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The potential value of improved ocean observation systems in the Gulf of Mexico

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Abstract

A number of coastal and ocean observation systems exist throughout the Gulf of Mexico (GOM), but the network of systems is not currently linked or integrated and at present not fully implemented. The network of local systems are diverse, typically involving unique mandates and several different funding sources at various levels of permanence. The purpose of this paper is to describe the ocean observation systems that currently exist in the GOM, and to identify and quantify the expected economic benefits that may result from the implementation of an integrated regional network. Improved ocean observation systems are expected to reduce the uncertainty of ocean/weather forecasting and to enhance the value of ocean/weather information throughout the Gulf region. The source of benefits and the size of activity from which improved ocean observation benefits may be derived are estimated for private sector, non-market, and public sector activities categorized according to marine transportation, commercial fishing, recreational fishing, search and rescue operations, and pollution management. The benefits of improved ocean observation systems to energy exploration, development, and production activities are estimated, and a discussion of potential benefits to lightering activities, environmental monitoring, royalty payments, and engineering design are highlighted.

Keywords: Benefit analysis; Ocean observation systems; Valuation strategies

1. Introduction

Extreme weather events play a major factor in human activities in the Gulf of Mexico (GOM), and each year about 12 tropical storms and hurricanes form in the Atlantic basin with 3 eventually reaching landfall. When a hurricane enters the GOM, oil production and transportation pipelines shut down, crews are evacuated, and refineries along the Gulf coast close. Drilling rigs are moved out of the projected path of the storm, ships are moved from port or diverted at sea, and supply vessels, commercial ships, and barges may be moved into one of Louisiana's many bayous where they have more protection from the storm. The Louisiana Offshore Oil Port (LOOP), the biggest and only deepwater oil port in the United States, closes to shipping and flows through on-shore pipelines are halted. Crude oil from the Gulf to the Midwest via the Capline pipeline, and the gasoline and distillate fuel conduit the Colonial Pipeline, also shut down ahead of the storm.

Weather information is valuable, and to the extent that improved ocean observation systems can improve the data on which weather/ocean forecasts is based, is potentially very beneficial. A few examples illustrate the scale and impact of the potential benefits associated with improved weather/ocean forecasting:

- The annual average damage incurred by hurricanes throughout the US has been estimated at \$5.1B [1–3].
- Reducing the length of coastline under hurricane warnings has been estimated to save on average \$640,000 per coastal mile in evacuation cost and preparedness action [4].
- During Hurricane Floyd in 1999, the Navy command's early warning gave the Atlantic Fleet sailors time to move 82 ships and submarines along the east coast out of port and harms way. The sortie cost the Navy over \$17 M, but a decision not to sortie may have resulted in billions of dollars in damages [5].

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- The benefits of improved El Nino forecasting to US agriculture by altering planting decisions have been estimated at \$265–300 M annually [6]. The state of knowledge of ocean data is incomplete and uncertain, and so improved ocean observation systems is expected to enhance the value of the information available to decision makers.

The National Oceanographic Partnership Program (NOPP) formulated a plan for an Integrated, Sustained Ocean Observing System (ISOOS) in a 1999 report to Congress [7], intending to move the US from what is now a largely ad hoc and fragmented approach to ocean observation to a coordinated and sustained activity similar to the existing national weather information system [8–11]. The implementation of ISOOS will require investments in infrastructure (networks and data management systems) and ongoing support for new and existing observation systems in the open and coastal ocean, and the benefits of a federal investment in ISOOS will depend on the expected costs and benefits of the resulting system. Federal support of ocean research in the US is about \$600 M a year, and the additional costs of implementing ISOOS are expected to grow from about \$30 M to \$100 M annually [7]. Estimating the scale of benefits in the GOM derived from improved ocean data is the task of this paper.

To estimate the potential benefits derived from *improved* ocean observing systems is a difficult task for at least three reasons:

1. Quantifying the value of current observation systems is subject to significant uncertainty;
2. A direct link between improved observation systems and cost savings is difficult to establish on a fundamental basis; and
3. It is not obvious which form of observation system, or combination of forms, will enhance the value of the existing configuration the most.

The configuration of the observation systems matter, but to delineate the cost–benefit of each selection is unknown, probably unknowable, and beyond the scope of estimation at this stage. Several possibilities exist:

- Increase area coverage,
- Increase system linkage,
- Increase frequency of data transmission, and/or
- Increase sensor capability.

Increasing the area coverage would involve introducing new buoys within existing or new areas (such as deepwater development clusters) while system linkage would be enhanced by additional interconnection between existing systems. Improving the frequency of transmission and the processing capability of the system would increase the information content of current systems.

The purpose of this paper is to identify and quantify the expected economic benefits of improved weather/ocean forecasting on activities that occur throughout the coastal and ocean environment of the GOM. Although we cannot provide a direct link between improved systems and cost savings, and we do not suggest the manner in which the configuration should be modified, an effort is made to delineate the general nature of the benefits in a realistic and *conservative* manner, which hopefully will stimulate debate and shed additional insight on the opportunities of the initiative. For a related cost–benefit analysis of a regional ocean observation system in Europe, see [12].

The outline of the paper is as follows. In Section 2, background information on the coastal and ocean observation systems in the GOM are summarized, and in Section 3, the methodology of the study is presented. In Section 4, the potential benefits of improved observation systems to maritime transportation, commercial and recreational fishing, search and rescue operations, and oil spill response and management are outlined. In Section 5, the potential benefits of improved weather forecasting to energy exploration, development, and production activities are described, and in Section 6, the potential benefits to lightering activities, environmental monitoring, royalty payments, and engineering design are discussed. In Section 7, conclusions complete the paper.

2. Gulf of Mexico coastal and ocean observation systems

2.1. Ocean observation system components

There are four basic elements common to all ocean observation systems:

- Data Collection;
- Data Transmission;
- Data Processing; and
- Data Presentation.

The data collection system depends on the purpose of the station and local conditions. Each station has sensors to measure environmental parameters, a data collection computer for controlling the sensors and storing the data on-site, one or more telemetry devices for transmitting data from the station, and solar panels and batteries to power the system. Refer to Fig. 1. The ocean observation system may be attached to an oil/gas platform or satellite structure (Fig. 2) or a floating buoy may be used (Fig. 3). Weather and ocean data in the GOM are also collected by commercial ships[1] and

[1] The Voluntary Observing Ship (VOS) program in the US has approximately 900 vessels participating each quarter. Observations are taken by deck officers every 3–6 h, transmitted in realtime and distributed via national circuits to aid professional meteorologists in marine forecasting.

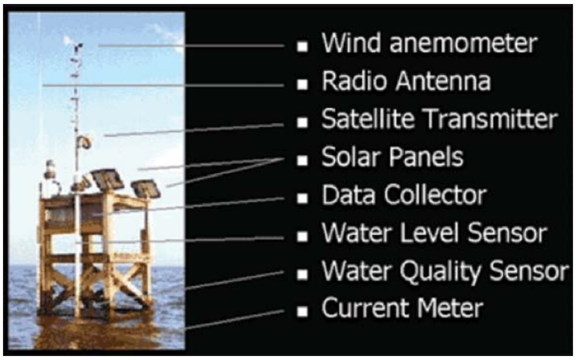


Fig. 1. Components of an ocean observation system. Source: TCOON—Texas A&M Corpus Christi.

satellite observation. The sensors used to measure environmental parameters include acoustic transducers for measuring water elevations, anemometers for wind speed and direction, Acoustic Doppler Current Profiling instruments, and multiparameter water-quality probes. Each sensor is interfaced to the data collection computer via serial communication ports or analog-to-digital conversion hardware.

Data transmission is required at one or more levels. Environmental data may be transmitted hourly, or half-hourly, and near-time data is transmitted every 3–6–12–24 h. The data transmission capability varies with the system. In Fig. 4 a schematic of the Wave-Current Monitoring System for Coastal Louisiana (WAVCIS) illustrates the flow of information common to all ocean observing systems.

The National Data Buoy Center (NDBC) maintains moored buoys and Coastal-Marine Automated Network (C-MAN) stations for oceanographic and meteorological observation (www.ndbc.noaa.gov). Drifting buoys are also deployed. The program is funded through the federal government and the systems are often incorporated into other observing system networks on a regional or local basis. The buoys and C-MAN stations transmit hourly via a geostationary data communications system. The data is processed and then distributed via the National Weather Service (NWS) communications network. The NDBC moored buoys provide meteorological data such as wind speed, wind direction, barometric pressure, air temperature, sea surface temperature, and sea state such as wave energy spectra. The C-MAN stations are augmented for enhanced meteorological capabilities (such as visibility and solar radiation) and oceanographic measurements (water level, surface waves, salinity, etc.).

A central repository for the data must be maintained and the application of its usage determines the requirements for data management. If the data is to be used to determine property boundaries, for example, long-term data sets are required to defend the accuracy of the datums in a legal context [13]. Recreational and lay

Fig. 2. An ocean observation system attached to a simple oil/gas platform. Source: LUMCON.

