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Germination, Shoot Growth, Root Growth and Seedborne Fungi of Fungicide Treated Wheat Seed in Mississippi

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ABSTRACT

Germination, shoot growth, root growth and incidence of fungi were determined for untreated, fenbuconazole- and myclobutanil-treated Wakefield wheat seed. Fungicide seed treatment did not significantly affect percent germination. Seed treated with 59 ml myclobutanil/45.4 kg of seed had 100% germination, and seedlings germinating from seed treated at 118 ml/45.4 kg presented abnormal growth and discoloration. Five seed treatments reduced seedling shoot growth and four treatments reduced root growth. All rates of myclobutanil reduced both shoot and root growth. Eleven fungal genera were isolated from treated and untreated seed. *Alternaria* spp. were the most frequently isolated fungi.

INTRODUCTION

Fungicide seed treatment is economical and practical in the management of crop disease (1,2,3,4). Seed treatment provides consistent performance under varying environmental conditions, safety to applicators and the environment, a wide margin between effective dosage and dosage harmful to plants, and limited residue (3).

Protectant fungicides are efficacious for plant disease caused by soilborne fungi. Penetrant fungicides provide protection with less active ingredient compared to protectant fungicides. Both amount of material required and the number of applications are reduced when penetrant fungicides are used. Protectant fungicides control a broad spectrum of pathogenic fungi; penetrant fungicides are more selective (2,5).

Demethylation inhibitor (DMI) fungicides specifically interfere with ergosterol biosynthesis. These fungicides are active against numerous phytopathogenic fungi. They are characterized by chemical variability without the loss of biological properties, apoplastic transport, xylem mobility, low applications rates, plant growth regulatory activity, and protective, curative and eradicative activity (6,3).

Fusarium spp. and *Cochliobolus sativus* (Ito & Kuribayashi) Drechs, ex Dastur are reported to cause seedling blight and loss of wheat stand (7). These fungi gain access to seed during anthesis and grain fill. The ability of infected seed to produce healthy stands the following growing season is hindered (1). Protectant fungicides provide limited control of seedborne fungi. Penetrant fungicides diffuse into the germinating embryo and provide control of fungi within seed (1,6).

This study was conducted to characterize seedborne fungi, germination, and seedling vigor of untreated, fenbuconazole- and myclobutanil-treated Wakefield wheat seed *in vitro*.

METHODS

Wakefield winter wheat seed were treated with fungicides to measure effects on germination, seedling vigor and seedborne fungi. Fenbuconazole or myclobutanil (Dow AgroSciences, Indianapolis, IN) was applied at low, medium and high rates. Recommended rates of fenbuconazole and myclobutanil are 0.8, 1.2 and 1.6 ml, and 0.4, 0.8 and 1.6 ml/623 g of wheat seed, respectively. A slurry was prepared by adding fungicide to 0.16 ml of Pro-Ized® seed colorant and subtracting this amount from a desired volume of 20 ml. Distilled water was added to the seed treatment plus the seed colorant to bring the total slurry to volume. Seed and fungicide slurry were combined in a glass jar and tumbled for 10 min to uniform coverage. Seed were then placed on a tray under a ventilation hood to dry for 8 hours. Controls consisted of seed treated only with distilled water and seed colorant.

To evaluate germination, 100 seeds from each treatment were placed in moist germination towels and incubated at 20^{o}C. Percent germination was recoded at 4 and 7 days according to Rules for Seed Testing of the Association of Official Seed Analysts (Anonymous, 2011). Root length and shoot length were also measured after 7 days. An additional 100 seeds from each treatment were placed on water agar (1.0 g/L) to assess fungal incidence. Fungi were identified to genus using standard taxonomic keys.

Germination data are reported following arcsine transformation prior to analysis. Analysis of variance and linear contrasts were performed using the Statistical Analysis System (SAS Institute, Inc. Cary, NC).

RESULTS

Fungicide seed treatment did not significantly affect percent germination of Wakefield wheat *in vitro*. Germination ranged from 96% for untreated seed or seed treated with 118 ml/45 kg of fenbuconazole to 100% for seed treated with 59 ml/45 kg of myclobutanil (Table 1). Seedlings from untreated and fenbuconazole-treated seed presented normal development. Seedlings germinating from myclobutanil-treated seed were pale green and stunted.

Table 1. Germination (%) of untreated, fenbuconazole- or myclobutanil-treated Wakefield wheat seed.

Seed treatment, rate per 45 kg seed	Germination (%)
Fenbuconazole 59 ml	98[z]
Fenbuconazole 89 ml	98
Fenbuconazole 118 ml	96
Myclobutanil 30 ml	97
Myclobutanil 59 ml	100
Myclobutanil 118 ml	98
Untreated control	96

[z]Germination percentages derived from 100 seed.

Fungicide seed treatment affected both *in vitro* shoot and root growth ($P \leq 0.0001$). All seed treatments except one significantly reduced shoot growth of seedlings compared to seedlings from untreated seed (Table 2). Shoot growth was greater for seedlings from untreated seed and from seed treated with 89 ml of fenbuconazole (Table 3). Seedlings from seed treated with 59 ml or 118 ml of myclobutanil produced the least shoot growth. Wheat seedlings from seed treated with fenbuconazole had significantly greater shoot growth compared to seedlings from seed treated with myclobutanil (Table 2).

All but two seed treatments significantly reduced root growth compared to the untreated control (Table 2). Seedlings from seed treated with fenbuconazole had significantly more root growth than seedlings from seed treated with myclobutanil. Seedlings from untreated seed produced the most root growth, and seedlings from seed treated with 30 ml of myclobutanil produced the least root growth (Table 3).

Table 2. Linear contrasts based on analysis of variance for the effect of untreated, fenbuconazole- or myclobutanil-treated Wakefield wheat seed on *in vitro* shoot and root growth.

	Shoot growth (cm)		Root growth (cm)	
Contrast	Estimate	Pr > t	Estimate	Pr > t
F vs M[z]	0.80	***[y]	1.69	***
F1 vs M1	0.58	***	2.76	***
F2 vs M2	1.05	***	2.29	***
F2 vs M3	0.76	***	0.04	NS
F1 vs F2	-0.19	NS	0.11	NS
F1 vs F3	0.14	NS	2.23	***
F2 vs F3	0.34	*	2.11	***
M1 vs M2	0.27	*	-0.35	NS
M1 vs M3	0.33	*	-0.48	*
M2 vs M3	0.05	NS	-0.13	NS
UC vs F1	0.234	*	0.244	NS
UC vs F2	0.04	NS	0.362	NS
UC vs F3	0.382	**	2.478	***
UC vs M1	0.816	***	3.004	***
UC vs M2	1.094	***	2.654	***
UC vs M3	1.146	***	2.522	***

[z] F = total treatment means for fenbuconazole applied to 45 kg seed at rates F1 = 59 ml, F2=89 ml, F3 = 118 ml, respectively.

M = total treatment means for myclobutanil applied to 45 kg seed at rates M1 = 30 ml, M2 = 59 ml, M3 = 118 ml, respectively.

UC = untreated control.

[y] *,**,*** statistically significant at $P \leq 0.05, 0.001, 0.0001$, respectively. NS = not significant.

Table 3. Mean shoot and root growth of Wakefield wheat seedlings developing from untreated, fenbuconazole- or myclobutanil-treated seed.

Seed treatment, rate per 45 kg seed	Shoot growth (cm)	Root growth (cm)
Fenbuconazole 59ml	2.74[z]	6.52
Fenbuconazole 89ml	2.93	6.41
Fenbuconazole 118ml	2.59	4.29
Myclobutanil 30ml	2.15	3.76
Myclobutanil 59ml	1.87	4.11
Myclobutanil 118ml	1.82	4.25
Untreated control	2.97	6.77

[z] Values represent mean of 100 seedlings.

Fungi of eleven genera were isolated from untreated- and fungicide-treated Wakefield wheat seed (Table 4). *Alternaria* spp., *Arthrinium* spp. and *Paecilomyces* spp. accounted for 75% of the fungi isolated. *Aspergillus* spp., *Curvularia* spp., *Fusarium* spp., *Nigrospora* spp., *Penicillium* spp., *Periconia* spp., *Rhizopus* spp. and *Trichoderma* spp. accounted for the remaining 25%. *Alternaria* spp. were most frequently isolated and *Curvularia* spp. were the least frequent. *Fusarium* spp. accounted for 8% of the total fungal population. The incidence of *Fusarium* spp. was numerically higher on seeds treated with 118 ml of myclobutanil and was numerically lower on seeds treated with 118 ml of fenbuconazole or 30 ml of myclobutanil. *Aspergillus* spp. were controlled by the application of fenbuconazole or myclobutanil (Table 4).

Table 4. The frequency (%) of fungi from untreated, fenbuconazole- or myclobutanil-treated seed.

		Fenbuconazole			Myclobutanil		
Fungi	Untreated	59 ml	89 ml	118 ml	30 ml	59 ml	118 ml
Alternaria spp.	43[z]	27	31	55	53	8	20
Arthrinium spp.	23	23	23	10	23	34	42
Aspergillus spp.	13	0	0	0	0	0	0
Curvularia spp.	0	2	0	0	0	0	0
Fusarium spp.	5	11	15	0	0	13	18
Nigrospora spp.	0	0	6	0	0	0	0
Paecilomyces spp.	0	37	14	0	0	45	20
Penicillium spp.	8	0	0	15	13	1	0
Periconia spp.	0	0	13	0	0	0	0
Rhizopus spp.	10	0	0	20	0	0	0
Trichoderma spp.	0	0	0	0	10	0	0

[z] Frequencies derived from the total population of fungi isolated.

DISCUSSION

Planting dates for wheat in Mississippi range from October 1 to December 10 (10). October is historically the driest month of the year in the state (11). In some areas of North America where wheat is planted into conditions of limited moisture, common root rot caused by *C. satius* and *Fusarium* spp. is responsible for yield losses of up to 6% annually. Imazalil is registered for use against common root rot caused by *C.* sativus, but results on effectiveness have been variable (7). Fenbuconazole and myclobutanil were chosen for this study because of fungitoxic activity to deuteromycete fungi, specifically dematiaceous hyphomycetes (12). Seed treatment with these fungicides takes advantage of activity to inhibit fungal growth. Neither material is effective once fungi begin to sporulate.

Fungi of eleven genera were isolated from 700 seed *in vitro*. *Alternaria* spp., *Arthrinium* spp. and *Paecilomyces* spp. accounted for 75% of the fungi isolated. *Alternaria* and *Arthrinium* spp. are reported to have minimal effect on wheat seed health (13). *Aspergillus* spp., *Fusarium* spp. and *Penicillium* spp. are reported to affect seed health (7). *Alternaria* and *Arthrinium* spp. were isolated from seed in all treatments in the study. The incidence of *Alternaria* and *Arthrinium* spp. was similar for both untreated and treated seed.

Aspergillus spp. were controlled by both seed treatment fungicides. *Alternaria* spp. were the most frequently isolated fungi in four of the seven treatments. Abou-Heilah (14) isolated seven genera of fungi from twelve wheat varieties. *Alternaria* spp. were isolated from all varieties and were not affected by fungicide seed treatment.

In this study, *Fusarium* spp. were the only pathogenic fungi isolated from untreated- and fungicide-treated seed. In a survey by Clear and Patrick (13), thirty-five genera were isolated from soft white wheat seed collected from elevators in Ontario, Canada. They recovered *Alternaria* spp. from all samples, and *Fusarium* spp. were the most frequently isolated pathogenic fungi.

Seed treatments did not affect seed viability. Percent germination of wheat seed was not affected by treatment with fenbuconazole or myclobutanil. Penetrant DMI fungicides do not enter wheat seed through the pericarp; instead, these materials enter germinating seedlings by contamination of the coleoptile (3). In previous studies, seed treatment with penetrant fungicides did not affect percent germination, but seed treated with nuarimol and triadimefon produced abnormal seedling growth and discolored foliage (1,3,5,15).

Seedlings developing from seed treated with 118 ml of myclobutanil expressed the most abnormal growth. This response to the highest rate of this fungicide is consistent with warnings on labeled products containing myclobutanil. Over-dosage and environmental stress can produce dark-green wheat foliage and shortened internodes. The ideal temperature for wheat germination and growth is between 10 and 24^{o}C (7). In this study, wheat seedlings were germinated at 21^{o}C in moist germinating towels creating optimal conditions for germination and growth.

Five treatments reduced shoot growth and four reduced root growth significantly. Seed treated with 89 ml of fenbuconazole produced shoot and root growth similar to wheat seedlings developing from untreated seed. Seed treated with fenbuconazole produced more shoot and root growth than seedlings from seed treated with myclobutanil. Barnard and Purchase (1) and Luz and Vieira (5) reported that seed treated with DMI fungicides had reduced coleoptile growth. Richardson (15) reported that an experimental DMI fungicide damaged both roots and leaves of emerging seedlings when applied as a seed treatment. Triazole fungicides are translocated to meristematic tissue of plants where gibberellin production and stigmasterol synthesis are disrupted (8). The reduction in cell elongation and division may play a role in reduced shoot and root growth of wheat seedlings observed in this study. Based on results in this study, applying fenbuconazole or myclobutanil as seed treatments will not reduce or improve germination, but some rates of fenbuconazole and all rates of myclobutanil can reduce root and shoot growth.

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Aquatic Plants of the Mississippi Coast

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ABSTRACT

The wetlands in Mississippi are a home for numerous aquatic plants. Correct identification and locating of the native, favorable species or the invasive, noxious species are: 1) required to understand species richness/dominance/diversity which can be used as an indicator of the habitat's health, complexity, stability, and status; and 2) the first step in habitat assessment for proper conservation and management. This study was designed to document common aquatic plants that occur on the Mississippi coast and to present them by habitat type and growth form. Shallow coastal and estuarine waters, salt marshes, tidal oligohaline marshes, freshwater marshes, and freshwater swamps were surveyed for emergent, floating-leaved, submerged, and free-floating aquatic plants from 2008 to 2010 within coastal Mississippi. The location was recorded, and photos of the plants were taken. The catalogued information was sorted by habitat type and plant growth characteristic.

Keywords: Aquatic plants; Mississippi; coastal wetlands; SAV; shoreline vegetation.

INTRODUCTION

Aquatic plants, also called hydrophytes, are the plants adapted to live in aquatic environments (Cronk and Fennessy 2001). They can occur in a range of growth forms: free-floating on the water surface, rooted with floating leaves, completely submerged, or emergent with roots in standing water or permanently water-logged soil. Free-floating aquatic plants grow suspended in the water column or float free on the water surface with no roots anchored in the sediment. Submerged aquatic vegetation (SAV) species are those plants growing completely beneath the surface of water, with most species rooted in the soil. Floating-leaved aquatics have leaves floating on the surface of the water while the roots are in the sediment. Emergent aquatics are rooted in the soil beneath the surface of water with stems, leaves, and reproductive organisms growing above the water (Cronk and Fennessy 2001).

These different types of aquatic plants have unique roles in their habitats. Some of these hydrophytes can be important for improving water quality, feeding other aquatic life, and stabilizing sediment (Larkum et al. 2006). Other hydrophytes may be harmful to their habitats (Hershner and Havens 2008), such as noxious species that form surface canopies, thus blocking light from penetrating through and preventing gas exchange. Many of these harmful hydrophytes also inhibit navigation and commercial/recreational activities. They are usually fast-growing, submerged or floating, and found in inland waters. Identification of the noxious, favorable, and native aquatic plants is important for understanding the conditions of their habitats, such as the diversity, dominance, and richness of the plants. Identification is also required in performing proper habitat assessments, which is needed for conservation and management (Tiner 1991).

Aquatic plants grow in wetlands, transitional areas between terrestrial and aquatic systems (Mitsch and Gosselink 2007). A wetland is characterized by the three components: presence of water/water table level, water-logged soil (hydric soil) conditions, and the presence of hydrophytes/absence of flooding-intolerant vegetation (Mitsch and Gosselink 2007). There are numerous kinds of aquatic plants that can be found throughout the Mississippi inland and coastal wetlands. The state also contains one of the most well-preserved, unmodified river basins of the United States: the Pascagoula River Basin. Nevertheless, there are few aquatic plant guide materials that exclusively list and address the Mississippi aquatic plants and their habitats. Especially, there is almost a dearth of published information on brackish and freshwater submerged aquatic species that occur along the Mississippi mainland coast (Weiland 1994).

