CHAPTER 28

A Comprehensive Wind, Wave and Current Measurement Program in the South China Sea

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Abstract

The South China Sea has been a prolific fishing ground and a busy shipping lane, and has recently become an important source of offshore oil and a center of rapidly growing economic activities. However, little systematic scientific study of the area has been carried out (Anonymous 1985 and Wyrtki 1961). Recently, several Metocean (meteorological and oceanographic) studies were performed to support the offshore petroleum production in the area. This paper summarizes these and other studies, and then, describes a comprehensive Metocean measurement program (Sharma et. el. 1991). Many distinctive and unique features of the measurement program are presented and discussed. Published samples of wind, waves, and current data are used to illustrate the complexity of oceanographic conditions in the area. Economic benefits of the measurement program are estimated approximately and found to be many times the cost of the program. While many important design decisions can be made with the 18 months of data, many other decisions need to be made conservatively in the absence of a multi-year Metocean dataset. A comparison with the condition in the Gulf of Mexico reveals many similarities and some differences. Future data needs and their possible benefits are also discussed briefly.

Introduction

The South China Sea (Figure 1) is a semi-enclosed sea very similar to the Gulf of Mexico. It has been a prolific fishing ground and a busy shipping lane, and now, some of the fastest growing nations of the Asia-Pacific region surround it. As economic activity grows in the

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area, the need for more and better meteorological and oceanographic will grow in this area.

First, we briefly review various studies conducted in this area to support economic activities. Then, we summarize a comprehensive Metocean measurement program with which we were closely involved. Benefits of past studies are conservatively estimated and it is found that a similar future measurement program could be very cost effective. Future data needs are briefly discussed. Finally, we present our conclusions and recommendations.

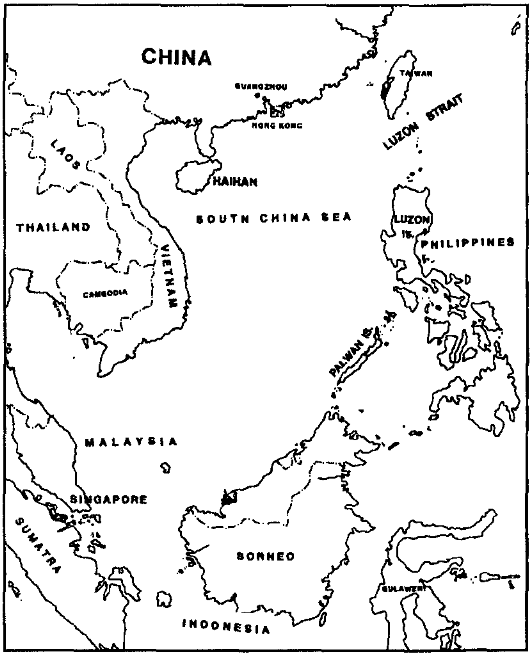

Figure1. Location Map

When China granted offshore leases to western companies in 1979, the only available Metocean information consisted of Wyrtki 19961 and SSMO (Synoptic Ship Meteorological Observation) data which consists of visual observations from ships in the area. For few preliminary planning purposes, these data are adequate, but are inadequate for final design criteria preparation. Inadequacy of general understanding of the South China Sea Oceanography became very apparent when Glomar Java Sea sank near Hainan Island in a minimal typhoon.

Prior Measurements & Analysis in the South China Sea

In 1959-61, a hydrographic survey of the area was conducted and the results were published as a report by Wyrtki (Wyrtki 19961). In 1979-1982, Academia Sinica conducted several oceanographic surveys in the area. Western visiting scientists went on many of these cruises. A summary of the collected data has been published as a report in Chinese (Anonymous 1985). Several other oceanographic studies have modeled transport in and out of South China Seas. Results of these studies are useful in understanding the oceanography of the area. However, theses studies did not include collection of wind, wave, and current data for model verification and calculation of operational and extreme design criteria.

Recently to meet some offshore industry needs, Oceanweather Inc. performed a proprietary hindcast study covering the entire basin using a third generation wave model. Wind, wave and depth averaged currents were hindcast in two hundred severest tropical storms during past 50 years. The same parameters were also hindcast for a continuous 10-year period. Using the hindcast results, extreme and normal operating criteria can be prepared. For more details, please refer to Cardone (Cardone 1994). This study's strong points include basin-wide coverage, excellent use of historical meteorological data such as surface weather maps and tropical cyclone summary data. However, to verify the model results the study could use only limited wave measurements in shallow water in the southern part of the basin.

There is no high-quality measured wave data available in the public domain. Several high-quality long term data sets have been acquired recently in the northern part of the South China Sea. Unfortunately, these data are proprietary and unavailable except for limited data which appear in published papers (Yuan 1988, Sharma 1991). Some of the published results will be presented here to illustrate the complexities of South China Sea Oceanography.