Fig. 3. A floating ocean observation system. Source: TABS I Buoy—Texas A&M.

users desire easy-to-understand presentations of data (e.g., graphics or summaries), while scientists need access to the raw data in a form that can be easily

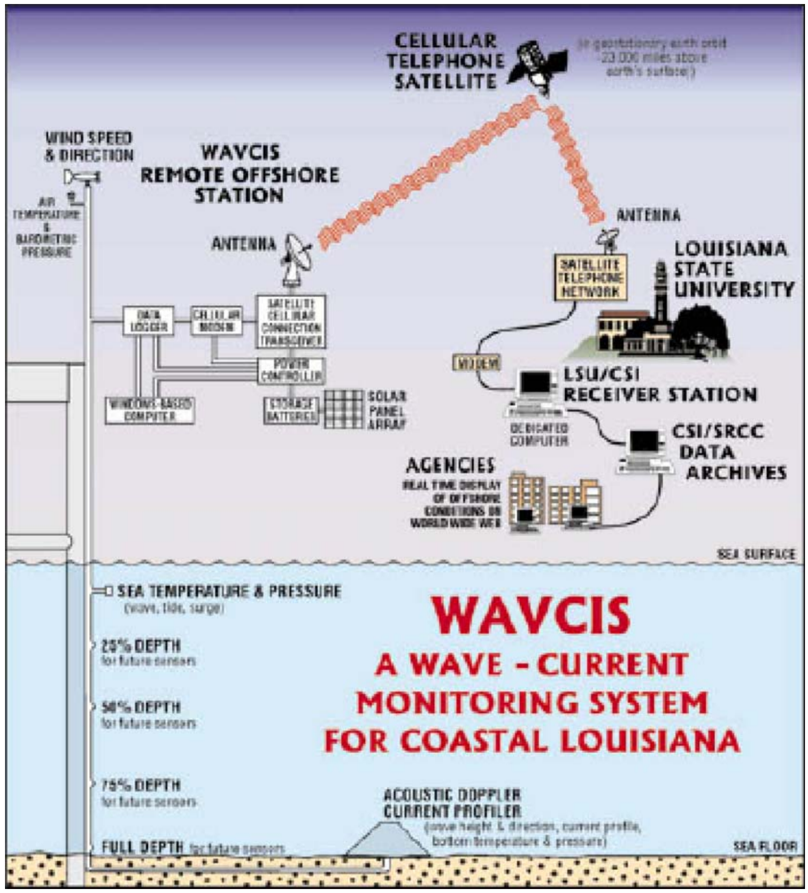


Fig. 4. A schematic of the data collection, transmission, and processing requirements of ocean observation systems. Source: WAVCIS—LSU.

imported into models. Applications such as marine transportation, oil spill response, and weather forecasting need near-real-time access to data sets and automated quality control systems.

2.2. *Gulf of Mexico system description*

Ocean observing systems have been initiated and maintained by many different agencies, universities, and industries. In the GOM, the mosaic is particularly complex with many different organizations, funding sources, and mandates evolving over the years. The systems are diverse in terms of their capability and application, but also share many common features.

The primary application of ocean observation data is to

- Provide nowcasts/forecasts of weather, wind speed, surface wave, current patterns, and general circulation;
- Predict climate trends on a global/regional scale; and
- Provide boundary/initial conditions for high resolution in the coastal zone.

Observational data on oceanographic and meteorological conditions throughout Texas, Louisiana, Mississippi, Alabama and Florida include near-time or real-time measurement of winds, waves, current, water density, nutrients, water quality, and biological indices. A summary of the program objectives, administrative agency, system inventory, and various funding sources is presented in Tables 1 and 2. The geographic distribution of the observing systems is shown in Fig. 5 and at a more detailed level in Figs. 6 and 7. For a description of the capabilities of each system, the NOAA website (www.csc.noaa.gov) maintains a particularly detailed summary with links to each system. See also [14–18].

2.3. *Capital and operating cost*

The cost to develop, deploy, and maintain ocean observation systems for a network of remote and geographically dispersed stations, and the associated cost to transmit, assemble, archive, format, and display the data is significant. The capital and operating cost depends upon factors such as the purpose of the system, local conditions, preference of the managing organization,

Table 1
US coastal and ocean observing systems—Western Gulf of Mexico

	WAVCIS[a]	TABS[b]	NDBC[c]	NWLON[d]	PORTS[e]
Program objective	Near real-time wave, current, and meteorological information program off the coast of Louisiana and Mississippi	Real-time data to support oil spill prevention and response off the coast of Texas	Real-time data on oceanographic and meteorological observations	Tide gauge and water level systems for Texas, Louisiana, and Mississippi	Real-time management information system to promote safe and efficient maritime transportation for Houston and Galveston
Administration	LSU/CSI	Texas A&M/G&ERG	NOAA	NOAA	NOAA
Inventory	3 Active stations 2 C-MAN platforms 4 NDBC moored buoys	10 Moored buoys 2 C-MAN platforms 4 NDBC moored buoys	5 C-MAN platforms 8 NDBC moored buoys	15 Active stations	5 Active stations
Funding sources	State of Louisiana, Energy companies, MMS, NOAA	State of Texas, Energy companies, Industry cooperative, NOAA	NOAA	NOAA	State of Texas, NOAA
	NGLI[f]	NERR[g]	USACOE[h]	TCOON[i]	LUMCON[j]
Program objective	Nowcast/forecast for the coastal areas of Mississippi, Louisiana, and Alabama for military training and coastal resource management	Real-time and near real-time data collection on water quality and meteorological data	Collects, processes, analysis, and reports on wave data	Near real-time data for tide monitoring along the Texas Gulf coast from Louisiana to the Mexican border	Coordinate and stimulate Louisiana's activities in marine research and education
Administration	Commander, Naval Meteorology and Oceanography Command, and EPA	NOAA Office of Coastal and Resource Management (OCRM)	USACOE Coastal Hydraulics Laboratory	Texas A&M/Conrad Blucher Institute for Survey and Sciences	Louisiana Universities Marine Consortium
Inventory		2/reserve	8 Active stations	60 Active stations	3 Active stations
Funding sources	US Navy, EPA	NOAA	US Army	Texas GLO Survey, Texas Water Board, CBI, NOAA	State of Louisiana

[a] WAVCIS: Wave Current Surge Information System.
[b] TABS: Texas Automated Buoy System.
[c] NDBC: National Data Buoy Center and C-MAN Stations. The C-MAN stations and NDBC moored buoys are counted as part of the WAVCIS and TABS systems.
[d] NWLON: National Water Level Observation Network.
[e] PORTS: Physical Oceanographic Real-Time System.
[f] NGLI: Northern Gulf of Mexico Littoral Initiative. Network is currently in the development stage.
[g] NERR: Weeks/Grand Bay National Estuarine Research Reserve.
[h] USACOE: US Army Corps of Engineers Wave Data Sites.
[i] TCOON: Texas Coastal Ocean Observation Network.
[j] LUMCON: Louisiana Universities Marine Consortium Environmental Monitoring.

Table 2
US coastal and ocean observing systems—Eastern Gulf of Mexico

	COMPS[a]	SEAKEYS[b]	NDBC[c]	NWLON[d]	PORTS[e]
Program objective	Near real-time wave, current, and meteorological information program off the coast of Florida	Long-term monitoring along the Florida coral reef tract and Florida Bay	Real-time data on oceanographic and meteorological observation system	Tide gauge and water level systems for Florida	Real-time management information system promote safe and efficient maritime transportation for Tampa Bay
Administration	USF	USF/Florida Institute of Oceanography	NOAA	NOAA	NOAA
Inventory		6 NDBC moored buoys	13 C-MAN platforms 6 NDBC moored buoys	13 Active stations	
Funding sources	US Coast Guard Citrus County OEM Pasco County ODP USGS, FDEP MMS, US Navy Mote Marine Lab	State of Florida, NOAA	NOAA	NOAA	NOAA

	NERR[f]	NERR[g]	USACOE[h]	IMAP[i]
Program objective	Real-time and near real-time data collection on water quality and meteorological data	Real-time and near real-time data collection on water quality and meteorological data	Collects, processes, analysis, and reports on wave data	Conducts ecological monitoring of Florida's inshore marine waters
Administration	NOA, AOCRM	NOAA OCRM	USACOE Coastal Hydraulics Laboratory	
Inventory	2/reserve	2/reserve	8 Active stations	
Funding sources	NOAA	NOAA	US Army	State of Florida EPA

[a] COMPS: West Florida Coastal Ocean Monitoring and Prediction Systems.
[b] SEAKEYS: Sustained Ecological Research Related to Management of the Florida Keys Seascape.
[c] NDBC: National Data Buoy Center Moored Buoys and C-MAN Stations.
[d] NWLON: National Water Level Observation Network.
[e] PORTS: Physical Oceanographic Real-Time System.
[f] NERR: Apalachicola Bay National Estuarine Research Reserve.
[g] NERR: Rookery Bay National Estuarine Research Reserve.
[h] USACOE: US Army Corps of Engineers Wave Data Sites.
[i] IMAP: Florida Inshore Marine Monitoring and Assessment Program.

