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Metocean Phenomena in the Gulf of Mexico and Their Impact on DP Operations

Chris Yetsko
Fugro GEOS (Houston)

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ABSTRACT

The environmental conditions in the Gulf of Mexico are characterized by sporadic, harsh and sometimes unpredictable metocean phenomena that occur and impact offshore operations. The paper will provide an overview of the key meteorological and oceanographic features understood to exist in the Gulf of Mexico, which can and do have an impact on DP operations. The focus of the first part of the paper will be on weather features in the deepwater region. It will provide an indication of the levels of wind speeds and associated waves that can be experienced.

The paper will then describe the genesis of the Loop Current and the current phenomena that are either directly or indirectly connected with it. These associated phenomena include eddies that spin off the Loop Current, submerged jets and also the near-bed current intensification that occurs in the vicinity of the Sigsbee Escarpment.

The final section will examine the operational support available in terms of real-time measurements, now-casts, and forecasts. The industry can use this type of support to enhance awareness and mitigate the impact of harsh metocean conditions.

1 Introduction

The successful completion of DP operations is dependent upon the prevailing metocean conditions. When considering the metocean effects of importance in the Gulf the Mexico, one must look at several different phenomena. Of obvious importance are hurricanes and winter storms, which can affect much of the offshore waters over the course of 2-3 days. Equally dangerous are smaller scale events such as squalls and submerged currents that may only impact a small area. This paper discusses critical metocean phenomena that affect DP operations and offers mitigation solutions for events such as high currents in the deepwater Gulf of Mexico.

2 Meteorological Features

The Gulf of Mexico, located between 20° and 30° N latitude, experiences two primary weather patterns throughout the year. From mid-fall through mid-spring, the main forcing for weather encountered in the Gulf comes from migratory weather systems crossing the continental U.S. This period contains the highest average wind speeds and wave heights, as a progression of cold fronts transect the Gulf resulting in rough conditions. By late spring the Gulf comes under the influence of the semi-permanent Atlantic high-pressure system and most of the sensible weather arrives from the east. This pattern is typically stable with only a few passing showers or thundershowers, but occasionally is interrupted by a strong tropical wave or tropical storm. Under the right conditions these tropical storms can grow into hurricanes, which can result in significant damage to offshore structures and necessitate evacuation of personnel.

2.1 Gulf of Mexico Tropical Systems - Climatology and Formation

A significant amount of time and effort is needed for each new offshore development so that the risks from metocean phenomena can be quantified. It is well known that the hurricane is the one of the main driving forces behind offshore design as this feature produces the highest wind and wave values that will be encountered. Indeed, hurricanes are also very important to offshore installation plans and can severely impact both the schedule and project budget.

The Atlantic Basin hurricane season officially starts on 01 June and concludes on 30 November. Although there have been tropical storms during every month of the year, storms which developed in December through April have all formed and affected areas outside the Gulf of Mexico.

Early in the hurricane season it is the Gulf and Caribbean waters that tend to warm most rapidly across the Atlantic Basin, leading to occasional storm formation. The most recent early season tropical storm of note was Allison, which affected the northwest Gulf of Mexico in early June 2001. Although not the strongest tropical storm (peak sustained winds of 45kts), Allison formed rapidly over the course of a day and moved inland over Southeast Texas. Tropical systems such as Allison are known as “homegrown”, meaning that they form either in the Gulf of Mexico, Bay of Campeche or northwest Caribbean Sea. This type of tropical system is in some ways most dangerous for DP operations, since it can progress from an innocuous mass of thunderstorms to a strong tropical storm within one day.

As the waters continue to warm across the Atlantic Basin, storm formation begins to occur over a much larger area. The level of formation in the Gulf steadily rises through July into August, with a similar trend noted from the Caribbean islands eastward to West Africa. This second region is the breeding ground for many of the strong hurricanes that travel westward underneath the semi-permanent Atlantic high pressure system to affect the Caribbean and eventually the Gulf of Mexico or U.S. East Coast. Unlike the homegrown systems there is sufficient lead-time to monitor and forecast the tropical storms and hurricanes approaching the Gulf of Mexico. A difficulty with forecasting often arises, however, when systems reach the central and western Caribbean, as recurvature toward the north will spare the Gulf from direct effects. Prudent hurricane forecasting is needed at this juncture to avoid unnecessary cost for evacuating personnel and securing offshore infrastructure.

