# The Impact of Tropical Cyclones on Gulf of Mexico Crude Oil and Natural Gas Production

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## 1. Summary


The Atlantic hurricane season of 2005 was the most active season since accurate record-keeping began in 1944.[1] There were 27 named storms including 15 hurricanes, seven of which were classified as Category 3 or higher. The paths of five of these major hurricanes passed through the Gulf of Mexico significantly disrupting oil and natural gas production. In particular, hurricanes Katrina and Rita crossed through the heart of the Gulf producing region, resulting in widespread shut-in production, some of which continues to the present. As of June 1, 2006, production of crude oil has been reduced by more than 162 million barrels and production of natural gas reduced by 784 billion cubic feet since the first of the hurricanes struck 9 months ago (Minerals Management Service, Hurricane Katrina/Hurricane Rita Evacuation and Production Shut-in Statistics Report ). This amounts to about 30 percent and 21 percent of a normal year's oil and natural gas production from the Federal offshore fields, respectively.


[1] The National Oceanic and Atmospheric Administration (NOAA) lists tropical cyclone statistics since 1851, however reliable data for the entire Atlantic basin are only available from 1944. (http://www.aoml.noaa.gov/hrd/tcfaq/E11.html)

In addition to the upstream impacts to Gulf production, hurricanes have had significant impacts on midstream and downstream infrastructure. Four hundred fifty-seven underwater pipelines were damaged, and the Louisiana Offshore Oil Port had to temporarily stop accepting shipments during both hurricanes. Finally, some onshore refineries and natural gas processing facilities suffered heavy damage. After Katrina hit Louisiana, nearly 2 million barrels per day of refinery capacity were shut down, due to either direct damage or interruption of power supplies. EIA estimates that at the height of the refinery outages (September 22-25, 2005), as much as 4.9 million barrels per day of refining capacity (nearly 29 percent of U.S. refining capacity and over 60 percent of refining capacity in the Gulf Coast region) were shut down. Some of the shutdowns were precautionary, ahead of the storms, but several refineries were damaged extensively, thus keeping them shut down for a relatively long time. For example, even as late as October 10, 2005, more than 2 million barrels per day of refining capacity were still shut down.

This report examines the historical impacts of tropical cyclones[2] on Gulf of Mexico crude oil and natural gas production over the period 1960 through 2005, and refinery operations over the past 20 years. Then, using the seasonal hurricane forecast published by the National Oceanic and Atmospheric Administration (NOAA) in May 2006, together with the fitted historical relationship between tropical cyclones and production impacts, we estimate possible ranges for total shut-in production during 2006. We emphasize the uncertainty of any forecast of shut-in production because of the difficulty of predicting whether Atlantic tropical cyclones will enter the Gulf of Mexico and threaten the oil and natural gas producing region. Additional uncertainty arises from the difficulty in predicting the duration, intensity, and damage caused by tropical cyclones in the Gulf of Mexico.

Seasonal storm-related disruptions to oil and natural gas production are difficult to predict, primarily due to the uncertainty involved in predicting the location and intensity of future tropical cyclones. Most tropical storms and even hurricanes that pass through the Gulf only temporarily disrupt oil and natural gas production while employees are evacuated to the mainland. Severe storms that threaten the Gulf producing region do not happen every year, and long-lasting shut-in production resulting from storm damage is generally rare. Given the history of storms and production losses and the current NOAA forecast, the total reduction in crude oil production from the Federal OCS during 2006 as a result of disruption from tropical storms and hurricanes may be expected to range from 0 to 35 million barrels. The reduction natural gas production from the Federal OCS during 2006 may range from 0 to 206 billion cubic feet.

The shut-in production ranges estimated in this report are conditional on the May NOAA forecast. NOAA emphasizes that its May hurricane outlook is based on climatological conditions that are still evolving. An updated hurricane outlook will be issued in August when conditions favorable for hurricanes are more predictable. There is the possibility that NOAA could substantially revise its projections for seasonal hurricane activity, as in

[2] Cyclone is a generic term for a low-pressure weather system that has a circular motion. Tropical cyclones originate over tropical or subtropical water and include tropical depressions, tropical storms, and hurricanes.

2005, when the May outlook, projecting hurricane activity for 2005 somewhat lower than what is currently projected for 2006, was revised substantially upward in August, prior to Hurricane Katrina. If a similar situation occurs in 2006, EIA estimates of shut-in crude oil and natural gas production would be significantly higher.

Section 2 of this report reviews the incidence of tropical cyclones in the Gulf of Mexico over the last 55 years. Section 3 presents the historical relationship between tropical cyclone activity in the Gulf and the production of crude oil and natural gas from the Federal outer continental shelf (OCS). Impacts on refinery operations during the past hurricane seasons are also reviewed. Section 4 develops two statistical models of the historical relationships between tropical cyclone activity and oil and natural gas production. These models underlie the projections discussed above.

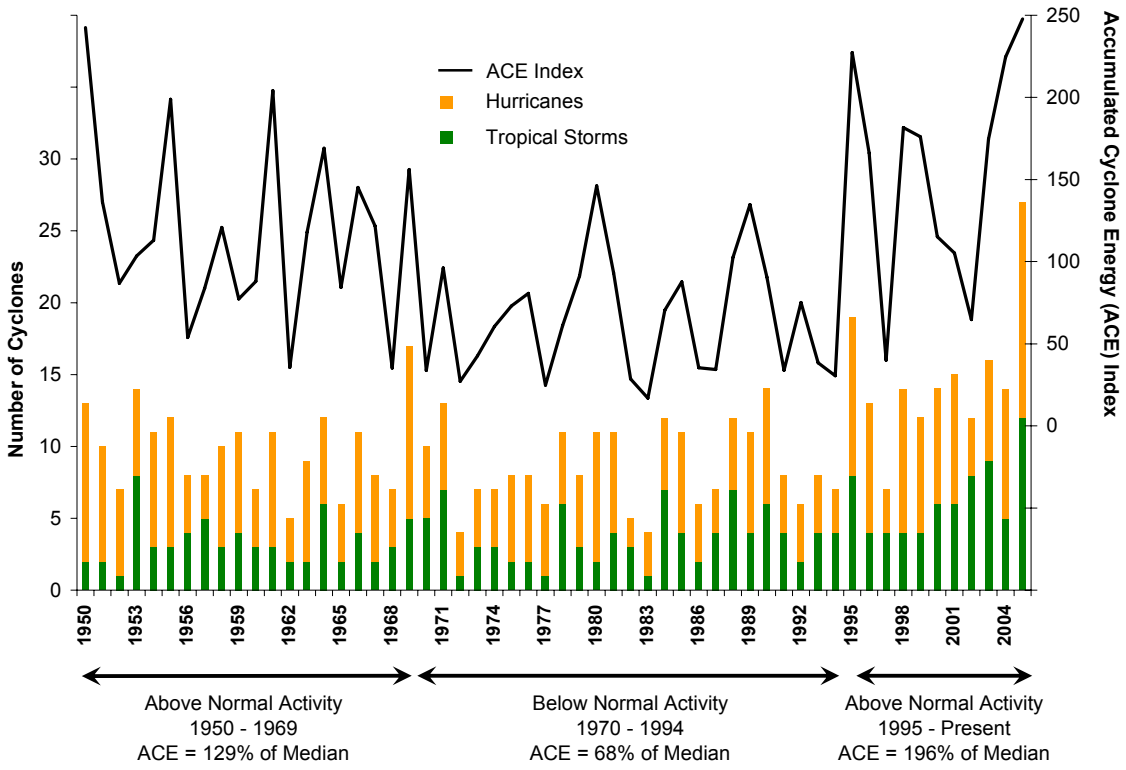
## 2. Tropical Cyclones in the Gulf of Mexico

Severe tropical weather is generally classified by the intensity of the weather system's wind speeds. Tropical depressions are cyclones having a maximum sustained wind speed of 38 miles per hour (mph), tropical storms have a maximum sustained wind between 39 mph and 73 mph, and hurricanes are cyclones with winds in excess of 73 mph. In the United States, hurricanes are categorized on the Saffir-Simpson scale by maximum wind speed: Category 1 (74-95 mph), Category 2 (96-110 mph), Category 3 (111-130 mph), Category 4 (131-155 mph), and Category 5 (156+ mph). Hurricane season in the Atlantic basin officially runs from June 1 through November 30, when ocean waters are warm enough to spawn tropical cyclones. However, about 75 percent of major hurricanes (Category 3 or greater) occur in August and September.