This study was designed to document common aquatic plants that occur on the Mississippi coast and to present them by habitat type and growth form. This paper was also prepared as a response to increased requests to provide the aquatic plant species and their locations in coastal river systems, particularly in relation to coastal restoration and development permits.

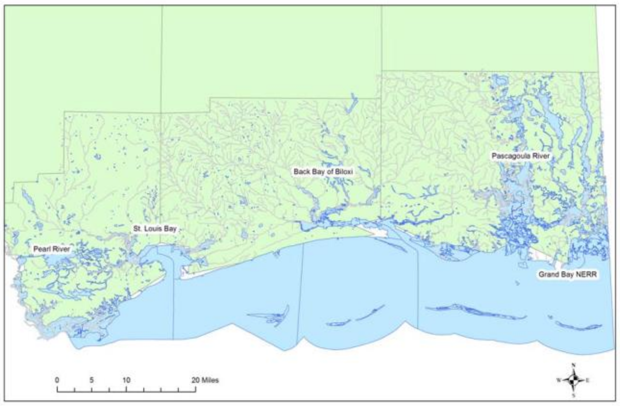

Figure 1 Field study areas along the Mississippi Coast

FIELD SITE AND METHODS

Coastal Mississippi has various aquatic plant habitats along the four major river systems: Pearl River, St. Louis Bay, Biloxi Bay, and Pascagoula River, which empty into the coastal estuaries. According to Eleuterius (1975), the Pearl and Pascagoula Rivers drain part of the North Central Plateau, the Jackson Prairie Belt, and Long-leaf Pine Regions and the Coastal Pine Meadows, while the St. Louis Bay and the Biloxi Bay Systems drain only the Longleaf Pine and Coastal Pine Meadows.

The field surveys were conducted in various areas along the Mississippi Coast (Fig. 1), including Pearl River, St. Louis Bay, Back Bay of Biloxi, Pascagoula River, Grand Bay National Estuarine Research Reserve, and beaches and wetland areas along Gulfport, Biloxi, Ocean Springs, Pascagoula, and Moss Point. Shallow coastal and estuarine waters, salt marshes, tidal oligohaline marshes, freshwater marshes, and freshwater swamps were surveyed for emergent, floating-leaved, submerged, and free-floating aquatic plants from May 2008 to June 2010. Each system was surveyed at least three times (spring, summer, and fall) to depict any seasonal variations in the species composition and phenological events. The location and species of plants were recorded using a hand-held GPS. Survey methods included raking from a boat and wading and snorkeling in the water, after SAV were observed to occur in a given location. Only obligate wetland plants, defined by U.S. Fish and Wildlife Service, were included.

Pictures of the plants were taken at several different scales using a 10 megapixel digital SLR camera (Nikon D80). Date, name of the location, GPS coordinates, habitat descriptions, general position within a map, species that were sampled and photographed, and the plants' growth status were recorded at each location.

When necessary and possible, plant samples were brought back to a laboratory of Jackson State University, Jackson, Mississippi to be pressed or preserved. Information on about 122 obligate wetland vascular plants that were studied was catalogued and sorted by habitat type and plant growth characteristic.

RESULTS

Estuarine seagrass/submerged aquatic vegetation (SAV)

Estuaries are partially enclosed coastal bodies of water into which one or more rivers and streams empty. The dominant vascular plants in the subtidal estuarine ecosystems were *Ruppia maritima* and *Halodule wrightii* (Table 1). These estuarine SAV species that grow in fully-saline environments are called seagrasses (Green and Short 2003). Seagrass beds protect shorelines from erosion, improve water quality by trapping sediments, provide habitat, and are highly productive. The productivity of these habitats is largely due to an abundance of algae and diatom phytoplankton, which feed a diverse food web (Larkum et al. 2006).

Table 1. Common vascular aquatic plants of subtidal estuarine waters

Scientific Name	Common Name	Growth Form
Ruppia maritima L. (Fig. 2)	Wigeongrass	Submerged
Halodule wrightii Asch. (Fig. 3)	Shoalgrass	Submerged

Figure 2 *Ruppia maritima* L. (Wigeongrass)

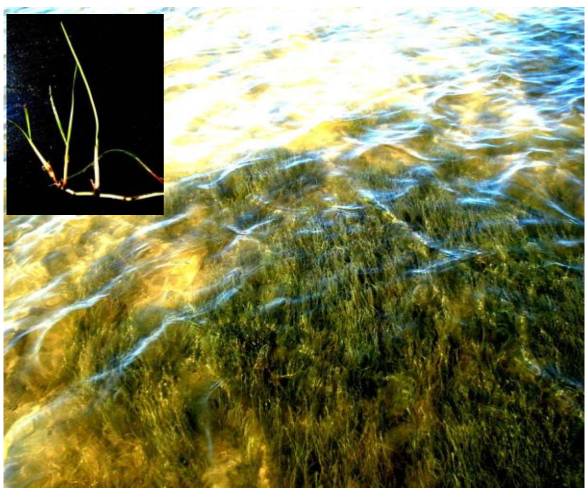

Figure 3 *Halodule wrightii* (den Hartog) den Hartog (Shoalgrass)

Salt marshes

Tidal salt marshes occur in the intertidal zone that is between low and high tides. Salt marshes are formed on low-energy coasts, such as estuaries, bays, and other protected coastal plains. Salt marshes are dominated by a few species of rooted grasses, rushes, and sedges that tolerate salt water, tidal fluctuation, and temperature extremes. Common salt marsh plants on the Mississippi coast include *Spartina* spp. and *Juncus roemerinus*, and *Schoenplectus* spp. (Table 2). Salt marshes are important nesting, nursery, and foraging habitats for animals. Organic detritus created from the dead marsh plant materials also supports detritus food webs of the coastal and nearshore marine ecosystems. Submerged aquatics grow in shallow openings, lagoons, sides of bayous, and ponds within salt marshes. In addition to *Ruppia maritima*, **common SAV in the salt marsh habitats are *Vallisneria*** *americana* (Table 2), which can be found in the areas close to freshwater sources.

Table 2. Common vascular aquatic plants of salt marshes

Scientific Name	Common Name	Growth Form
Spartina alterniflora Loisel. (Fig. 34a)	Smooth Cordgrass, Saltmarsh Cordgra	Emergent
Spartina cynosuroides (Roth (Fig. 4b)	Big Cordgrass	Emergent
Spartina patens (Aiton) Muhl. (Fig. 4c)	Salt Meadow Cordgrass	Emergent
Juncus roemerianus Scheele (Fig. 5a, 5b)	Black Rush, Black Needlerush	Emergent
Distichlis spicata (L.) Greene (Fig. 5c, 5d)	Saltgrass, Spikegrass	Emergent
Schoenoplectus pungens (Vahl) (Fig. 6a)	American Bulrush, Three-square Bulru	Emergent
Schoenoplectus robustu (Pursch) M.T. Strong (Fig. 6b)	Cone-cup Spikerus Long-tubercled Sp rush	Emergent
Ruppia maritima L. (Fig	Wigeongrass	Submerged
Vallisneria americana Michx. (Fig. 7)	American Eelgrass American Wildcel	Submerged

Figure 4. a. *Spartina alterniflora* Loisel (Smooth Cordgrass); b. *Spartina cynosuroides* (L.) Roth (Big Cordgrass); and c. *Spartina patens* (Air.) Muhl. (Salt Meadow Cordgrass)

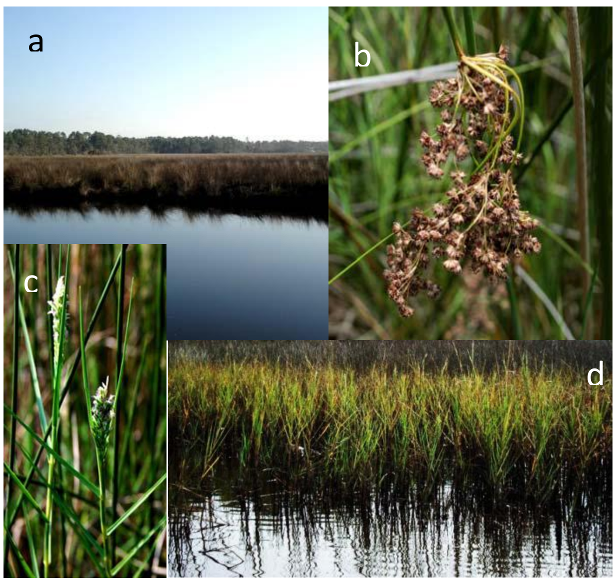

Figure 5. a. and b. *Juncus roemerianus* Scheele (Black Needlerush); c. and d. *Distichlis spicata* (L.) Greene (Saltgrass)

Figure 6 a. *Schoenoplectus pungens* Vahl. (American Bulrush); b. *Schoenoplectus robustus* Pursh (Alkali Bulrush)

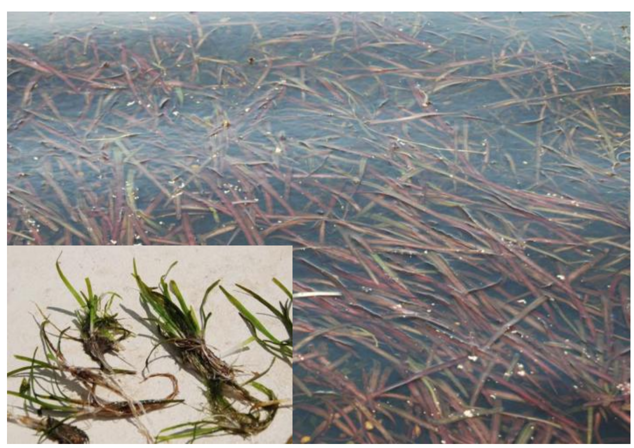

Figure 7 *Vallisneria americana* Michx. (American Wildcelery)

Tidal oligohaline marshes

Tidal oligohaline marshes are non-woody, plant-dominated wetlands that occur in the low-salinity brackish (0.5-5 ppt) zones along tidal rivers and streams and bayous. These ecosystems are very productive and support a higher number of animal/plant/microbe species compared to salt marsh ecosystems. *Cladium jamaicense*, *Spartina cynosuroides*, *Spartina patens*, and *Sagittaria lancifolia* are often the abundant emergent plants that form extensive stands along the edges of tidal channels (Table 3). *Phragmites australis* also occurs and is most abundant in the lower Pearl River regions, near the state border with Louisiana. Common SAV species that occur in tidal oligohaline marshes of Mississippi include *R. maritima*, *V. americana*, *Najas guadalupensis*, *Potamogeton pusillus*, and *Zannichellia palustris* (Table 3).

Table 3. Common vascular aquatic plants of oligohaline marshes

Scientific Name	Common Name	Growth Forn
Cladium jamaicense Crantz (Fig. 8)	Jamaica Swamp Sawgrass, Sawgrass	Emergent
Spartina cynosuroides (Fig. 4b)	Big Cordgrass	Emergent
Spartina patens (Fig. 4c)	Salt Meadow Cordgra	Emergent
Sagittaria lancifolia L. (Fig. 9)	Bulltongue Arrowhead	Emergent
Juncus effusus L. (Fig. 10)	Softstem Rush	Emergent
Phragmites australis (Cav.) Trin. *ex*. Steud. (Fig. 1	Common Reed	Emergent
Najas guadalupensis (Spreng.) Magnus (Fig 12a)	Southern Naiad, Southern Water-nymp	Submerged
Potamogeton pusillus] (Fig. 12b)	Small Pondweed, Thin-leaf Pondweed	Submerged
Zannichellia palustris (Fig. 12c)	Horned Pondweed	Submerged
Ruppia maritima L. (Fig. 2)	Widgeongrass	Submerged
Vallisneria americana Michx. (Fig. 7)	American Eelgrass, American Wildcelery	Submerged

Figure 8 *Cladium jamaicense* Crantz (Sawgrass)

Figure 9 *Sagittaria lancifolia* L. (Bulltongue Arrowhead)

Figure 10. *Juncus effusus* L. (Softstem Rush)

Figure 11 *Phragmites australis* (Cav.) Trin. *ex* Steud (Common Reed)

Figure 12. a. *Najas guadalupensis* (Spreng.) Magnus (Southern Naiad); b. *Potamogeton pusillus* L. (Small Pondweed); and c. *Zannichellia palustris* L. (Horned Pondweed)

Freshwater marshes

Freshwater marshes are often found in open areas near rivers, streams, bayous, ponds, and lakes. Freshwater marshes can be categorized into tidally and non-tidally influenced marshes. The water in freshwater marshes is usually rich in minerals. Species diversity is generally higher in freshwater marshes than in salt marshes. Non-woody plants, such as grasses and sedges, are common. Bulrushes (*Schoenoplectus* spp.), Cattails (*Typha* spp.), Pickerelweed (*Pontederia cordata*), Smartweed (*Polygonum* spp.), Alligatorweed (*Alternanthera philoxeroides*), and Wildrice (*Zizania aquatica*) are often found at the edges of these marshes (Table 4). Floating-leaved aquatics, including *Nuphar lutea*, *Nelumbo lutea*, *Nymphaea odorata*, and *Eichhornia crassipes* also can grow abundantly in freshwater marshes (Table 4). SAV species in this habitat include *V. americana*, *Najas guadalupensis*, *P. pusillus*, *Zannichellia palustris*, *Myriophyllum* spp. and *Proserpinaca* spp (Table 4). Often times, invasive aquatic plants such as *E. crassipes* and *A. philoxeroides* can grow rapidly and alter the freshwater marsh ecosystems.

Table 4. Common vascular aquatic plants of freshwater marshes

Scientific Name	Common Name	Growth Form
Schoenoplectus tabernaemontani Gmelin (Fig. 13)	Bulrush, Soft-stem Bulrush	Emergent
Typha domingensis Pers. (Fig. 14a)	Southern Cattail	Emergent
Typha latifolia L. (Fig. 14b)	Broadleaf Cattail	Emergent
Pontederia cordata L. (Fig. 15)	Pickerelweed	Emergent
Polygonum spp. L. (Fig. 16)	Knotweed species, Smartweed	Emergent
Alternanthera philoxeroides (Mart.) Griseb. (Fig. 17)	Alligatorweed	Emergent
Zizania aquatica L. (Fig. 18)	Annual Wildrice	Floating-leaved
Nuphar lutea (L.) Sm. (Fig. 19a)	Spatterdock, Yellow Cowlily, Yellow Pond	Floating-leaved
Nelumbo lutea Willd. (Fig. 19b)	American Lotus, Yellow Lotus	Floating-leaved

Nymphaea odorata Soland *ex* Ait. (Figs. 19c and 19d)	American Water-lily, Fragrant Water-lily	Floating-leaved
Eichhornia crassipes (Mart.) Solms (Fig. 20)	Waterhyacinth	Floating-leaved
Vallisneria ameriana Michx. (Fig. 7)	American Eelgrass, American Wildcelery	Submerged
Najas guadalupensis (Spreng.) Ma (Fig. 12a)	Southern Naiad, Southern Water-nymp	Submerged
Potamogeton pusillus L. (Fig. 12b)	Small Pondweed, Thin-leaf Pondweed	Submerged
Zannichellia palustris L. (Fig. 12c)	Horned Pondweed	Submerged
Myriophyllum spp. L. (Figs. 21a, 21b, 21c)	Watermilfoil	Submerged / Emerged
Proserpinaca spp. L. (Fig. 21d)	Combleaf Mermaidwe Mermaidweed	Submerged / Emerged

Figure 13 *Schoenoplectus tabernaemontani* Gmelin (Softstem Bulrush)

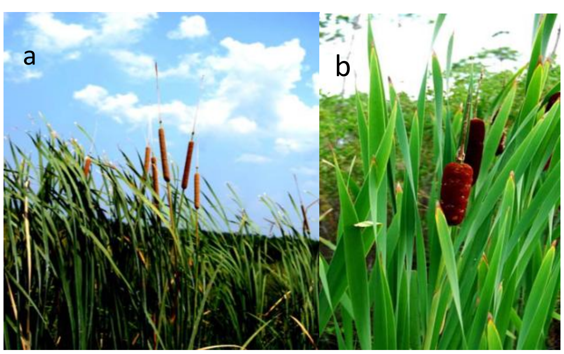

Figure 14. a. *Typha domingensis* Pers. (Southern Cattail); b. *Typha latifolia* L. (Broadleaf Cattail)

Figure 15. *Pontederia cordata* L. (Pickerelweed)

Figure 16 *Polygonum* spp. (Smartweeds)

Figure 17. *Alternanthera philoxeroides* (Mart.) Griseb. (Alligatorweed)

Figure 18 *Zizania aquatica* L. (Annual Wildrice)

Figure 19. a. *Nuphar lutea* (L.) Sibth. & Sm. (Spatterdock); b. *Nelumbo lutea* (Willd.) Pers. (American Lotus); and c. and d. *Nymphaea odorata* Soland *ex* Ait (Fragrant Water-Lily)

Figure 20 *Eichhornia crassipes* (Mart.) Solms (Waterhyacinth)

Figure 21. a. *Myriophyllum spicatum* L. (Eurasian Watermilfoil); b. *Myriophyllum pinnatum* (Walt.) B.S.P. (Cut-Leaf Watermilfoil); c. *Myriophyllum aquaticum* (Vell.) Verdc. (Parrot Feather); and d. *Proserpinaca pectinata* Lam. (Mermaidweed)

Freshwater swamps

Swamps are wetlands dominated by woody vegetation and trees. Cypress-tupelo swamps are common in Mississippi (Penfound 1952). Common tree species include Bald Cypress (*Taxodium distichum*), Pond Cypress (*Taxodium ascendens*), and Water Tupelo (*Nyssa aquatica*) (Table 5). Swamps are seasonally or permanently flooded by shallow water that is typically slightly acidic and low in nutrients. *Polygonum* species and *A. philoxeroides* can grow abundantly along the shores (Table 5). In these highly colored (black) swamp waters, free-floating plants, such as *Lemna minor*, *Spirodela polyrhiza*, and *Wolffiella gladiata*, are abundant (Table 5).