The Atlantic hurricane season reaches a peak in activity late in August into mid September when ocean water temperatures are at their highest, adding fuel to each potential system. This is also the time frame when tropical systems affecting the Gulf can either be homegrown or of the variety that traverse the entire Atlantic.

By late September and especially into October, the river of high altitude air known as the jet stream begins moving south across Canada into the northern portions of the U.S. This causes storm systems to once again traverse the United States with their associated cold fronts entering the Gulf. Winds at mid- and high- levels of the atmosphere over the Gulf become hostile to tropical formation, resulting in a sharp decrease during October. Formation is still encountered across the Caribbean and southwest Atlantic Ocean owing to warm waters and less hostile upper level winds, but as the season ends in November these areas experience a significant drop in tropical storm formation.

As mentioned earlier, homegrown tropical systems present some of the greatest challenges to DP operations. The responsibility for naming of tropical depressions, storms and hurricanes lies with the Tropical Prediction Center in Miami, Florida. Most hurricane evacuation plans prepared by offshore operators include provision for shutdown and evacuation once a system has been named. However, the most prudent plan would allow for these operations to commence in advance of a homegrown storm being named, especially since the industry has pushed farther offshore in the form of deepwater developments. There have been several instances (including T.S. Allison) where a yet unclassified tropical system *produced* tropical storm type conditions in the Gulf of Mexico. This obviously has serious implications for vessel station keeping as well as subsea operations using DP.

2.1.1 Hurricane-Induced Currents

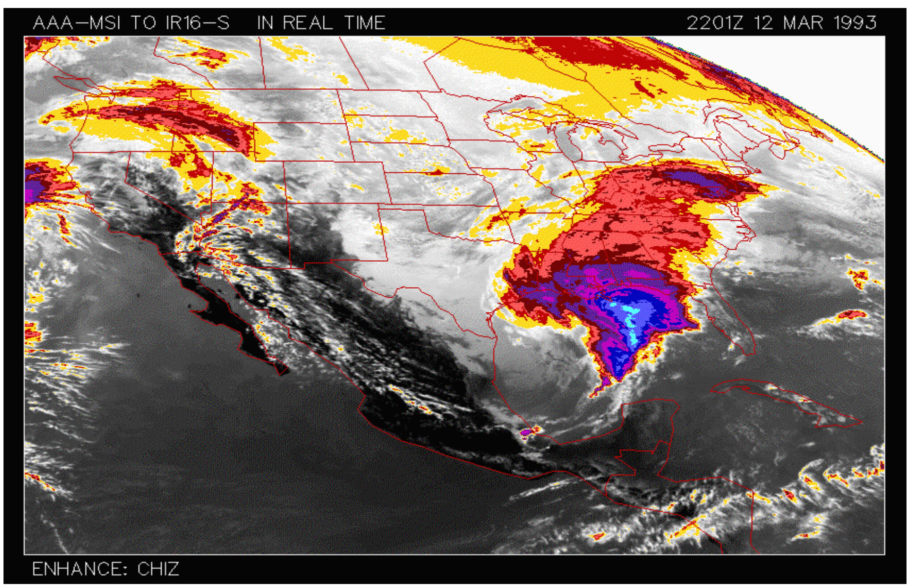
Rapid fluctuations in the weather can also result in a modification of the Gulf of Mexico circulation, especially over the upper continental slope and shelf. Atmospheric events such as hurricanes can generate strong episodic currents to considerable depths. Hurricane-driven surface currents of 2-3knots are not unknown and the resulting flows can be traced as deep as 2500ft or more over the continental slope. The decay of these events shows in the water column as a series of inertial oscillations that propagate downwards (and horizontally) over several days after the passage of the hurricane. However, these events are rare and there are obvious challenges in obtaining high quality data near the track of the storm's center.

2.2 Gulf of Mexico Winter Storms

When compared to the strongest Gulf hurricanes, the most severe winter storms in the Gulf of Mexico produce much lower winds and waves. However, the conditions experienced during winter events still command respect and attention by entities with personnel and equipment offshore.

