical Mode Decomposition and the Hilbert Spectrum for Nonlinear non-stationary Time Series Analysis, Proc. R. Soc. Lond. A, 454, 903-995.

Lai, R.J., 1992: The Gulf of Mexico – Indices of Global Ocean Processes, MTS'92, October 19-21.

Minerals Management Service, 1999: DeSoto Canyon Eddy Intrusion Study Annual Report: Year 3, MMS Pub No. 99-56.

Simpson, J.H., T.P. Pippeth, P. Hyder and I. Lucas, 2000: Inertial Oscillation Near the Critical Latitude for Diurnal Resonance, 2000 Ocean Sciences Meeting, January 24-28.

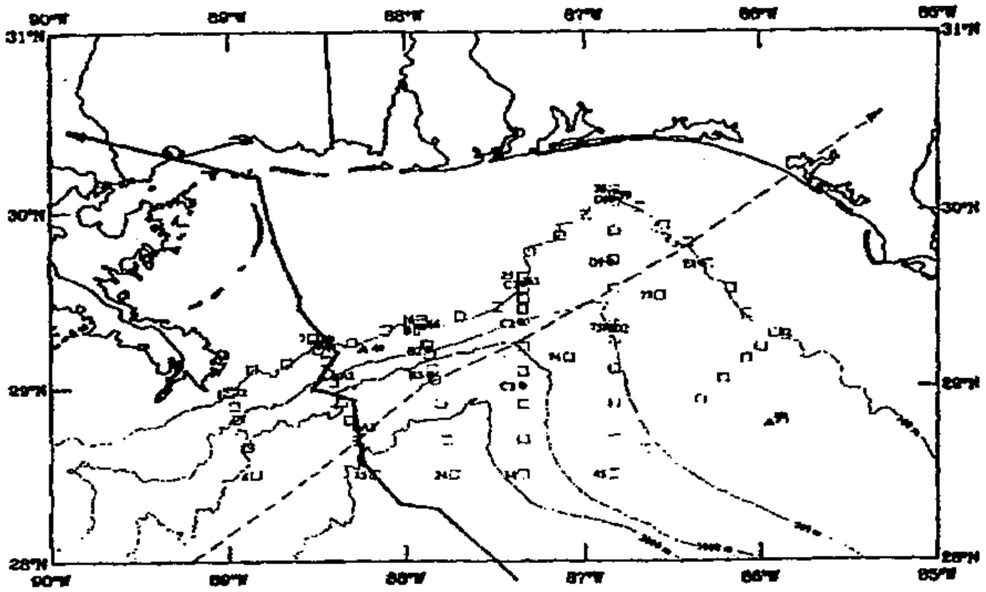


Figure 1. Instruments lay out for DeSoto Canyon Eddy Intrusion Study. Mooring locations are shown as solid dots. Hydrographic stations are shown by an open box. Marine buoys are shown in solid triangle. The solid line represents the path of Hurricane Georges and dotted line is for Hurricane Earl.

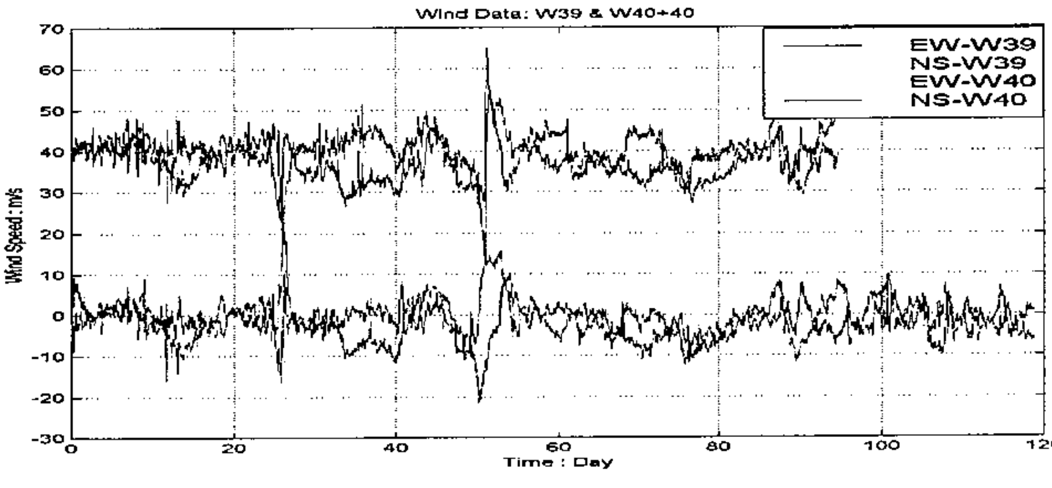
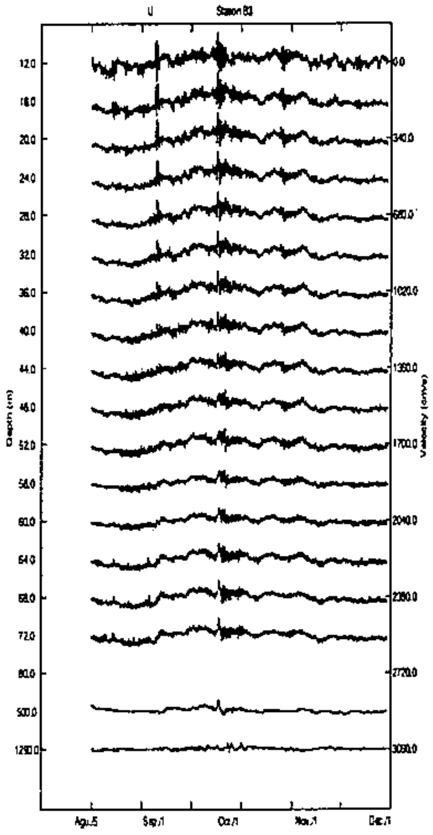


