Evaluating Hydrodynamic Uncertainty in Oil Spill Modeling

GIS in Water Resources (CE 394K)

Term Project

Fall 2011

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Introduction

The goal of this project is to provide a continuously-updated series of forecast models from prior times with different time spans that predict the present real-time. The difference between these old forecasts and observed data is used to quantify model error. This error is used to estimate how uncertainty evolves over time for new forecasts, and hence the forecast time horizon over which the forecast is believable. Hydrodynamic models are inherently mechanistic, translating given tidal and wind forcing into time and space-varying velocities. By setting up a continuously-cycling set of sequenced hydrodynamic models (Figure 1), we can provide an ensemble of model predictions for creating a first-level estimate of the combined forecast and hydrodynamic uncertainty.

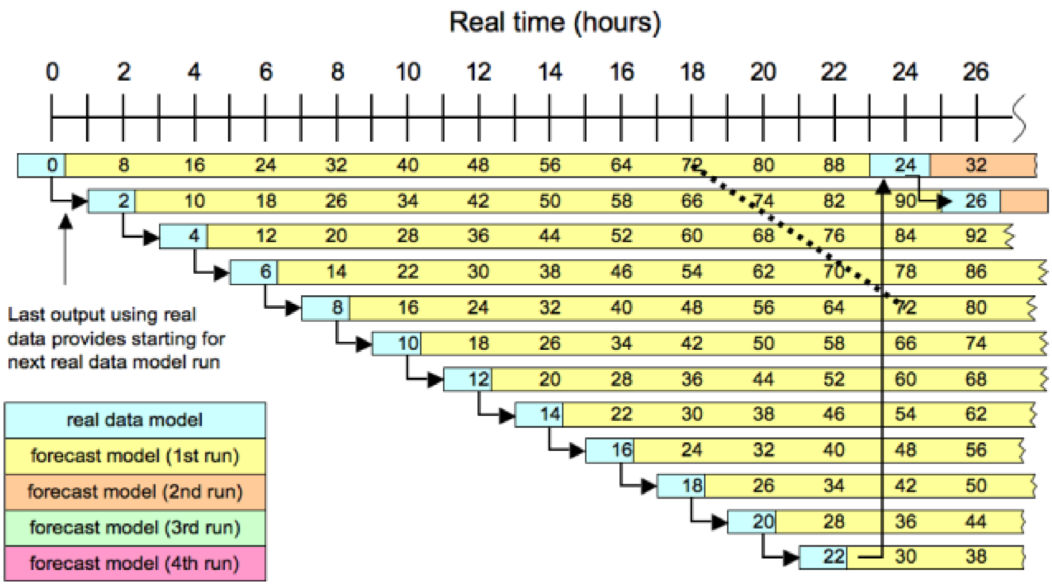

Figure 1

As is shown in Figure 1, we begin with a hydrodynamic model that has been run diagnostically up to real-time=0, after which a forecast is begun on CPU-1 (first row in yellow on upper panel of Figure 1). With a 4:1 run-time to real-time ratio, the model on CPU-1 finishes a forecast out to 88 hours after 22 hours of real-time (i.e. 66 hours ahead of real-time). After the model on CPU-1 has started running, new wind and tide observations become available. To make use of this data, a new model is started on CPU-2 beginning with the last diagnostic model results (real-time=0). This new model is run diagnostically through the available new wind/tide data (up to real-time=2 hours), after which it continues in forecast mode. Since CPU-1 used forecast data for zero to two hours, its forecast will likely diverge from the CPU-2 model using observed data during the same time interval. As the two models continue forward in time, the difference between them provides insight into the uncertainty associated with the initial forecast data.

Therefore, to obtain and analyze the observed wind/tide data become the first step of this project. Through analyzing the distribution of wind and tide spatial and time series, we would know the approximate uncertainty of the models running, which in turn, will provide us an insight of how stability our sequenced hydrodynamic models are.

According to this term project, the focus is on how to analysis wind and tide data and assess the corresponding results along the Texas coast.

Methods

Data source and selection:

Generally, wind and tide data belong meteorological data fields which are monitored by the National Weather Service department by real-time hours. In order to provide the national infrastructure, science, and technical expertise to monitor, assess, and distribute wind, gust, tide, current, water level, and other coastal oceanographic products and services that support NOAA's mission of environmental management, assessment and prediction, the Texas Coastal Ocean Observation Network (TCOON), provide a modern state-of-the-art water-level measurement system along the Texas coast(Figure 2).

For the reason that wind speed or direction is a process of random variation series, it is reasonable to select a corresponding long time period to investigate the characteristic (annual maximum speed, annual mean speed, annual distribution of direction and etc.) of wind. For another reason that there are 31 stations along the Texas coast, it is not necessary to study each of them in order to yield the research results, because each station has the same possibility to monitor different wind series, instead of random possibility like wind speed or direction at one specific time period. Thus, it is rational to choose on typical station to monitor and a corresponding long time period to investigate.