NOAA describes the intensity of tropical cyclones using the Accumulated Cyclone Energy (ACE) index. This measure accounts for both the strength of the wind during the storm and the duration of the storm. Specifically, it is defined as the sum of the squared maximum sustained wind speeds (in knots) for all six-hour intervals while the tropical cyclone is classified as either a tropical storm or hurricane. NOAA uses this measure to describe the intensity of particular storms and to describe the seasonal intensity (as the sum of ACE indices for all storms).[3]

[3] Further information about the ACE index and its use in describing seasonal cyclone activity is available at http://www.cpc.noaa.gov/products/outlooks/background_information.shtml.

**Figure 1. North Atlantic Accumulated Cyclone Energy (ACE) Index and Number of Tropical Cyclones, 1950 - 2005**




Note: Median Atlantic ACE index = 89.3 for 1950-2005.
Source: Hurricane tracking data from National Oceanic and Atmospheric Administration. (http://hurricane.csc.noaa.gov/hurricanes/download.html)

Figure 1 shows the annual Atlantic basin ACE index for 1950-2005 along with the number of tropical storms and hurricanes. One important pattern to note is that the seasonal intensity of tropical cyclones runs in what are termed multi-decadal cycles. During the 1950s and 1960s, hurricane activity was above normal, while the 1970s, 1980s, and early 1990s exhibited below-normal activity. Since 1995, the Atlantic has again been experiencing above-average activity with an ACE index almost twice the median value for the entire period.

A summary of the seasonal average levels of tropical cyclone activity for all available years and for the most recent above-average period are shown in Table 1. Since 1950, an average of 10 tropical cyclones have occurred in the Atlantic basin with 20 percent of those eventually becoming major hurricanes. These statistics highlight the cyclical increase in hurricane activity since 1995. The ACE index for the entire Atlantic over the period 1995-2005 is nearly double the median value for 1950-2005, and about 40 percent higher in the Gulf of Mexico. Much of this increase is due to the hyperactive 2005 hurricane season. Appendix A3 details seasonal hurricane activity and its impact from 1960-2005.

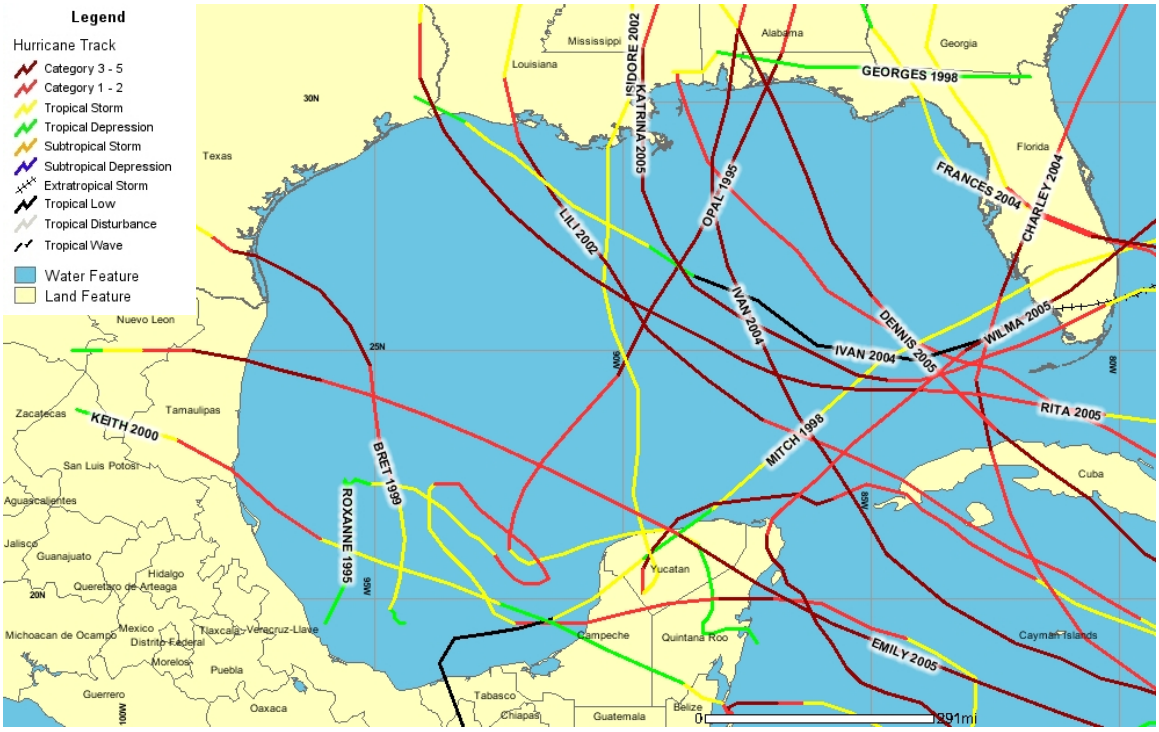
| Table 1. Annual Median Tropical Cyclone Activity, 1950-2005 | | | |
|---|---|---|---|
| | | **1950 - 2005** | **1995 - 2005** |
| **Atlantic Basin** | Tropical Cyclones | 10 | 14 |
| | Tropical Storms | 4 | 6 |
| | Hurricanes | 6 | 9 |
| | Major Hurricanes | 2 | 4 |
| | ACE Index | 89.3 | 174.5 |
| **Gulf of Mexico** | Tropical Cyclones | 3 | 6 |
| | Tropical Storms | 1 | 3 |
| | Hurricanes | 2 | 2 |
| | Major Hurricanes | 1 | 1 |
| | ACE Index | 11.9 | 16.3 |

Source: National Oceanic and Atmospheric Administration and EIA calculations.

Atlantic tropical storms and hurricanes usually follow one of three general paths: along the Eastern seaboard, across Florida and striking the Gulf Coast, or through the Caribbean Sea and moving north to strike the Gulf Coast. The longer a storm lingers over warm water, the more power it absorbs. About one-third of Atlantic tropical cyclones eventually pass through the Gulf of Mexico.[4] Figure 2 maps the track of major hurricanes that passed through the Gulf from 1995-2005. Green and yellow segments of each path represent tropical depressions and tropical storms, respectively. The red segments indicate that the tropical cyclone had achieved hurricane strength, with the dark red indicating a major hurricane. Further information about these storms is listed in Appendix A2. The map highlights the intense weather experienced by the Texas, Louisiana, Mississippi, and Alabama coasts over the last decade.

[4] For this analysis, the Gulf of Mexico is defined as the area within the rectangle bounded by 18° N – 31° N latitude and 81° W – 98° W longitude.

**Figure 2. Major Hurricanes in the Gulf of Mexico, 1995-2005**



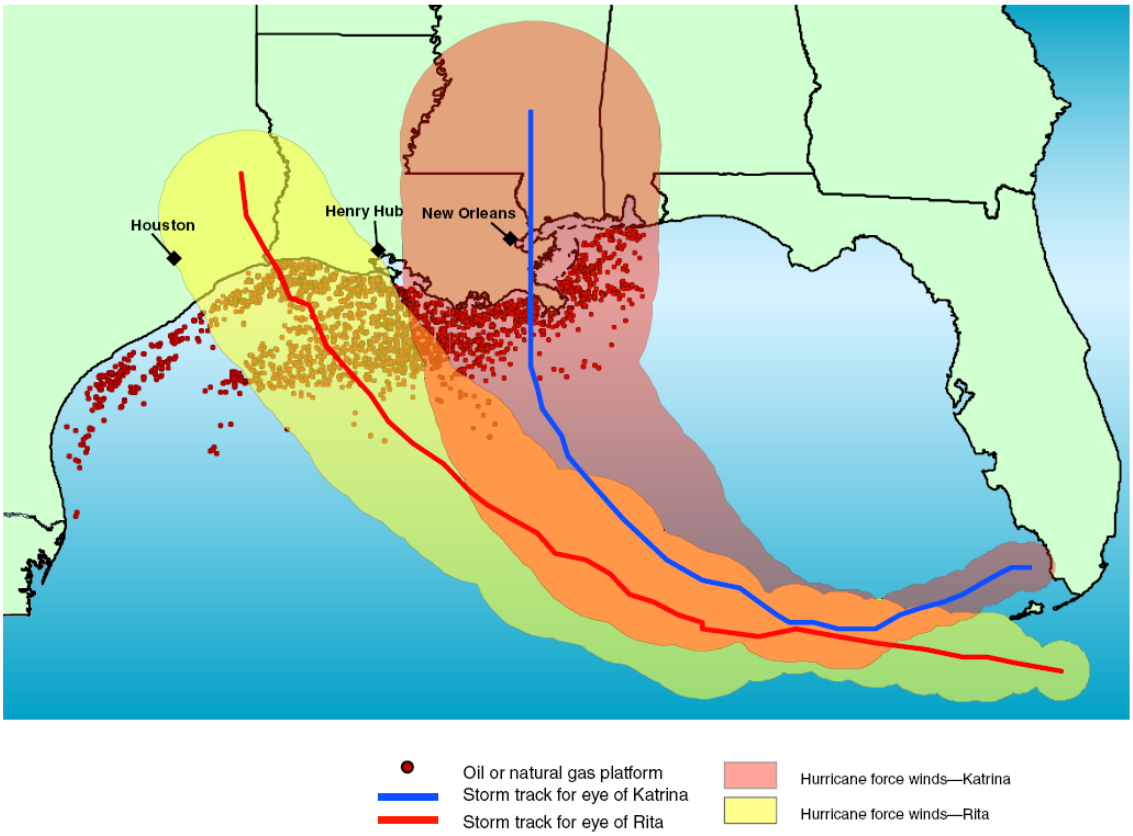

Source: National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (http://hurricane.csc.noaa.gov/hurricanes/)