Table 5. Common vascular aquatic plants of freshwater swamps

Scientific Name	Common Name	Growth Fo
Taxodium distichum (L.) R (Fig. 22a, 23b)	Bald Cypress	Emergent (Tree)
Taxodium ascendens Bron (Fig. 22c, 22d)	Pond Cypress	Emergent (Tree)
Nyssa aquatica (Fig. 22e)	Water Tupelo, Tupelo Gum	Emergent (Tree)
Alternanthera philoxeroid (Mart.) Griseb. (Fig. 17)	Alligatorweed	Emergent
Polygonum spp. L. (Fig. 1(	Knotweed species, Smartweed	Emergent
Lemna minor L. (Fig. 23a)	Common Duckweed, Little Duckweed	Free-floating
Spirodela polyrhiza (L.) Schleid. (Fig. 23b)	Giant Duckweed, Big duckweed	Free-floating
Wolffiella gladiata (Hegel Hegelm. (Fig. 23c)	Florida Mudmidget	Free-floating

Figure 22. a. and b. *Taxodium distichum* (L.) Rich (Bald Cypress); c. and d. *Taxodium ascendens* Brongn. (Pond Cypress), and e. *Nyssa aquatica* L. (Water Tupelo)

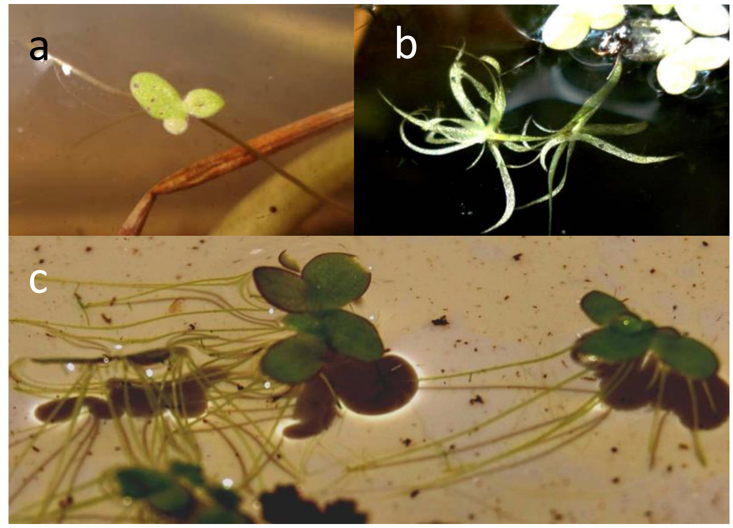

Figure 23. *Lemna minor* (Common Duckweed) (a); *Spirodela polyrhiza* (Giant Duckweed) (b); and *Wolffiella floridana* (Florida Mudmidget) (c)

DISCUSSION

The plant communities within the coastal areas encompass estuaries, tidal saltwater marshes, tidal oligohaline marshes, tidal freshwater marshes, and freshwater swamps (Wieland 1994). *Halodule wrightii* and *Ruppia maritima* were the only seagrass species that were found in the mainland coastal areas in the Grand Bay National Estuarine Research Reserve (Fig. 1, Table 1).

Saltwater marsh areas near the Gulf such as Biloxi Bay and the lower regions of Pearl and Pascagoula Rivers (Fig. 1) are mainly vegetated by the submerged *R. maritima* that tolerates a wide range of salinities (Kantrud 1991); the *R. maritima* beds often occur along *Spartina alterniflora* Loisel (Smooth Cordgrass) shores (Table 2). In brackish areas (mean salinities < 4 parts per thousands, ppt) along *Juncus roemerianus*, *Spartina* and *Schoenoplectus* marsh shores, *Vallisneria americana* often grows along with *R. maritima* (Table 2). The size of *V. americana* in these areas varies greatly with blade lengths ranging from 3 cm to longer than 1.2 m.

Compared to the shoreline vegetation distribution that rather changes orderly by seasonal growth of *Schoenoplectus* spp., *J. roemerianus*, *D. spicata*, and *Spartina* spp., the growth and abundance of the submerged *R. maritima* and *V. americana* are substantially influenced by the amount/timing of precipitation, winter/early spring temperatures, wind direction, and storms during a period precedent to the growing season. Hence, the salt and brackish marsh areas experience significant temporal fluctuations in presence and abundance of SAV.

Freshwater submerged species that are easily confused with *R. maritima* such as *N. guadalupensis*, *P. pusillus*, and *Z. palustris* often grow together densely in the freshwater and oligohaline areas where the emergent vegetation is characterized as intermediate marsh types (Tables 3 and 4, Eleuterius 1973). Relative abundance between *Ruppia*/*Vallisneria* and *Najas*/*Potamogeton*/ *Zannichellia* in the same locations changes with season and also depends on the amount of freshwater inputs (i.e. rainfall). The freshwater species that tolerate mild brackish conditions occur primarily along the shores dominated by *Sagittaria lancifolia*, *Cladium jamaicense*, *Schoenoplectus* spp. and *J. roemerianus*. While the dominant high marsh vegetation was *J. roemerianus* and *S. cynosuroides* in Pascagoula River and Biloxi Back Bay, *Phragmites australis* (Cav.) Trin. *ex* Steud (Common Reed) was predominant in many areas in Pearl River. *Myriophyllum spicatum*, known to be invasive SAV in other Gulf States, did not appear to overgrow or be invasive in the Mississippi coastal waters. Floating leaved or free-floating plants also occurred in the freshwater marshes and swamps (Tables 5 and 6).

ACKNOWLEDGEMENTS

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Efficacy of Non-conventional Fungicides for Control of Pythium Root Rot in Poinsettia (*Euphorbia pulcherrima* Wild. ex Klotzsch)

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ABSTRACT

Pythium root rot, caused by *Pythium aphanidermatum*, is considered the most consistent and serious soil-borne disease problem in poinsettia production. Greenhouse management practices typically include a fungicide drench when cuttings are transplanted. Standard conventional fungicide, mefenoxam (metalaxyl), is a high-risk fungicide for resistance. A key component of resistance management is integrating non-conventional fungicides into a disease management program. This study evaluated the efficacy of non-conventional fungicides (phosphonates, biologicals) compared to the absence of a fungicide and to a conventional fungicide for control of Pythium root rot of poinsettia. Two evaluations resulted in the control of Pythium root rot with preventive applications of non-conventional fungicides Magellan, Aliette, or a biofungicide, conventional tank mix, RootShield Plus/Subdue MAXX. A significant decrease in disease severity and area under the disease progress curve values were observed, while growth index, shoot dry weight, and root vigor were significantly improved for plants treated with non-conventional fungicides compared to untreated *Pythium*-inoculated plants. Pythium root rot disease severity and area under the disease progress curve values were reduced when plants were treated with Aliette or the conventional standard, Subue Maxx. Results indicated the potential use of non-conventional fungicides in a poinsettia disease management program for acceptable control of Pythium root rot. Results also demonstrated the need for continued research with these fungicides to minimize the inconsistent efficacious nature observed in this study.

Keywords: Pythium, poinsettia, phosphonates, biofungicides, fungicide resistance, Pythium root rot

INTRODUCTION

Pythium root rot is considered the most consistent and serious soil-borne disease problem in poinsettia (*Euphorbia pulcherrima* Wild. ex Klotzsch) production (1). The disease occurs early in the production of poinsettia plants and may either be isolated or widespread with potential loss of an entire crop (2). Several *Pythium* species have been implicated in the disease; however *Pythium aphanidermatum* (Edson) Fitzp. is the least characterized (3). *Pythium* spp. typically attacks below the soil surface and may extend up into the base of the stem. The lower stems and roots often develop a brown or black, soft, water-soaked and rotted appearance. The cortical tissue of rotted roots sloughs leaving an exposed stele (3). Plant wilt and sudden death can result due to rotted, dysfunctional roots. Plants that do survive often appear stunted or wilted and may experience leaf drop (2). *Pythium irregulare* Buisman and *P. ultimum* Trow are common pathogens of poinsettia roots, but P. *aphanidermatum* may account for most of the Pythium root rot epidemics of poinsettia plants in commercial production (4).

Pythium root rot of poinsettia is favored by prolonged saturation or poorly drained soils (5), excessive fertilizer application (6) and pH > 5.5 (7). The disease frequently occurs in young cuttings when moisture and fertility may be above optimal ranges to increase root establishment. Along with sanitation practices to reduce disease incidence, greenhouse poinsettia production practices often include a fungicide drench at transplant with repeated applications in young plants. Standard conventional fungicides include mefenoxam (metalaxyl) and propamocarb. Mefenoxam is characterized by the Fungicide Resistance Action Comittee as a high-risk fungicide for resistance development (8). Populations of *P. aphanidermatum* causing Pythium blight in turfgrass were shown to be insensitive to mefenoxam (9) and *Pythium* spp. with dual propamocarb and mefenoxam insensitivity were isolated from poinsettia roots (10). Resistance management is a vital component of greenhouse production of floriculture crops when pathogens such as *Pythium* spp. are the target fungi. A key component of resistance management is integrating non-conventional fungicides through rotations and/or tank-mixes into a disease management program. This study was designed to identify alternative, non-conventional fungicides (phosphonate, biological) that provide a reduction in Pythium root rot severity compared to untreated *Pythium*-inoculated poinsettia plants.

MATERIALS AND METHODS

Two greenhouse evaluations were conducted in 2010. 'Prestige Red' poinsettia rooted cuttings were transplanted to 6-inch azalea pots. Greenhouse temperatures ranged from 105 ^{o}F to 70 ^{o}F (day/night). An 80% shade cloth covered the plants on a 10:00 am to 4:00 pm daily schedule. Preventive treatments of non-conventional fungicides, including biofungicide and phosphonate applications (Table 1) were initiated four days prior to the inoculation with *P. aphanidermatum*. A conventional fungicide, considered an industry standard, was also included for efficacy comparison (Table 1). Both evaluations were arranged in a randomized complete block design with 10 replicates and 8 replicates per treatment in evaluation I and II, respectively. Poinsettia management practices were employed and included daily fertigation with Peter's Excel 15-5-15 CalMag (15N-2P-12K; J.R. Peters, Inc., Allentown, PA) at 0.33 oz N/gal to maintain adequate fertility and soil moisture.

Table 1. Non-conventional fungicide, active ingredients, application rates, timing, and methods for control of Pythium root rot in Prestige Red poinsettia plants.

Treatment and Rate/100 gal (per stated unit)	Active Ingredient	Application Timing^{z}/Method
RootShield Plus® 12.0 oz	*Trichoderma harzianum* strain T-22; *T. virens* strain G-41	1 app prior to Pythium inoculation / soil drench
RootShield Plus® 8.0 oz	*Trichoderma harzianum* strain T-22; *T. virens* strain G-41	1 app prior to Pythium inoculation / soil drench
RootShield® 4.0 oz	*T. harzianum* strain T-22	1 app prior to Pythium inoculation / soil drench
RootMate® 4.0 oz	*T. virens* strain G-41	1 app prior to Pythium inoculation / soil drench
Subdue MAXX® EC 1.0 fl oz (conventional)	mefenoxam	1 app prior to Pythium inoculation / soil drench
Magellan® drench 12.0 fl oz	mono- and dibasic sodium, potassium and ammonium phosphites	1 app prior to Pythium inoculation; 14 d / soil drench
Magellan® foliar 4.0 pt	mono- and dibasic sodium, potassium and ammonium phosphites (Phosphites)	1 app prior to Pythium inoculation; 14 d / foliar
Aliette® WDG 9.6 oz	aluminum tris	1 app prior to Pythium inoculation; 30 d / soil drench
RootShield Plus® 8.0 oz *fb*^{y} RootMate® 4.0 oz	*Trichoderma harzianum* strain T-22; *T. virens* strain G-41 fb *T. virens* strain G-41	1st app prior to Pythium inoculation *fb* 1 app 1 (WAT^{x}) / soil drench
RootShield Plus® 12.0 oz *fb* RootMate® 4.0 oz	*Trichoderma harzianum* strain T-22; *T. virens* strain G-41 fb *T. virens* strain G-41	1st app prior to Pythium inoculation *fb* 1 app 1 (WAT) / soil drench
RootShield Plus® 8.0 oz *fb* Magellan® 6.0 fl oz	*Trichoderma harzianum* strain T-22; *T. virens* strain G-41 fb (Phosphites)	1st app prior to Pythium inoculation *fb* 1 app 6 (WAT)

		/ soil drench
RootShield Plus® 8.0 oz *plus* Subdue Maxx® EC 0.5 fl oz	*Trichoderma harzianum* strain T-22; *T. virens* strain G-41 plus mefenoxam	1 app prior to Pythium inoculation / soil drench
Untreated *Pythium*-inoculated 0.02 oz infested rice / pot	*Pythium aphanidermatum*-infested rice[w]	4-d post treatment
Untreated uninoculated 0.02 oz sterile rice	sterile rice	4-d post treatment

[z] Initial treatments applied four days prior to inoculating plants with *Pythium*-infested rice.

[y] *fb* indicates followed by, pertaining to the order of treatment application.

[x] WAT = week after treatment.

[w] *Pythium aphanidermatum*-infested rice was prepared by macerating a four-day-old colony growing on potato dextrose agar in 8.45 fl oz sterile distilled water, poured over sterile rice and incubated in the dark at 82 °F for three days.