Many other proprietary studies have been performed to support specific project needs. Several design criteria studies were performed by China Ocean Technology Company, Oceanweather Inc., and possibly others. To support the needs of specific projects, many operators measured specific features affecting their operations. Some of those data are of oceanographic interest but unavailable for research.

To support the construction and maintenance of their gas pipeline from Hainan Island to Hong Kong, Arco measured currents along their pipeline route. Currents in several typhoons were measured. During their drilling programs, Oxy and Amoco Orient vessels experienced very strong soliton currents. The measurement yielded some of the strongest soliton currents ever, and these measurements were subsequently useful in developing environmental design criteria.

To support their many offshore operations, Arco developed and implemented a typhoon emergency response plan. Corona et. el. (Corona 1996) presented the results of their implementation at the 1996 Offshore Technology Conference in Houston. In one year evaluation period, the study prevented 1,200 round trip helicopter flights (2,400 flight hours) transporting equivalent of 24,000 personnel. Besides saving the cost of flight time and vessel downtime, the emergency response plan greatly reduced the inherent transportation risks associated with flights in inclement weather. From the information provided in the paper, it is conservatively estimated that the total savings could easily exceed several tens of million dollars. A similar proprietary study was performed for the Liuhua project. The results of the study are unavailable to public. An informal evaluation of the method indicated that savings in evacuation cost and downtime were several million dollars.

A better and simpler typhoon evacuation method has been developed recently (Sharma 1996). In this method, it is recognized that the long lead time needed for shutting down offshore operations presents special problems because the historical forecast errors for such long lead time are very high. Meteorological forecasts are used as recieved along with a few simple and easy measurements at site. Many oceanographic and meteorological features which consistently affect typhoon parameters are used in such a way that safety is not compromised. Using this method the essential operations could be continued by delaying total evacuation without risking even a single life. The method is implemented in a simple calculation method using PC applications such as

Excel, Lotus or Project. The calculation method is activated when a typhoon is about 800 miles away from the operating area. At this time, the safety engineer enters the number of helicopters available, their passenger capacities, round trip time and total number of personnel on the rig in order of their evacuation priority. From this information, time needed for various levels of evacuation including total evacuation is calculated. Meteorological forecasts without any modification are used in this method. From the forecast parameters, the arrival time of the edge of severe wind conditions unsuitable for helicopter operations is calculated. At all forecast time steps, the total evacuation time is maintained smaller than the quickest possible arrival time of the adverse edge of the typhoon. This could be achieved either by partial evacuation or by chartering more and/or bigger helicopters. Full evacuations are avoided most of the time because only a small fraction of all typhoons occurring within say 400 nautical miles of a site come close enough to affect operations. Using this method, operation managers could delay, or possibly avoid coplete shut down without risking any life.

Many proprietary Metocean studies were performed to evaluate the possible exploitation of a difficult prospect named Liuhua in 1000 feet water depth located at 150 miles Southeast of Hong Kong in the South China Sea. Very little results of these proprietary studies are available in journal papers or conference proceedings. The following description of a comprehensive meteorological and oceanographic measurement program are based on scant published results.

Liuhua Measurement Program

In 1987-88, a consortium of Chinese Scientific Agencies and Oceanor of Norway deployed the following measuring instruments:

- two acoustic Doppler current profilers,
- four Aandera current meters,
- an ultrasonic current meter (UCM-30),
- Marex buoy for waves and wind,
- directional Wavec buoy,
- anemometers at four different elevations on a drilling rig,
- water temperature, oxygen content, and salinity,
- air pressure, tidal elevation.

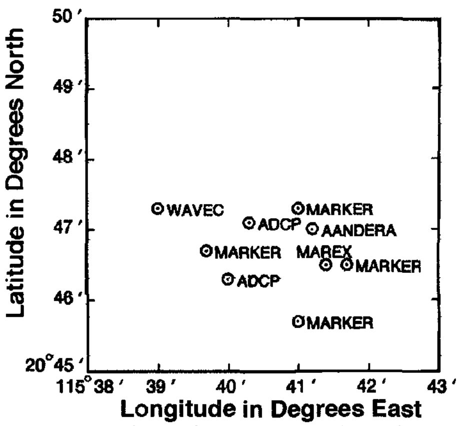

Figure 2. Instrument Location

The instruments were spread out in a well thought out pattern to allow future 3-dimensional current studies (Figure 2). As presented on the figure 2, four different current meters are located at the corners of a trapezoid with each side equal to about one nautical mile. So, the upstream and downstream current meters registered a soliton pulse current about 15 to 20 minutes apart. Also, eddy currents can be clearly resolved with a suitable computer program.

Recognizing that the measurement program was in a frontier area, many unique and special steps were taken to insure success. Some of the **unique** and **distinctive** features of the measurement program were:

- global cooperative project organization,
- careful planning to overcome extremely unfavorable logistics,
- satellite search and rescue methods,
- redundant instruments for reliability,
- patrolling of instrument area to prevent theft, and
- quality control at every step.