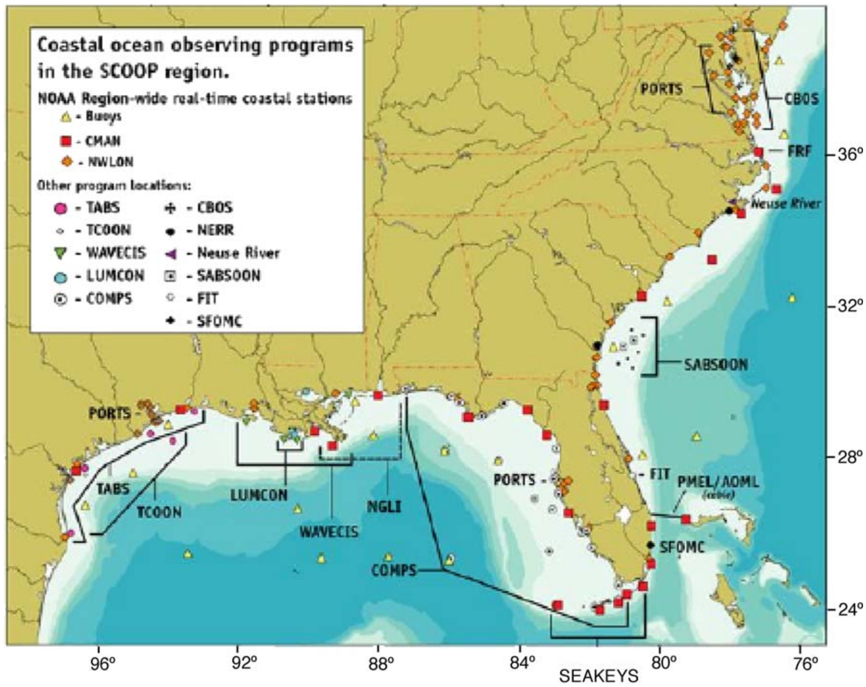


Fig. 5. Geographic distribution of ocean observing stations in the Gulf of Mexico. Source: SURA Initiative.

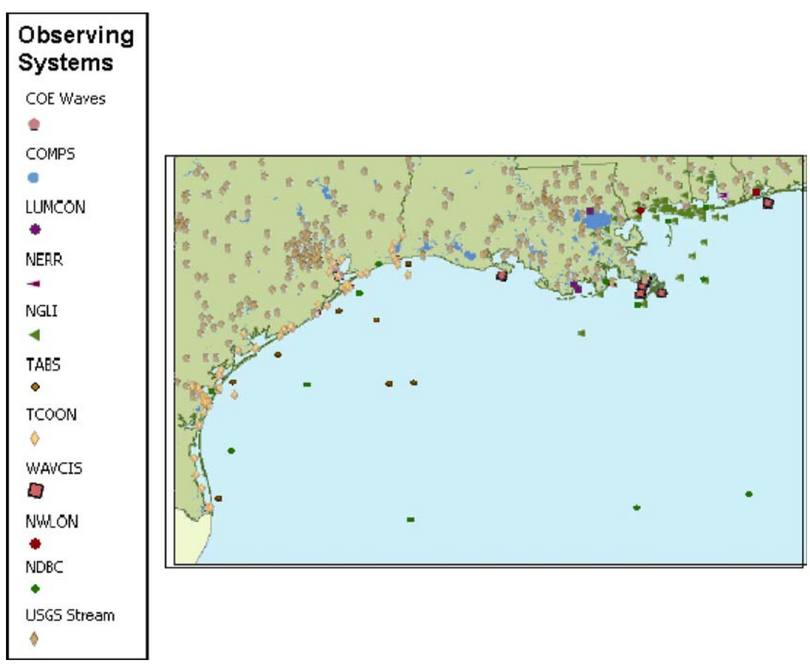


Fig. 6. Western Gulf of Mexico ocean observation systems. Source: NOAA.

system configuration, coverage, and amount of data processing.

The cost of ocean observation systems can be considered in terms of capital expenditures (CAPEX), goods with a lifetime of more than one year, and operating expenditures (OPEX), goods and services with a lifetime of less than one year. Typically, CAPEX items include the cost of the buoys, sensors, and computers that process the collected data. OPEX covers the personnel for preparation and maintenance,[2] data system and web page operation, data communications costs, travel and ship time for deployment and

[2] Routine maintenance includes cleaning the sensors, ground-truthing, calibration of the oceanographic recorders, etc.

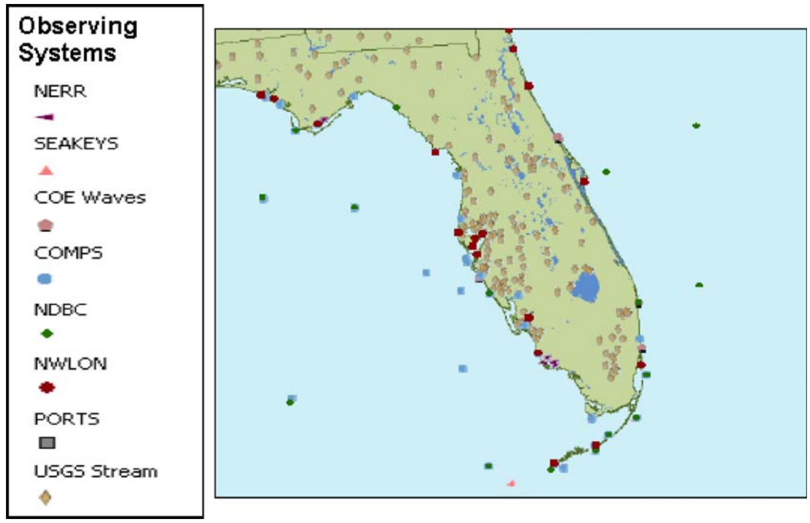


Fig. 7. Eastern Gulf of Mexico ocean observation systems. Source: NOAA.

recovery,[3] and hardware for replacing damaged equipment. Insurance premiums, overhead, interest and amortization of loans, if appropriate, is also considered operating expenses.

Each observation system in the GOM is unique, and so it is difficult to compare the capital and operating cost for each system directly. A rough estimate of the CAPEX for a standard observation system in the GOM is $100,000. The cost to build a floating buoy depends upon the sensors used and the experience of the assembly team. A TABS I buoy (see Fig. 3), for example, costs roughly $30,000 for parts and $15,000 for assembly, while a TABS II buoy (Fig. 8) can be built for roughly $50,000/parts and $20,000/assembly [19]. The annual operating cost for a standard observation system range between $50,000/buoy and $100,000/buoy.

3. Methodology

The state of knowledge of ocean data is incomplete and uncertain, and so improved ocean/weather observation systems are expected to enhance the value of the information and create additional network externalities [8]. The potential impact of savings that may be incurred from improved ocean observation systems was first estimated by Kite-Powell and Colgan in a study focused on the Gulf of Maine [20]. Kite-Powell and Colgan performed order-of-magnitude assessments for general categories of benefits using the following methodology.

Step 1: Value activity A that uses and/or is impacted by ocean forecasts, $V(A)$.

Step 2: Assume that the benefit of improved ocean observation systems is expressed by some small factor, $\varepsilon(A) > 0$, of the valuation $V(A)$.

Step 3: Compute the value of improved observation systems in region R, $V(R) = \sum_A \varepsilon(A)V(A)$.

The valuation strategy is based on estimating $V(A)$ from public sources of information and hypothesizing the value of $\varepsilon(A)$ for each activity identified. The selection of $\varepsilon(A)$ is hypothetical but not unreasonable within the framework of the model and the scope of the valuation. Ideally, it would be desirable to derive the value of epsilon (A) and to ascertain the cost to achieve a desired level of $\varepsilon(A)$, but establishing these relationships is beyond the state of knowledge of observation systems. No direct link between $\varepsilon(A)$ and $V(A)$ can be "derived" and it is difficult to "justify" $\varepsilon(A)$ on a fundamental level. The default condition is to assume $\varepsilon(A)$ "small" (e.g., 1%, 1 day, etc.), and this is considered a "reasonable," and in all instances, a conservative estimate of the expected benefits to be incurred.

The primary constituency for weather forecasts is the general public and the commercial sector (airlines, utilities, etc.), while the main constituency for ocean forecasts is the commercial and government sector, including the shipping and offshore industries; service industries; operations such as drilling, dredging, cable laying, and pipe laying; the coast guard; and state agencies responsible for environmental management. User groups that will benefit from improved observation data include

- Marine transportation;
- Commercial fishing;
- Recreational fishing;
- Search & rescue;

[3] Buoys are sometimes lost or damaged due to collision with ships, adverse weather, and cutting by fisherman, and they must be found, repaired or replaced.

Fig. 8. TABS II Buoy. Source: Texas A&M.