According to tide, tide is the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the moon and the sun and the rotation of the Earth. Because tide is driven by the gravitational forces and the rotation of the Earth, there must be a certain regular pattern in time series. There are 5 time variables of tide which are higher high water, lower high water, high water, low water, higher low water and lower low water. Each of them is abided by the pattern in a certain time series. Therefore, it is also believable to choose one single station to monitor and a particular time series when the tide would happen to investigate.

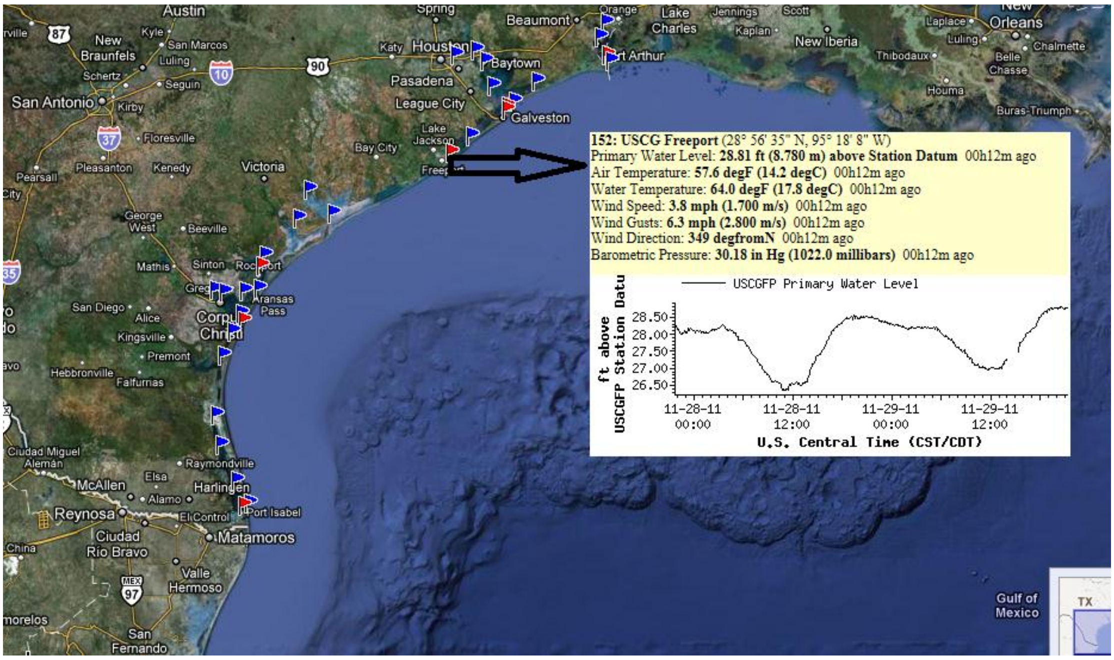

Figure 2

The station selected in this project is called USCG Freepor and it gets a DNR ID of 152 which is located at 28 ° 56' 35" N, 95 ° 18' 8" W (Figure 3). The station collects meteorological data every 6 minutes. In order to ensure the accuracy of a random sample of data, the project selects the time series from 11/21/2010 to 11/21/2011 to investigate.

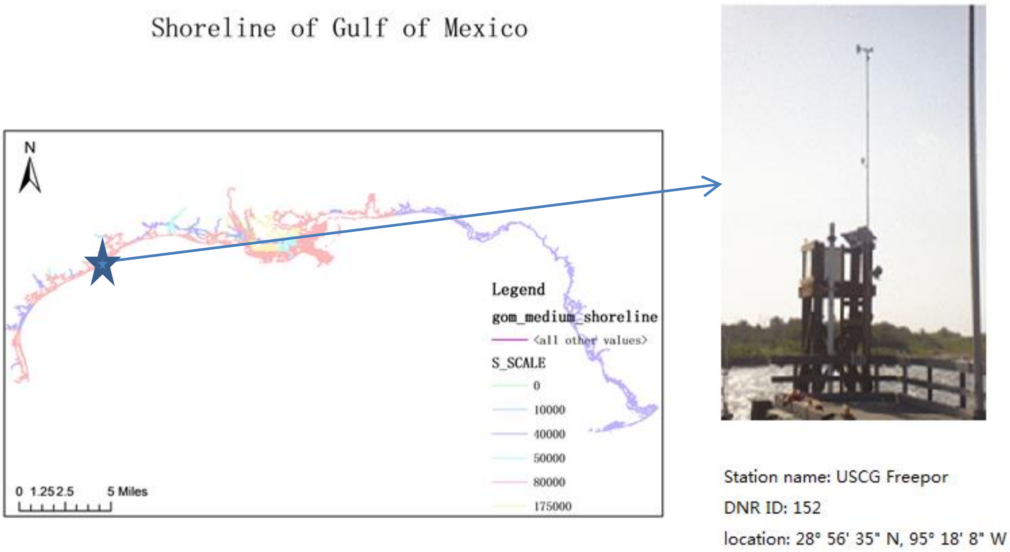

Figure 3

Wind analysis

First, the project takes a general look at the annual (11/21/2010 to 11/21/2011) average offshore wind speed in the United States at a scale of 90 m (Figure 4). By using ArcGIS, it is easier to find that the pink area (8.0-8.5 m/s) covers most of the offshore and there are red distributions (10.0-10.5 m/s) along the northeast and part of west offshore. Around the Texas coast, there exists green distribution (7.0-7.5 m/s). Generally, the average offshore wind speed of the country does not show any sudden range or instability.