## 3. Tropical Cyclone Impacts on Gulf of Mexico Crude Oil and Natural Gas Production and Refinery Operations

The Gulf of Mexico region is an important source for U.S. production of crude oil and natural gas. In 2004, crude oil production from the Federally-administered OCS fields was about 27 percent of total U.S. production (EIA, Petroleum Supply Annual). Gulf natural gas production was about 20 percent of the U.S. total in 2004 (EIA, Natural Gas Monthly). Texas, Louisiana, Alabama, and Mississippi also contribute significant onshore and State-administered offshore oil and natural gas production.

Federally-administered offshore oil and natural gas production occurs on the OCS, meaning all submerged lands lying seaward and outside of the area of lands beneath navigable waters of each of the respective States subject to the jurisdiction and control of the United States. The Minerals Management Service (MMS) has the primary responsibility for monitoring fossil fuel production on the OCS. Nearly all Gulf OCS production occurs in the Western and Central MMS planning areas roughly defined as the offshore area north of the southern-most tip of Texas and west of the Florida panhandle. Oil and natural gas platforms are especially concentrated south of the Louisiana coastline (Figure 3).

**Figure 3. Hurricanes Katrina and Rita**
**Relative to OCS Oil and Natural Gas Production Platforms**




Source: Government Accountability Office, "Natural Gas: Factors Affecting Prices and Potential Impacts on Consumers" (GAO-06-420T), February 2006.

When severe weather threatens, platform operators undertake certain procedures to protect workers and facilities. First, non-essential personnel are evacuated to onshore location. Second, movable equipment is secured to avoid loss. Finally, the well is secured by plugging the wellhead or closing wellhead valves so that oil and natural gas cannot escape in the event the platform is destroyed or dislodged from its moorings. The production that is forgone during these precautions is referred to as shut-in production. In order to assess the industry-wide impact of severe weather on Gulf oil and natural gas production, MMS requests evacuation and shut-in production data from offshore producers. Since at least 1998, these statistics have been collected using Form MMS-132, which operators submit whenever evacuation of personnel or curtailment of production occurs as a result of hurricanes, tropical storms, or other natural disasters. Evacuation and shut-in production statistics reports for recent tropical storms and hurricanes are posted on the MMS website.[5]

[5] http://www.gomr.mms.gov/homepg/whatsnew/hurricane/index.html

Hurricanes Katrina and Rita passed directly over the OCS producing region (Figure 3). At one point just prior to the landfall of Katrina, 79 percent of Gulf platforms were evacuated and 1.4 million barrels per day of oil (95 percent of normal Gulf OCS daily production) and 8.8 billion cubic feet per day (88 percent or normal Gulf OCS production) were shut in. Katrina destroyed 44 platforms as it passed over the OCS producing region, including some of the deepwater projects that are still under construction. As Rita passed over the producing region, 93 percent of platforms were evacuated and 100 percent of normal daily oil production and 81 percent of normal natural gas production were shut in. Sixty-nine platforms were destroyed by the hurricane-force winds. In addition to the upstream impacts to Gulf production, the hurricanes had significant impacts on midstream and downstream infrastructure. Four hundred fifty-seven underwater pipelines were damaged, and the Louisiana Offshore Oil Port had to temporarily stop accepting shipments during both hurricanes. Finally, some onshore crude oil refineries and natural gas processing facilities suffered heavy damage. After Katrina hit Louisiana, nearly 2 million barrels per day of refinery capacity were shut down either due to direct damage or interruption of power supplies. More than 4.9 million barrels per day of refinery capacity were shut down after Hurricane Rita hit the Texas coast.

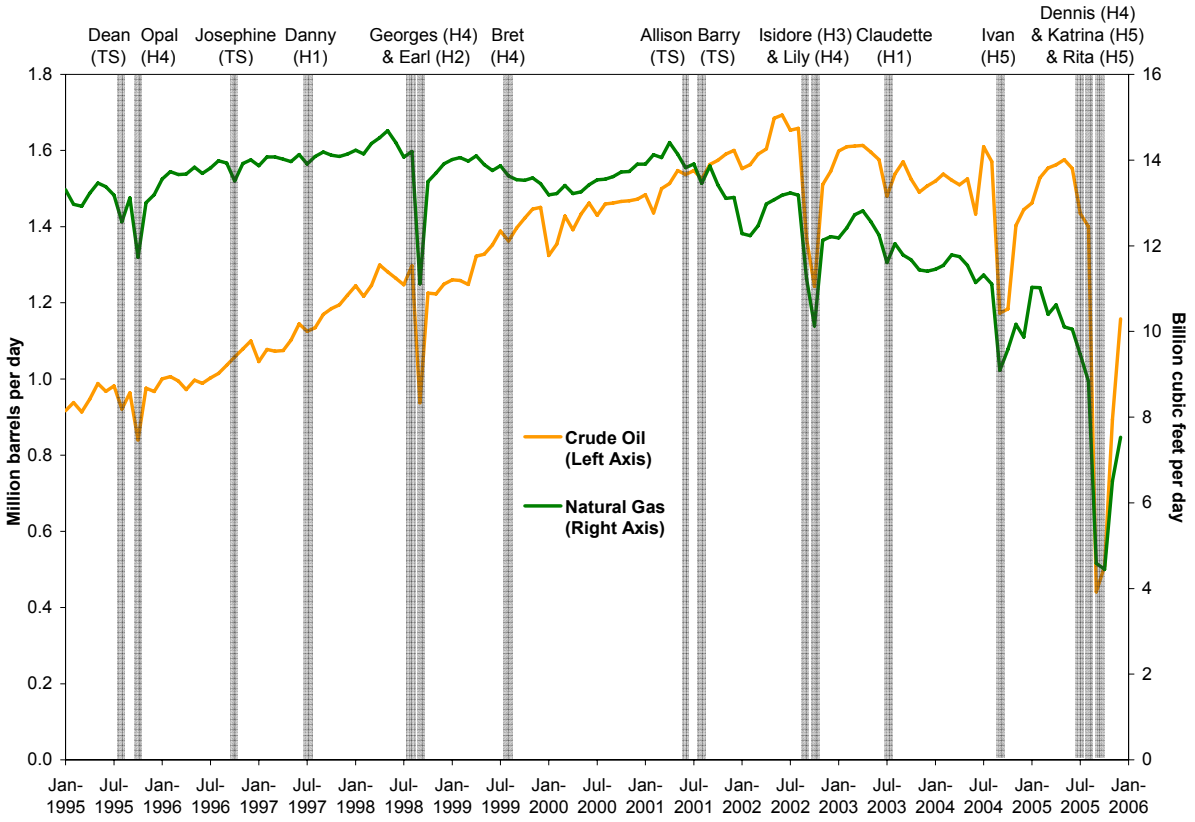
Although Hurricanes Katrina and Rita caused long-lasting effects on oil and natural gas operations in the Gulf of Mexico, severe weather in the region has historically had only a relatively minor impact. Figure 4 shows the production of oil and natural gas in the Gulf OCS for 1995-2005 with the effects of various Gulf of Mexico tropical storms and hurricanes highlighted. There have been 6 major hurricanes during the past decade that have caused significant disruption in oil and natural gas production: Opal (1995), Georges (1998), Lili (2002), Ivan (2004) and Katrina/Rita (2005). However, with the exception of Ivan (which shut in about 25 percent of monthly production) and Katrina/Rita (which shut in about 70 percent of monthly production), most disruptions have been temporary with near-normal production returning the following month. In fact, most Gulf tropical cyclones only shut in production for a few days. For example, in 1997 Hurricane Danny passed within 50 miles of the center of OCS production, yet it registered a barely perceptible drop in daily production rates, shutting in about 2 percent of that month's oil and natural gas production. Hurricane Bret (1999) with 125 mile per hour winds slightly impacted crude oil production but had almost no effect on the trend in natural gas production.