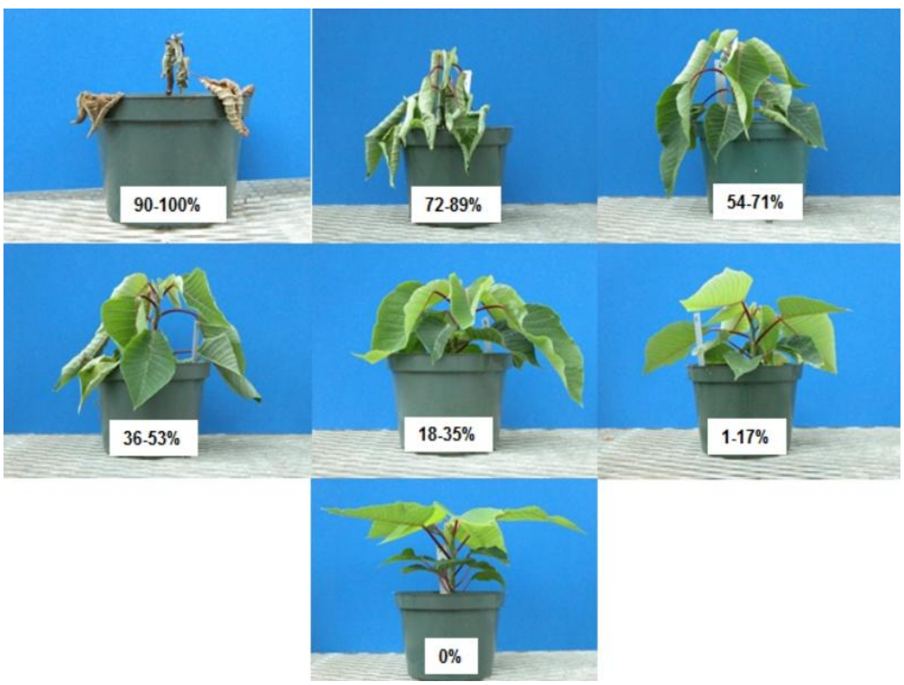

Fig. 1. Disease severity of Prestige Red poinsettia plants based on percentage of plant wilt post inoculation with *Pythium aphanidermatum*.

Assessments including disease severity were made for both evaluations weekly and based on percent plant wilt post inoculation with *P. aphanidermatum* (Fig. 1). At the end of each evaluation the cumulative disease severity for each poinsettia treatment was calculated using Campbell and Madden's (11) area under the disease progress curve (AUDPC) estimated as $\sum_i^{n-1}(y_i + y_{i+1} / 2)(t_{i+1} - t_i)$ where y is disease severity, n is the number of weekly assessments, and ($t_n - t_i$) is the total duration time. Plant growth index (shoot height from bench-top, width (widest point) and perpendicular width divided by 3) was determined 42 days after inoculation (DAI) at which time *Pythium*-inoculated plants were dead. Each evaluation was terminated with destructive sampling for shoot dry weight (154 ^{o}F for 72 hours) and a visual root vigor rating (1 to 7; 1 = dead root system, 7 = unaffected root system) for plants. Analysis of variance using the GLM procedure of SAS (Ver. 9.2, SAS Institute Inc., Cary, NC) was used to evaluate non-conventional fungicide effects on disease severity and poinsettia growth and development. Disease severity is presented as percentage of severity (Fig. 1) following arcsine square-root transformation. Mean separation was based on Fisher's protected least significant difference test at $P \leq 0.05$. Treatment means were also compared to the untreated *Pythium*-inoculated poinsettias using Dunnett's test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Poinsettia plants treated with Magellan® (NuFarm Americas, Inc. Research Triangle Park, NC) drench and Aliette® (Bayer Environmental Science, Research Triangle Park, NC) had a significant reduction ($P \leq 0.05$) in disease severity in Evaluation I. The untreated *Pythium*-inoculated plants were dead resulting in 72% greater disease severity than Aliette. Magellan® drench at 42 DAI. The Aliette® treatment also controlled Pythium root rot as effectively as Subdue MAXX® (Syngenta Professional Products, Greensboro, NC) when disease severity and AUDPC were considered (Table 2). The plant growth index of Magellen® drench and Aliette® treated plants was significantly greater ($P \leq 0.05$) than that of untreated *Pythium*-inoculated plants. Shoot dry weight and root vigor were also improved for plants treated with Magellan® drench (Table 2). Although plants had improved growth and development compared to no treatment, those treated with Magellan® drench or Aliette® were smaller than the untreated uninoculated plants (Table 2). Reduced plant growth or stunting is a characteristic of poinsettia plants affected by Pythium root rot (2, 6). Despite marginal stunting and reduced root vigor, plants treated with Magellan® drench and Aliette® maintained aesthetic qualities (22% and 19% disease severity, respectively) with inconspicuous leaf wilt. *Pythium*-affected roots in the phosphonate and biofungicide treatments ranged from slightly stunted and discolored to severely rotted (Table 2). Plants with severe root rot also had reduced shoot dry weight and growth index values. Disease severity and AUDPC of plants treated with biofungicides were similar to the untreated *Pythium*-inoculated plants (Table 2).

Table 2. The effect of non-conventional fungicides on Prestige Red poinsettia disease severity, area under the disease progress curve, growth index, shoot dry weight and root vigor 42 days post inoculation with *Pythium aphanidermatum*, evaluation I.

Treatment and Rate/100 gal (per stated unit)	Severity[z] (%)	AUDPC[y]	Growth Index[x]	Shoot Dry Weight[w] (g)	Root Vigor[v]
RootShield Plus® 12.0 oz	52.0	115.2	11.2	2.0	2.5
RootShield Plus® 8.0 oz	54.0	113.9	13.0	1.1	2.5
RootShield® 4.0 oz	79.0	174.3	3.9	0.5	0.9
RootMate® 4.0 oz	64.0	155.2	9.0	0.8	1.4
Subdue MAXX® EC 1.0 fl oz	19.0*[u]	17.8*	31.1*	8.2*	5.5*
Magellan® drench 12.0 fl oz	22.0*	49.3*	21.4*	3.4*	4.9*
Magellan® foliar 4.0 pt	57.0	141.5	9.4	0.9	2.0
Aliette® WDG 9.6 oz	19.0*	6.7*	19.1*	2.3	3.4
RootShield Plus® 8.0 oz *fb* RootMate® 4.0 oz	40.0	85.5	14.8	1.6	1.9
RootShield Plus® 12.0 oz *fb* RootMate® 4.0 oz	48.0	136.1	10.4	1.1	1.9
RootShield Plus® 8.0 oz *fb* Magellan® 6.0 fl oz	57.0	132.5	9.4	0.9	1.8
RootShield Plus® 8.0 oz *plus* Subdue MAXX® EC 0.5 fl oz	70.0	159.6	7.4	1.2	1.3

Untreated *Pythium*-inoculated	68.0	164.7	6.1	0.7	1.4
Untreated uninoculated	0.0*	2.8*	34.9*	9.6*	7.0*
ANOVA P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
ANOVA CV	75.58	77.43	66.67	77.96	77.43
ANOVA MSE	35.0	80.52	9.58	1.90	2.12
Fisher's LSD (α = 0.05)	31.0	71.3	8.5	1.7	1.9

[z] Visual assessment based on 0 to 100 percent wilt. Means based on 10 replications.
[y] AUDPC = the sum of disease based on weekly ratings 14 to 42 days post inoculation with *Pythium aphanidermatum*. Means based on 10 replications.
[x] Poinsettia growth index determined by the additive factors of shoot height from bench top, width of widest point, and perpendicular width divided by 3. Means based on 10 replications.
[w] Shoot dry weight determined in grams 72 hours post drying in 154 ^{o}F oven. Means based on 10 replications.
[v] Root vigor visually assessed on a scale of 1 to 7 where 1 = dead root system and 7 = unaffected root system. Means based on 10 replications.
[u] *indicates significant difference compared to the *Pythium*-inoculated control based on Dunnett's test at *P* = 0.05. Means based on 10 replications.

Table 3. The effect of non-conventional fungicides on Prestige Red poinsettia disease severity, area under the disease progress curve, growth index, shoot dry weight and root vigor 42 days post inoculation with *Pythium aphanidermatum*, evaluation II.

Treatment and Rate/100 gal	Severity[z] (%)	AUDPC[y]	Growth Index[x]	Shoot Dry Weight[w] (g)	Root Vigor[v]
RootShield Plus® 12.0 oz	35.0	174.6	23.1	7.5	5.4
RootShield Plus® 8.0 oz	18.0	106.3	27.3	6.0	3.4
RootShield® 4.0 oz	58.0	264.3	15.2	8.0	3.9
RootMate® 4.0 oz	23.0	119.7	26.8	8.2	5.8
Subdue MAXX® EC 1.0 fl oz	1.0*[u]	6.8*	39.6*	13.8*	7.0*
Magellan® drench 12.0 fl oz	38.0	174.5	22.0	7.2	4.3
Magellan® foliar 4.0 pt	58.0	298.5	12.6	3.6	2.9
Aliette® WDG 9.6 oz	32.0	152.4	23.1	5.4	4.4
RootShield Plus® 8.0 oz *fb* RootMate® 4.0 oz	72.0	303.1	14.6	1.4	2.1
RootShield Plus® 12.0 oz *fb* RootMate® 4.0 oz	55.0	234.6	18.2	6.4	4.1
RootShield Plus® 8.0 oz *fb* Magellan® 6.0 fl oz	82.0	409.9	3.6	1.7	1.3
RootShield Plus® 8.0 oz *plus* Subdue MAXX® EC 0.5 fl oz	4.0*	3.1*	44.4*	17.2*	7.0*
Untreated *Pythium*-inoculated	54.0	271.8	15.5	4.8	3.3
Untreated uninoculated	2.0*	1.0*	43.7*	17.2*	7.0*

ANOVA P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
ANOVA CV	93.1	90.2	70.3	67.9	46.7
ANOVA MSE	35.4	162.5	16.5	5.2	2.1
Fisher's LSD (α = 0.05)	35.1	161.4	16.4	5.2	2.0

[z] Visual assessment based on 0 to 100 percent wilt. Means based on 8 replications.
[y] AUDPC = the sum of disease based on weekly ratings 14 to 42 days post inoculation with *Pythium aphanidermatum*. Means based on 8 replications.
[x] Poinsettia growth index determined by the additive factors of shoot height from bench top, width of widest point, and perpendicular width divided by 3. Means based on 8 replications.
[w] Shoot dry weight determined in grams 72 hours post drying in 154 ^{o}F oven. Means based on 8 replications.
[v] Root vigor visually assessed on a scale of 1 to 7 where 1 = dead root system and 7 = unaffected root system. Means based on 8 replications.
[u] * indicates significant difference compared to the *Pythium*-inoculated control based on Dunnett's test at P = 0.05.

Poinsettia plants treated with the RootShield® Plus[+] (BioWorks, Inc. Victor, NY)/Subdue MAXX® tank mix and Subdue MAXX® alone out-performed ($P \leq 0.05$) the untreated *Pythium*-inoculated plants in evaluation II. Disease severity was up to 98% greater in the untreated *Pythium*-inoculated plants resulting in the AUDPC being 91 times greater than the RootShield Plus®/Subdue MAXX® tank mix. Plants treated with RootShield Plus®/Subdue MAXX® tank mix or Subdue MAXX® alone had low disease severity (<4.0%) as well as AUDPC and were similar to the untreated uninoculated plants (Table 3). Plants treated with RootShield Plus®/Subdue MAXX® tank mix or Subdue MAXX® had robust growth indices resulting in high shoot dry weight and root vigor values (Table 3). The phosphonates and other biofungicides did not provide adequate control for acceptable poinsettia growth and development over the 42 day evaluation (Table 3).

CONCLUSIONS

Pythium root rot of poinsettia was controlled in an acceptable manner when treated with preventive applications of Magellan® drench, Aliette®, or RootShield Plus®/Subdue MAXX® tank mix. The non-conventional fungicides provide additional resources for Pythium root rot control in a poinsettia production setting. The use of non-conventional fungicides for poinsettia disease management may be beneficial tools for resistance management and increased longevity of highly effective conventional fungicides such as Subdue MAXX®. The RootShield Plus®/Subdue MAXX® tank mix contained a reduced rate of a conventional standard fungicide while providing excellent disease control.

Product efficacy of phosphonates and biofungicides for control of Pythium root rot was inconsistent in the evaluations. This type of observation has also been made by growers at industry meetings and reported in efficacy trials (12,13). This study demonstrated the potential control of Pythium root rot using non-conventional fungicides that may become more practical for growers as continued research efforts focus on improved application timing, application intervals, and tank mix/rotation protocols.

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Assessment Of The Quality Of Water Collected From The Surface Waters Of Houston And Galveston, Texas One Year After Hurricane Gustav And Hurricane Ike

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ABSTRACT

Good water quality in a watershed is a function of physical, chemical, and biological properties which can sustain all uses. It is critical for sustenance of life. Human activities can definitely affect water quality in watersheds. Also, hurricanes are one of the ecological and natural phenomena that can affect water quality. The purpose of this study was to determine the extent to which surface waters from Galveston and Houston, Texas were polluted one year after Hurricane Gustav and Hurricane Ike, and to find out if the bodies of water met the Mississippi Water Quality Criteria (MSWQC)/EPA standards. We also compared the distribution of pollutants in the different bodies of water. During the months of July and September 2009, water samples were collected at three different sites from a water body at a location 5 miles north of Galveston In September, 2009, water samples were also collected from three different sites along the Buffalo Bayou of Houston in the vicinity of the University of Houston, Texas. The water samples were taken to the Alcorn State University (ASU) Laboratory and tested according to the directions of the manufacturers of LaMotte pollution test kits. The chemical parameters tested namely, alkalinity, ammonia-nitrogen, carbon dioxide, chlorine, dissolved oxygen, water hardness, nitrate, phosphate, sulfate, and sulfide were recorded in parts per million (ppm). The results were recorded, analyzed, and compared with the Mississippi Water Quality Criteria (MSWQC)/EPA standards. Based on the results, the water samples from Galveston and Houston met the Mississippi Water Quality Criteria (MSWQC)/EPA standard with the exception of carbon dioxide, water hardness, and phosphate. There were some variations in contaminant concentration readings between water samples from Galveston and Houston.

INTRODUCTION

Good water quality in a watershed is a function of good physical, chemical, and biological properties which can sustain all uses. It is critical for maintenance of life. Human activities can definitely affect water quality in watersheds. Also, hurricane is one of the ecological and natural phenomena that can affect water quality. We depend on surface and groundwater for our drinking water. We also need water to generate energy, to grow our crops, to harvest fish, to run machinery, and to carry wastes. We use water for washing and cleaning, industrial abstraction, recreation, cooking, gardening and angling. It is a habitat for a variety of plants and animals. (Gwynedd Council, 2004). Freshwater is also vital as a habitat for fish, invertebrates such as mayflies, shrimps and snails and also many water plants. Human activities can pollute rivers. Industries, housing, agriculture, horticulture, transport and discharges from the many disused mines can all affect water quality (loc. cit.). Pollution may arise as point sources, such as discharges through pipes which may be easily identifiable, or may be more dispersed over a wider area, known as non-point source.

Non-point source can arise from many sources and although individually the sources may be small, their collective impact can be damaging. Diffuse pollution can be derived from current and past land use in both agricultural and urban environments as well as *storms.* Surface waters are affected by rainfall that washes over and off the land (run-off), and storms. Diffuse pollution may result from release of a variety of substances in many different situations including hurricanes.

Hurricane Gustav made landfall along the Louisiana coast and parts of Texas on September 1, 2008 (Figure 1). The *storm* was the seventh tropical cyclone and second major hurricane of the 2008 Atlantic Hurricane season. Gustav caused serious damage and casualties in Haiti, the Dominican Republic, Jamaica, the Cayman Islands, and Cuba and in the United States including Houston and Galveston. Before making landfall in the US, Gustav caused severe destruction and casualties throughout the Caribbean, and Cuba. As of September 5, 153 deaths had been attributed to Gustav in the U.S. and Caribbean, and damage was predicted at 22 billion dollars. (http//en.wikipedia.org/wiki/Hurricane _ Gustav).

Figure 1. Hurricane Gustav just after U.S. landfall (Wikipedia Encylopedia)

Hurricane Ike was the ninth named *storm* of the season and fifth hurricane of the 2008 Atlantic hurricane season. It made U.S. landfall at Galveston, Texas on September 13 (Figure 2). Hurricane force winds extended for more than 275 miles from the center of the eye of the storm. The storm battered the coastal areas of Texas with heavy winds, rains and a storm surge of as much as 13 feet of water. At least three million people lost power after heavy winds and rains knocked down power lines (CNN, 2008). In Houston, glass windows shattered as the winds tore through the metropolitan area with greater speeds around skyscrapers than at ground level. So areas flooded from Gustav were flooded once again from Ike. (Guardian Unlimited, 2008).