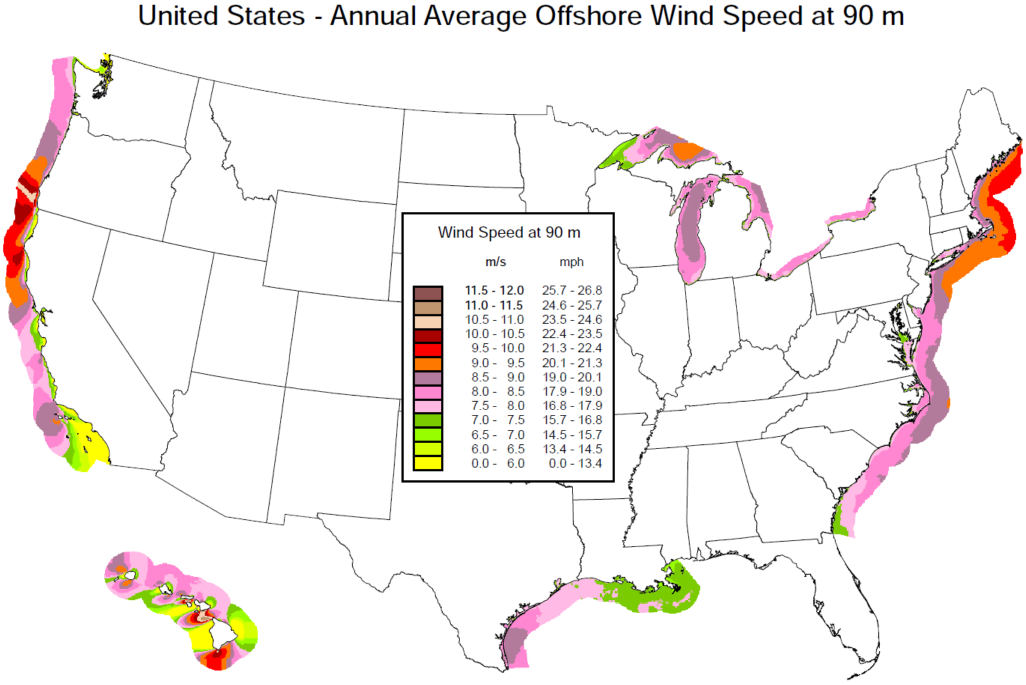

Figure 4

Now, let's take a deep look at the study area, Texas coast (Figure 5). In the same time period, it does not show any difference with the above National scale layout. Obviously, most of the coast is covered by the pink color under this annual average wind speed parameter.

Therefore, in order to analyze the uncertainty of the wind characteristic, it is necessary to undergo other investigations to analyze parameters such as the maximum of the wind speed, the monthly-mean wind speed distribution, the average wind directions which would lead to the oil spill movement, and some parameter that would give us a larger picture of the wind change characteristic which is the major factor of uncertainty. In addition, it is also necessary to analyze the gust which is a brief increase in speed of the wind during a very short period of time. The duration of a gust is usually less than 20 seconds. In general, the gust speed is more than 50% of the average wind speed or even higher. Thus, gust is also a major concern that would make the oil spill more unstable.