As a result, the actual data recovery was substantially higher (about 95%) than the initial overall goal of 80%. Eighteen months of nearly continuous wind, wave, current, water temperature data were recorded. The measured data contains many features of special scientific and design interest. The following are some of the most important features:

- complex storm current profiles,
- interaction of typhoon and cyclonic eddy,
- interaction of typhoon and monsoon,
- waves higher than forecast from wind,
- intense current of a short duration (possible internal soliton signature), and
- relation between current and sea temperature.

To illustrate the above oceanographic features, sample data are presented and discussed.

Meteorological & Oceanographic Features

Wind, wave current and other meteorological parameters were continuously measured from August 1987 to February 1989. The instruments in the operating area were affected by 11 typhoons and 12 winter monsoon storms. The following paragraphs briefly describe some of the most important meteorological and oceanographic features:

Typhoons

Four typhoons registered significant wave heights over 7 meters (23 feet) and one over 9 meters (30 feet). Seven other distant passages of typhoons were recorded. Significant wave heights much greater than those predicted by a parametric model were measured in typhoons embedded in monsoon winds. Typhoon Nina passed over the instrument area while it was in its tropical storm stage. A maximum wind of 22 meters per second was measured by the two wind instruments mounted on the Marex buoy at a 6 meter elevation, but the measured waves were much higher than expected for a 22 meters per second typhoon.

Wind, waves and currents measured in Typhoons Betty and Cary are presented here (Figure 3) to demonstrate the quality and quantity of the collected data. Typhoon Cary followed Typhoon Betty within 6 days. Typhoon Betty entered the South China Sea in the evening of the same day the instruments were deployed. Even though the measuring instruments experienced only the outer periphery of the typhoon, the forceful presence of a dangerous typhoon is visible in the recorded data. Typhoon winds were from the east superimposed on southwest monsoon wind.

A diurnal cycle in the measured wind speeds can be seen on the plot. This cycle corresponds to a land breeze sea breeze effect at the site. This effect so far from land was unexpected.