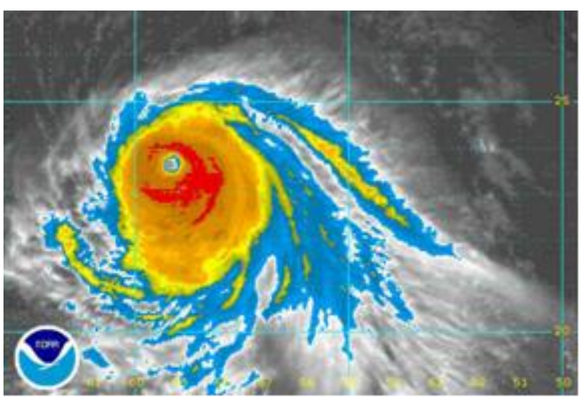

Figure 2. The appearance of Hurriance Ike (the Ultimate Chase

Acholonu and Jenkins (2007) reported on the water quality of freshwater bodies in New Orleans, Louisiana one year after Hurricane Katrina and concluded, among other things, that the three water bodies investigated, did not completely meet the Mississippi Water Quality Criteria (MSWQC)/EPA Standard. The present study was conducted during two field trips to Houston and Galveston with K-12 teachers from schools in the Alcorn State University (ASU) environs and Ecology Club members of ASU respectively to observe the damages caused by Hurricane Gustav and Hurricane Ike (Figs 3-8).

Figure 3. Above shows Leonard H.O. Spearman Technology Building and below, a girls dormitory at TSU damaged by Hurricane Gustav.

Figure 4. Above damaged Galveston Beach wall, below buildings damaged by hurricane Ike in Galveston, TX.

Figure 5. Damaged and abandoned buildings in Galveston, TX.

Figure 6. TSU science building damaged by Hurricane Gustav (above). Participants in the workshop/research field trip (below) (left to right) Consultants Dr. Osueke (TSU), Dr. Sapp (TSU), Dr. Acholonu (ASU), and Dr. Humphreys (TSU)

Figure 7. Church building under reconstruction in Galveston after Hurricane Ike (above) Field trip participants and consultants at TSU.

Figure 8. Field trip particpatants carrying collected water samples back to ASCU from Galeston, TX.

The purpose of this study was to determine the extent to which surface waters from Houston and Galveston, Texas were polluted one year after Hurricane Gustav and Hurricane Ike, and to find out if the bodies of water met the Mississippi Water Quality Criteria (MSWQC)/EPA Standard. It was also to compare the distribution of pollutants in the different bodies of water.

MATERIAL AND METHODS

Collection Sites

Galveston, Texas

Water samples were collected with two plastic water bottles from each of three sites about 50 meters apart at a location 5 miles north to Galveston on July 24, 2009. A second collection was made on September 24, 2009 (Figure 9).

Figure 9. Map of Texas showing Houston (left) and Galveston (right) (pubs.usgs.gov/fs/fs-110-02/images/fig1.htm)

Houston, Texas

Water samples were collected with two plastic water bottles from each of three sites about 50 meters apart from the Buffalo Bayou of Houston in the vicinity of the University of Houston on September 24, 2009(Figure 9).

Procedure

All water samples were taken to the Alcorn State University Laboratory and tested according to the directions of the manufacturers of LaMotte pollution test kits and essentially, the methods of Acholonu and Jenkins (2007). Ten chemical parameters were tested and recorded in parts per million (ppm) namely, alkalinity, ammonia-nitrogen, carbon dioxide, chlorine, dissolved oxygen, water hardness, nitrate, phosphate, sulfate, and sulfide and the results were analyzed.

RESULTS

All water samples collected from a location 5 miles north of Galveston and Buffalo Bayou near the University of Houston were tested for possible pollutants/contaminants. Based on the results, the water samples from Galveston and Houston met the Mississippi Water Quality Criteria (MSWQC)/EPA Standard with the exception of carbon dioxide, water hardness, and phosphate (Table 1 and Figure 10). There were some variations in contaminant concentration readings between water samples from Galveston and Houston. (Table 1 and Fig. 10).

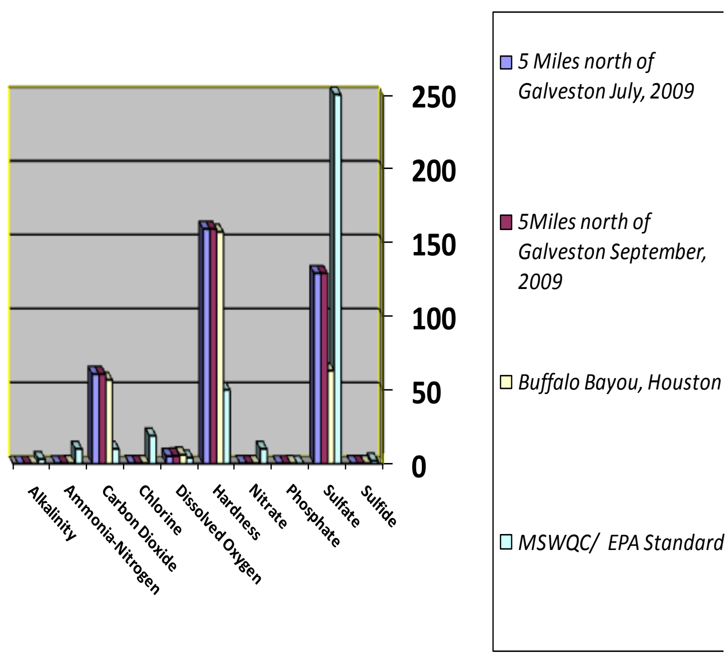

Figure 10. Distribution of Pollutants in Surface Waters from Galveston and Houston, Texas

Table 1. CHEMICAL PROFILE OF SURFACE WATERS FROM HOUSTON AND GALVESTON, TEXAS (Average Readings)

Parameters Tested	Water Sample Collected 5 Miles north of Galveston July 2009	Water Sample Collected 5 Miles north of Galveston September 2009	Water Sample Collected from Buffalo Bayou Houston September 2009	MSWQC/ EPA Standard
Alkalinity	0ppm	0ppm	0ppm	3.06/.02
Ammonia-Nitrogen	0.2ppm	0.23ppm	0.3ppm	10
Carbon Dioxide *	61.0ppm	61.0ppm	53.0ppm	10
Chlorine	0.3ppm	0.3ppm	0.3ppm	19/11
Dissolved Oxygen	5.1ppm	5.4ppm	6.1ppm	4(min)
Water hardness*	159ppm	159ppm	156ppm	50
Nitrate	0.3ppm	0.3ppm	0.3ppm	10.0
Phosphate*	0.23ppm	0.23ppm	0.3ppm	0.1
Sulfate	129ppm	129ppm	63.3ppm	250
Sulfide	0.33ppm	0.33ppm	0.3ppm	2

*= Parameters that exceeded the MSWQC/EPA Standard

DISCUSSION

This study showed that the surface waters were polluted but not as much as expected. Only three out of ten parameters tested exceeded the Mississippi Water Quality Criteria (MSWQC)/EPA Standard, namely: carbon dioxide(61.0ppm/10, 61.0ppm/10, 53.0ppm/10), water hardness(159ppm/50, 159ppm/50, 157ppm/50,) and phosphate(0.23ppm/0.1, 0.23ppm/0.1, 0.3ppm/0.1) (Table 4). Interestingly, the concentration of these contaminants exceeded acceptable levels in all water samples tested from both locations.

The distribution of pollutants in the different bodies of waters was wide or fairly considerable. With the exception of alkalinity, all of the parameters tested were found in each of the water bodies (Tables 1,2,3,4). A comparison of the readings of the present study with Hurricane Katrina recordings (Acholonu and Jenkins 2007) shows that less parameters exceeded the Mississippi Water Quality Criteria (MSWQC)/EPA Standard then in the Hurricane Katrina. Over 50% of the test results exceeded the Mississippi Water Quality Criteria (MSWQC)/EPA Standard while in this study only 30% (3 of 10) did. That is, the water bodies were less contaminated in Houston and Galveston one year after Hurricane Gustav and Hurricane Ike than water bodies in New Orleans, LA one year after Hurricane Katrina. It is however recommend that periodic assessments be made on these water bodies to know whether the pollutants are increasing beyond the norm or remaining stable. Water is the driver of nature and needs to be tested often (Smith and Smith 2001).

Table 2. Water Samples Collected 5 Miles north of Galveston July, 2009.Distribution of Pollutants

Parameters Tested	Site 1	Site 2	Site 3	Average	MSWQC/ EPA Standard
Alkalinity	0ppm	0ppm	0ppm	0	3.06/.02
Ammonia-Nitrogen	0.2ppm	0.2ppm	0.3ppm	0.23	10
Carbon Dioxide*	60ppm	62ppm	60ppm	61.0	10
Chlorine	0.3ppm	0.3ppm	0.2ppm	0.3	19/11
Dissolved Oxygen	7.2ppm	3.4ppm	4.6ppm	5.1	4(min)
Water Hardness *	157ppm	162ppm	158ppm	159	50
Nitrate	0.3ppm	0.3ppm	0.3ppm	0.3	10.0
Phosphate*	0.3ppm	0.2ppm	0.2ppm	0.23	0.1
Sulfate	98ppm	97ppm	192ppm	129	250

Sulfide	0.3ppm	0.4ppm	0.3ppm	0.33	2

Table 3. Water Samples Collected 5 Miles north of Galveston September, 2009. Distribution of Pollutants

Parameters Tested	Site 1	Site 2	Site 3	Average	MSWQC/ EPA Standard
Alkalinity	0ppm	0ppm	0ppm	0.0	3.06/.02
Ammonia-Nitrogen	0.2ppm	0.2ppm	0.3ppm	0.23	10
Carbon Dioxide*	60ppm	62ppm	60ppm	61.0	10
Chlorine	0.3ppm	0.3ppm	0.2ppm	0.3	19/11
Dissolved Oxygen	5.6ppm	7.2ppm	3.4ppm	5.4	4(min)
Water Hardness*	157ppm	162ppm	158ppm	159	50
Nitrate	0.3ppm	0.3ppm	0.3ppm	0.3	10.0
Phosphate*	0.3ppm	0.2ppm	0.2ppm	0.23	0.1
Sulfate	98ppm	97ppm	192ppm	129	250
Sulfide	0.3ppm	0.4ppm	0.3ppm	0.33	2

*= Parameters that exceeded the MSWQC/EPA Standard

Table 4. Water Sample Collected from Buffalo Bayou, Houston, September, 2009.
Distribution of Pollutants

Parameters Tested	Site 1	Site 2	Site 3	Average	MSWQC/ EPA Standard
Alkalinity	0ppm	0ppm	0ppm	0	3.06/.02
Ammonia-Nitrogen	0.3ppm	0.2ppm	0.3ppm	0.3	10
Carbon Dioxide*	50ppm	60ppm	60ppm	53.0	10
Chlorine	0.3ppm	0.3ppm	0.2ppm	0.3	19/11
Dissolved Oxygen	5ppm	7ppm	6.2ppm	6.1	4 (min)
Water Hardness*	152ppm	158ppm	160ppm	156	50
Nitrate	0.3ppm	0.3ppm	0.3ppm	0.3	10.0
Phosphate*	0.3ppm	0.2ppm	0.3ppm	0.3	0.1
Sulfate	60ppm	70ppm	60ppm	63.3(63)	250
Sulfide	0.4ppm	0.2ppm	0.3ppm	0.3	2

*= Parameters that exceeded the MSWQC/EPA Standard

A comparison between the July and September 2009 readings of the Galveston water samples showed that both had practically equal readings. So, little or no variation occurred. But a comparison between Galveston sample readings and the Houston ones showed that both had a 0 ppm for alkalinity. Carbon dioxide concentration was slightly more in Galveston than in Houston (60.7/56.7). Dissolved oxygen (DO) was more in Houston samples than in Galveston ones and sulfate concentration was more in Galveston than in Houston (Table 1, Fig 10).

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Oil Spill and Sea Surface Effects Over Gulf of Mexico Using Environmental Modeling and Satellite Data

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ABSTRACT

The Deep Horizon oil rig explosion on April 20, 2010 52 miles southeast of Venice, Louisiana, USA has caused fears that an oil slick can become catastrophic and drastically influence the environment and ecology of the Gulf of Mexico region. In the present study, we investigate the Gulf of Mexico oil spill effects on the environmental changes in the atmospheric circulations using Weather Research Forecast (WRF) model simulations in combination with the observed satellite derived data over the Gulf such as sea surface temperature (SST), and tropical cyclone heat potential (TCHP). The WRF model simulations were carried out for the period June 1- 3, 2010 about a month after the accident that falls into the onset of hurricane season. The model simulations captured the observed increase in SST, and showed westerly wind patterns of a high pressure system similar to the wind reversal circulations due to El Niño conditions. The observations and model simulations show that the large scale oil slick has affected the weather patterns associated with the loop current and eddies over the Gulf leading to an increase in both SST and TCHP. Though the conditions over the Gulf are favorable for an increased tropical storm/cyclone frequency and strength, not many appear to be taking place particularly major hurricanes along the US Gulf Coast. In the absence of any other major factors responsible for affecting the Gulf, the onset of a high pressure system in the region may be attributed to the changes in wind patterns.

Keywords: Oil Slick**,** weather modeling, loop current, atmospheric circulations, sea surface temperature, tropical cyclone heat potential, tropical cyclone/hurricane, wind shear, El Niño

INTRODUCTION

The Deepwater Horizon oil rig accident occurred on April 20, 2010 52 miles southeast of Venice, Louisiana, over the Gulf of Mexico. Soon after the accident, the exploded rig began discharging oil at the rate of 35,000 to 60,000 barrels per day. Scientists and engineers quickly responded to the incident and geared up efforts to control and contain the flow of the oil spilling from the ill fated oil rig. Initially, the rig was spewing out oil at a staggering rate of at least 5000 barrels/day, and in over a month more than 3.5 million gallons of oil had been poured out, spreading thousands of miles of oil slick over the Gulf of Mexico. It is estimated that in three months a staggering 200 million gallons of oil has been poured into the Gulf due to the oil spill. To monitor the update of oil spill in the Gulf, government officials have opened the Deepwater Horizon web site in addition to other websites of national agencies , universities and private (NASA, 2010; NOAA Office of Response, 2010; Gulf of Mexico Oil Spill Response, 2010; Louisiana Serve Commission, 2010; University of South Florida, 2010). Of particular concern with the Gulf of Mexico oil spill was that it could get entrained into the loop current and be carried away into the Atlantic Ocean rather than being contained for removal. The dynamics of an oil spill on the sea surface is governed predominantly by ocean currents and wind, in addition to weathering. The warm Caribbean water enters the Yucatan Straits and exits into the Florida Straits in a clockwise flow extending northward to the Gulf Coast forming the Loop Current (Hoffman et. al, 1986). The dynamics of the loop current are variable and complex, and during its cycle eddies (anticyclonic and cyclonic) are spun off from the Loop Current. The location of the oil spill as of May 14, 2010 and overlay of the spill region with the ocean loop currents are shown in Figure 1 (National Geographic News, 2010., FGBNMS, 2012). In response to the disaster, researchers have geared up to meet the challenge and several research investigations have been undertaken to study and understand the influence of the oil spill on the environment and ecosystem.

Figure 1. Satellite observations of oil slick region overlaid over the Gulf of Mexico corresponding to its location on May 18, 2010. The block shows the region of Gulf coast surrounding the oil slick (National Geography News May 18, 2010; the satellite image courtesy MODIS/NASA; diagram courtesy FGBNMS/NOAA available FGBNMS. (2012). FLOWER GARDEN BANKS NATIONAL MARINE SANCTUARY FINAL MANAGEMENT PLAN, page 17, http://flowergarden.noaa.gov/document_library/mgmtdocs/fmp2012/fmp2012lores.pdf)

The mechanism of oil spreading by deepwater spills is complex and not as well known as those from tanker spills of known amount occurring at the surface. US Department of Commerce in association with other national agencies has made available a selected bibliography on the resources on oil spills, response and restoration and gives an overview of the various aspects by the disaster (Fiolek et al, 2010).