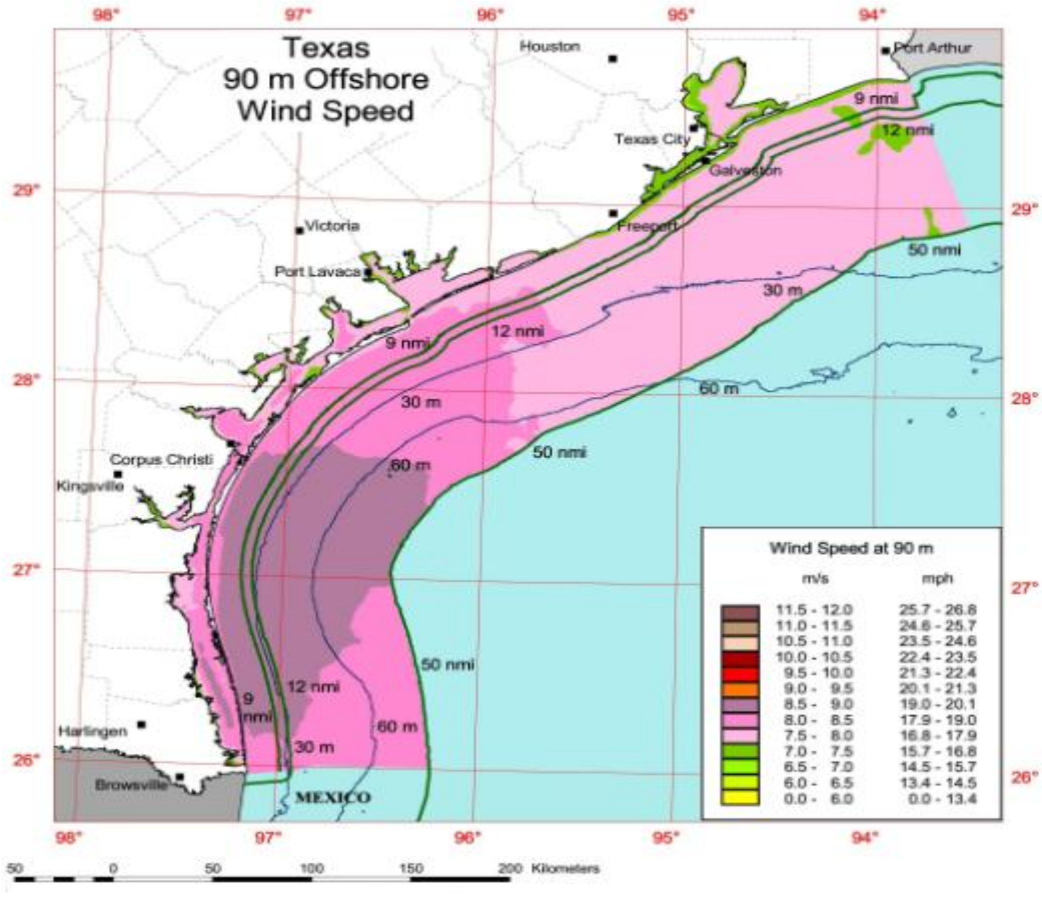

Figure 5

Tide analysis

Generally, tide has a regular time pattern which is showed in the water level at different time period. Below (Figure 6) is the contrast of before and during the specific time period of tide at the station selected.

Figure 6

Thus, not as wind, it is easier to analyze the tide characteristics for the reason of its regular time pattern. The study would only focus on the time period when the tide is coming and check the different parameters to verify if they follow the natural regulation.

Result and Discussion

Wind analysis results

Instead of analyzing the annual average wind speed, it is more obvious to understand the cause of oil spill uncertainty by looking at the wind distribution via unit test time (6 minutes). Below (Figure 7) is the result:

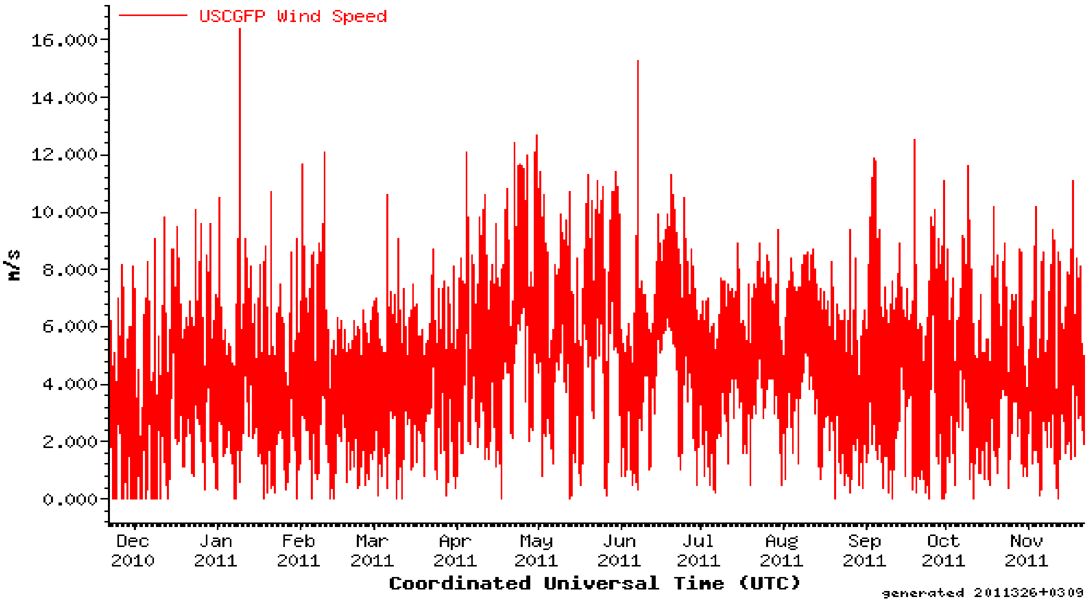

Figure 7

Through the analysis, the maximum of the wind speed which occurs in 01/09/2011 is 16.4 m/s and the average is 4.762546 m/s. Thus, we know exactly the change of wind speed during every 6 minutes.

In order to understand the wind speed distribution change better, it is necessary to investigate the monthly-mean wind speed distribution (Figure 8). Firstly, calculate the monthly-mean wind speed by exporting data into EXCEL and then, make the graph according to time period, for example: from 11/21/2010 to 12/21/2010.