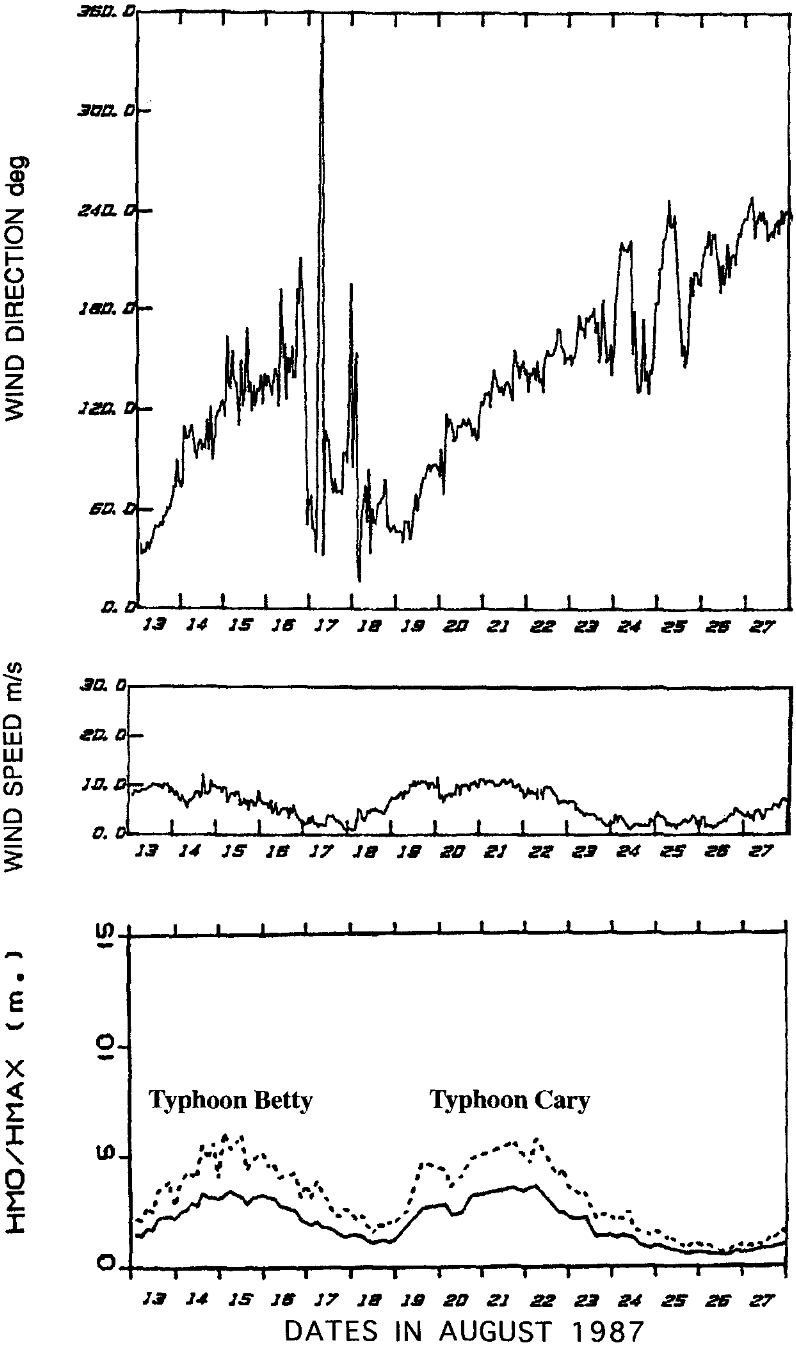

Figure 3. Wind direction, wind speed and wave in Typhoons Betty and Cary.

The waves reflect the distant passage of Typhoons Betty and Cary. A maximum significant wave height of 3.5 meters was recorded in both typhoons.

While the wind and wave responses were similar in the two typhoons, the current responses were entirely different (Figure 4). The mean current during Typhoon Betty increased without any significant change in the diurnal current amplitude. In contrast, the mean current during Typhoon Cary increased only slightly, but the diurnal current amplitude increased significantly. The combined maximum current measured during the two typhoons are nearly equal.

If the sharp spike in the beginning of data had been measured by only one current meter, it could have been rejected as a spurious noise. In this case, the same spike was measured by all three current meters, and the spike could not be rejected. Similar spikes are seen

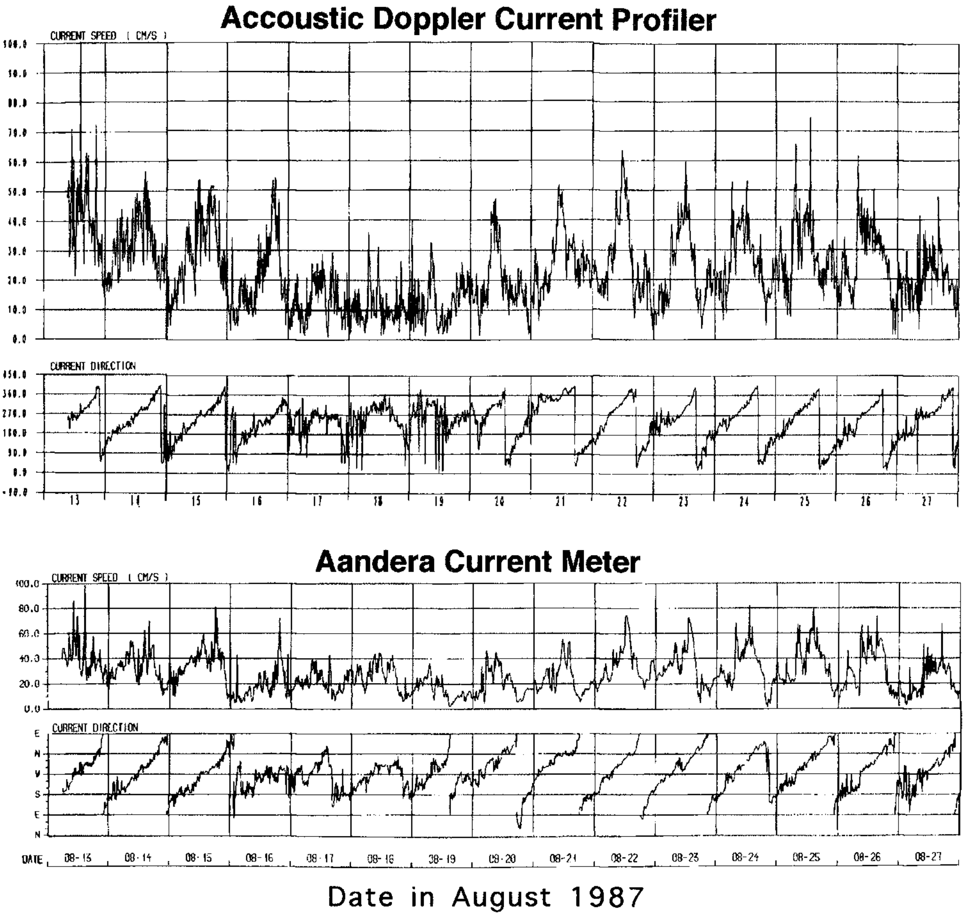

Figure 4. Currents measured by an ADCP and an Aandera current meter in Typhoons Betty and Cary.