Figure 2. Measured wind data at Buoy 39 and 40 during 1998 hurricane season are shown in East-West (EW) and North-South (NS) direction.



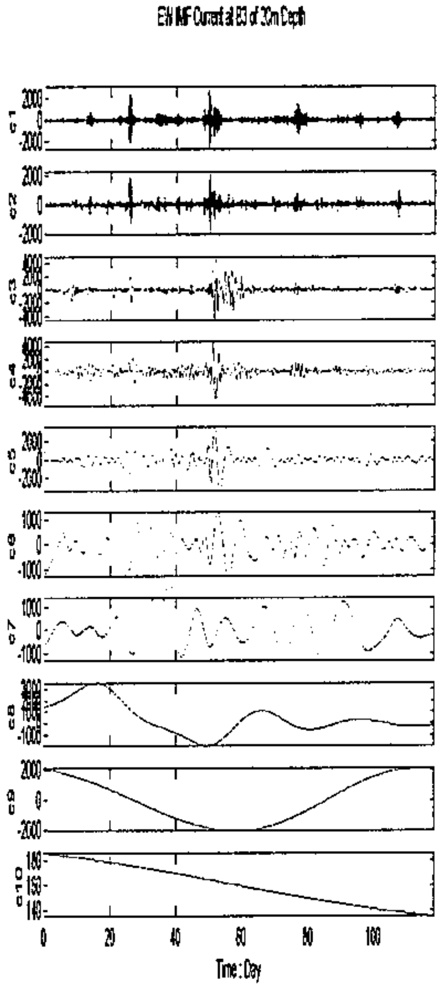


Figure 3. Measured Currents at B3 station.

Figure 4. Current components by using EMD method.

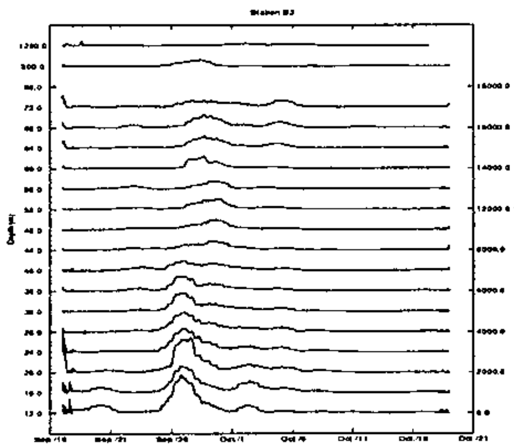


Figure 5. Total energy of first four components of IMF current.