By the first week of June, 2010 the oil slick started becoming massive and wide spread off the Gulf Coast (Figure 1). Additionally, considerable effects in the environment became apparent, such as changes in SST and atmospheric circulations. Incidentally, the occurrence of the oil slick in the region coincides with the onset of hurricane season over Atlantic Ocean.

Decision makers, emergency response managers, and scientists use NOAA satellite derived data and the related products to determine the flow of the ocean surface water and in identifying and tracking ocean circulation features (AOML, 2010). These satellite derived ocean measurements - Sea Surface Temperature, Tropical Cyclone Heat Potential, Sea Height Anomaly, and Isotherm depth are produced for each of the seven ocean basins. The satellite derived ocean data are being used to understand the importance of ocean related processes - Higher values of sea level are associated with the ocean circulation features such as Loop Current and warm eddies, while lower values are associated to colder features. Several studies are also being carried out to investigate the link between these data and the atmospheric processes such as growth or intensification of tropical disturbances over the ocean (Goni et al, 2009., Shay et al, 2000., Goni et al 2003).

The Advanced Research Weather Research and Forecasting (ARW) Model or simply called as WRF model is a commonly used environmental numerical modeling in the research community suited for a wide range of applications, from simulating meteorological fields to operational forecasting. The WRF model is based on fully compressible non-hydrostatic equations and the prognostic variables include the three dimensional wind, perturbation quantities of potential temperature, geo-potential, surface pressure, turbulent kinetic energy and scalars such as water vapor mixing ratio, cloud water. The details of Advanced Research WRF (ARW) model are described by Skamarock et al (Skamarock, 2008) and also available for the users at the UCAR public domain website (UCAR, 2010). The WRF model is a regional scale model that has a resolution in the range 10 km to 100 km and is successfully used to capture atmospheric circulations and forecast hurricanes. Significant use of WRF model is being explored by research community in a number of areas, such as convection-resolving Numerical Weather Prediction, hurricane forecasting, regional climate studies, and air chemistry/quality research (Tuluri et al, 2010., Yerrammilli et al, 2012., Davis et al, 2008).

The observed impacts of the spill on SST and atmospheric circulation, together with the critical timing of the event with the hurricane season motivated us to consider the first week of June, 2010 as a period of study for weather model simulations. The research is directed to investigate the environmental effects due to the oil slick. In the present study, we use Weather Research Forecast (WRF) model output and satellite data over the Gulf of Mexico to examine the oil spill effects on the changes in SST and weather patterns, and their consequences on the tropical disturbances in the region.

Materials and Methods

Observations and Data

The Deepwater Horizon Response and other national agencies covered the time series of the oil spill accident using satellite imagery by Moderate Imaging Spectroradiometer (MODIS) instrument on satellites Terra and Aqua, Advanced Synthetic Aperture Radar (ASAR) on ENVISAT. The observed sea surface temperatures and tropical cyclone heat potential are taken from the NOAA source (NOAA Satellite Information Service, 2010; AOML, 2010) and shown in Figures 2 - 13 respectively, for some selected periods in the months of April and May of 2009, 2010, and 2011.

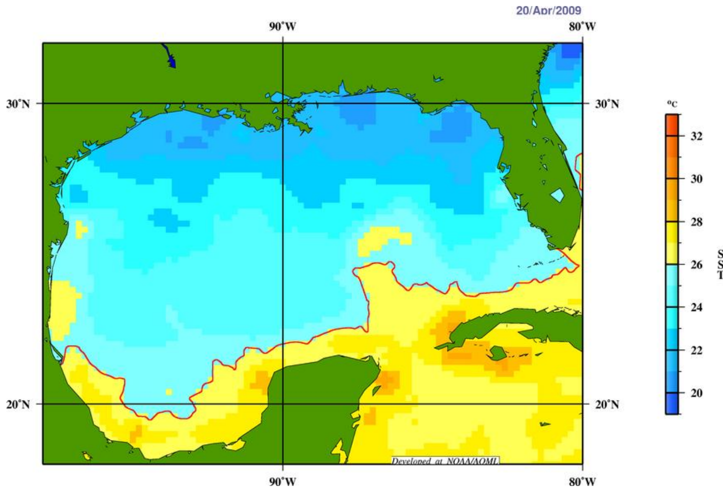


Figure 2: Gulf of Mexico: Satellite charts of SSTs on April 20, 2009 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

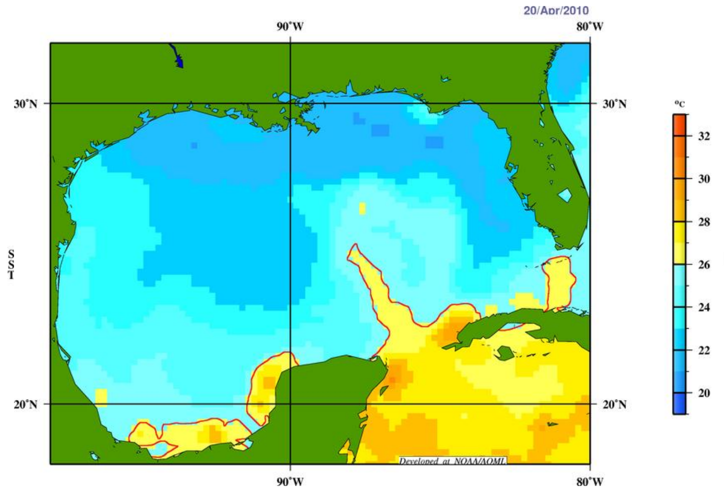


Figure 3: Gulf of Mexico: Satellite charts of SSTs on April 20, 2010 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.htm

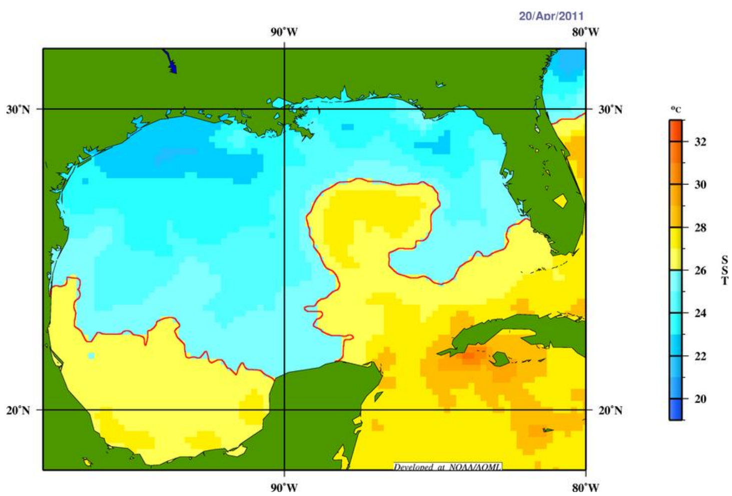


Figure 4: Gulf of Mexico: Satellite charts of SSTs on April 20, 2011 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

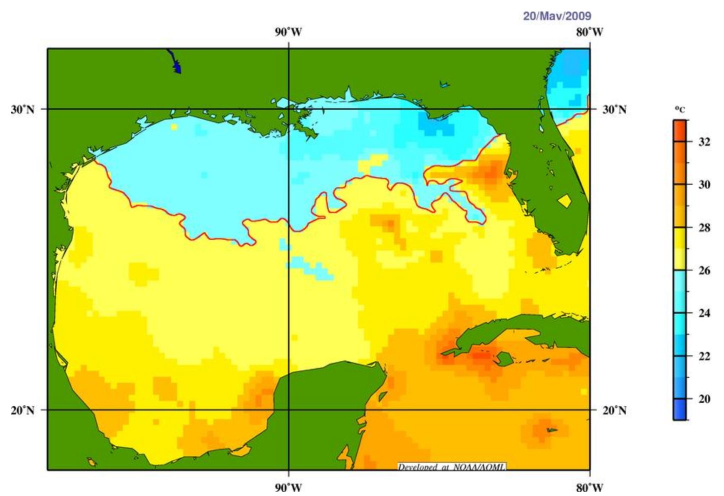


Figure 5: Gulf of Mexico: Satellite charts of SSTs on May 20, 2009 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

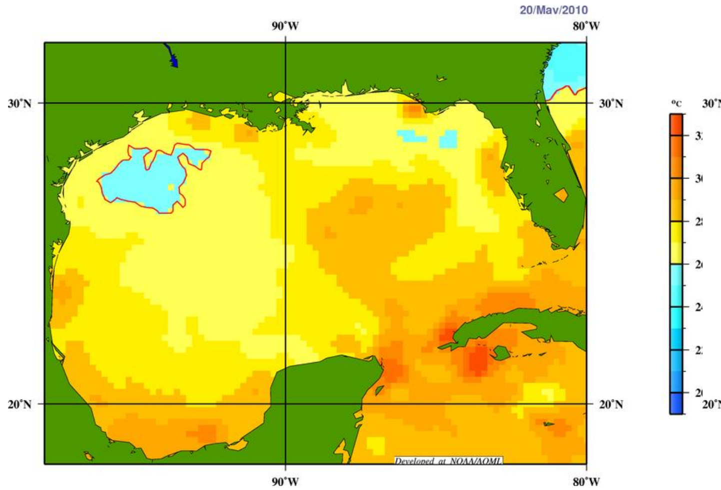


Figure 6: Gulf of Mexico: Satellite charts of SSTs on May 20, 2010 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

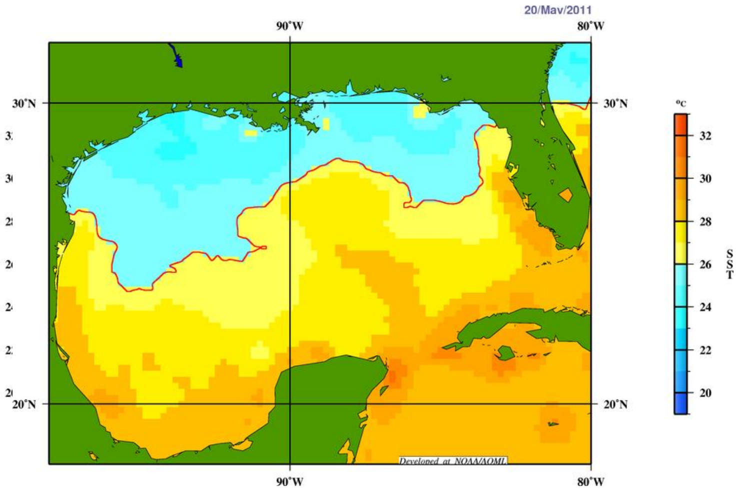


Figure 7: Gulf of Mexico: Satellite charts of SSTs on May 20, 2011 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

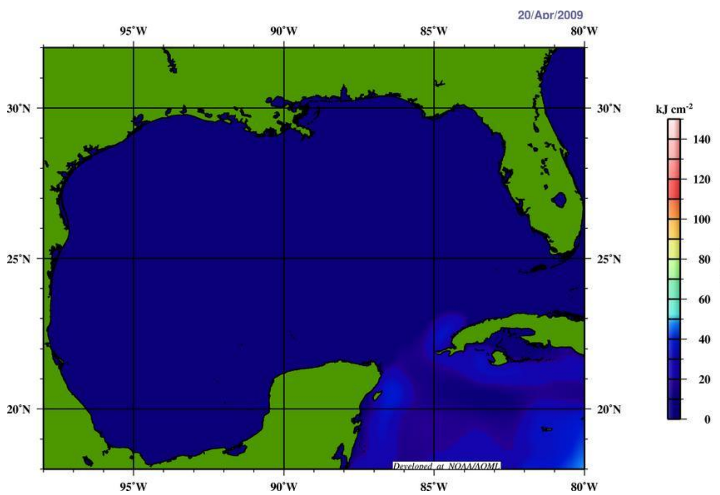


Figure 8: Gulf of Mexico: Satellite charts of Tropical Cyclone Heat Potentials on April 20, 2009 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

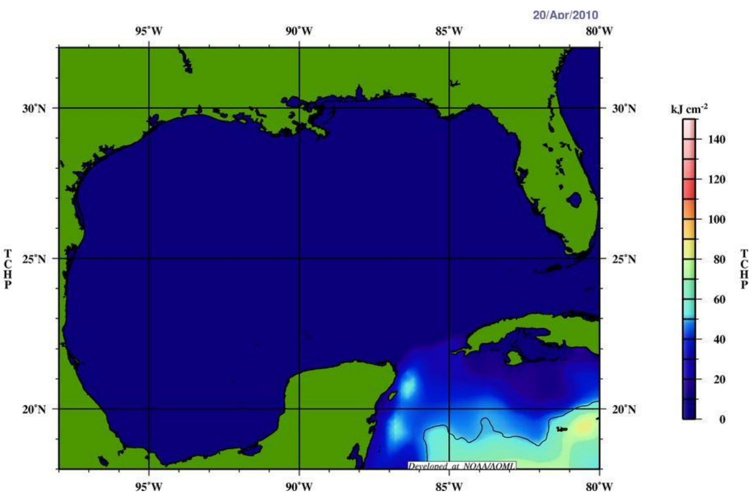


Figure 9: Gulf of Mexico: Satellite charts of Tropical Cyclone Heat Potentials on April 20, 2010 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

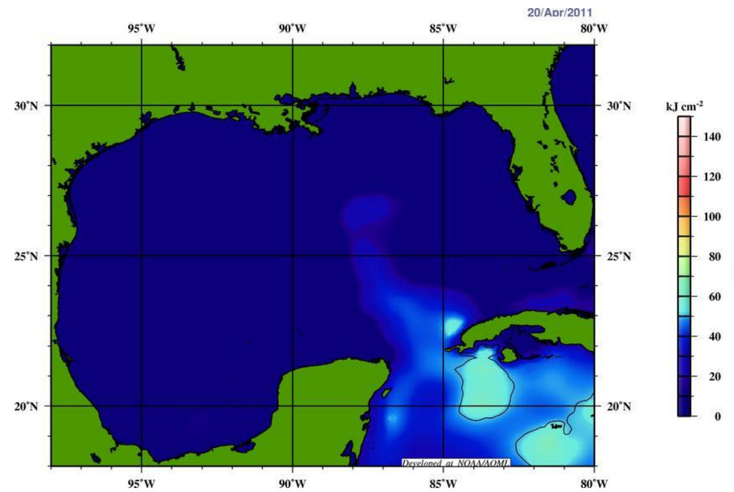


Figure 10: Gulf of Mexico: Satellite charts of Tropical Cyclone Heat Potentials on April 20, 2011 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

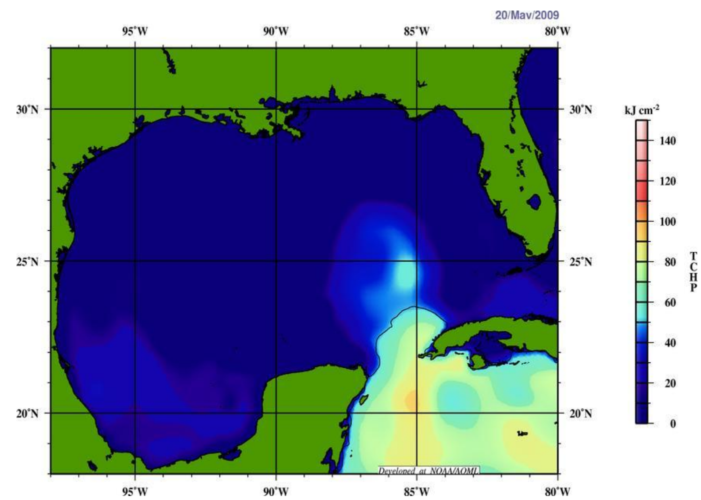


Figure 11: Gulf of Mexico: Satellite charts of Tropical Cyclone Heat Potentials on May 20, 2009 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