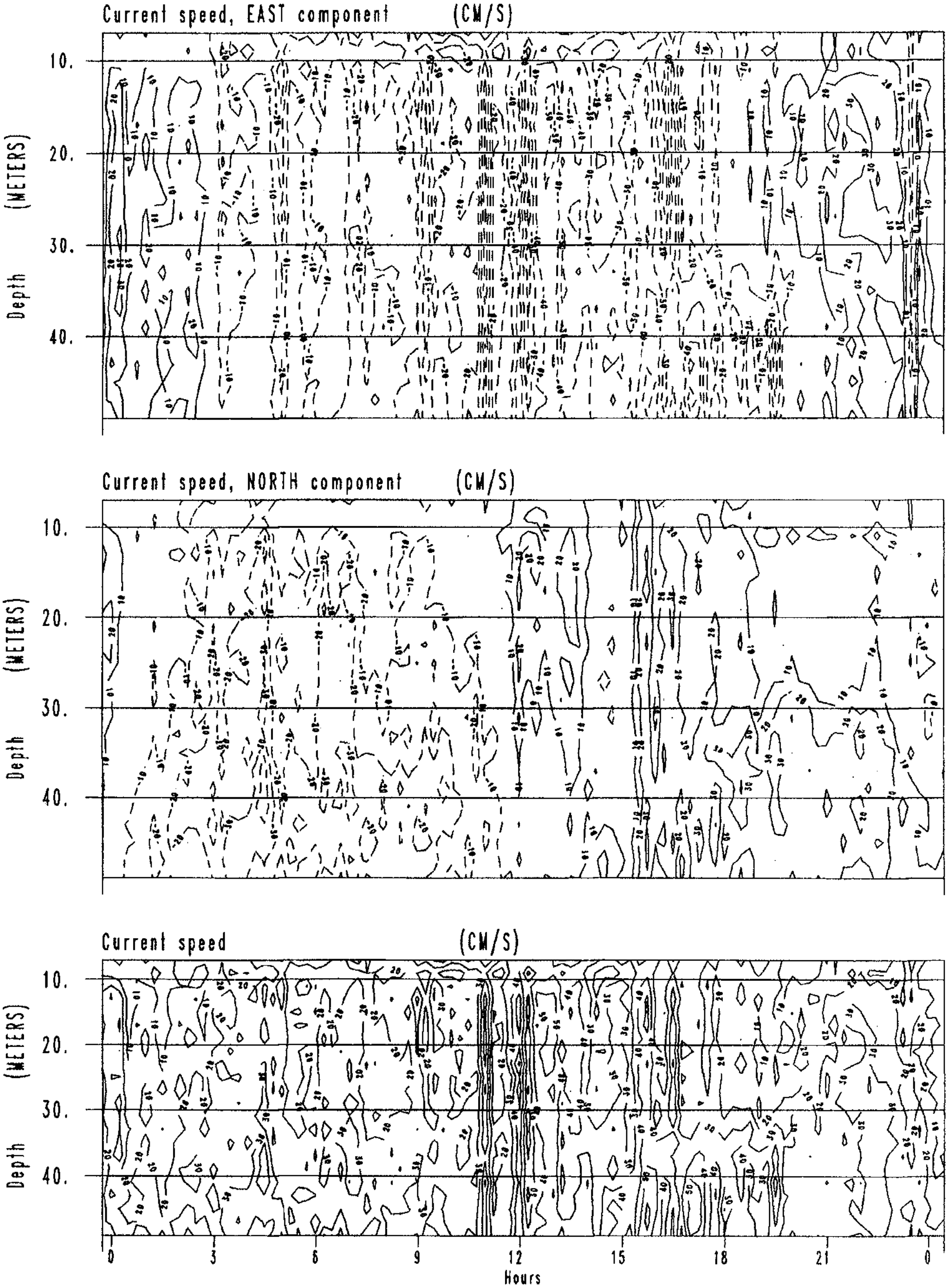

Figure 5. Contour plot of currents at all depth bins and time steps measured by an ADCP at -65 meter on August 14,1987

when 1 to 2-minute average soliton data are converted to the same averaging period as used in this measurement program.

Acoustic Doppler Current Profiler Data

The data collected by the acoustic Doppler current profiler at -65 meter at two meter depth bins and all hours of August 14 are presented in Figure 5 as a contour plot. On this plot we see a strong current at about 1300 hours UTC. The currents are the combined effect of wind, tide and oceanic currents.

Figure 6 shows hourly current data recorded at every two-meter-depth with the acoustic Doppler current profiler at -65 meters on August 22, 1987 at 11 hours 43 minutes and 43 seconds UTC. Currents are nearly equal thoughout the mixed layer depth. The current directions are also nearly constant from the sea surface to -55 meters. Currents are nearly constant between -20 and -55 meters depths. There is a sharp decrease in current at -15 meter, then a still sharper increase at -10 meters. The depth resolution in this case is 2 meters and the standard error in velocity measurement is 4 cm per sec. Data from three bins near the surface and close to the acoustic Doppler current profiler are suspect and excluded from our presentation.