Based on the result of the Fig.8, we can conclude that the average monthly wind speed get much higher during March, April, May and October which give us an prediction that the uncertainty of oil spill will increase in these four Months.

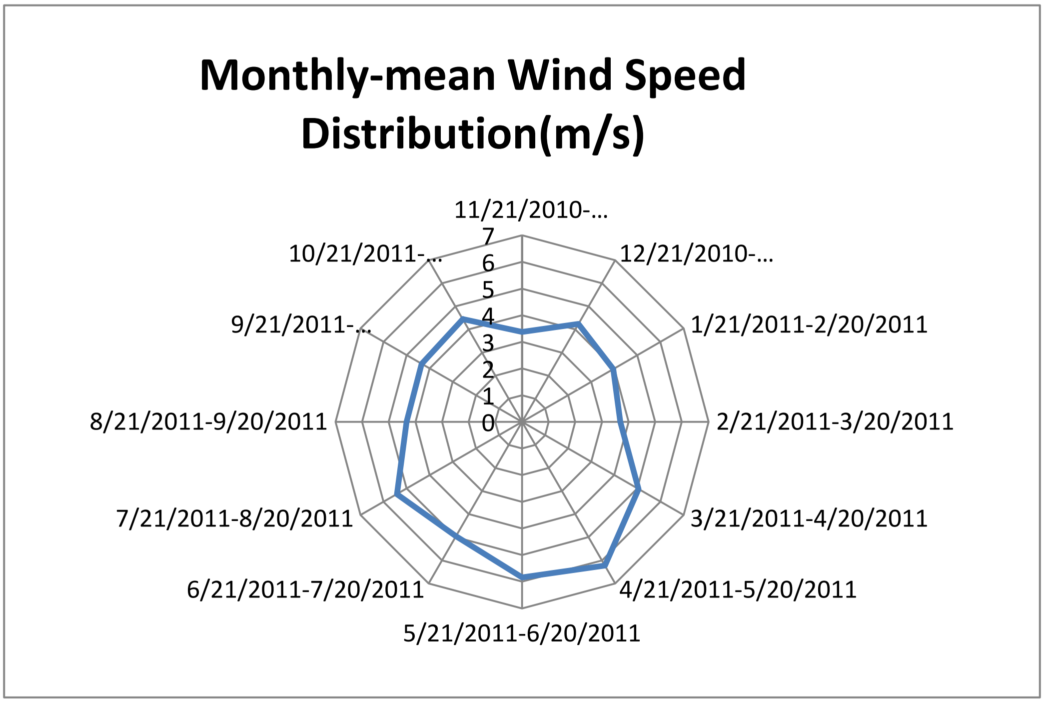

Figure 8

Furthermore, to check the result above, it is also necessary to analyze the difference ratio of the monthly–mean wind speed. By using the formula:

(Monthly mean wind speed – Average monthly mean wind speed)/ Average monthly mean wind speed

We can come up with the Monthly-mean Wind Speed Difference Ratio graph (Figure 9).

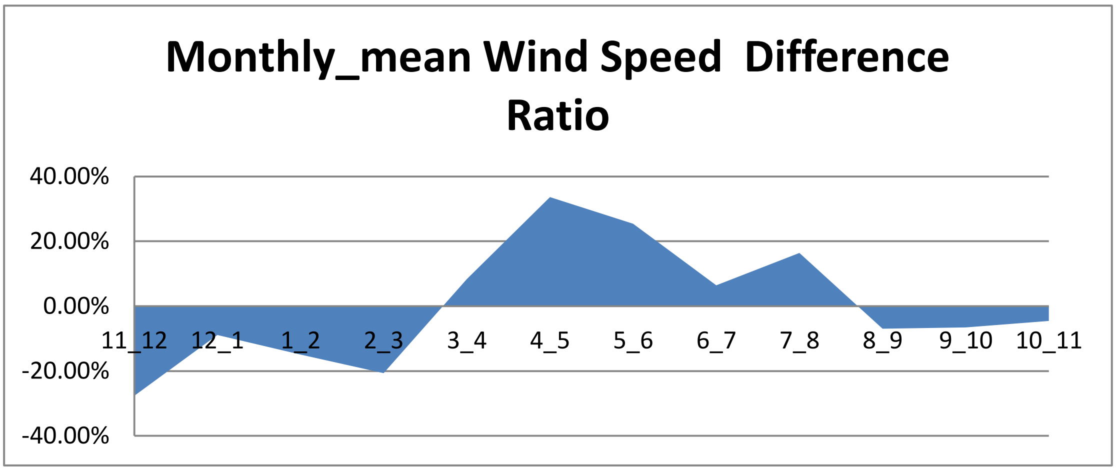

Figure 9

From the graph, we know that the March, April, May and October are the months which would have increasing uncertainty in oil spill.

Below (Figure 10) is the result of the wind direction distribution. We can see that the monthly mean wind direction changes in a small range but the moment wind direction changes a lot which will lead to a great uncertainty for the oil spill.