- Oil spill response operations;
- Energy drilling activities;
- Energy development activities, and
- Energy production activities.

Each user group is now considered and the potential benefits expected to be incurred is estimated.

4. Potential benefits of improved ocean observation systems

4.1. Maritime transportation

In the early 1950s, the US Navy established a ship-routing service to provide information on currents, winds, and waves to optimize the transit time for its vessels and minimize exposure to severe weather [21]. Today, several commercial organizations such as Ocean Routes (www.oceanroutes.com) and Ocean Weather (www.oceanweather.com) provide the same service to commercial ships and private individuals. The basic principles of ship routing are both simple and complex. Meteorologists predict wind speeds and directions for areas of interest based on buoy and ship wind data, satellite measurements, NOAA reconnaissance, and analyst's input. Proprietary software is then used to calculate spectral and wind fields and wave heights [22], and routes are computed to determine maximum attainable and safe speeds for any type of ship or vessel. See Figs. 9 and 10.

Vessel operators also depend on information about wave and fog conditions at harbors for planning activities, berthing and docking operations, and ship loading and unloading. If a significant number of GOM transits make use of improved marine forecasts to shorten their transit by even a fraction of an hour, reduced fuel consumption and operating expenditures and avoided storm damage is expected to result [23].

The GOM has considerable commercial shipping traffic that enters the northern Gulf ports. Eight of the top 20 busiest US ports, ranked by total tons, are in the GOM [24]. These include South Louisiana-1, Houston-2, New Orleans-4, Corpus Christi-5, Beaumont-11, Lake Charles-12, Mobile-13, and Tampa-17. In terms of the cargo value, eleven of the top 20 US ports are in the GOM [24].

To estimate the operational cost savings that may result from improved observation systems, data is required on vessel traffic and estimated operational cost. Traffic data at the port level is acquired from the US Army Corps of Engineers' (USACOE) *Waterborne Commerce of the United States for 2001*, and operating cost data is compiled by the USACOE for vessels categorized according to draft, type (tanker, bulk, container, general cargo), and flag (foreign, US).

In Table 3, a summary of the number of inbound trips for 7-year old diesel vessels that maintain at least an 18-foot draft for select GOM destinations are presented for both foreign and domestic flag, passenger/dry cargo and tanker vessels.

The annual operating cost in million dollars for single-hull foreign and US flag tankers is estimated from USACOE data as a function of draft as follows:

$$\mathrm{OPEX(foreign,\ tanker)} = 1.778 + 0.093\,\mathrm{dft},\ R^2 = 0.95,$$

$$\mathrm{OPEX(US,\ tanker)} = 5.254 + 0.192\,\mathrm{dft},\ R^2 = 0.94.$$

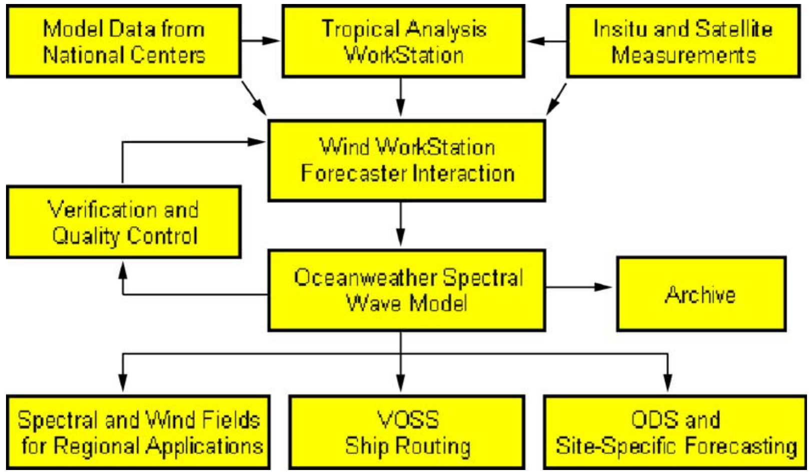


Fig. 9. Forecast runstream flowchart. Source: OceanWeather.

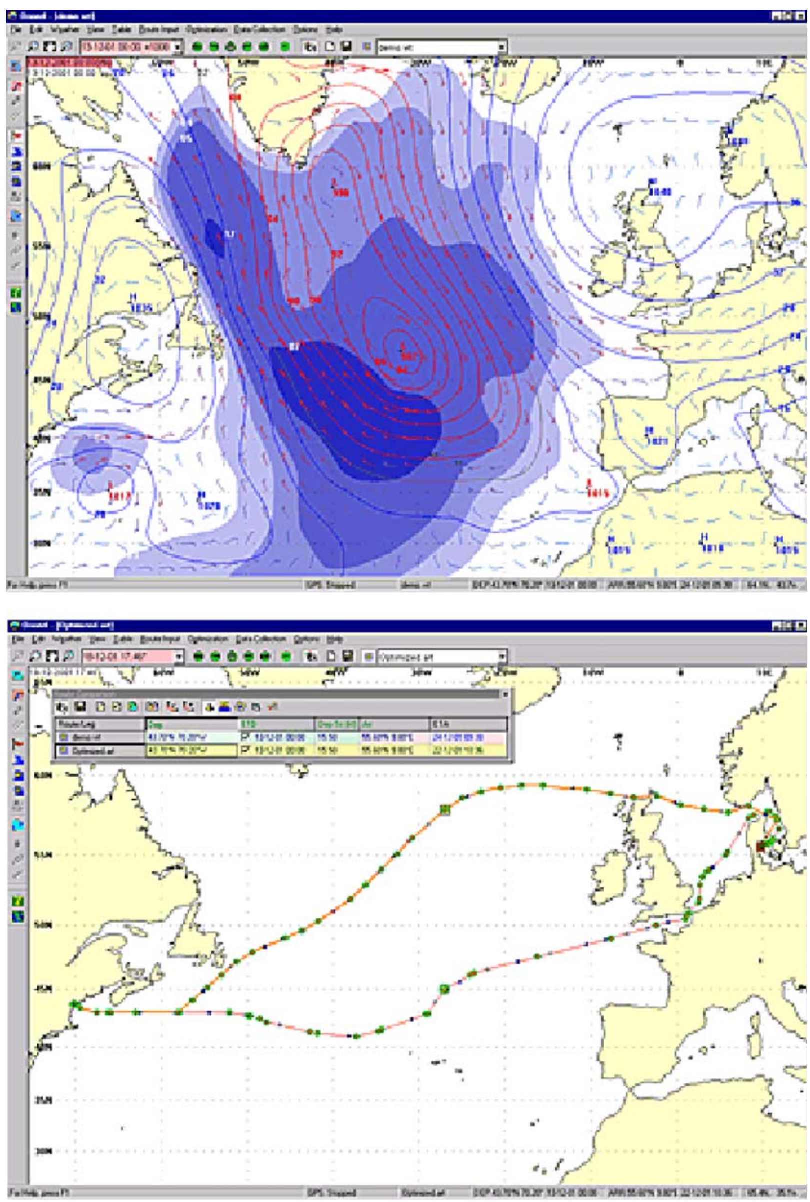


Fig. 10. Ocean information and ship route optimization. Source: OceanRoutes.

For foreign and US flag containerships

$$\mathrm{OPEX(foreign,\ cont.)} = 1.36 + 0.108\,\mathrm{dft},\ R^2 = 0.88,$$
$$\mathrm{OPEX(US,\ cont.)} = 4.13 + 0.257\,\mathrm{dft},\ R^2 = 0.98.$$

The annual operating cost for ocean-going vessels entering a given port is calculated in terms of vessel type and flag as

$$\mathrm{TOPEX(type,\ flag)} = \sum_{\mathrm{dft}\geqslant 18}^{70} n(\mathrm{dft})\mathrm{OPEX(type,\ flag)},$$

where the TOPEX(type, flag) = Total annual operating cost for vessels entering port ($), n(dft) = Number of vessels with draft dft, and OPEX(type, flag) = Estimated operating cost of vessel with draft dft ($).

The estimated operating cost for the primary GOM destinations is shown in Table 4. Passenger and dry cargo ships are assumed to be proxied by general containerships. The total daily operating cost for large draft vessels entering port is estimated at $200 M, or roughly, $8.4 M per hour. If improved ocean observation systems allowed a small percentage of ships to save 1 hour on their transit times entering or leaving the GOM, then significant savings would result. For example, if 1% of ships used improved ocean data to reduce operating times by just 1 hour per transit, then roughly $30.7 M would be saved per year.

Table 3
Number of inbound trips for self-propelled vessels with draft ⩾18 ft for select Gulf of Mexico destinations (2001)

Destination	Foreign		Domestic	
	Passenger & Dry Cargo	Tanker	Passenger & Dry Cargo	Tanker
Brownsville, TX	124	33	—	17
Corpus Christi, TX	345	742	—	95
Free Port, TX	115	524		28
Galveston, TX	218	34	—	276
Houston, TX	2561	2192	38	250
New Orleans, LA	2187	481	33	12
South Louisiana, LA	730	512	—	170
Tampa, FL	760	250	20	403

Source: US Army Corps of Engineers.