The slab like measured currents are of special scientific and design interest. The design

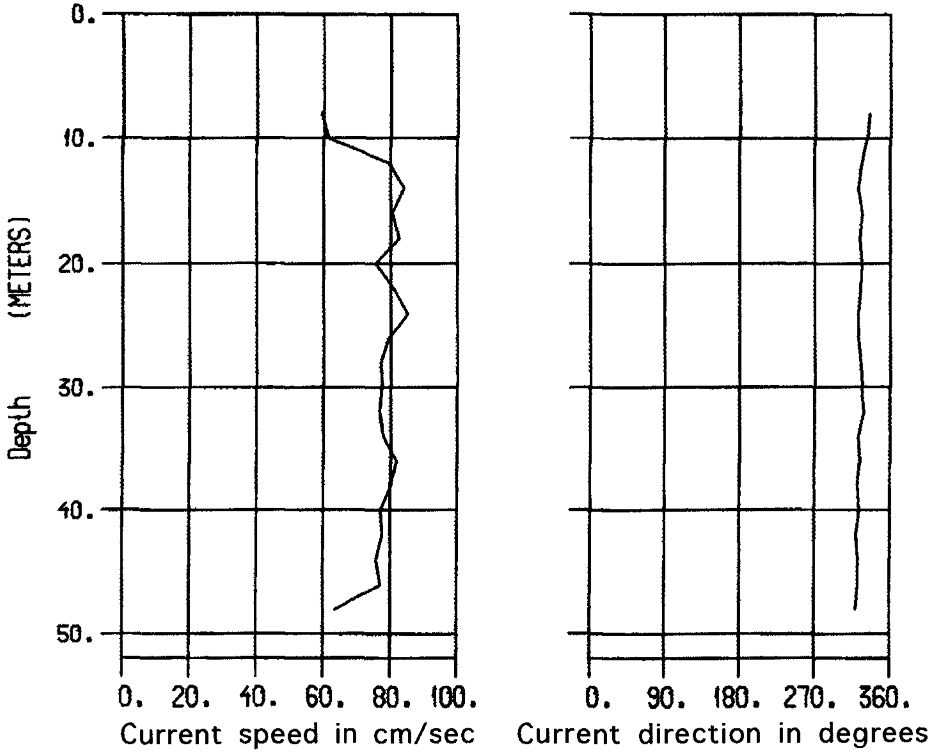

Figure 6. A sample urrent profile in the upper mixed layer.

current near sea surface which should be associated with the design wind and wave could be very different depending on whether a shear or a slab current profile (Figure 7) is acceptable. The cost of building offshore structures with large projected area near surface (such as a tension leg platform or a floating unit) could be up to 20% lower if a slab current profile is acceptable.

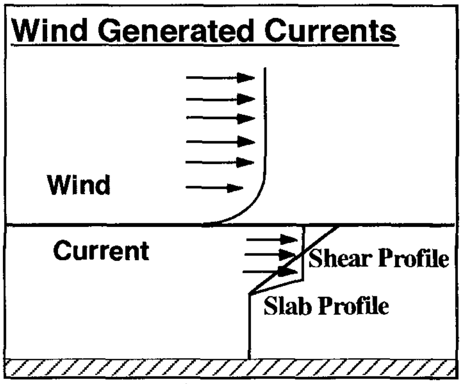

Figure 7. Wind generated current profiles for design use.

Tidal and Oceanic Current

Figure 8 presents an example of relation between sea water temperature and tidal and oceanic currents measured by the Aandera current meter at -50 meters from October 16 to October 20, 1987. The tidal currents are predominantly diurnal. Current speed and temperature appear to be correlated. A periodic change in temperature from 24.C to 28.C over several tidal cycles suggests the ingress and egress of the Dongsha cold eddy over the instrument area (Figure 9). These and