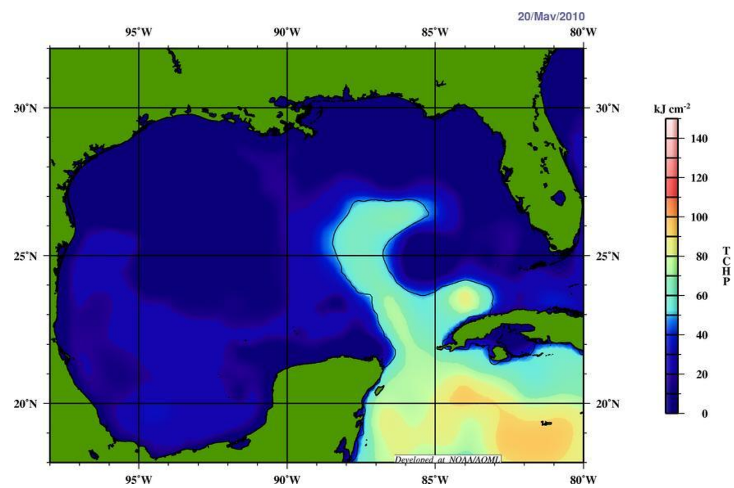


Figure 12: Gulf of Mexico: Satellite charts of Tropical Cyclone Heat Potentials on May 20, 2010 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

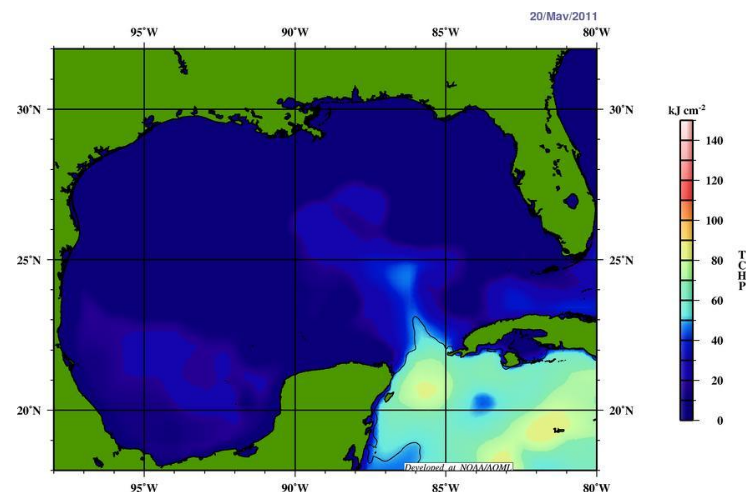


Figure 13: Gulf of Mexico: Satellite charts of Tropical Cyclone Heat Potentials on May 20, 2011 of AOML, Atlantic Oceanographic and Meteorological Laboratory, 2010. Available from http://www.aoml.noaa.gov/phod/cyclone/data/go.html

The satellite imagery consists of Gulf of Mexico basin generated contour maps of SST, TCHP, SHA, and depths of 26^0C Isotherms. Sea surface temperature (SST) maps provides a measure of the surface ocean conditions, the tropical cyclone heat potential (TCHP) maps the integrated vertical temperature from the sea surface to the depth of the 26°C isotherm, Sea height anomaly maps shows the difference of sea level from average conditions, while sea height maps shows absolute values of the sea level. The SSTs data is also available from many buoy stations over the Gulf of Mexico (National Data Buoy Centre, NOAA, 2010), and the buoy station 42040 located about 64 nautical miles south of Dauphin Island, Alabama, is closest to the most persistent area of the oil slick. Based on this buoy data the time series of SSTs and dew points during the summer period of May 01 – June 15, 2010 are given elsewhere and are shown in Figure 14 (Spencer, 2010). The observed regional temperature contours are shown in Figure 15 for a selected record in June, 2010 (NOAA Satellite Information Service, 2010). The satellite generated climatology of SSTs in the month of April, May, and June over Gulf of Mexico (NODC, 2012) is given in Figures 16 – 18.

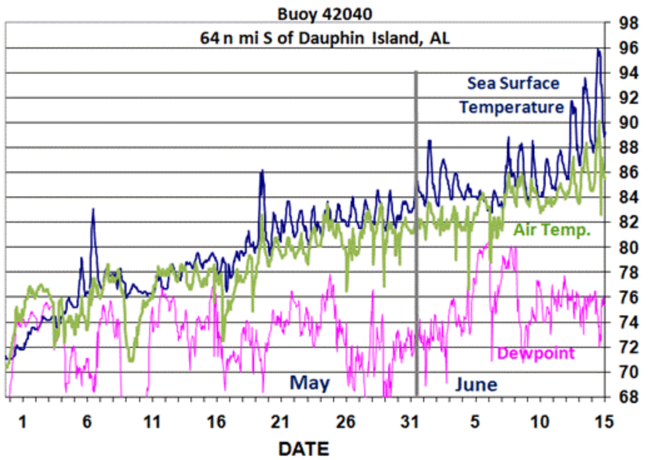
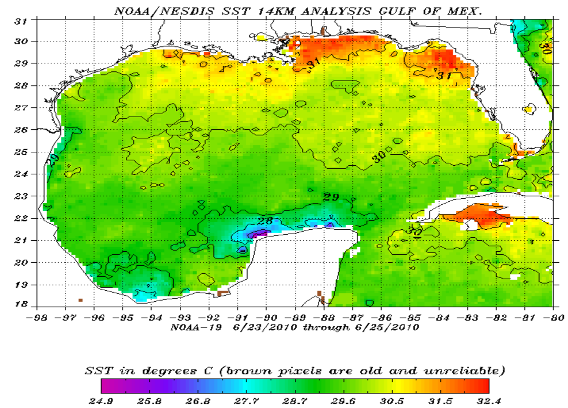


Figure 14. Time series of SSTs and dew points observed from the buoy station 4242040 located about 64 nautical miles south of Dauphin Island, Alabama of National Data Buoy Centre, NOAA, 2010.

Available: http://www.ndbc.noaa.gov/station_history.php?station=42040



Figue 15. Gulf of Mexico: Sea Surface Temperature Contour chart as on June 13, 2010 of NOAA Satellite Information Service, 2010

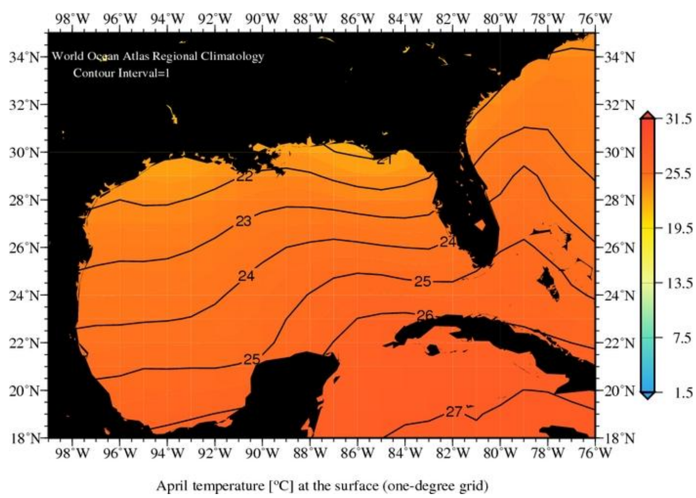


Figure 16: Gulf of Mexico: Satellite generated climatology chart of SSTs in the month of April over Gulf of Mexico of NODC, 2012. Available:http://www.nodc.noaa.gov/cgi-bin/OC5/GOMclimatology/gomregclfig.pl?parameter=t

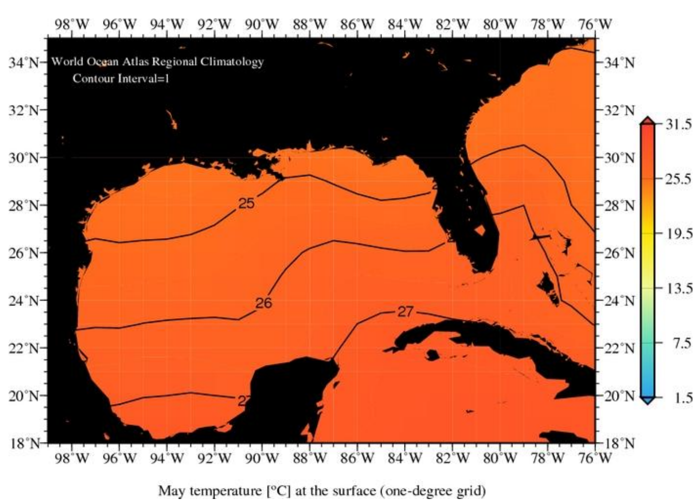


Figure 17: Gulf of Mexico: Satellite generated climatology chart of SSTs in the month of May over Gulf of Mexico of NODC, 2012. Available:http://www.nodc.noaa.gov/cgi-bin/OC5/GOMclimatology/gomregclfig.pl?parameter=t

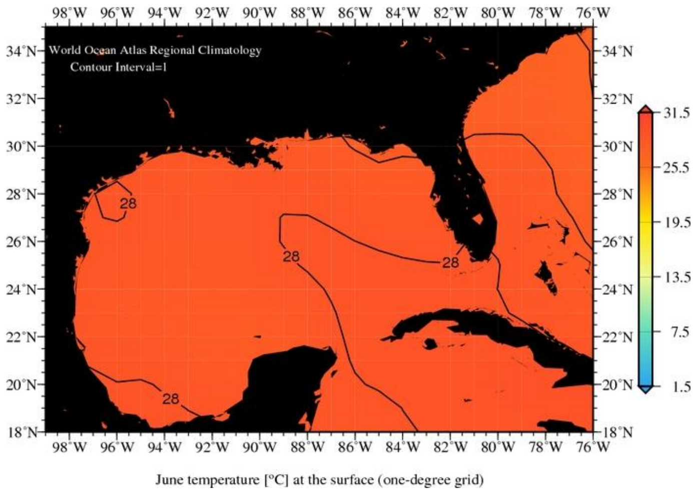


Figure 18: Gulf of Mexico: Satellite generated climatology chart of SSTs in the month of June over Gulf of Mexico of NODC, 2012. Available: http://www.nodc.noaa.gov/cgi-bin/OC5/GOMclimatology/gomregclfig.pl?parameter=t

Weather Modeling Simulations

In the present work, WRF model is run for the period June 1 to 3, 2010 primarily in view of the predominant changes in SST and wind patterns that started to show up as a result of the impact of the growing oil slick in the region. Secondarily, the first week of June happened to be the beginning of the hurricane season and the tropical disturbances are predicted to be happening in the region.

The weather modeling simulations were run using NCAR Advanced Research Weather Research Forecast (ARW) model (version 3.1) developed by NCAR (Skamarock et al, 2008). Intrinsically, the WRF numerical model uses a 3rd-order Runge-Kutta split-explicit time integration solver. The WRF modeling system is run in two parts: the WRF Preprocessing System (WPS) and the WRF modeling core. WPS is executed by three processors that define the WRF modeling domain, generate map, elevation/terrain, and land-use data, and generate horizontally interpolated input meteorological fields to the WRF grid.

WPS does the conversion of real terrestrial and weather data from US Geological Survey (USGS) sources into a suitable WRF input data format. Besides defining the model domain, WPS interpolates various terrestrial data sets (such as land terrain and land use) to the corresponding model grids, and produces geological static fields such as terrain, land use, soil types etc.

The WRF numerical modeling solver interpolates the meteorological fields (such as temperature, pressure, wind speed, heat fluxes etc) processed by WPS to the WRF vertical levels and generates initial and lateral boundary conditions. Large scale forecast models such as North American Mesoscale (NAM) model are used to generate meteorological data in a gridded binary (GRIB) data. Such forecast meteorological data are archived for general use by the community and are freely available from the NCEP FTP site: ftpprd.necep.gov. and used for initialization and time-dependent lateral condition data to run the WRF solver.

The model solver integrates the atmospheric equations and interfaces with the physics schemes to generate forecasts of meteorological variables such as temperature, wind speed, pressure, heat fluxes etc. The physics schemes are used to simulate land surface, surface layer, and boundary layer dynamics, along with cumulus convection, microphysics, and radiation.

The WRF model output gives many time-dependent, two-dimensional meteorological and geographical parameters that can be selected in an output file in the netCDF format (http://www.unidata.ucar.edu). Some of the generally used model output parameters are pressure, temperature, wind speed components, precipitation, water vapor, latitude, and longitude. The WRF model also provides graphics tools for visualization of the model output results such as temperature, pressure, precipitation, wind speed and directions etc. Several programs are supported, including RIP4 (based on NCAR Graphics), NCAR Graphics Command Language (NCL), and conversion programs for other readily available graphics packages: GrADS and Vis5D. Graphic Tools facilitate visualization of the model output and we have used GrADS in the present work. The details of these programs are described in the chapters of the user's guide (Skamarock et al, 2008).

In our WRF model simulations, a single domain centered at 24^0 N, -89^0 E is configured with Lambert Conformal Conic projection of spacing 15 km and grid size in the east-west and north-south direction is 128 x 112. The model is initialized at 0000 UTC, on June 1, 2010 and integrated for 72 hours up to 0000, June 4, 2010 with 6 hours interval update of the boundary conditions. The details of the model run are given in our earlier work (Tuluri et al, 2010).

Terrain and land cover data at the resolution of ~0.9 km as available from US Geological Survey (USGS) sources are used to interpolate to the model grid domains. The file that can be obtained at http://www.mmm.ucar.edu/ wrf/src/wps_files/geog.tar.gz contains all the necessary terrain and land cover data files (30", 2', 5', and 10' resolution). To initialize the WRF model for initial and boundary conditions, the meteorology datasets are taken from the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) Final Analysis (FNL) available at 1 degree spatial resolution at 6 hours intervals (NCEP, 2012). The NCEP GFS data sets consists of several meteorological variables such as geopotential height, temperature, wind speed components, absolute vorticity, relative humidity, vertical velocity, cloud water mixing ratio, pressure, vertical speed shear, convective available potential etc.

To simulate complex physical processes such as convection, radiation, surface emissivity or planetary boundary layer effects, WRF model uses several physics schemes. By experience from previous studies, we have noted that best agreement with the observations is obtained with the following schemes of different physical processes as summarized in Table 1:

Table 1: Details of the physics and grid configuration used in WRF (ARW) model

Dynamics of Vertical Resolution	Primitive equation, no-hydrostatic 35 levels
Domains	Domain 1
Horizontal Resolution Grid Points Center of Domains	90 km 128x112 24^0 N, -89^0 W
Initialization Radiation Surface Processes Boundary Layer Cumulus Scheme Explicit Scheme	NCEP Global analysis data; 2 way Dudhia scheme for short wave radiation, Rapid radiative transfer model (RRTM) for long wave radiation Noah land surface model Blackadar Planetory Boundary Layer Parameterization Grell cumulus parameterization WSM3 simple ice mixing (Microphysics) scheme

WSM3 simple ice microphysics scheme (Hong et al, 2004): WSM5 is for WRF-Single-Moment Microphysics scheme of category 3. It is microphysics scheme to simulate atmospheric heat and moisture tendencies, microphysical rates, and surface fall. The features of this option are - microphysics with ice, Ice processes below 0 deg C, Ice number is function of ice content Ice sedimentation and time-split fall terms

Dudhia scheme for atmospheric shortwave radiation (Dudhia, 1989): It is a radiation scheme to simulate atmospheric temperature tendency and Surface radiativefluxes. The features of this option are - Simple downward calculation, Clear-sky scattering, Water vapor absorption, Cloud albedo and absorption

Rapid radiative transfer model (RRTM) for long wave radiation (Milawer et al, 1997): The features of this radiation scheme are - Spectral scheme, K-distribution, Look-up table fit to accurate calculations, Interacts with clouds, Ozone/CO2 from climatology

Grell cumulus parameterization of cumulus scheme (Grell et al, 2002): It is a physics scheme to simulate atmospheric heat and moisture/cloud tendencies, and surface rain fall. The features of this option are - Multiple-closure (e.g. CAPE removal, quasi-equilibrium), Multi-parameter (e.g maximum cap, precipitation efficiency), Explicit updrafts/downdrafts, Mean feedback of ensemble is applied, Weights can be tuned (spatially, temporally) to optimize scheme (training)

Blackdar Plentary Boundary Layer parameterization (Zhong et al, 2004): Plentary Boundary Layer parameterization (PBL) schemes are very critical in the environmental numerical modeling and are used to parameterize the unresolved turbulent vertical fluxes of heat, momentum, and constituents such as moisture within the planetary boundary layer and throughout the atmosphere. The scheme considers boundary layer fluxes (heat, moisture, momentum) and vertical diffusion. The features of this option are - Parabolic non-local-K mixing in dry convective boundary layer, Depth of PBL determined from thermal profile, Explicit treatment of entrainment, Vertical diffusion depends on rain free atmosphere,

Noah land surface model (Chen et al, 2001): The physical process considers surface layer of atmosphere diagnostics (exchange/transfer coefficients) and Land Surface: Soil temperature /moisture /snow prediction /sea-ice temperature. The features of this option are – Vegetation effects included, Predicts soil temperature and soil moisture in four layers, Predicts snow cover and canopy moisture, Handles fractional snow cover and frozen soil, Diagnoses skin temp and uses emissivity, Provides heat and moisture fluxes for PBL

The WRF numerical model simulations were performed on a Linux cluster that has eight nodes of four 2.8 GHz processors and 2 GB of RAM each and 7.5 TB memory storage. The model is executed for the period June 1 – 3, 2010 over the Gulf region to obtain sea surface temperatures (SST), wind speed and directions. The model output results for wind circulations are overlaid with the SSTs to see the characteristics of the wind patterns in the Gulf region and are given in Figures 19 - 21.