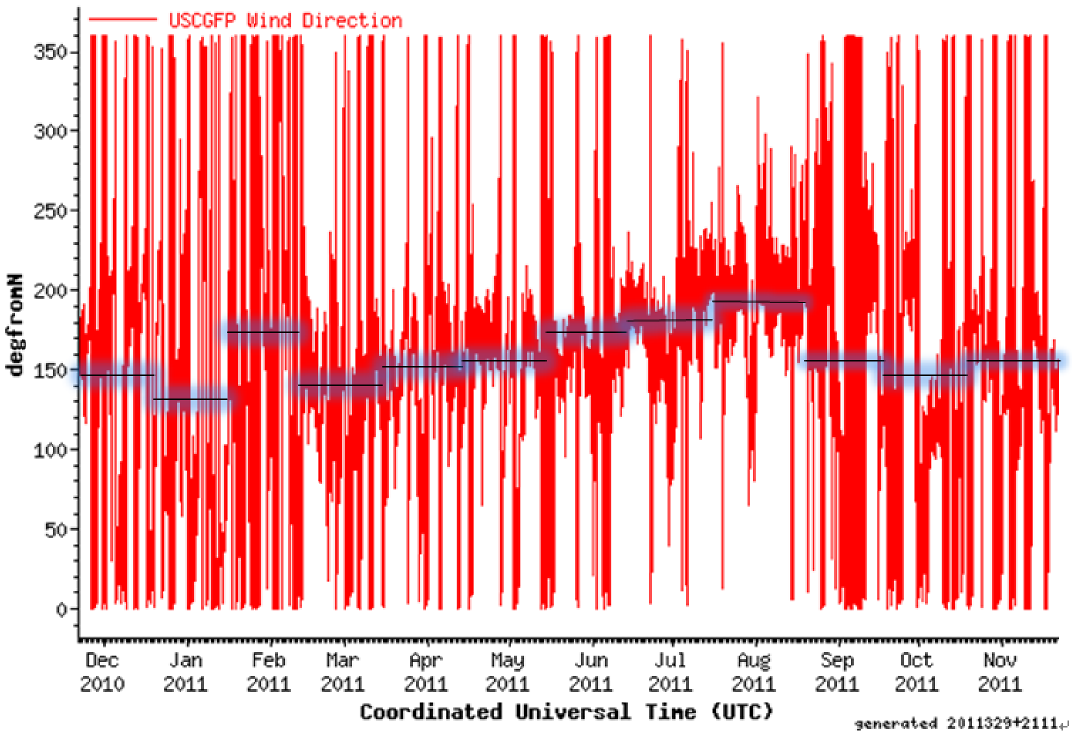

Figure 10

Below (Figure 11) is the result of wind gusts distribution.

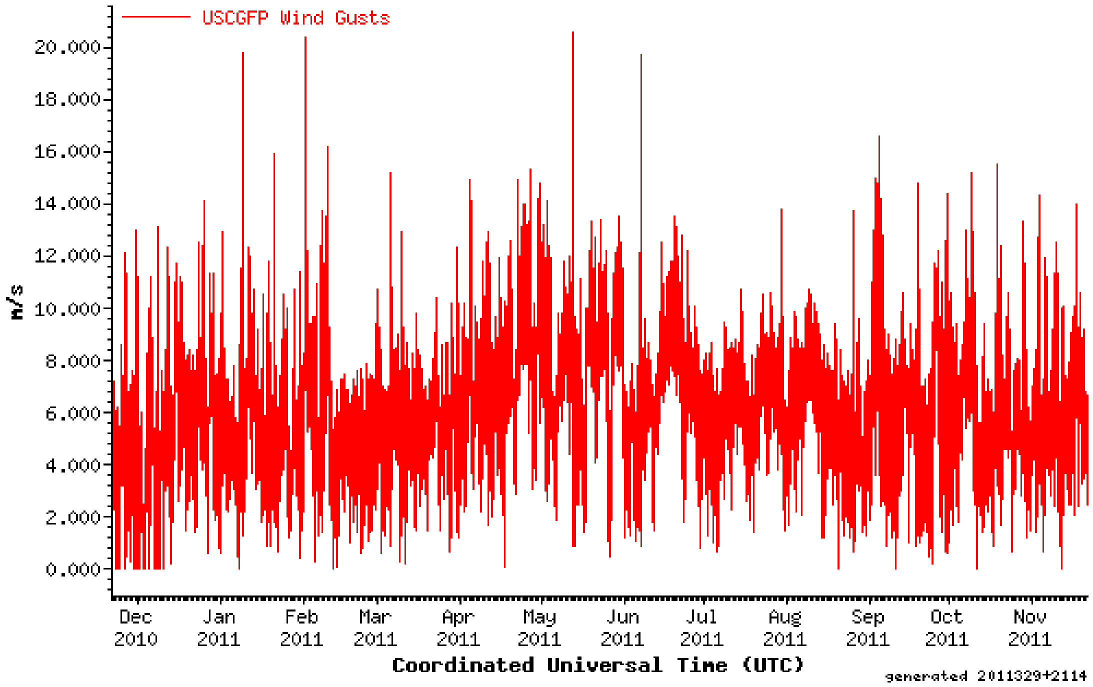

Figure 11

Unlike the wind speed distribution, the maximum gust speed occurs in 5/12/2011 which is 20.6 m/s and the average is 6.14 m/s. And we also have the results of monthly-mean wind gusts distribution (Figure 12) and its difference ratio (Figure 13). From the analysis of the gusts, we come up with the same result as the analysis of wind speed. March, April, May and October show a much higher possibility of increasing oil spill uncertainty.