Gulf tropical storms and hurricanes typically cause small disruptions when measured on a seasonal basis. The average seasonal shut-in production (as a percentage of normal annual Gulf OCS production) from 1960-2005 is 1.4 percent for crude oil and 1.3 percent for natural gas.[6] However, these averages are skewed upwards by the 19 percent of oil production and 18 percent of natural gas production that was shut in during 2005 (total shut-in production through June 1, 2006, according to MMS totaled 30 percent and 21 percent for crude oil and natural gas, respectively). The median seasonal shut-in

[6] This report uses estimates of shut-in crude oil and natural production that are based on historical MMS production data. Appendix A1 discusses the estimation methodology.

production has only been 0.6 percent and 0.5 percent of annual Gulf OCS oil and natural gas production, respectively.

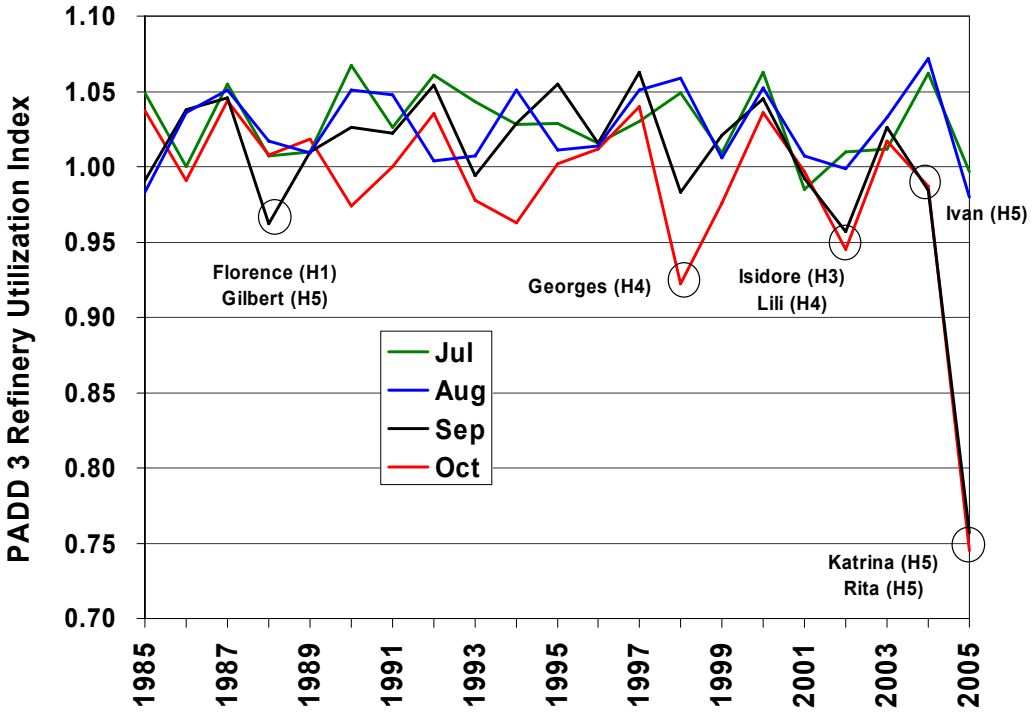
**Figure 4. Federal Gulf of Mexico (OCS)**
**Oil and Natural Gas Production, 1995-2005**




Note: Not all cyclones are highlighted on chart. TS = Tropical Storm. H*n* = Category *n* hurricane.
Source: EIA, Minerals Management Service and National Oceanic and Atmospheric Administration.

There is no long-term data source that tracks the impact of hurricanes and tropical storms on the refinery sector. Refinery utilization rates are generally affected by overall capacity availability relative to demand, forced outages, and seasonal maintenance and product turnaround cycles, as well as by hurricanes. Despite the inherent difficulty of isolating the effect of storms on refineries, EIA has developed a simple index of normalized capacity utilization for refineries in the Petroleum Administration for Defense District (PADD) 3, which encompasses the Gulf Coast. Figure 5 displays the monthly normalized index (monthly utilization rate divided by the average January-through-June utilization rate) for PADD 3 refinery capacity for the months of July through October, when disruptions related to tropical storms and hurricanes are most likely to occur. The index highlights the uniqueness of the refinery damage experienced in 2005.

**Figure 5. Hurricanes in 1988, 1998, 2002, 2004, and 2005 Impacted Refineries on the Gulf Coast**




Note: The Refinery Utilization Index is calculated by taking the ratio of the refinery utilization in a given month divided by the average utilization for January through June in the same year.

## 4. Forecasting Shut-In Production

In May of each year, NOAA publishes projections about the upcoming hurricane season in the Atlantic basin, which includes the Caribbean Sea and the Gulf of Mexico (NOAA: 2006 Atlantic Hurricane Outlook).[7] These projections are primarily driven by their forecasts of the seasonal ACE index, which measures the collective intensity and duration of all tropical storms and hurricanes in the Atlantic. For 2006, NOAA expects the seasonal Atlantic ACE index to be 118 – 179 (135 – 205 percent of its normal level). This range corresponds to an 80 percent chance of an above-normal hurricane season during 2006. Although this forecast predicts a very active hurricane season, it is considerably lower than the Atlantic activity observed last year, which had an ACE index 280 percent of the normal level.

[7] Accuweather (http://hurricane.accuweather.com/hurricane/index.asp?partner=accuweather) and the Tropical Meteorology Project at Colorado State University (http://tropical.atmos.colostate.edu/forecasts/) provide similar hurricane season forecasts.

In addition to the ACE projections of overall tropical cyclone activity, NOAA expects 13 to 16 named tropical cyclones, 8 to10 hurricanes, and 4 to 6 major hurricanes forming in the Atlantic basin during 2006. However, it is important to note that NOAA's forecasts do not detail the predicted level of hurricane activity for individual localities within the Atlantic such as the Gulf of Mexico.

Seasonal hurricane-related disruptions to oil and natural gas production are difficult to predict, primarily due to the uncertainty involved in predicting the location and intensity of future tropical cyclones. However, an analysis of historical impacts can provide some insight into the range of potential effects given a seasonal hurricane forecast.[8] For this analysis, two models for using the NOAA seasonal predictions were developed to form expectations of the range of annual crude oil and natural gas shut-in production. The first model is based on the forecast Atlantic basin ACE index and the second model uses the predicted number of Atlantic tropical cyclones. The equations are estimated based on seasonal tropical cyclone activity and Gulf OCS production records from 1960 through 2005.

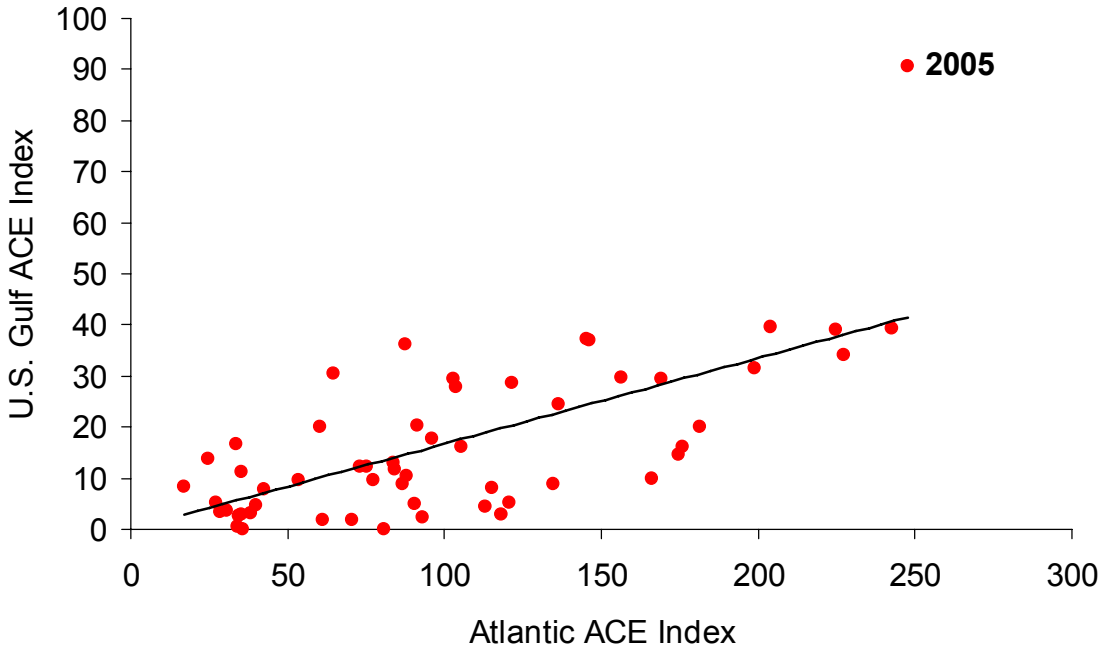
Each model consists of two linear regressions. The first equation relates the NOAA forecast of the Atlantic ACE or the number of Atlantic tropical cyclones to a Gulf of Mexico ACE or the number of Gulf of Mexico tropical cyclones, respectively. The second equation relates the Gulf of Mexico ACE or number of tropical cyclones to shut-in crude oil or natural gas production. Neither regression equation includes a constant term since a season with no hurricane activity implies no hurricane-related disruptions. This dual-stage regression approach was adopted instead of a reduced form regression directly relating Atlantic hurricane activity to shut-in production in order to isolate the sources of forecast uncertainty. Estimation results for both models are shown in Appendix A4.