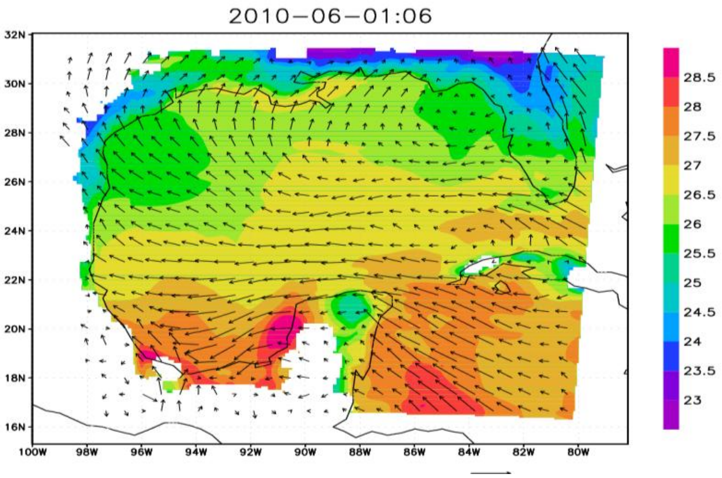


Figure 19: Modeling simulations of wind and SST over Gulf of Mexico, as on June 01, 2010 at UTC 0006 (midnight local)

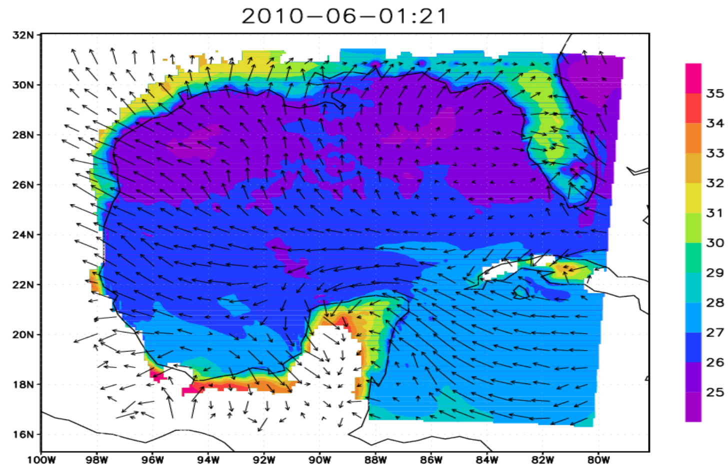


Figure 20: Modeling simulations of wind and SST over Gulf of Mexico, as on June 01, 2010 at UTC 0012 (06 am local)

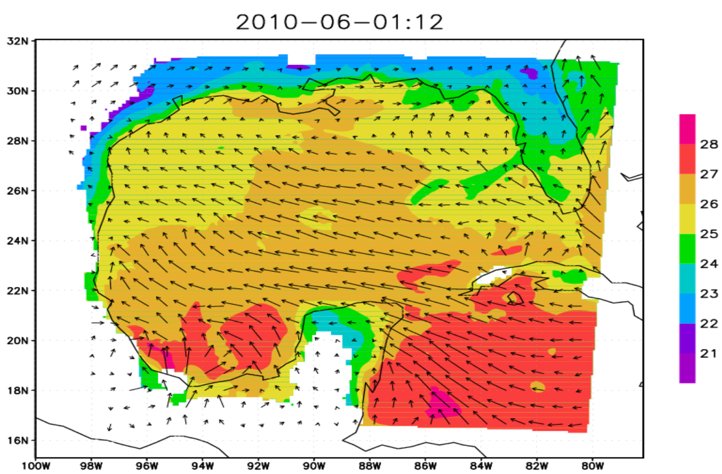


Figure 21: Modeling simulations of wind and SST over Gulf of Mexico, as on June 01, 2010 at UTC 0021 (03 pm local)

Results and Discussion

Comparison of satellite observations for SST in the Gulf region (Figures 2 – 7 and Figures 16 - 18) shows higher SST in the range of 28 – 31^0 C overall during the time of oil spill incident (Figures 6, and 15) corresponding to an increase of 2 – 3^0 C above the average June SST climatology of 27^{0}C (Figure 18). During the period from May 1 to June 15, 2010, the buoy data also shows high SSTs ranging from 88^{0}F (31^0 C) to 96^0 F (36^0 C) but no corresponding changes in the dew points (Figure 14). Comparison of the heat potential charts (Figures 8 - 13) shows a maximum of about 80 J/cm^3 over the oil slick area (Figure12). This is 60 J/ cm^3 greater than the climatological increase of 20 J/cm^3. Even in the month of August, the satellite data shows an extended period of wide spread high pressure of 1024 mb over the Gulf Coast (NOAA Satellite Information Service, 2010). The buoy data also show record high temperatures during summer period of May 01 – June 15, 2010 over the region. Apparently, at the time of oil spill incident the observed data show a relative increase in sea surface temperatures over the Gulf of Mexico in comparison with the climatology temperatures to the corresponding periods of April, May, and June over the region (Figures 16 – 18).

The WRF model simulation results help understand the significance of the observed data with the physical processes taking place over the Gulf region. Figures 19 – 21 show the model simulations of wind patterns overlaid on SST on June 1, 2010 at three instants of the day – midnight, morning, and afternoon. Similar patterns were observed for the remaining days of the simulation period from June 1 – 3, 2010. The model simulated weather circulation patterns in the Gulf Coast region, and captured the observed high SSTs. It also corresponds to the higher heat potentials (TCHP). Wind patterns of clockwise circulation of high pressure system related to eddies have been observed near and over the oil spill during midnight and morning hours at 6.00 am local time (1200 UTC). A strong South-Easterly and weak westerly flow associated with sea breeze circulation and anti cyclonic circulation is also observed (Figure 21) during the afternoon at 3 pm local time (2100 UTC). Based on an ocean-atmosphere coupled system, we presume that the altered wind patterns of high pressure system are responsible for the increase in higher SSTs, similar to that in El Niño conditions (Philander, 1990) in the region. Normally, a cyclonic cool eddy is associated with upwelling of cold and nutrient-rich water from the deep Gulf toward the surface. If the widely spread massive oil slick overlays a cyclonic (cool) eddy (Figure 1), the oil slick could limit the evaporation of the water and hence suppress the otherwise upwelling. The suppression of upwelling can lead to lowering of evaporation and increasing of SST and therefore alter the wind patterns from easterly to westerly associated with the loop current and eddy as seen in the model simulations. The observed data of dew points near the oil slick (Figure 14) compared to that recorded at a farther station (Spencer, 2010) also supports the decrease in evaporation of the warm water. The changes in the wind patterns are similar to those of a high pressure system (Figure 21) like that in El Niño conditions. In the absence of any other major events affecting the Gulf, the wind shear due to the reversal in wind patterns (Philander, 1990), as well as low evaporation due to the oil slick (Hofmann, 2004; Masters, 2010) may contribute to the reduced tropical cyclone strength as in the case of the tropical depression/storm reported in June 01, 2010 and Alex on June 24, 2010 (NHC, 2010). The blocking high induced by the changes in wind patterns associated with the loop current and eddies may have a negative effect on the strength and track of a passing tropical cyclone or other storms that would be formed during the rest of the hurricane season.

The observed increase in TCHP and the corresponding increase in SST may not be valid for the deep water; nevertheless the associated affects on the wind patterns will be due to the shallow water that experiences the higher SST. The source of a storm's energy is the evaporating warm sea water of higher SSTs. The storm's energy can be controlled by at least three factors such as evaporation, wind patterns, and warm eddies in the Gulf. Generally, warm ocean conditions close to shore have a positive effect on the intensification of the storm before landfall. On the other hand, the changes in precipitation, evaporation and air temperature could affect the passing storm's track or reduce its intensity by weakening the winds. Therefore, altering the source of a storm's energy by changes in evaporation or pressure associated with winds can affect the track and intensity of the hurricane. Since a widespread oil slick can act as an agent to limit evaporation or to alter the wind patterns, it exhibits a negative effect on the growth of the storm over the ocean. Further, El Niño like conditions also suppresses the growth of tropical storms in the Gulf of Mexico during the period of June and July due to large wind shear (Philander, 1990). The decrease in evaporation due to the oil slick will further augment the reduction (Hofmann, 2004; Masters, 2010).

The NOAA forecast of 2010 Atlantic hurricane season predicted an active season similar to that of 2005 (see Table 2). The prediction is in close agreement with the number of storms observed in 2010 (NHC, 2010). Unlike the hurricane season of 2005, very few of the storms observed in 2010 had their landfall over the Gulf coast (see Figure 22 and Table 3; and NHC, 2005).

Table 2: 2010 Atlantic Hurricane Season

Storm type	NOAA Forecast August, 2010	2010 Actual	Average Season
Tropical Storms	14 - 20	19	11
Hurricanes	8 - 12	12	6
Major Hurricanes	4 - 6	5	2

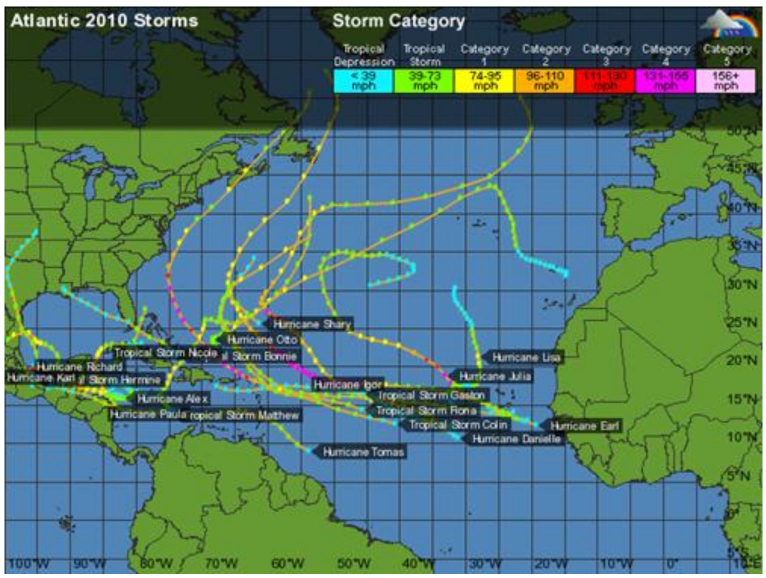


Figure 22. Summary of 2010 Atlantic storm tracks (http://www.wunderground.com/hurricane/at2010.asp;http://www.nhc.noaa.gov/2010atlan.shtml)

Table 3: Timeline of the 2010 Atlantic Hurricane Season

Category	Name	Dates	Max Wind(MPH)	Land Fall/ Dissipation
H	ALEX	25 JUN-2 JUL	105	Landfall: Belize/Mexico
TD	TWO	8-9 JUL	35	Landfall:South Padre Island, Texas
TS	BONNIE	22-24 JUL	40	Dissipated:Northern Gulf of Mexico
TS	COLIN	2-8 AUG	60	Dissipated: northwest of Bermuda
TD	FIVE	10-11 AUG	35	Landfall: Louisiana
MH	DANIELLE	21-31 AUG	135	Extratropical/Newfoundland

MH	EARL	25 AUG-5 SEP	145	Landfall: Nova Scotia
TS	FIONA	30 AUG-3 SEP	65	Degraded/south of Bermuda
TS	GASTON	1-2 SEP	40	Dissipated/Lesser Antilles
TS	HERMINE	5-9 SEP	70	Extratropical/Oklahoma
MH	IGOR	8-21 SEP	155	Extratropical/Newfoundland
MH	JULIA	12-20 SEP	135	Extratropical/westward over ocean
MH	KARL	14-18 SEP	120	Dissipated/southern Mexico
H	LISA	20-26 SEP	85	Dissipated/ Azores Islands
TS	MATTHEW	23-26 SEP	60	Dissipated/Mexico
TS	NICOLE	28-29 SEP	40	Landfall: East coast
H	OTTO	6-10 OCT	85	Dissipated/portugal
H	PAULA	11-15 OCT	100	Tropical depression/Cuba
H	RICHARD	21-26 OCT	90	Dissipated/North of Gulf of Mexico
H	SHARY	29-30 OCT	75	Extratropical/east over the atlantic
H	TOMAS	29 OCT-7 NOV	100	Extratropical/Nova Scotia

Though the conditions over the Gulf are favorable for an increased tropical storm/cyclone frequency and strength as expected otherwise during the hurricane season (June 1 to November 30), not as many appear to take place over Atlantic Ocean, particularly major hurricanes passing the US Gulf Coast. In the absence of any other major factors responsible for affecting the Gulf, the blocking high or high pressure system in the region may be attributed to the changes in wind patterns.

Conclusions

Model results for the Gulf of Mexico from June 01-03, 2010 (about a month after the Deep Horizon accident) showed significant changes in the wind patterns in the atmosphere. The model captured the observed high SSTs which also corresponded to higher TCHP. The changes in the wind patterns were associated with the loop current and eddy currents masked by the oil slick in the region. We attribute the wind reversal to a manifestation of a high pressure system, such as would be formed in El Niño conditions, resulting from limiting of evaporation with corresponding increase of SSTs. At the time that oil was spewing into the Gulf of Mexico, the region was showing elevated SSTs in excess of those expected due to seasonal heating alone. The higher SSTs and TCHP are favorable to support the occurrence of intense and frequent tropical storms during the season. However, the region also experienced an elongated high pressure system for longer periods up to August, 2010 and beyond. The blocking high induced by anomalous changes in the weather patterns associated with the loop current and eddies, may be responsible for a reduction in frequency and strength, and deviation of track of tropical storms, particularly major hurricanes that tend to pass towards the US Gulf coast region.

The present work demonstrates that during a catastrophic event like that of an oil spill can drastically affect the environment that can greatly alter the naturally prevailing conditions such as physical processes over the region of the ocean. For example, such incidents taking place at a time of hurricane season would greatly impact the outcome of the forecasting models. In such situation, by combining the observed satellite data and numerical modelling one can obtain information on the environmental impacts on the ocean and atmospheric interactions leading to physical changes such as wind patterns, eddy currents, and high pressure systems. In particular surface wind fields is of importance in accurately predicting the movement of oil spills and ensure accurate assessment of the oil spill risk. Incorporating such changes in the model simulations can help predict better forecasting of the environment. While the satellite derived ocean data help understand the ocean surface water circulation dynamics, the environmental numerical modelling help understand the influence of atmospheric effects on the ocean. Hence, in the case natural disasters or catastrophic events combining environmental modelling simulations and satellite derived data help decision makers, policy managers, and scientists to make a better emergency response planning.

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