Table 4
Estimated total daily operating cost for select Gulf of Mexico destinations (2001)

Destination	Foreign		Domestic	
	Passenger & Dry Cargo ($M)	Tanker ($M)	Passenger & Dry Cargo ($M)	Tanker ($M)
Brownsville, TX	1.5	0.4	—	0.6
Corpus Christi, TX	4.2	9.8	—	3.1
Free Port, TX	1.4	7.2	—	0.9
Galveston, TX	2.6	0.4	—	8.9
Houston, TX	31.2	29.2	1.3	7.5
New Orleans, LA	26.1	6.6	1.1	8.9
South Louisiana, LA	8.8	6.8	—	5.3
Tampa, FL	9.2	3.3	0.7	13.6
Total	85.0	63.7	3.1	48.8

4.2. Commercial fishing

GOM commercial landings are shown in Table 5. Nine of the top 20 US ports for commercial fishery landings are in the GOM and contribute roughly 43% of the total US value [25]. Better ocean information will extend commercial activity and by increasing the number of days at sea. Improved data may also allow the regulatory regime to operate more efficiently.

The estimated average value per fishing day is estimated by assuming a 365-day fishing season, and then assuming an incremental improvement of one day due to improved ocean observation systems. The benefit of improved data to commercial fishing operations in the GOM is estimated at $2.1 M per year.

4.3. Recreational fishing

In 2001, over 3 M marine recreational fishing participants took over 23 M trips and caught a total of 163 M

Table 5
Gulf of Mexico commercial landings and estimated average value per fishing day (2001)

State	Weight (1000 pounds)	Value ($1000)	Average Value ($1000/day)[a]	Annual Benefit ($1000)[b]
Florida, West Coast	78,105	143,810	394	394
Alabama	24,740	43,170	118	118
Mississippi	213,889	50,561	139	139
Louisiana	1,191,460	342,748	939	939
Texas	97,370	218,030	597	597
Total, GOM	1,605,564	748,319	2050	2050
Total, US	9,491,858	3,228,236	8844	8844

Source: National Marine Fisheries Service.
[a] Assumes a 365-day fishing season.
[b] Assumes 1 additional fishing day per year.

Table 6
Marine recreational fishing trips and estimated annual benefit (2000, 2001)

State	Estimated angler trips (1000)[a]	Number of marine anglers (1000)[a]	Willingness to pay ($M)[b]	Annual benefit ($M)[c]
Florida, West Coast	20,783	4778	(478, 2389)	(4.8, 23.8)
Alabama	1362	333	(33, 167)	(0.33, 1.7)
Mississippi	1172	236	(24, 118)	(0.2, 1.2)
Louisiana	3684	681	(68, 341)	(0.7, 3.4)
Texas	497	695	(70, 348)	(0.7, 3.5)
GOM	27,498	6723	(673, 3363)	(6.7, 33.7)

Source: National Marine Fisheries Service.
[a] Average of 2000 and 2001 data.
[b] Assumes a willingness to pay of \$100–\$500 per angler for each fishing day.
[c] Assumes a 1% increase in the value of annual benefits.

fish in the GOM [25]. About 72% of the trips were made in Florida, followed by 16% in Louisiana as shown in Table 6. The most commonly caught non-bait species were spotted seatrout, red drum, white grunt, blue runner, sand seatrout, Spanish mackerel, and Atlantic croaker. The largest harvests by weight were for red drum, spotted seatrout, sheepshead, red snapper, Spanish mackerel, king mackerel, and dolphin [26].

Improved coastal monitoring and weather data increases the benefits of recreational fishing since boaters and fishers can spend more time on the water. Benefits are measured by multiplying an estimate of the number of increased days on the water by the value per day to the boater or fisherperson. To value a day at sea contingent valuation is employed.

Contingent valuation simplifies the process of valuing natural resources by asking people directly what monetary value they place on identified resources; e.g., "How much are you willing to pay for an extra day at sea?" Contingent valuation is controversial, however, because it is entirely hypothetical and because it assumes that people respond to the survey as they would to a marketplace transaction—while empirical studies suggest the responses do not accurately predict people's actual behavior. Another criticism of contingent valuation challenges whether respondents have sufficient information to make an accurate valuation because people have little experience placing monetary value on unpriced natural resources. Contingent valuation is nonetheless a convenient and direct measure for valuation, and in Table 6, the marine recreational fishing values based on an estimate of the number of marine anglers in the GOM and a willingness to pay[4] of \$100–\$500 per angler per additional fishing day is shown. The annual benefit resulting from a 1% increase in recreational fishing days ranges between \$6.7 M and \$33.7 M.

4.4. Search and rescue operations

Improved ocean observation systems can reduce search and rescue (SAR) costs and may improve the efficiency of SAR missions, increasing the success rate and lowering mission cost. Better forecasts should also reduce the number of boats on the water during high-risk periods, thus reducing mishaps and the number of SAR missions.

The US Coast Guard conducts on average 5700 SAR missions each year in the GOM representing about 15% of the Coast Guard's total SAR activity (www.uscg.gov). Significantly, nearly 600 lives are saved each year while some 110 lives are lost (30 *after* the Coast Guard has been notified that they are at risk). A 1% improvement in SAR effectiveness due to improved ocean/weather forecasting, or a 1% increase in the lives saved and a 1% decrease in lives lost, would result in seven additional lives saved per year. If a human life is valued conservatively at \$4 M, roughly \$28 M per year in economic value would be achieved.

4.5. Oil spill management and response

The risk of oil spills arise from activities associated with the exploration, development, production, and transportation of offshore oil and gas resources, as well as from the transport of oil across the ocean to port facilities. During the 1970s and early 1980s most of the crude oil and products moved by water was associated with inland barges or coastwise movement between US production/processing and consumption regions. By the mid-1980s, waterborne commerce of foreign imports of crude oil and petroleum production exceeded coastwise transportation, and today is completely dominated by foreign imports [24]. The National Research Council recently released a comprehensive report on the impact of oil spilled in the ocean [27], and the interested reader

[4] A number of studies on the willingness to pay have been performed over the years with values ranging between less than \$100 to over \$2000 per day. No general agreement on consensus values exist and it is for this reason that each angler was assumed to place a common value of \$100–500 per additional fishing day.

is encouraged to consult this report for more comprehensive information.

Oil spill response is site specific and occurs within a complex, dynamic, and uncertain environment. The environmental effects of oil spills vary widely depending on factors such as the amount and type of oil spilled, weather conditions, the location of the spill relative to natural resources, the quality and sensitivity of effected resources, seasonal factors, and the thoroughness and speed of cleanup and restoration efforts.

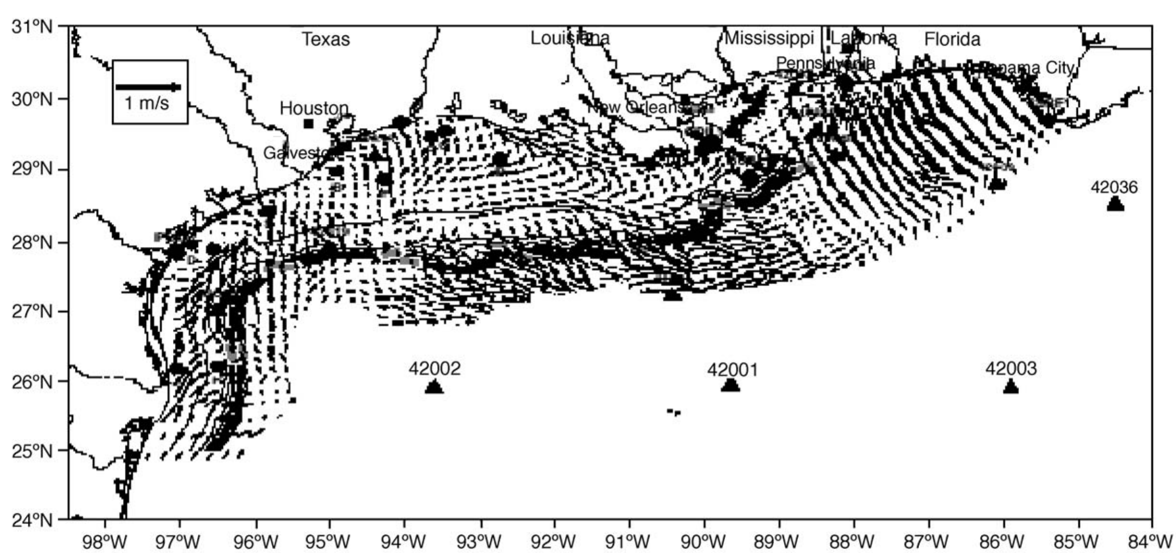
Oil spills in coastal waters are especially damaging and clean-up can be very expensive. In accord with the Oil Pollution Act of 1990 [28], response activities must deal with the legal constraints and interest of various political entities as it attempts to minimize ecological damage and the quality of human life due to an oil spill. Better knowledge of wind and water currents will assist in the management and clean-up of oil spills, but it is important to remember that ocean observation systems form *one* component of the information resources required to provide for a better and more informed operational decision.