## A. Model 1: Using the NOAA Forecast of the Atlantic ACE Index to Estimate Shut-In Production

The first model uses the NOAA seasonal Atlantic ACE index forecast as the basis for estimating the expected level of shut-in production. For 2006, NOAA expects the seasonal ACE index to be 118 – 179 (135 – 205 percent of its normal level). The first equation relates the Atlantic ACE index to the Gulf of Mexico ACE index (Appendix A4). This equation contains significant uncertainty with only 48 percent of the variation in Gulf ACE explained by variation in the seasonal Atlantic ACE (Figure 6). Note that the 2005 hurricane season was an extreme outlier compared to other years. Excluding 2005 from the regression does not significantly alter the fitted relationship between Atlantic ACE and Gulf ACE.

[8] Shut-in production projections for 2006 reflect only disruptions resulting from tropical cyclones occurring during the 2006 hurricane season. Any lingering shut-in production from Katrina and Rita is not included.

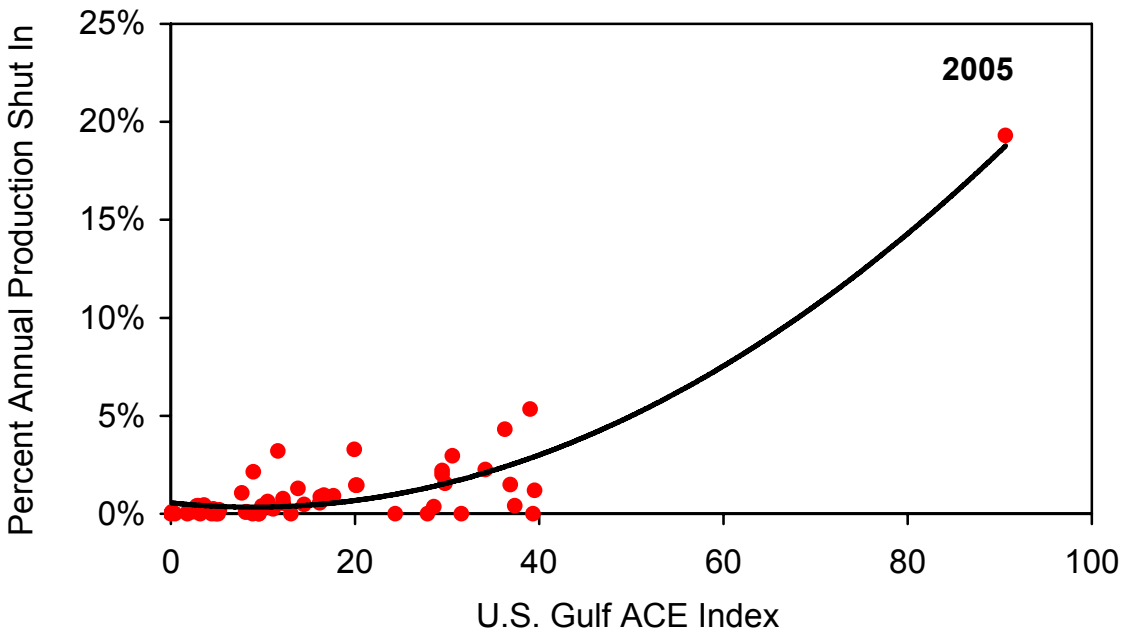
**Figure 6. Relationship Between Gulf of Mexico ACE and Atlantic ACE Indexes**




Source: National Oceanic and Atmospheric Administration and EIA calculations.

The second regression equation relates the square of the Gulf of Mexico ACE index to the percentage of normal annual Gulf OCS crude oil or natural gas production that is shut in (Appendix A4). The percentage rather than volume of production shut in is used to control for the significant increase in offshore production over the last 45 years. The ACE index is squared to reflect the observation that hurricane-related damage rises more than proportionally to hurricane intensity. The fit of the crude oil production equation is relatively robust with 88 percent of the variation in shut-in production explained by variation in the Gulf ACE (Figure 7). The estimated parameters do not significantly change when 2005 is excluded from the regression, but the $R^2$ value falls to 32 percent. The results for the natural gas production equation are similar.

**Figure 7. Relationship Between Shut-in Crude Oil Production and Gulf of Mexico ACE**




Source: National Oceanic and Atmospheric Administration, Minerals Management Service and EIA calculations.

We use the estimated parameters from the two regression equations to produce a point estimate of the expected Gulf ACE and a point estimate of the expected impact on crude oil and natural gas production given the average of the NOAA Atlantic ACE forecast. Perhaps more importantly, we also describe the uncertainty of the shut-in production volume prediction. In order to estimate a possible range of shut-in production, we combine the uncertainty inherent in both regression equations by performing a Monte Carlo simulation of the sampling distribution for shut-in crude oil production given the range for the NOAA Atlantic ACE forecast. Specifically, expected values and associated standard forecast errors for the Gulf ACE and expected shut-in production are estimated given the projected lower and upper bounds for the forecasted NOAA Atlantic ACE index. A sampling distribution is simulated for the Gulf ACE, which is then linked via the estimated regression parameters to a sampling distribution for shut-in production. For simplicity, we assume that the Atlantic ACE is uniformly distributed between the forecasted bounds, and the (squared) Gulf ACE and shut-in production are normally distributed.[9] Expected values and 95-percent confidence intervals given the NOAA forecasted ACE range can be calculated from the simulated sampling distributions.

Assuming the 2006 Atlantic ACE index falls somewhere in the range projected by NOAA, the 95 percent confidence interval for the estimated Gulf ACE index ranges from 0 to 51 (Table 2). Based on the mean of the NOAA forecast Atlantic ACE index the corresponding estimated Gulf ACE index is 26.

[9] Accurate information about the probability distribution of ACE indices was unavailable.

The estimated Gulf ACE index yields estimated shut-in production of 1.8 percent of annual Gulf OCS crude oil production (forecast by EIA to be 530 million barrels in 2006)[10] and 1.8 percent of annual Gulf OCS natural gas production (forecast to be 3.3 trillion cubic feet in 2006 (Table 2) based on the mean of the NOAA Atlantic ACE forecast. These projections exceed the 1960-2005 median annual shut-in levels of 0.6 and 0.5 percent and the mean seasonal shut-in level of 1.4 and 1.3 percent for crude oil and natural gas, respectively, but are much lower than the production disruptions experienced in 2005. A hurricane season with comparable shut-in levels would be 1995 when tropical storm Dean and hurricane Opal caused relatively widespread but temporary disruptions of about 1.5 – 2.5 percent of annual Gulf OCS production.

It is important to emphasize the inherent uncertainty of these projections given the range of the NOAA Atlantic ACE index forecast and the uncertainty in the relationships between the Atlantic and Gulf ACE indexes and between the Gulf ACE index and shut-in production volumes. The 95-percent confidence interval for the volume of shut-in production ranges from 0 to 30 million barrels of crude oil and 0 to 178 billion cubic feet of natural gas. The high ends of these ranges are similar to the type of situation experienced in 2004 when Hurricane Ivan struck the Gulf Coast and shut in 38 million barrels of oil and 151 billion cubic feet of natural gas. An additional point to keep in mind is that this analysis assumes the 2006 Atlantic ACE will fall somewhere within the forecasted range, yet NOAA indicates that there is a 20 percent probability that hurricane activity in the Atlantic basin could be near-normal or even below-normal. There is even a possibility that the Gulf producing region could again be struck with hurricanes as strong as Katrina or Rita.