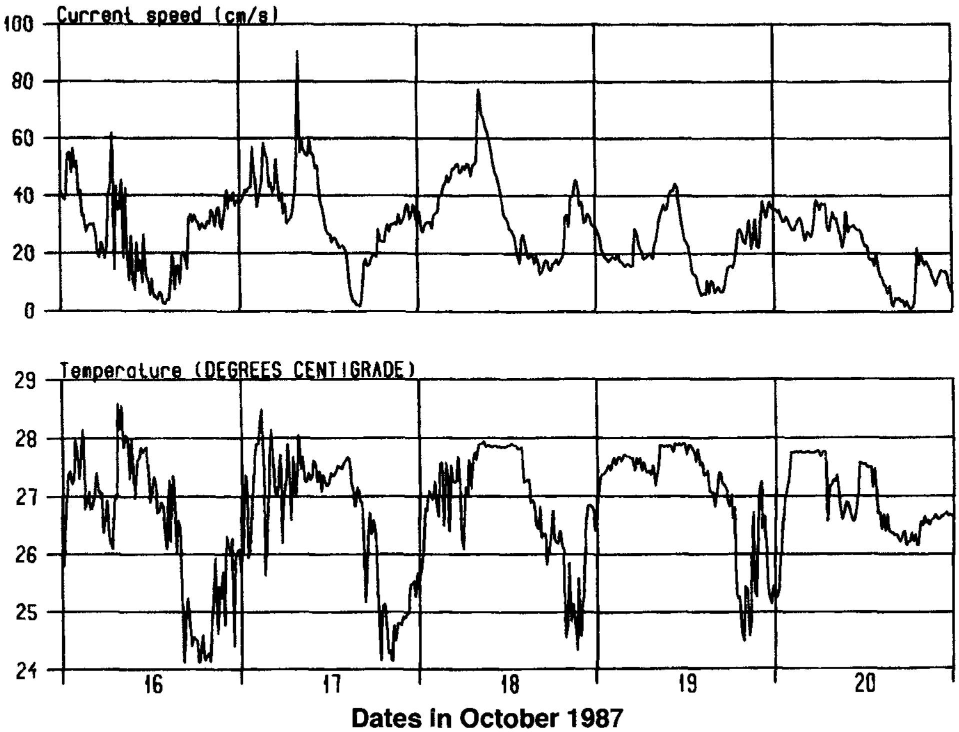

Figure 8. Current and temerature measured by Aandera current meter at -50 meter.

other aspects of eddy and oceanic current effects need to be pursued by acquiring sea surface temperature images for the periods in question.

It should be noted that the current directions make a complete loop in each tidal cycle. In such currents, a floating tanker will weathervane one full circle during each tidal cycle.

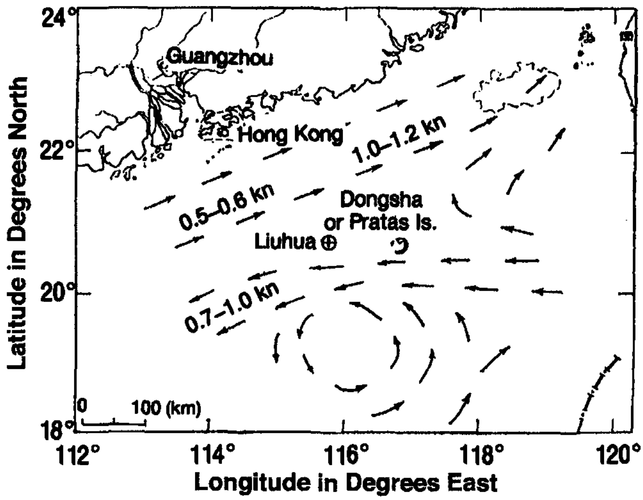

Figure 9. Dongsha Eddy Current in Summer

Strong Cold Front Passage

Wind, wave and current during the passage of a strong cold front are interesting because wind speed and direction change rapidly. With the passage of a strong cold front on the evening of September 25 immediately following our deployment, the wind velocity jumped from less than 2 meters per second to 12 meters per second within three hours. Also, the wind direction changed from north to south and then north again. During the passage of this cold front through Hong Kong, wind gusts up to 60 kilometer per hour were recorded by land based anemometers.

While the sudden jump in wind is very clearly seen in the wind record, the wave record shows a smaller jump from calm seas to about 3 meters significant. Interestingly enough, the effect on current is entirely unnoticeable. This is to be expected because during a sudden passage of a cold front, wind speeds and directions change so fast that the sea does not have enough time to respond.

Marine Fouling

Although marine fouling caused malfunctioning of the Aandera current meter at -50 m, photographs of marine growth constitute an important data base for marine fouling, which is an important parameter in design and operations. All other current meters and buoys functioned properly despite marine growth.

Every type of surface within about 100 meters of the sea surface were fouled mainly by two barnacles species (pollicipes polymerus and lepas anatifera). Near the surface, the fouling clusters were large and populated by bigger specimens (up to 2 inch). Both the cluster size and their density decreased with increasing depth. Macroscopic fouling was not observed below -100 meters. However, we cannot rule out long-term fouling of the structural elements below 100 meters, because the surfaces were not examined for short-term microscopic fouling.

Comparison with the Gulf of Mexico

A comparison of the meteorological and oceanographic conditions in the South China Sea and the Gulf of Mexico is instructive and has many practical uses. While tidal currents are very small in both the Gulf of Mexico and the South China Sea, severe tropical storms affect both basins. Maximum intensities of tropical storms in both operating areas are comparable, but the frequency of occurrence in the South China Sea is about 3 times that in the Gulf of Mexico.

The deep water Gulf of Mexico operations are occasionally shut down by strong oceanic currents caused by the Loop Current and its anti-cyclonic eddies. In the South China Sea, the background oceanic current is weak but appears to intensify under the influence of a typhoon during the Northeast Monsoon. Cyclonic wind field in a hurricane or typhoon has been known to interact with weak cyclonic eddies in both basins. The effect of this interaction on design and operation is poorly understood because no simultaneous measurement of good quality is available.