While cold fronts crossing the Gulf from mid-fall into mid-spring certainly produce rough conditions (winds in excess of 30kts, waves in excess of 13ft) these systems are not the most severe to occur. Therefore, this discussion will be restricted to winter season low-pressure systems that form within the Gulf and track northeastward over the Eastern Seaboard of the U.S. These storms, traditionally known as "Gulf lows", present many of the same challenges encountered during a homegrown tropical system situation. Gulf lows form when an upper level disturbance crosses the southern tier of the U.S. or northern Mexico. When the disturbance reaches Texas or northeast Mexico it spawns a surface low pressure over the northern Gulf. Under the right conditions and proper jet stream positioning, the system deepens rapidly as it tracks through the offshore leases. This scenario is important for DP operations because the strongest winds and highest waves initially only affect a small area. Therefore, operability windows at a particular location could be shortened or lengthened depending on the actual formation point. As the storm strengthens the affected area increases and operations over much of the Gulf are halted.

The most severe Gulf winter storm in recent memory occurred on 11-12 March 1993. A strong disturbance crossed the southern United States causing low-pressure to form over the northern Gulf late on the 11th and during the 12th. Although many low-pressure systems have formed and deepened over the Gulf, this storm was unique in its rapid rate of deepening. It produced sustained winds of 45kts with gusts greater than 55kts and significant wave heights approaching 33ft, primarily in the Louisiana offshore waters. The "Storm of the Century" went on to produce record snowfall and wind speeds over the entire East Coast during the 13th.



Gulf of Mexico Winter Storm – 11-12 March 1993

2.3 Offshore Squalls

In terms of DP operations, squalls quite possibly present the greatest danger due to their low lead-time and rapidly changing conditions over a short period of time. The threat of squalls exists throughout the year in the Gulf, although the mechanisms that cause them vary from season to season.

The primary causes of summer squalls are easterly waves. These systems traverse the Caribbean then cross the Gulf of Mexico from east to west, typically producing thunderstorms and areas of rain at a given location for an average of 24-36 hours. Squalls can also result from weak upper level disturbances over the Gulf, which produce thunderstorms due to the combination of cold upper level temperatures and the warm Gulf waters. The result of these features is primarily heavy rainfall and strong, gusty winds along the squall's front flank. However, since mid- and upper-level winds are normally moderate during these events the maximum surface wind gusts observed are usually in the range of 40kts-45kts.

More severe impacts from Gulf of Mexico squalls occur in the fall, winter and spring months. It is during these months when strong weather systems cross the continental United States, often causing cold fronts to sweep across the Gulf waters. This occurrence is often accompanied by fast winds aloft, which increases the probability of mixing down momentum to the ocean surface in a squall.

The radar image below shows a line of storms, also known as a squall line, crossing the High Island lease areas offshore Galveston. In this type of squall situation almost all locations along the leading edge of the line have the possibility of observing winds in excess of 45kts with rapid directional changes. However, the most significant wind speeds (greater than 60kts) occur where the line bows out, giving rise to the term bow echo. This particular line has one main bow echo extending from the coast to just offshore, and another further south along the line. Since these lines travel at speeds in excess of 40kts there is often little lead-time for DP operators. The bow echo phenomenon as described is made even more dangerous since the bowing effect causes not only an acceleration of that part of the squall line but also an increase in surface wind speeds.