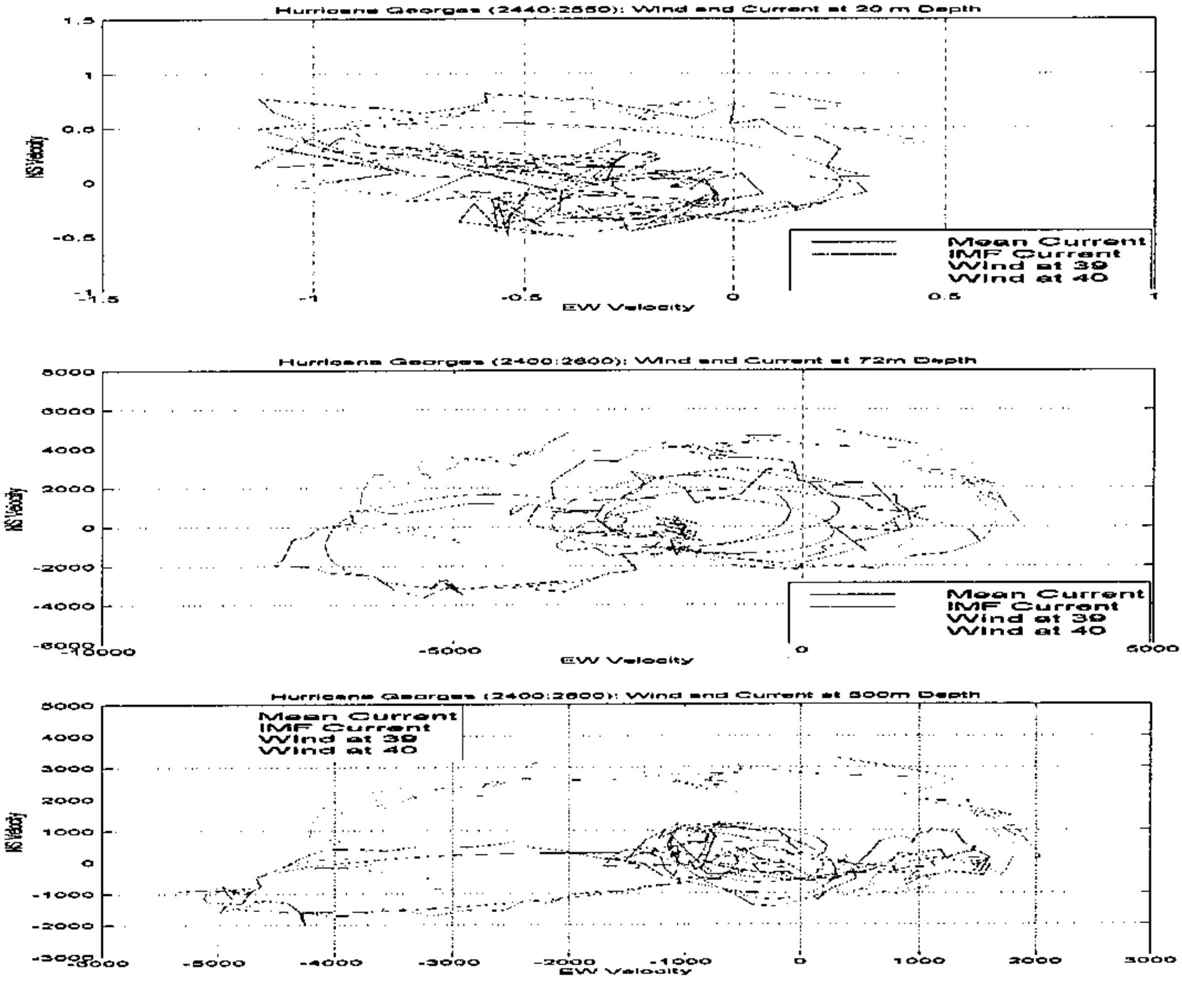


Figure 6. Progressive vector diagram of wind, mean current, and IMF component of C5 at different water depth: (a) 20 m, (b) 72 m, and (c) 500 m of station B3.

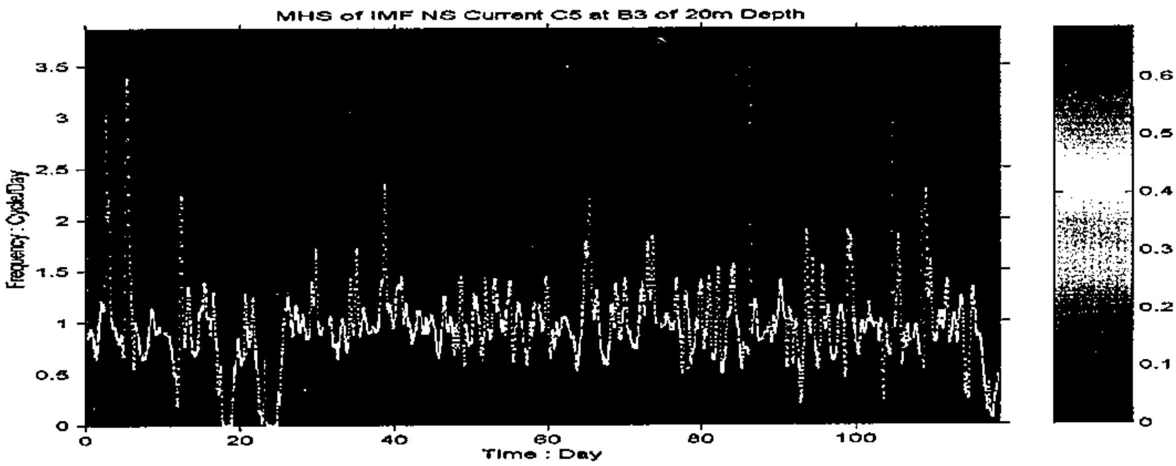


Figure 7. Hilbert spectrum of IMF NS current C5 of Station B3 at 20 m depth.