Four factors influence oil spill response: the type of oil (e.g., heavy crude, distillate fuel, etc.); the amount of oil spilled; the spill conditions, which are described by sea temperature, ocean current, wind and weather conditions; and proximity to ecologically sensitive areas. Once notice has been received that a spill has occurred these factors must be assessed to determine the spill response.

Clean up operations employ one or more methods such as mechanical systems, chemical dispersants, burning, and bioremediation depending on prevailing spill conditions. Timing is critical to effective clean up. Floating oil spreads rapidly, and a slow response may allow oil to spread over a large area so that boom is not effective in containment. Floating oil also emulsifies as it mixes with water lending treatment with dispersants ineffective after a given time window has passed.

Information to support operational decisions during an oil spill is provided through a variety of sources. Typically, decision-making is aimed at supporting a "minimum regret" as opposed to a "maximum win" strategy [17]. In a "maximum win" strategy, the best estimates of wind, currents, and the initial distribution of the pollutant is collected and the resulting forecast taken as the threat. A "minimum regret" strategy on the other hand uses whatever analysis techniques are available as input data. The situation unit presents the command with not only the "best guess" of where the oil will go but also with alternate possibilities that might present a significant threat. Reliable near-time data on the wind and wave conditions is essential for good decision making as shown in Fig. 11 in a typical oil spill response output screen.

There are many social costs associated with an oil spill. Many cost can be measured as direct economic cost—such as the cost of clean up—while indirect cost such as damage or harm to wildlife cannot be measured in a market transaction. Indirect social cost are typically valued using "willingness-to-pay" techniques or an assessment of the loss in consumer surplus. The estimated unit cost of a barrel of oil spilled or reaching shore across the OCS planning areas is summarized in Table 7 [29]. The total estimated cost for the GOM region is assumed to range between $(888, 1445) per barrel of oil spilled.



Forecast current vector field (at 2m depth) from POM (barotropic 3D) using forecast wind for 0000 (UTC) January 14, 2001.
Vector scale is indicated at upper left hand corner.
Locations of NDBC (triangle) and TABS (circle) stations indicated by symbols.

Fig. 11. Forecast current vector field used in oil spill response management. Source: TABS—Texas A&M.

Table 7
Estimated unit cost elements per barrel spilled and reaching shore

OCS Planning Area	Control ($)[a]	Cleanup ($)	Property Lost ($)	Recreation and Tourism ($)	Wildlife and Ecological ($)[a]
Straights of Florida	(64, 99)	(565, 872)	272	(133, 448)[b]	30[b]
Eastern GOM	(66, 103)	(546, 843)	46	(90, 320)	154
Central GOM	(55, 85)	(650, 1002)	46	(52, 190)	154
Western GOM	(58, 90)	(249, 385)	46	(143, 514)	116
Average	(61, 94)	(503, 776)	103	(107, 368)	114

Source: Minerals Management Service.
[a] Per barrel spilled.
[b] Mid-Atlantic region.

Table 8
Number and volume of spills for the 8th Coast Guard district

Year	Number of Spills	Volume of Spills (1000 barrels)
1990	3205	117
1991	3572	14
1992	3616	23
1993	3477	15
1994	3465	26
1995	3363	36
1996	4678	19
1997	4699	15
1998	4224	11
1999	3836	18
2000	4177	21
Average (1973–2000)	3132	74

Source: US Coast Guard.

The number of spills in the US Coast Guard District 8, which includes Texas, Louisiana, Mississippi, Alabama, and the Florida panhandle, and the volume of spills is shown in Table 8. Roughly one-half of the volume spilled came from tank vessels, and 60% of the volume involved crude or heavy oil. The 8th District was responsible for nearly 40% of the spills and 38% of the total volume across the United States. 11 percent of the total volume of oil spill occurred in the open ocean (12–200 miles) which would normally not realize a significant improved response with enhanced ocean forecasting.

The impact of a 1% improvement in oil spill response is estimated to result in the following cost savings:

(74,000 bbl/yr)$(888/bbl, 1445/bbl)(1-0.11)(0.01) = $(0.58M/yr, 0.95M/yr).

5. Potential benefits to energy exploration, development, and production activities

A four-stage sequence of activity is generally followed in offshore energy development projects:

1. Exploration;
2. Development;
3. Production; and
4. Decomissioning.

In the exploration stage, areas that are considered to have prospects of containing oil and gas reserves are drilled with exploratory wells and stratigraphic test wells. In the development stage, the mineral deposit is prepared for commercial production. This includes the acquisition, construction, and installation of facilities to extract, treat, gather, and store the oil and gas. In contrast to a single exploratory well for which drilling can last anywhere from 2 weeks to 3 months, drilling the wells off a platform can last many months and extend over several years. Development activities typically include drilling and equipping development wells, development-type stratigraphic test wells and service wells, and the construction and installation of production facilities such as flow lines, separators, treaters, heaters, manifolds, measuring devices, storage tanks, natural gas cycling and processing plants, and waste disposal systems. The ongoing operation of the facility is considered the production phase. In production, the oil and gas is gathered, lifted to the surface, treated, processed, and possibly, stored. When the useful life of a production platform is reached, the equipment and structure is removed and the well casing severed and closed below the seabed.

5.1. Drilling activities

Offshore drilling may be subject to significant delays caused by the weather, and weather downtime can play an important factor in the total costs of the operation. Waves are one of the most obvious environmental concerns for offshore operations and constitute the primary cause of downtime and reduced operating efficiency. Weather downtime can impact drilling operations in various ways; e.g., weather too severe for operations involving supply boats may lead to delay if stock levels on the rig decline to a critical level; weather may impact anchoring up and moving time; weather may be too severe for drilling to occur; and extreme weather may result in damaged or lost drill strings and risers. If operating limits are exceeded because wave heights, ocean currents, or eddies are too strong, drilling operations will be temporarily abandoned and resumed when conditions fall within the operating capabilities of the equipment.

Safe working conditions for many offshore operations may be approximately specified by the critical values of wind speed and wave height, and for deepwater drilling activities, current profile, as shown in Table 9. The GOM is a fairly benign operating environment for most of the year, but downtime due to weather can be an important factor in determining the total drilling costs, and in the deepwater, can play a significant role. Empirical evidence suggests that 1–3% of drilling cost is due to waiting on weather [30], although this is subject to significant variation depending on the time of year of drilling activity and the water depth of the operation.

Drilling activities generally follow three stages:

1. Start limits. Weather must be below these limits before an operation will start (or restart after abandonment).
2. Suspend limits. Work will be paused if the environment exceeds these limits. Work recommences as soon as weather conditions drop back below the threshold.
3. Abandon limits. Task will be abandoned if these limits are exceeded. Work will not be restarted until weather conditions fall below the start limits.

The occurrence of a hurricane warning or alarm is enough to disrupt drilling operations, and a significant amount of operating time can be lost to "false alarms" [31,32]. In deepwater operations, loop currents and the eddies associated with them are also common phenomena that may damage/lose drilling strings/risers and impact the drilling schedule [33,34]. To a large extent, the impact of severe weather on drilling depends on the choice of rig the operator has chosen for the operation.

Many different rigs can be used to drill an offshore well and rig selection depends upon factors such as the type of well being drilled, water depth and environmental criteria, the type and density of the seabed, expected drilling depth, load capacity, frequency of moves, ability to operate without support and rig availability.

If weather and environmental conditions are expected to be a problem, then sophisticated all-weather semis can be used to hedge against weather downtime. The increase in availability is achieved through the higher capital cost of the equipment, which in turn is passed to the operator in higher day rates. Jack-ups are cheaper but are more prone to weather delay. The choice is up to the operator: the trade-off is between drilling availability and dayrate.

Deepwater operations are complex and risky endeavors, and it is difficult to estimate the impact of the metocean environment on drilling operations. The cost of deepwater drilling can represent a significant portion of the total field development costs, and so operators pay particular attention to the environment to minimize the magnitude of the risk. Because of the potentially catastrophic effect a powerful eddy can have on a drilling riser, it is common to monitor the approach of an eddy (by satellite and by standby vessel), and pull the riser or circulate the stroke pipe before the eddy actually reaches the platform. "Eddy Watch" and "Eddy Net" are monitoring systems operated by Horizon Marine (www.horzonmarine.com) that provides real-time ocean current maps. Horizon Marine also predicts the likelihood that an eddy will encounter a particular site. See Fig. 12.

ChevronTexaco, BP, and Marathon use Acoustic Doppler Current Profiles (ADCP) on various active production facilities and drilling rigs throughout the Gulf. The capital cost of the system is roughly \$70,000/site with an annual operating cost of \$20,000. Offshore operators Shell, ChevronTexaco, and BP also employ ADCP measurements in areas without ongoing activity at a cost of \$200,000-\$300,000/site. Shell currently has the most measurement sites in the GOM (12), followed by ChevronTexaco (1) and BP (1).