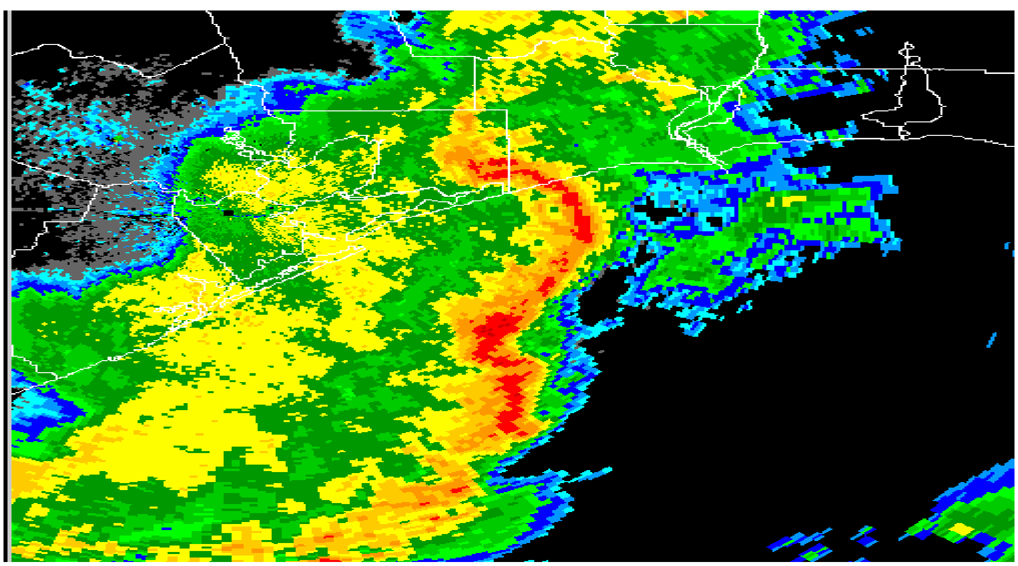


Image courtesy of http://www.nssl.noaa.gov/mag/bowecho/

3 Loop Current and Associated Effects

3.1 Characteristics

A strong persistent current flows into the Gulf through the Yucatan Strait as the Yucatan Current and exits through the Florida Strait as the Florida Current. The clockwise flow extending into the Gulf to join the two is known as the Loop Current. The Loop Current either directly or indirectly influences the deepwater circulation of the northern Gulf. The mean surface speed of the Loop Current is about 1 knot, but a speed of 6kts has been observed. It is detectable to around 2500ft below the surface.

A characteristic of the Loop Current is its northward intrusions into the eastern Gulf. These have a periodicity of around 11 months, possibly forced by the annual cycle of winds over the Gulf. The northward penetration can be associated with the shedding of a Loop Current eddy and the subsequent collapse of the Current to the southern extremity of the Gulf, where it takes a more direct path to the Florida Strait.

The Loop Current also impacts the circulation closer inshore by entraining eastern Gulf shelf water within the main current. It affects directly the eastern margin of the main hydrocarbon-bearing region, while associated eddies impact the whole of the deepwater western Gulf.

3.2 Eddies

Loop Current eddies (LCE) are major warm core features of some 200-mile diameter that rotate clockwise (anticyclonically). They are extremely important to the dynamics of the Gulf because they transport huge quantities of salt, heat and momentum across the western deepwater region.

Detachment of eddies occurs when the Loop Current extends north into the Gulf. Peaks in the timing of LCE detachment have been observed at 6 and 11.6 months, with a smaller peak at 9 months. This correlates well with the frequency of northward intrusion. While the dynamics behind the process of detachment are not fully understood, there is a clear analogy with Gulf Stream ring separation. Instability within the Loop Current as it begins to turn east may start the formation of these eddies.

Loop Current Eddies are detectable to about 2500ft depth and once detached from the Loop Current they move west or southwest at around 2.5 miles/day. There is often more than one LCE in the western Gulf at any one time as they last for up to a year. Their path across the deep Gulf is characterized by sprints and stalls; during the latter eddies are influenced by other processes that can alter their trajectory. The LCEs decay along the Mexican shelf, where they interact with other LCEs and the bathymetry sometimes producing cyclonic eddies.

The Loop Current and LCEs are important to the offshore industry because of their high currents speeds, both at the surface (3-4kts) and through large portions of the water. Until recently there had been few direct measurements of LCEs, but eddy tracking with satellite data, drifters and other tools is now a routine procedure in the Gulf. Eddy 'Juggernaut' was measured in 1999 and had current speeds of 3kts at the surface and 2kts at 325ft. It had a semi-axis major length of 275 miles by the time it reached the central Gulf.

3.3 Submerged Currents

Submerged currents represent a problem of concern for DP operations. This phenomenon is characterized by high sub-surface current speeds at roughly 650 to 2300ft depth. Speeds can be in excess of 3kts, and there are often lower current speeds above and below the zone of strong currents. The vertical extent of these is usually less than 325ft and the jets may also be associated with strong vertical velocities. Durations of submerged current events vary from a few hours to about a day.

3.4 Near-Bed Intensified Currents

The intensification of currents near to the seabed are caused by topographic Rossby waves (TRW's), thought to be triggered by the Loop Current, that control the lower layer dynamics of the central and western Gulf. Observations in 6500ft of water at about 90°W show a gradual increase in current speeds towards the bottom with a period of about two weeks, characteristic of TRW's. High-speed events of 1.75kts at 30ft above the bed have been recorded.