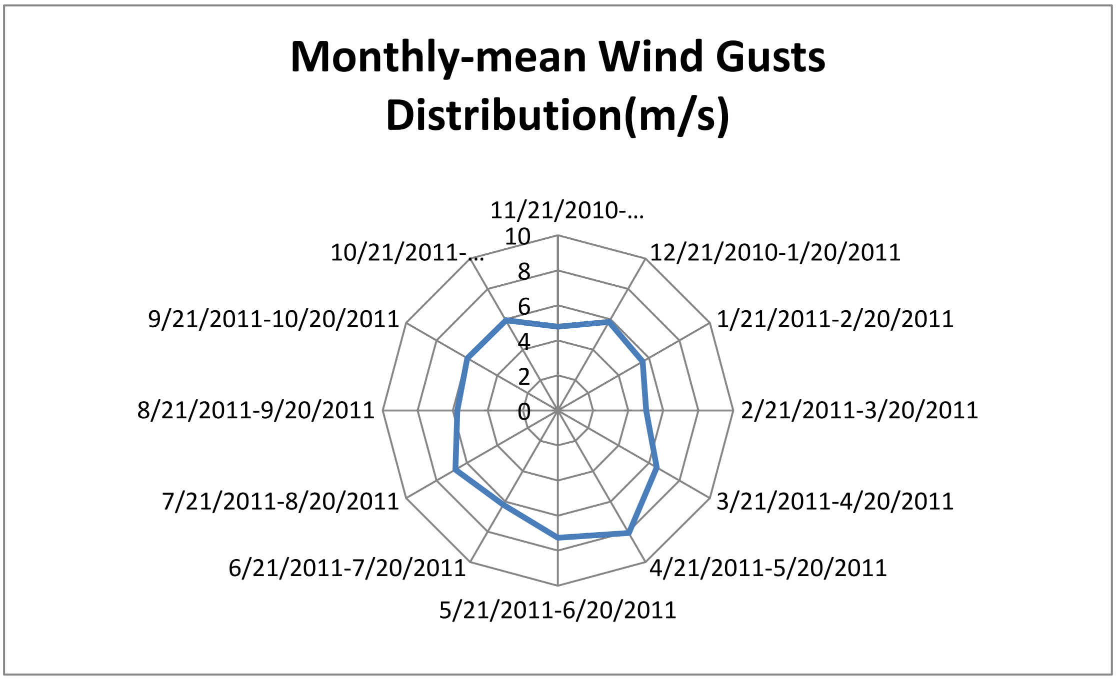

Figure 12

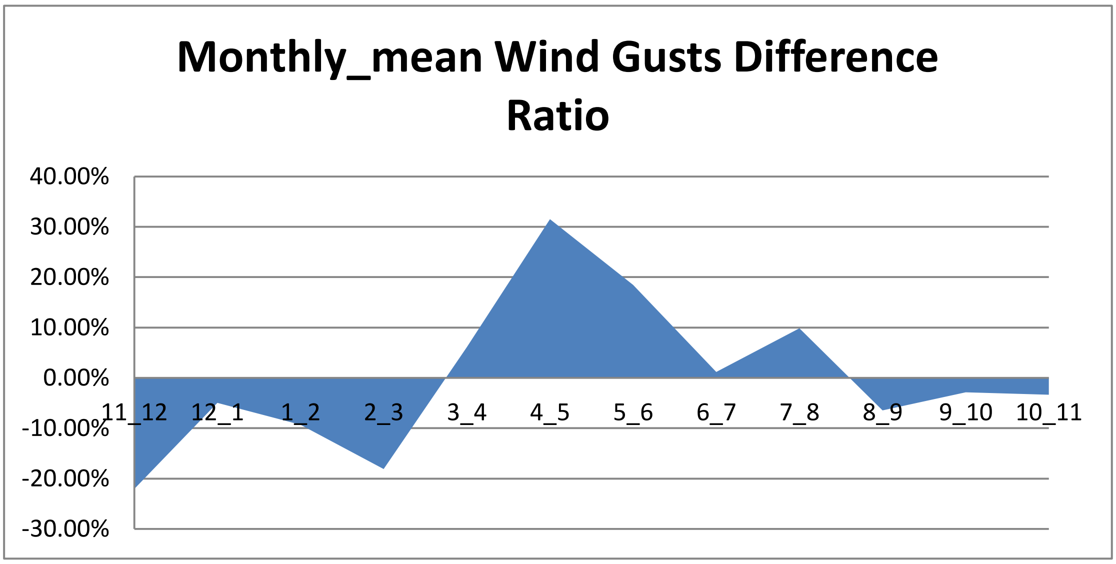

Figure 13

Tide analysis results

There are 5 time variables of tide which are higher high water, lower high water, high water, low water, higher low water and lower low water. Plot the 5 time variables via time change and the result is below (Figure 14):