**Table 2. Model 1 Estimated 2006 Cumulative Crude Oil and Natural Gas Shut-In Production Compared to 2005 Amounts**

| | 2006 Estimates | | | |
|---|---|---|---|---|
| | Mean | Low [a] | High [a] | 2005 |
| Atlantic ACE Index Forecast | 149 | 118 | 179 | 248 |
| Estimated Gulf of Mexico ACE Index | 25.9 | 1.23 | 50.5 | 90.6 |
| Estimated Crude Oil Volume Shut In | | | | |
| Percent of annual Gulf OCS production | 1.8 % | 0 % | 5.6 % | |
| Total volume, million barrels | 9.8 | 0 | 29.5 | 110 [b] |
| Estimated Natural Gas Volume Shut In | | | | |
| Percent of annual Gulf OCS production | 1.8 % | 0 % | 5.4 % | |
| Total volume, billion cubic feet | 59.8 | 0 | 178 | 683 [b] |

[a] The Atlantic ACE index ranges are given by NOAA's 2006 Hurricane Outlook. The ranges for Gulf ACE and shut-in production represent truncated 95-percent confidence intervals that are conditional on the forecasted Atlantic ACE range.
[b] Shut-in production for 2005 continues into 2006. As of June 1, 2006, a cumulative total of 162 million barrels of crude oil and 784 billion cubic feet of natural gas had been lost.
Note: Shut-in volumes based on projected 2006 Gulf OCS production of 530 million barrels of crude oil and 3.3 trillion cubic feet of natural gas.
Source: National Oceanic and Atmospheric Administration and EIA calculations.

[10] Short-Term Energy Outlook, June 2006 (http://www.eia.doe.gov/emeu/steo/pub/contents.html).

## B. Model 2: Using the NOAA Forecast of the Number of Atlantic Cyclones to Estimate Shut-In Production

The second model is similar to the first except that it measures hurricane activity by the expected number of tropical cyclones instead of the seasonal ACE index. The regression equations are structured as they are in the first model with the first equation relating the number of Atlantic tropical cyclones to the number of Gulf tropical cyclones and the second equation relating Gulf tropical cyclones to shut-in crude production (Appendix A4). The first regression equation has an $R^2$ of 62 percent and the second has an $R^2$ of 84 percent.

Given NOAA's prediction for 13 to 16 Atlantic storms, about 5 tropical cyclones are expected to pass through the Gulf of Mexico but could range from 2 to 8 based on a 95-percent confidence interval (Table 3). This translates into an expectation that 2.7 percent of annual Gulf crude production will be shut in as a result of hurricane activity with a likely range of 0 to 6.6 percent. Based on NOAA's forecast, 2.5 percent of annual Gulf natural gas production is expected to be shut in, with an upper bound of 6.2 percent under a 95-percent confidence range. As with the results from the previous model, the expected level of shut-in production is relatively small given NOAA's forecast, yet lost production could possibly approach the impact seen with Ivan if the Gulf of Mexico experiences 8 or more tropical cyclones.

**Table 3. Model 2 Estimates of 2006 Cumulative Crude Oil and Natural Gas Shut-In Production Compared to 2005 Amounts**

| | 2006 Estimates | | | |
|---|---|---|---|---|
| | Mean | Low [a] | High [a] | 2005 |
| Number of Forecast Atlantic Tropical Cyclones | 14.5 | 13 | 16 | 27 |
| Estimated Gulf of Mexico Tropical Cyclones | 5 | 2 | 8 | 12 |
| Estimated Crude Oil Volume Shut In | | | | |
| Percent of annual Gulf OCS production | 2.7 % | 0 % | 6.6 % | |
| Total volume, million barrels | 14 | 0 | 35 | 110 [b] |
| Estimated Natural Gas Volume Shut In | | | | |
| Percent of annual Gulf OCS production | 2.5 % | 0 % | 6.2 % | |
| Total volume, billion cubic feet | 84 | 0 | 206 | 683 [b] |

[a] The Atlantic ACE index ranges are given by NOAA's 2006 Hurricane Outlook. The ranges for Gulf ACE and shut-in production represent truncated 95-percent confidence intervals that are conditional on the forecasted Atlantic ACE range.
[b] Shut-in production for 2005 continues into 2006. As of June 1, 2006, a cumulative total of 162 million barrels of crude oil and 784 billion cubic feet of natural gas had been lost.
Note: Shut-in volumes based on projected 2006 Gulf OCS production of 530 million barrels of crude oil and 3.3 trillion cubic feet of natural gas.
Source: National Oceanic and Atmospheric Administration and EIA calculations.

The current NOAA outlook for the Atlantic hurricane season implies that a total of 1.8 percent (Model 1) to 2.7 percent (Model 2) of annual Gulf crude oil and natural gas production is expected to be shut in due to hurricane activity during the 2006 season, somewhat above the level of shut-in production of a normal year. However, there is a large amount of uncertainty surrounding these expected values. Even under the assumption that the intensity of Atlantic hurricanes does fall within the forecasted range, shut-in production could exceed 6 percent of normal seasonal production if the producing region is struck by one or more significant hurricanes, a situation similar to the aftermath of Hurricane Ivan. If the Atlantic hurricane season is more intense than NOAA currently predicts, shut-in production could be even higher.

The Gulf of Mexico producing region is particularly vulnerable to hurricane-related production disruptions. The level of shut-in production depends on a variety of factors including not only the intensity and location of cyclones, but also the ability of platform operators to respond to the threat of damaging hurricanes. Oil and natural gas producers along the OCS have responded to this vulnerability in numerous ways including stocking up on replacement parts to speed recovery, upgrading communication systems, and development of more stable and stronger platform infrastructure. As technology improves over time, the threat of shut-in production will likely be reduced.

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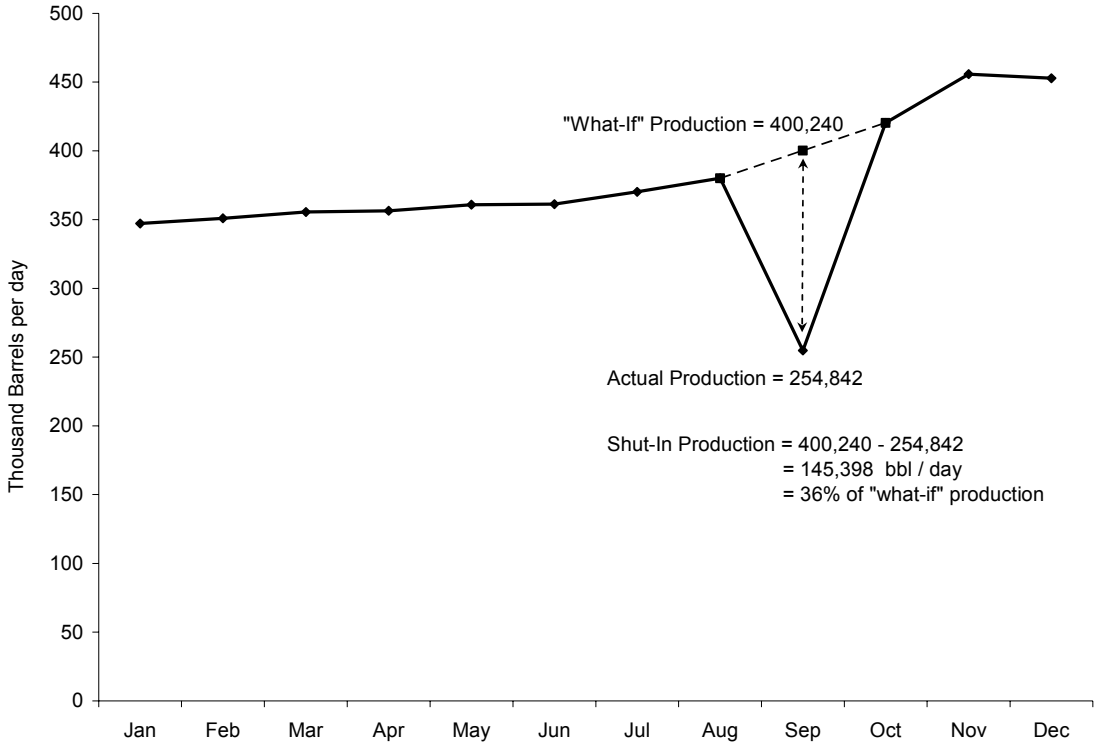
Last Updated: June 6, 2006
URL: http://www.eia.doe.gov/emeu/steo/pub/pdf/hurricanes.pdf

# 5. Appendices

## A1. Methodology for Estimating Historical Shut-in Production

MMS collects shut-in information directly from oil and natural gas producers in the Gulf of Mexico. However, evacuation and shut-in production statistics reports are only available for a few recent hurricanes. For this analysis shut-in volumes are estimated based on crude oil and natural gas Gulf OCS production data reported by MMS. Although MMS has collected production data since 1945, only data from 1960-2005 are used in the analysis since production prior to this period was too insignificant to detect meaningful trends. The methodology is based on the observation that tropical cyclone disruptions often cause noticeable but temporary drops below short-term production trends. Figure A1 illustrates this methodology by showing the impact of Hurricane Betsy in September 1965.

**Figure A1. Crude Oil Production, 1965**




Source: Minerals Management Service and EIA calculations.