TRW's are Rossby waves (also known as planetary waves as they owe their origin to the shape and rotation of the earth) that have been modified by the local topography. They are characterized by little change in speed and direction with elevation above the seabed. They actually intensify as the seabed is approached until the effect of friction at the seabed reduces the speed. However, the sparse existing data does not show what is forcing these waves, nor the extent of their penetration up the continental rise and slope, nor how their character might change from east to west. The understanding of near bottom currents was enhanced by a measurement campaign called GULL (carried out in 2000 & 2001) which sought to characterize the near bed currents in several parts of the Gulf, including areas along the Sigsbee Escarpment.

This phenomenon directly affects deepwater subsea DP operations, especially those involving ROV's near the seabed.

3.5 Monitoring and Mitigation

Monitoring and mitigation of the features discussed above is crucial to the successful completion of DP operations.

3.5.1 Hurricanes and Winter Storms

Oceanographers and meteorologists use a variety of statistical methods to quantify the risks from hurricanes and winter storms at any given location in the Gulf of Mexico. Historical buoy information is one source of information used to investigate past storm events. However, the most comprehensive tool being used today is hindcast models, which use data collected by satellite, reconnaissance and research aircraft and at the surface to specify the spatial and temporal evolution surface wind field in past cyclones. The wind analysis methodology is described most recently by Cox and Cardone (2000). Although this remains as the best method to estimate the expected n-year winds and waves due to hurricane, the databases need to be updated regularly to account for significant Gulf of Mexico events. A prime example of this is Hurricane Lili, which affected many of the offshore Louisiana lease areas in 2002.

Real-time monitoring of hurricanes, winter storms and squalls is accomplished through satellite, radar and surface observations as well as the regular issuance of forecasts and warnings.

Offshore installations are increasing being outfitted with instruments so that long-term meteorological records can be obtained.

3.5.2 Currents

For design and operability requirements of an offshore development a long duration (greater than one year) current measurement campaign is most important. Ideally, the measurements would be taken through the water column at or very near the proposed location.

In light of the MMS Notice to Lessees (NTL) concerning required deepwater current measurements, the benefits of a real-time monitoring system are increasingly becoming available for DP operations. A real-time system can involve a number of approaches. If a drilling rig is being used, an ADCP (Acoustic Doppler Current Profiler) can be mounted and provide continuous velocity readings. A variation on this would be a towed ADCP using a support vessel near the location. These approaches provide key current speed and direction information near the surface and through the water column with the range dependent on the type of ADCP that is used.

The monitoring and mitigation of eddies call for different approaches to be taken. One of the best ways to monitor eddy movement is through the use of altimetric data from geostationary satellites. The altimeter data is used to help show the gradients of sea surface heights over a given area, allowing oceanographers to determine the position and structure of ocean features such as warm and cold eddies. Altimetric data can also be assimilated into ocean forecast models to aid in the prediction of current speed and direction. Another way eddies are monitoring is through transects of the eddy feature using ADCP dips from a supply vessel. This approach allows for rapid sampling of an eddy and gives information regarding its width, depth and associated current speeds. An important piece of data that comes from transects is the location of the leading edge of high current speeds. This information is very helpful for DP decision-makers, especially if equipment such as risers, is exposed to the current through depth.

Through accumulation of measured data a variety of questions regarding DP operations can be answered. Of most importance is the use of quality controlled current measurements to understand the phenomena that occur in the Gulf of Mexico. Secondly, real-time data can be used to assess the performance of a functional DP system. Finally, data can be used after an event to determine the causes and effects and what steps can be taken the next time a similar situation occurs.

As mentioned above, numerical models can also be used as a mitigation tool to predict current speed and direction. This tool is relatively new for oceanographers, especially when compared to the atmospheric models that have been used by meteorologists for some time now. With time, the increasing level of measurement in deepwater regions of the Gulf and enhanced knowledge of phenomena will help refine and improve these models resulting in a valuable resource for DP operation planning and support.

REFERENCES

2000 Cox, A. T. and V. J. Cardone. Operational system for the prediction of tropical cyclone generated winds and waves. 6th International Workshop on Wave Hindcasting and Forecasting, November 6-10, 2000, Monterey, CA.