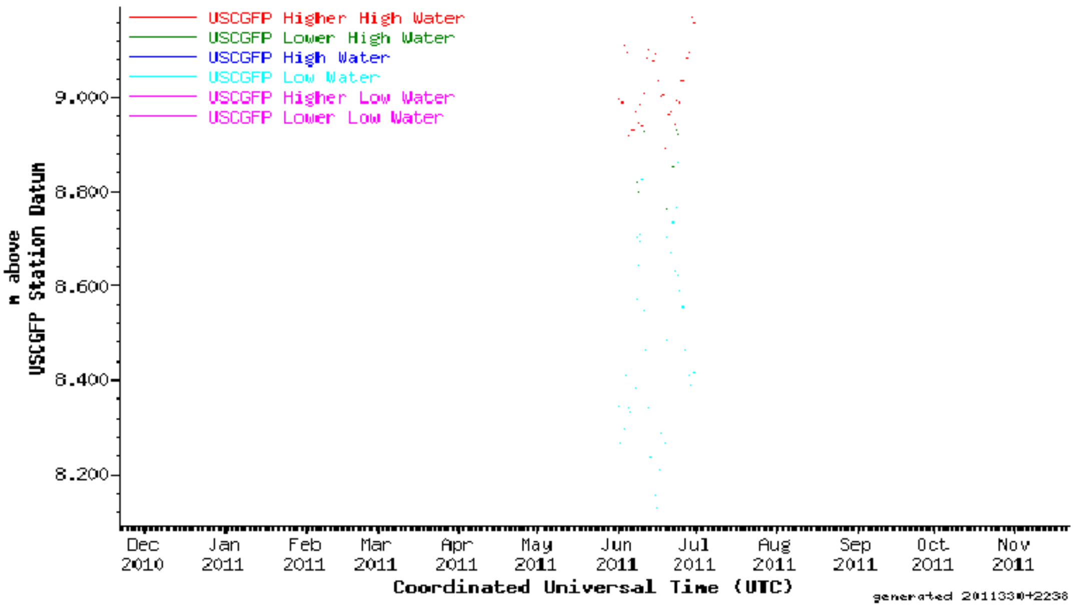

Figure 14

Based on the result, it is explicit to figure out that June is very time period that the tide would happen. To check the results, it is necessary to calculate each of the 5 variables' maximum and minimum (Table 1).

parameters	higher high water	lower high water
max(m)	9.172(6/29/2011 9:18)	8.932(6/23/2011 14:42)
min(m)	8.891(6/19/2011 12.42)	8.763(6/19/2011 22:06)
ave(m)	9.021133	8.59571
parameters	high water	low water
max(m)	9.172(6/29/2011 9:18)	8.864(6/24/2011 9:30)
min(m)	8.763(6/19/2011 22:06)	8.127(6/16/2011 2:42)
ave(m)	8.990568	8.492297
parameters	higher low water	lower low water
max(m)	8.864(6/24/2011 9:30)	8.696(6/09/2011 22:48)
min(m)	8.705(6/19/2011 19:54)	8.127(6/16/2011 2:42)
ave(m)	8.7565	8.419414

Table 1

As a result, the variables match the natural regulation and the performance is believable. For example: the maximum of higher high water equals to the maximum of high water (the light blue color in the above table).

Conclusion

The station selected in this project, USCG Freepor, has provided us a general insight of how wind and tide factors would have impact on the uncertainty of oil spill modeling along Texas coast. As a result, it would successfully help the exist models to improve and offer reference for the future models of oil spill.

Firstly, the wind speed changes significantly via corresponding short time period which will lead to the increasing of uncertainty, rather than the annual average wind speed which shows little changes. Secondly, the monthly mean wind direction changes in a small range but the moment wind direction changes a lot which will lead to a great uncertainty for the oil spill. Thirdly, based on wind and gusts speed difference ratio, we also conclude that March, April, May and October will have a higher possibility of increasing the uncertainty of oil spill. In addition, tide will also increase the uncertainty of oil spill in June.

Reference

Ben R. Hodges, PhD. GLO proposal extract, "Evaluating Hydrodynamic Uncertainty in Oil Spill Modeling", Project description

Texas Coastal Ocean Observation Network
http://lighthouse.tamucc.edu/TCOON/HomePage

National Weather Service Weather Forecast Office
http://www.srh.noaa.gov/lch/?n=tides

NOS Water Level Observation Network
http://tidesonline.noaa.gov/geographic.html