Specifically, for those months in which a tropical cyclone passed through the Gulf of Mexico, a "what-if" production amount is calculated as the associated monthly value on a trend line connecting production in the month preceding hurricane activity and production in the month of recovery. Shut-in production is then defined as the difference

between “what-if” production and actual production. If the associated “what-if” production value lies below actual production, then shut-in production is assumed to be zero. For seasons in which tropical cyclones occurred in consecutive months, the period of hurricane activity was lengthened accordingly. In some cases when major hurricanes had lingering effects over several months, a differentiation was made between shut-in production for a given month and cumulative shut-in production. Seasonal shut-in production equals the sum of the monthly shut-in levels for a given year. Although many factors affect month-to-month changes in crude oil production, shut-in estimates calculated using this estimation methodology are relatively well correlated with the values derived from available MMS reports (see Appendix A2 for a comparison of reported MMS shut-in statistics and estimated shut-in production for recent major Gulf hurricanes.).

## A2. Gulf of Mexico Major Hurricanes, 1995-2005

| Name | Start Date | End Date | Maximum Category | ACE Index | Closest Distance[a] | Shut-In Crude Oil (bbl) | | Shut-In Natural Gas (mcf) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MMS | Estimated | MMS | Estimated |
| Opal | 9/30/95 | 10/5/95 | 4 | 11.06 | 230 | 2,238,699 | 4,369,734 | 21,003 | 42,114 |
| Roxanne | 10/9/95 | 10/18/95 | 3 | 16.24 | 468 | N/A | | N/A | |
| Georges | 9/16/98 | 9/29/98 | 4 | 39.37 | 195 | N/A | 13,583,381 | N/A | 99,332 |
| Mitch | 10/22/98 | 11/5/98 | 5 | 35.86 | 509 | N/A | 1,481,738 | N/A | 32 |
| Bret | 8/19/99 | 8/23/99 | 4 | 11.60 | 325 | N/A | 1,721,662 | N/A | 5,677 |
| Keith | 9/29/00 | 10/6/00 | 4 | 12.21 | 580 | N/A | 420,628 | N/A | 0 |
| Isidore | 9/18/02 | 9/26/02 | 3 | 17.81 | 91 | 4,500,000 | 17,292,538 | 27,500 | 116,980 |
| Lili | 9/23/02 | 10/4/02 | 4 | 16.46 | 27 | 9,900,000 | | 61,500 | |
| Charley | 8/10/04 | 8/14/04 | 4 | 10.59 | 608 | 1,255,444 | 1,343,814 | 4,105 | 0 |
| Frances | 8/25/04 | 9/7/04 | 4 | 45.92 | 454 | 61,896 | | 118 | |
| Ivan [b] | 9/3/04 | 9/23/04 | 5 | 70.38 | 25 | 38,004,500 | 27,447,748 | 150,710 | 118,760 |
| Jeanne | 9/14/04 | 9/27/04 | 3 | 24.24 | 495 | N/A | | N/A | |
| Dennis | 7/5/05 | 7/11/05 | 4 | 18.76 | 302 | 5,297,404 | 4,645,767 | 23,246 | 32,717 |
| Emily | 7/12/05 | 7/21/05 | 5 | 32.87 | 387 | 240,024 | | 1,583 | |
| Katrina [c] | 8/24/05 | 8/30/05 | 5 | 20.01 | 138 | 108,775,910 | 103,545,194 | 560,766 | 613,262 |
| Rita [c] | 9/18/05 | 9/25/05 | 5 | 25.15 | 77 | | | | |
| Wilma | 10/17/05 | 10/25/05 | 5 | 39.02 | 566 | 543,119 | 106,715 | 3,097 | 31,226 |

Notes: N/A = Not available. Estimated shut-in production may include effects from other cyclones not reported in table.

[a] Closest distance (in miles) of hurricane track to geographic center of all Outer Continental Shelf platforms.

[b] Shut-in production for hurricane Ivan is cumulative through December, 2004.

[c] Shut-in production for hurricanes Katrina and Rita is cumulative through December, 2005.

## A3. Seasonal Hurricane Summary, 1960-2005

| | ACE Index | | Total Cyclones | | Tropical Storms | | Total Hurricanes | | Intense Hurricanes | | Shut-In Crude Oil | | Shut-In Natural Gas | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Atlantic | Gulf | Atlantic | Gulf | Atlantic | Gulf | Atlantic | Gulf | Atlantic | Gulf | Million Bbl | % of Normal | Billion CF | % of Normal |
| 1960 | 88.0 | 10.5 | 7 | 3 | 3 | 1 | 4 | 2 | 2 | 2 | 0.3 | 0.6% | 0.5 | 0.2% |
| 1961 | 204.1 | 39.5 | 11 | 3 | 3 | 1 | 8 | 2 | 7 | 2 | 0.7 | 1.2% | 13.6 | 3.9% |
| 1962 | 35.6 | 0.0 | 5 | 0 | 2 | 0 | 3 | 0 | 1 | 0 | 0.0 | 0.0% | 0.0 | 0.0% |
| 1963 | 117.9 | 2.8 | 9 | 1 | 2 | 0 | 7 | 1 | 2 | 0 | 0.4 | 0.4% | 0.9 | 0.2% |
| 1964 | 169.0 | 29.5 | 12 | 5 | 6 | 2 | 6 | 3 | 6 | 2 | 2.3 | 2.0% | 14.1 | 2.1% |
| 1965 | 84.3 | 11.6 | 6 | 3 | 2 | 2 | 4 | 1 | 1 | 1 | 4.5 | 3.2% | 10.7 | 1.4% |
| 1966 | 145.2 | 37.4 | 11 | 3 | 4 | 1 | 7 | 2 | 3 | 2 | 0.7 | 0.4% | 4.5 | 0.5% |
| 1967 | 121.7 | 28.6 | 8 | 2 | 2 | 0 | 6 | 2 | 1 | 1 | 0.8 | 0.4% | 17.1 | 1.3% |
| 1968 | 35.2 | 11.1 | 7 | 3 | 3 | 1 | 4 | 2 | 0 | 0 | 0.6 | 0.2% | 6.4 | 0.4% |
| 1969 | 156.2 | 29.8 | 17 | 3 | 5 | 1 | 12 | 2 | 5 | 1 | 4.6 | 1.6% | 29.0 | 1.5% |
| 1970 | 33.7 | 16.6 | 10 | 5 | 5 | 3 | 5 | 2 | 2 | 2 | 3.2 | 1.0% | 15.9 | 0.7% |
| 1971 | 96.2 | 17.7 | 13 | 3 | 7 | 1 | 6 | 2 | 1 | 0 | 3.5 | 0.9% | 12.6 | 0.5% |
| 1972 | 27.1 | 5.3 | 4 | 1 | 1 | 0 | 3 | 1 | 0 | 0 | 0.7 | 0.2% | 6.9 | 0.2% |
| 1973 | 42.5 | 7.7 | 7 | 2 | 3 | 1 | 4 | 1 | 1 | 0 | 3.9 | 1.1% | 20.0 | 0.6% |
| 1974 | 60.5 | 20.1 | 7 | 1 | 3 | 0 | 4 | 1 | 2 | 1 | 5.0 | 1.5% | 27.9 | 0.8% |
| 1975 | 73.0 | 12.2 | 8 | 2 | 2 | 0 | 6 | 2 | 3 | 2 | 1.7 | 0.5% | 13.7 | 0.4% |
| 1976 | 80.7 | 0.1 | 8 | 1 | 2 | 1 | 6 | 0 | 2 | 0 | 0.3 | 0.1% | 4.6 | 0.1% |
| 1977 | 24.7 | 13.8 | 6 | 2 | 1 | 0 | 5 | 2 | 1 | 1 | 3.7 | 1.3% | 41.8 | 1.1% |
| 1978 | 61.0 | 1.9 | 11 | 3 | 6 | 3 | 5 | 0 | 2 | 0 | 0.5 | 0.2% | 0.4 | 0.0% |
| 1979 | 91.3 | 20.2 | 8 | 5 | 3 | 2 | 5 | 3 | 2 | 1 | 3.9 | 1.5% | 52.0 | 1.1% |
| 1980 | 146.2 | 36.9 | 11 | 4 | 2 | 2 | 9 | 2 | 2 | 1 | 4.0 | 1.5% | 45.5 | 0.9% |
| 1981 | 93.0 | 2.4 | 11 | 2 | 4 | 2 | 7 | 0 | 3 | 0 | 0.2 | 0.1% | 2.6 | 0.1% |
| 1982 | 28.6 | 3.3 | 5 | 2 | 3 | 1 | 2 | 1 | 1 | 0 | 0.3 | 0.1% | 1.7 | 0.0% |
| 1983 | 16.8 | 8.2 | 4 | 2 | 1 | 0 | 3 | 2 | 1 | 1 | 0.3 | 0.1% | 17.5 | 0.4% |
| 1984 | 70.5 | 1.8 | 12 | 2 | 7 | 2 | 5 | 0 | 1 | 0 | 0.0 | 0.0% | 5.8 | 0.1% |
| 1985 | 87.7 | 36.3 | 11 | 6 | 4 | 2 | 7 | 4 | 3 | 2 | 15.8 | 4.3% | 295.5 | 6.8% |
| 1986 | 35.5 | 2.9 | 6 | 1 | 2 | 0 | 4 | 1 | 0 | 0 | 1.4 | 0.4% | 10.8 | 0.3% |
| 1987 | 34.4 | 2.7 | 7 | 2 | 4 | 1 | 3 | 1 | 1 | 0 | 0.4 | 0.1% | 8.2 | 0.2% |
| 1988 | 102.6 | 29.5 | 12 | 5 | 7 | 2 | 5 | 3 | 3 | 1 | 6.8 | 2.2% | 93.1 | 2.0% |
| 1989 | 134.8 | 9.0 | 11 | 4 | 4 | 2 | 7 | 2 | 2 | 0 | 6.2 | 2.1% | 49.8 | 1.1% |
| 1990 | 90.6 | 4.9 | 14 | 2 | 6 | 1 | 8 | 1 | 1 | 0 | 0.0 | 0.0% | 0.3 | 0.0% |
| 1991 | 33.8 | 0.4 | 8 | 1 | 4 | 1 | 4 | 0 | 2 | 0 | 0.0 | 0.0% | 0.0 | 0.0% |
| 1992 | 75.1 | 12.2 | 6 | 1 | 2 | 0 | 4 | 1 | 1 | 1 | 2.4 | 0.8% | 22.5 | 0.5% |
| 1993 | 38.4 | 3.2 | 8 | 2 | 4 | 1 | 4 | 1 | 1 | 0 | 0.0 | 0.0% | 0.8 | 0.0% |
| 1994 | 30.5 | 3.6 | 7 | 3 | 4 | 3 | 3 | 0 | 0 | 0 | 1.4 | 0.4% | 0.0 | 0.0% |
| 1995 | 227.2 | 34.2 | 19 | 7 | 8 | 3 | 11 | 4 | 5 | 2 | 8.0 | 2.3% | 68.9 | 1.4% |
| 1996 | 166.1 | 9.9 | 13 | 4 | 4 | 2 | 9 | 2 | 6 | 0 | 1.5 | 0.4% | 15.5 | 0.3% |
| 1997 | 40.0 | 4.6 | 7 | 1 | 4 | 0 | 3 | 1 | 1 | 0 | 1.0 | 0.2% | 6.3 | 0.1% |
| 1998 | 181.6 | 19.9 | 14 | 6 | 4 | 4 | 10 | 2 | 3 | 0 | 15.1 | 3.3% | 99.4 | 1.9% |
| 1999 | 176.1 | 16.2 | 12 | 3 | 4 | 1 | 8 | 2 | 5 | 1 | 2.8 | 0.6% | 14.8 | 0.3% |
| 2000 | 115.1 | 8.1 | 14 | 4 | 6 | 2 | 8 | 2 | 3 | 0 | 0.4 | 0.1% | 1.8 | 0.0% |
| 2001 | 105.2 | 16.3 | 15 | 5 | 6 | 4 | 9 | 1 | 4 | 1 | 4.9 | 0.9% | 29.9 | 0.6% |
| 2002 | 64.8 | 30.6 | 12 | 6 | 8 | 4 | 4 | 2 | 2 | 2 | 17.3 | 3.0% | 117.0 | 2.5% |
| 2003 | 174.5 | 14.5 | 16 | 6 | 9 | 4 | 7 | 2 | 3 | 0 | 3.3 | 0.6% | 23.3 | 0.5% |
| 2004 | 224.6 | 39.0 | 14 | 6 | 5 | 3 | 9 | 3 | 6 | 2 | 30.2 | 5.3% | 111.9 | 2.7% |
| 2005 | 247.8 | 90.6 | 27 | 12 | 12 | 5 | 15 | 7 | 7 | 5 | 109.9 | 19.3% | 683.3 | 18.1% |