The *Joint Association Survey on Drilling Costs* estimated that the total cost of drilling in the GOM in 2000 was \$4.6B [35]. If we assume that 1–3% of the total cost is due to waiting on weather and that improved ocean observation systems can mitigate 1% of the costs, then the expect savings is computed as \$300,000 and \$1.5M.

Operator Savings—Drilling
Assumptions:

- Total annual offshore drilling cost: \$3-5B;
- Waiting on weather is responsible for 1–3% total costs;
- Better ocean observation systems can reduce weather downtime 1% relative to current conditions.

Expected Savings:
(\$3-5B)(0.01–0.03)(0.01) = \$300,000–1.5 M.

Table 9
Typical limiting conditions for offshore weather-sensitive activities

Activity	Limiting Conditions
Evacuation by crew boat	WH < 5 ft, Daylight[a]
Evacuation by helicopter[b]	WS < 40 mph, Daylight[c]
Deepwater drilling	WS < 80 mph, WH < 8 ft
Lifting and coupling	WH < 5 ft
Evacuation by helicopter[d]	WS < 50 mph, WH < 5 ft
Current velocity	CV < 1–2 knots[e]

[a] WH = Wave height.
[b] Fixed structures.
[c] WS = Wind speed.
[d] Floating structure.
[e] CV = Current velocity.

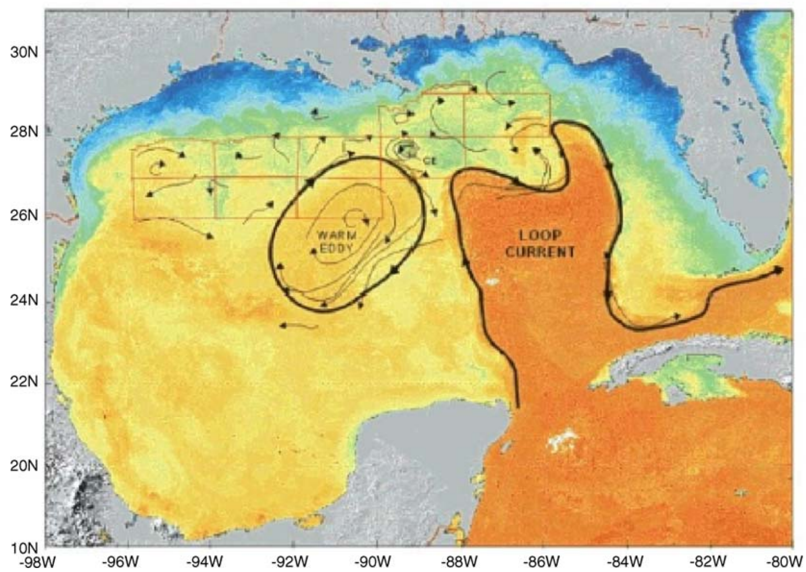


Fig. 12. Eddy watch. Source: Horizon Marine, Inc.

5.2. Development activities

One of the primary goals in any construction project is predictability, but because of the nature and location of the operation, offshore construction activities will always be uncertain and unpredictable. There are numerous independent uncontrollable variables in the offshore environment, such as adverse sea conditions and weather, availability and performance of equipment, defects in plans and specifications, and work conditions that result in delay, and often, significant financial repercussions. Delay is a common risk in offshore construction projects and the parties of the contract apportion risks for delays that may be encountered. In the case of weather risk, construction contractors will frequently quote a lump sum (base) bid that includes weather downtime, except downtime due to named tropical storms, for work during the prime season (May 15–October 15).

There are a wide variety of construction vessels used in the GOM and contractors plan their operations using ocean/weather forecast to avoid adverse weather and operating conditions. Typical offshore construction craft include crane vessels, drill ships, dive support vessels, survey vessels, cable lay vessels, pipelay vessels, multi-purpose support vessels, dredging vessels, trawling vessels, and accommodation vessels. The vessels come in a variety of shapes and sizes, from rectangular barges to jack-ups and semi-submersibles.

Offshore construction vessels differ from merchant ships because they do not trade cargo between ports and their most critical operations and loading conditions occur while working on the high seas (and not at the start or end of their voyage). Construction vessels also differ from passenger ships since they are much stronger and the design standards have to satisfy a multitude of strict safety regulations.

There are guidelines for marine operations such as barge transportation, platform mating and lift-off, etc. In barge transportation, for example, weather forecast are normally provided at 12 hour intervals and contain forecasts for the next 24 and 48 hours, with the weather outlook for the coming 3–5 day period. Tows are designed to withstand a 10-year return period for extreme environmental conditions for the most exposed part of the route for the month or months during which the transportation takes place. For long duration tows passing through areas having different characteristic seastates, the worst seastate for the route is identified and used in the design of the cargo, grillage, and seafastenings [36,37].

During construction activities, a moving vessel is installing (or removing) something on a fixed seabed, which leads to the requirement that vessel motions be minimized as much as possible to maximize the operational window. There are typically two options by which major projects are installed and completed offshore: floatover, in which the unit is lowered into place from its transportation vessel, or heavy lift, in which the unit is lifted into place with large vessel-mounted cranes. The transportation and installation limitations of the construction approaches dictate the size, weight and weight distribution of the modules. The heavy-lift method of installation is able to complete installations in challenging sea-states and has some inherent advantages in flexibility, but the use of such equipment is also more costly. Lay barges, for instance, are designed to operate at different wave heights, allowing the operator to choose the barge to the sea conditions in the area. The prime risk factor is the weather, and specifically, the day-to-day wave heights. Large barges are significantly more expensive than standard barges; e.g., a barge that can operate in 2-m wave height cost about \$250,000/day while the cost for a 5-m wave height cost about \$500,000/day. If pipeline installation is finished late, or delayed by unexpected ocean conditions, the direct cost of delay expressed in terms of the above dayrates and the opportunity cost of nonproductive structures and wells is likely to be substantial.

Order-of-magnitude savings for construction and transportation activities in the GOM with the occurrence of a hurricane event are estimated as follows. Refer to Table 10.

(1) Operator Savings—Construction
Assumptions:

- Activity: 50 installed structures/yr, 50 removed structures/yr;
- Construction activity level at time of hurricane passage: 50% total structures;
- Number of structures in hurricane path: 50% total structures;
- Derrick barge cost: \$100,000/day;
- Weather forecasting model improvement: 10% or more accurate prediction saving 3–5 days work time.

Expected Savings
(50 + 50)(0.50)(0.50)(0.10)(\$100,000/day)(3–5 days) = \$0.75–1.25 M/yr.

(2) Operator Savings—Supply Vessel
Assumptions:

- Number of active supply vessels: 500/day;
- Number of supply vessels in hurricane path: 50% total structures;
- Supply vessel cost: \$20,000/day;
- Weather forecasting model improvement: 10% or more accurate prediction saving 3–5 days work time.

Expected Savings:
(500)(0.50)(0.10)(\$20,000/day) (3 days) = \$1.5–2.5 M/yr.

5.3. Production activities

Production facilities in the GOM extract, process, and transport 3 M BOE per day which is forecast to increase through this decade as deepwater oil and gas production comes on line [38,39]. The occurrence of an extreme weather event—a hurricane or tropical storm—force operators to shut down facilities and evacuate personnel. Considering the fact that human safety is an issue in these decisions, it is not unusual that GOM operators take a ‘‘conservative’’ approach in their planning activity.

Safe working conditions for many offshore operations may be approximately specified by the critical values of wind speed and wave height. The limiting conditions for the operation of helicopters are usually defined in terms of wind speed, while wave height must fall below a given threshold to ensure safe lifting, coupling, and drilling operations, or transfer operations with a crew boat. Crew boats and helicopters are the primary method of transportation to evacuate offshore personnel. Helicopters can fly in all but the most extreme winds, while evacuation by boat is more weather sensitive (Table 9). The number of personnel involved in an evacuation depends on the type of structure: a small drilling rig may have a crew less than 10 while a large production platform could have over 100. In the GOM, there are currently about 25,000 offshore workers on any given day.

The direct cost involved with a hurricane event includes:

- Shut-down cost, C_1;
- Evacuation cost, C_2;
- Downtime cost, C_3;
- Damage assessment cost, C_4;
- Facility repair cost, C_5;
- Start-up cost, C_6.

Improved ocean observation systems are expected to allow *some* of these costs to be reduced, delayed, or possibly avoided—in particular C_2 and C_3—although it is clear that *no* observation system cannot mitigate the actual damage of the event unless boats and drilling vessels are moved out of the track of the storm that otherwise would not have been moved. Shut-down and start-up cost (C_1, C_6), damage assessment cost (C_4), and facility repair (C_5) depend on the track and strength of the storm and the amount of damage inflicted and are not influenced by improved ocean observation systems except in the development design stage [40].