Before a hurricane approaches an operating area in the Gulf of Mexico, sky is usually clear with no wind, wave or current (in the absence of the Loop Current or its eddies). In the South China Sea, similar conditions exist before a typhoon approaches during the Southwest Monsoon (April-August). However during the Northeast Monsoon (September-March), strong wind, wave and current may be present even before a typhoon approaches. As a result, even a low intensity storm could produce very high waves with rapidly changing intensity and directions of wind, wave and current. Such events were recorded during the measurement program. Extreme design conditions could be governed by such conditions, and operating conditions could be more dangerous than the intensity of a typhoon may suggest.

Both basins have only few straits connecting them with open ocean. Even though most oceanic conditions, such as stratification, etc. are similar in the two basins, soliton induced strong currents have been noted only in the South China Sea.

While many comprehensive Metocean studies have been performed for the Gulf of Mexico, but very few similar studies have been performed for the South China Sea.

Applications & Benefits

The collected data has been applied to meet a variety of industry needs. Some of the most notable applications include:

- Wind and wave measurements were used in real time for operational planning and weather forecasting.
- Collected data were used extensively in developing both extreme and operational design criteria.
- Typhoon wave and current hindcast models were evaluated using the measured data. Monsoon effects on typhoon waves and currents are especially significant.

Possible future applications of data include:

- Complex measured currents could be studied to improve extreme and operational design criteria particularly using joint probability methods.

- Wave and current models could be evaluated using all data.
- Duration analysis of benign and inclement weather could be performed for operational planning.
- Real time wind, wave and current measurement integrated with a forecasting model could improve accuracy of forecasting in both NE Monsoon and typhoon resulting in lower cost of day-to-day operations, and enhanced safety of personnel & production platforms.
- Collected data could be used in future to develop better design criteria.

Only a very crude estimate of the benefits of the measurement program is possible. Even a rough conservative estimate shows that the value of benefits is many times the 2.2 million dollars spent on the measurement program.

First, drilling and testing operations during the measurement program benefited from the improved accuracy of forecasts, and many days of operating costs were saved at daily rates of up to $500,000. Eighteen months of good quality data enabled safety evaluation of many unconventional but cheaper alternative production systems. Even assuming only 2% savings in the total cost of the final production system, the savings would be about 15.2 million dollars. Similar dollar amount savings are possible in the cost of a Tension Leg Platform if measured average slab current profiles are used in design.

Conclusions

Comprehensive Metocean data has been collected in a difficult area to support economic development. In comparison with other areas of similar interest, quantity of Metocean information available for the South China Sea is very small.

Some of the most important conclusions are presented below:

- A difficult measurement program in a remote area has been completed successfully to provide a valuable service to the industry.
- Extremely valuable deep water current data has been collected for operational planning purposes, especially for remotely controlled underwater operations.
- Pure tidal current ellipses will cause floating tankers to weather vane full circle in each tidal cycle in the absence of wind driven currents.
- Dongsha cold eddy appears to move in and out of the operating area during a tidal cycle. Wind velocity and direction also influence the location of the cold cyclonic eddy.
- Measured currents are much more complex than expected.
- The operational wind and wave climate is most severe during the winter monsoon.
- Typhoons imbedded in winter monsoons could be the worst weather conditions.
- A cost-effective measurement program is possible in a remote area.
- Site-specific data can improve the accuracy of monsoon and typhoon forecasts.
- Estimated benefits of a metocean measurement program are many times the cost of the measurement.

Recommendations

Countries surrounding the South China Sea have some of the fastest economic growth rates within the Asia-Pacific region. Here, coastal and marine economic activities are growing exponentially. However, very little comprehensive meteorological and oceanographic data are available to support these economic activities. The finished measurement program and studies provide acceptable data for preliminary design criteria purposes, but, are insufficient to resolve many important design criteria issues, such as (i) joint occurrence probability of the northeast monsoon and a typhoon, (ii) joint probability of wind, wave, and current in a storm, and (iii) the role of complex currents in design criteria. Safe but economic design criteria are needed to design infrastructures for offshore oil production, a coastal plant or a harbor. Day-to-day operations could be interrupted by severe weather or typhoon. With good knowledge, one could plan operations to minimize downtime without compromising safety. Therefore, it is recommended that

- More environmental data should be collected preferably through a joint industry project.
- Ongoing site-specific Metocean measurement should be made part of economic activities in an offshore area.
- Measured data should be integrated with day-to-day weather forecasting and severe storm warning services.
- Collected data should be archived and made readily available for research and design criteria development.
- Extended current analysis of collected data could improve our understanding of the complex currents in the area resulting in safer and more cost-effective design and operating criteria.

Acknowledgments

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