Note: Gulf of Mexico statistics are calculated only for cyclone tracks within the region bounded by 18° N – 31° N latitude and 81° W – 98° W longitude.

Source: National Oceanic and Atmospheric Administration, Minerals Management Service, and EIA calculations.

## A4. Regression Results

**Model 1.**
**Gulf of Mexico ACE Index = Function(Atlantic ACE Index)**
**Percent Annual Production Shut In = Function(Gulf of Mexico ACE Index)**

Dependent Variable: Gulf ACE Index
Method: Least Squares
Date: 05/24/06 Time: 10:00
Sample: 1960 2005
Included observations: 46

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Atlantic ACE Index | 0.173526 | 0.015283 | 11.35436 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.479555 | Mean dependent var | 16.46957 |
| Adjusted R-squared | 0.479555 | S.D. dependent var | 16.55679 |
| S.E. of regression | 11.94438 | Akaike info criterion | 7.819897 |
| Sum squared resid | 6420.065 | Schwarz criterion | 7.859651 |
| Log likelihood | -178.8576 | Durbin-Watson stat | 1.720728 |

Dependent Variable: Percent Crude Oil Production Shut In
Method: Least Squares
Date: 05/24/06 Time: 09:33
Sample: 1960 2005
Included observations: 46

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Gulf Ace Index^2 | 2.29E-05 | 1.10E-06 | 20.78070 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.882762 | Mean dependent var | 0.014359 |
| Adjusted R-squared | 0.882762 | S.D. dependent var | 0.029493 |
| S.E. of regression | 0.010098 | Akaike info criterion | -6.331410 |
| Sum squared resid | 0.004589 | Schwarz criterion | -6.291656 |
| Log likelihood | 146.6224 | Durbin-Watson stat | 2.101413 |

Dependent Variable: Percent Natural Gas Production Shut In
Method: Least Squares
Date: 05/25/06 Time: 19:07
Sample: 1960 2005
Included observations: 46

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Gulf Ace Index^2 | 2.18E-05 | 9.38E-07 | 23.27721 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.907780 | Mean dependent var | 0.012589 |
| Adjusted R-squared | 0.907780 | S.D. dependent var | 0.028278 |
| S.E. of regression | 0.008587 | Akaike info criterion | -6.655572 |
| Sum squared resid | 0.003318 | Schwarz criterion | -6.615819 |
| Log likelihood | 154.0781 | Durbin-Watson stat | 2.045357 |

**Model 2.**
**Gulf of Mexico Tropical Cyclones = Function(Atlantic Tropical Cyclones)**
**Percent Annual Production Shut In = Function(Gulf Tropical Cyclones)**

Dependent Variable: Number of Gulf Tropical Cyclones
Method: Least Squares
Date: 05/24/06 Time: 11:55
Sample (adjusted): 1960 2005
Included observations: 46 after adjustments

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Number of Atlantic Basin Tropical Cyclones | 0.330987 | 0.017842 | 18.55064 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.621104 | Mean dependent var | 3.260870 |
| Adjusted R-squared | 0.621104 | S.D. dependent var | 2.185150 |
| S.E. of regression | 1.345058 | Akaike info criterion | 3.452251 |
| Sum squared resid | 81.41316 | Schwarz criterion | 3.492004 |
| Log likelihood | -78.40177 | Durbin-Watson stat | 1.950696 |

Dependent Variable: Percent Crude Oil Production Shut-In
Method: Least Squares
Date: 05/24/06 Time: 12:04
Sample: 1960 2005
Included observations: 46

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Number of Gulf Tropical Cyclones^2 | 0.001103 | 6.38E-05 | 17.29148 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.837488 | Mean dependent var | 0.014359 |
| Adjusted R-squared | 0.837488 | S.D. dependent var | 0.029493 |
| S.E. of regression | 0.011889 | Akaike info criterion | -6.004861 |
| Sum squared resid | 0.006361 | Schwarz criterion | -5.965108 |
| Log likelihood | 139.1118 | Durbin-Watson stat | 1.415407 |

Dependent Variable: Percent Natural Gas Production Shut-In
Method: Least Squares
Date: 05/31/06 Time: 08:12
Sample: 1960 2005
Included observations: 46

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Number of Gulf Tropical Cyclones^2 | 0.001007 | 7.16E-05 | 14.07022 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.777269 | Mean dependent var | 0.012589 |
| Adjusted R-squared | 0.777269 | S.D. dependent var | 0.028278 |
| S.E. of regression | 0.013345 | Akaike info criterion | -5.773781 |
| Sum squared resid | 0.008015 | Schwarz criterion | -5.734028 |
| Log likelihood | 133.7970 | Durbin-Watson stat | 1.419536 |