Hurricane motion is controlled by the state of the surrounding atmosphere, and forecasts based upon more accurate and timely measurements of that state are themselves more accurate. If the forecast associated with a hurricane event can be improved, then production can stay on-line a greater period of time without sacrificing safety or environmental considerations, and in the best case, perhaps not shut-down at all. Order-of magnitude estimates for evacuation and lost production savings are provided as follows:

(1) Operator Savings—Evacuation
Assumptions:

- Manned platforms in hurricane path: 750;
- Rigs in hurricane path: 100;
- Evacuation cost: \$10,000/platform, \$50,000/rig;

Table 10
Summary of potential benefits of improved ocean observation systems in the Gulf of Mexico

Application	Nature of Benefit	Annual Potential Benefits ($M)
Marine transportation	Operational savings	30.7
Commercial fishing	Additional fishing day	2.1
Recreational fishing	Additional fishing day	(6.7, 33.7)
Search and rescue	Lives saved	28.0
Oil spill response	Improved response	(0.6, 1.0)
Subtotal		(68.1, 95.5)
Drilling activity	Improved operations	(0.3-1.5)
Construction	Improved operations	(0.8, 1.3)
Supply vessels	Improved operations	(1.5, 2.5)
Evacuation	Improved operations	(1.3, 2.5)
Lost production	Improved operations	(3.8, 7.5)
Subtotal		(7.7, 15.3)
Lightering	Improved operations	?
Env. monitoring	Improved management	?
Government royalty	Reduced delay	0.2
Engineering design	Improved design	(9.0, 15.0)
Subtotal		(9.2, 15.2)
Total		(85.0, 126.0)

- Weather forecasting model improvement: 10–20% more accurate prediction on hurricane path/zone to avoid evacuation.

Expected Savings
(750)(0.10–0.20)($10,000/platform) + (100)(0.10–0.20)($50,000/rig) = $1.25–2.5 M/yr
(2) Operator Savings—Lost production
Assumptions:

- Net income margin per BOE: $5/BOE.
- One-half of GOM production shut-in: 1.5 MMBOE/day.
- Weather forecasting model improvement: 0.5–1 day continued production.

Expected Savings:
(1.5 MMBOE/day)($5/BOE) = $3.8–7.5 M/yr.

6. Other potential benefits

6.1. Lightering activities

Lightering is the ship-to-ship transfer of cargo, usually crude oil or its derivative products, from tankers too large to transit a port to smaller tankers capable of transiting the waterways to the discharge berth. Lightering operations take place in the GOM and the east and west coast of the United States, but the majority of operations, some 80%, take place in the GOM [41]. Between 1993 and 1997 about 1.4 MMbbl/d and 3 lifts per day were lightered in the GOM.

Nine areas have traditionally been used for lightering in the GOM since the late 1970s, and there are currently four designated lightering zones and three areas where lightering is prohibited. The age of the tanker and whether or not it is double-hulled will determine whether the tanker may use the traditional lightering area or designated lightering zone.

Weather plays an important role in the maneuvering of the vessels as they come alongside each other, moor, and possibly, anchor. The maneuvering and mooring operations typically take place while the vessels are underway, and the preferred heading during the approach and mooring is such that the ship to be lightered has the winds slightly on her port or starboard quarter. Real-time knowledge of wind direction, speed, and ocean currents is necessary for a safe and successful lightering operation. The mooring master determines whether the transfer will take with the vessels at anchor, drifting, or steaming. The chosen method depends on the weather conditions as well as those forecast within the next 24 hours.

A Marine Board study committee concluded that lightering has an excellent safety record, and that this record is likely to be maintained or even improved through ongoing improvements to the shipping industry, including the increased availability of essential weather information to shipping companies and mariners. The study committee recommended that the USCG should encourage the NWS and the US Navy to deploy additional weather buoys in the GOM and tailor forecasts to support lightering activities [42].

6.2. Environmental monitoring

Red tides, which are blooms of single-cell algae that produce potent toxins harmful to marine organisms and humans are a natural phenomenon in the GOM, and occur primarily off southwestern Florida and Mexico. These algal blooms can result in severe economic and public health problems, and are responsible for fish kills and invertebrate mortalities.

Waterways draining into the GOM transport wastes from 75% of US farms and ranches, 80% of US cropland, hundreds of cities, and thousands of industries located upstream of the GOM coastal zone. Urban and agricultural runoff contributes large quantities of pesticides, nutrients, and fecal coliform bacteria.

Activities that have contributed or are still contributing to the degradation of coastal water conditions along the Gulf Coast include the petrochemical, industrial, agricultural, power plants, pulp and paper mills, fish processing, municipal wastewater treatment, maritime shipping, and dredging. Nonpoint sources are difficult to regulate and currently have the greatest impact on the

GOM coastal water quality. Nonpoint pollutant sources include agriculture, forestry, urban runoff, marinas, recreational boating, and atmospheric deposition.

One of the greatest concerns for GOM coastal water quality is an excess of nutrients which can lead to noxious algal blooms, decreased seagrasses, fish kills, and oxygen-depletion events. Improved ocean observation systems is expected to allow environmental activity in the region to be better understood and monitored.

6.3. Delayed royalty payments

Weather related production shut-downs defer royalty payment to the federal government which can be valued as the difference between receiving the money today and receiving the money in the "future." In the case of a hurricane event, the exact manner in which production is recovered is unknown, but logical inferences serve to approximate modes of expected recovery.

If we assume that the lost production due to a hurricane event will only be made up in the far future, then the associated royalty loss is estimated as

$$V_{\mathrm{roy},1}(H) = 0.125(L(H) - L'(H))p_t,$$

where 12.5% represents an average royalty rate and p_t is the average hydrocarbon price of a GOM benchmark at the time of the event, $L(H)$ is the lost production under current ocean observation systems, and $L(H')$ is the lost production under improved systems. If lost production is assumed to be made up incrementally over a period of β years after the event, the value of the lost production discounted at time t at r_t% is evaluated as

$$\begin{aligned} V_{\mathrm{roy},2}(H) = {} & 0.125(L(H) - L'(H))p_t \\ & - \frac{0.125(L(H) - L'(H))p_{t+1}}{\beta(1 + r_{t+1})} \\ & - \cdots - \frac{0.125(L(H) - L'(H))p_{t+\beta}}{\beta(1 + r_{t+\beta})^{\beta-1}}. \end{aligned}$$

If improved ocean observation systems lead to a reduction in lost production of 3–5% of the nominal production levels, and if the hydrocarbon price and discount rate is assumed constant at $p_t = \$20$/BOE and $r_t = 5\%$, then since approximately 3 MM BOE is extracted, processed, and transported each day in the GOM, royalty loss is estimated to range between

$$V_{\mathrm{roy},1}(H) = \$225,000 - \$375,000,$$

under the first model (no recovery), and under the second model (uniform recovery over a β-year horizon) royalty loss is calculated as

$$V_{\mathrm{roy},2}(H) = \$26,000 - \$50,000,$$

for $\beta = 2$ and 5. The actual value of royalty loss probably falls somewhere between these limits, and for simplicity an estimate of the expected savings is computed as

$$E[V_{\mathrm{roy}}(H)] = \tfrac{1}{2}E[V_{\mathrm{roy},1}(H)] + \tfrac{1}{2}E[V_{\mathrm{roy},2}(H)] = \$169,000.$$

6.4. Engineering design

The forces produced by wind, wave, and current are the primary design loads on mobile drilling units and other offshore structures. The forces are dynamic and ever-changing and rarely can they be expressed as a mathematical function of time.

The common method for wave loads is to base the calculations on one or more design waves of specified height and period. Structures are designed for a specified wind and current velocity as well as a wave of specified height and period. These criteria describe the "100 year storm" and refers to the worst wind, wave, and current conditions expected in any arbitrarily chosen 100 year period.

The optimal design of an offshore facility, especially floating production facilities in the deepwater GOM, requires knowledge of the response of the structure to environmental loading, which in turn, is critically dependent on the acquisition of reliable data on current profile and wave height [43,44]. Design criteria and modifications generally do not allow simple analysis, but structural engineers the authors contacted suggested the following order-of-magnitude assessment. If the current profile was known with 10–15% more accuracy, the potential design savings on deepwater (floating) facilities may be on-the-order of \$2–5M per structure. Improved wave forecasting is less critical, leading to an estimated design savings of \$500,000 per structure. Improved wind forecasting is not a critical design element and is not likely to lead to any savings.

Operator Savings—Design
Assumptions:

- Deepwater structures installed: 3–5 structures/year;
- Current/wave improved forecast: 10%;
- Design savings: \$3M/structure.

Expected savings:
(3–5 structures/year)(\$3M/structure) = \$9–15 M/yr.

7. Conclusions

Improved ocean/weather observation systems in the GOM are expected to enhance the value of the information currently available and benefit several user groups. The purpose of this paper was to describe the ocean observation systems in the GOM and the manner in which ocean data is used. The value of the benefits derived from improved ocean observation systems was estimated to range between \$85 M and \$126 M.

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